Kiran Golwalkar

Process Equipment Procurement in the Chemical and Related Industries

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Dedicated to my teachers who taught me at the engineering institutes, my colleagues who were very cooperative and explained the process plants at the start of my career, and the workers from whom I could learn practical things.

Preface

It gives me great pleasure to present this practical guide to the technical and purchase managers of the chemical process and related industries for the procurement of equipments. It was observed that considerable time is wasted in unnecessary correspondence with the vendors/manufacturers of plant and machinery in clarifying the exact requirements of the purchaser if these are not clear while floating inquiries. This sometimes led to project delays, cost overruns, inability to stabilise plant operations in time and therefore inability to meet commitments made to the customers.

It is felt that timely and correct procurements of the right type of equipments/machineries with all the required features and constructed with the appropriate (suitable for the intended use) materials of construction (MOC) can ensure a smooth and safe scheduled start-up of the project at the budgeted cost (or minimising cost overruns).

Procurement of the right equipment enables safety in operations and can minimise breakdowns and environmental pollution. In addition, it would be easier to maintain product quality and reduce the cost of production.

I have attempted to explain when to procure new equipment, how to prepare specifications for floating inquiries, and guidelines for detailed technical discussions with vendors in the chemical and related industries.

The guidelines presented cover the common equipment used in chemical plants and related industries and effluent treatment facilities such as pumps, blowers, reactors, heat exchangers, waste heat recovery boilers, heat and acid resistant lining as well as auxiliary equipments and utility services such as water treatment plants, cooling towers, refrigeration systems, DG sets, etc. The management will find judicious investment in essential facilities like maintenance equipments, proces control lab, fire fighting, personal safety devices, elevated storage for water useful for safe and efficient working of the plant and hence have been included.

It is hoped that technical and purchase managers will find this book useful for procuring and/or replacing equipments, process technology, raw materials etc. at reasonable cost and will help the projects to be started on schedule. The book is also intended to serve the engineering students in technical institutes and universities and young engineers starting out in their careers for making them familiar with practical aspects of various equipments and machineries before they assume responsibilities in chemical plants.

The book gives a checklist to the plant managements for procurement of the correct equipment in an efficient timeframe insuring that projects are not delayed. It can also increase the readers' understanding for posing the right inquiries to engineers, plant managers, and product vendors when acquiring industrial equipment and supplies.

Suggestions and constructive criticism for improving this book are welcome from persons associated with the chemical process industries. The guidelines are *suggestive* rather than *stipulative*. Obviously, individual requirements will vary as per specific situations.

K. R. Golwalkar

Acknowledgement

My aims in writing this book were:

- To familiarize the readers (*including students in technical institutes*) with the basic working principles and practical aspects of many items/systems used in industries
- To provide the readers with check lists/guidelines for floating inquiries for them
- To enable short listing and final selection of vendors for procurement of/purchasing these equipments (by discussing with the vendors the practical aspects of their safe, efficient operation, ease of maintenance and commercial matters)

Sources of my information

I have referred to standard text books, Chemical Engineers' Handbook etc for process information, basic working principles and general description about the items/equipments as well as advertisements in trade journals and from material uploaded on the internet by manufacturers for promoting sales of their products.

Since, the practical aspects for procurement are not generally available, in standard textbooks, Chemical Engineer's Handbook, etc., this information was developed, modified and presented in a simplified manner for the reader. Reference listing is provided wherever the material from other sources was used as a starting point.

Subsequently, check lists/guidelines were prepared for the selection and procurement. These are based on my own experience of working in many chemical industries in India and other countries for procurement, erection, commissioning and operation.

The inputs from the engineers and technicians at these plants have been very useful in preparation of these guidelines. The technical literature (*given to me by sales engineers of several companies*) and the discussions with many vendors have also been referred to.

I am grateful to the senior professionals who spared their valuable time, reviewed the book and gave some very constructive suggestions.

Mr Mandar Bokare (*my ex-student*) had also been very helpful in preparing the manuscript and I thank him for the same.

I am grateful to Respected **Mr Michael Luby**, Senior Publishing Editor, Engineering,and Respected **Ms Merry Stuber**, Associate Editor, Engineering of Springer Science+Business Media, and Respected **Ms Sakshi Narang** (Production Editor) and **Mr Vivek Pradhan** (Project Manager), Springer Production for their support and guidance and thank them for the same.

References

I have referred to the following sources for writing the book.

1. Chemical Engineers' Handbook-for material conveying systems, heat recovery systems, cyclones, scrubbers, evaporators, thermal and mechanical compressors etc
2. Own experience of operating various chemical plants in India, Kenya, Thailand, Indonesia and visits to industrial exhibitions in India for equipments, instruments; and technical information/ brochures collected
3. Class notes by my own teachers
4. Personal correspondence and discussions with senior engineers and representatives of manufacturers of catalysts (Catalyst India Ltd, Mont-Edison at Jakarta), Refractory materials (ACE-Calderys Refractories, SKG Refractories), fabricators of mechanical equipments (VK Engineers, India and many others), Scrubbing systems and Candle Demisters-(Evergreen Technologies) ….
5. Technical literatures and advertisements placed in various technical journals (Chemical week, Chemical Engineering World) by manufacturers/fabricators for pumps, blowers, agitated reactors
6. Information uploaded on the Wikipedia/Internet by various manufacturers/fabricators for pumps and blowers, Waste Water Treatment Plants (figures for Dissolved Air Flotation by renowned vendors Pan American Environmental, Hydro Systems Supply, EDUR were also referred), Tower packings (Topack Ceramic Industries, Nilgiri Chemical Stoneware) Steam Operated Chilled water Plants (Thermax C and H div), Gas Induction Reactors (Omega-Kemix, Amar Equipments)
7. Technical literatures from Vendors of Instrumentation systems (KD Instrument, ENDEE Engineers)
8. Offers from and personal discussions with Manufacturers of Waste Heat Recovery boilers (Thermal Systems-(Hyd) India, AVU Engineers, A.P. India)

I have tried to present the *guidelines for procurement* of the various equipments and systems by referring to the information/working principles of the various equipments uploaded on the Internet by above renowned manufacturers. However, the reader is advised to contact these companies for more detailed proprietory information and procuring the required equipments as per need

I do not claim that all the various equipments are designed by me and the information given in this book is entirely my own. Hence I am grateful to all the above sources. If I have missed some names due to oversight, the omission is not intentional; and sincerely regretted.

K. R. Golwalkar

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About the Author

Kiran R Golwalkar is a consulting chemical engineer based in India and has experience of erection, commissioning, operation of many chemical plants in India, Kenya, Thailand, Indonesia. He can be contacted on the e-mail…. krgolwal@gmail.com

1 Process Equipment Procurement: Need and Options

1.1 Introduction

Chemical industries have to face problems due to stiff global competition, availability of cheaper products, increasing cost of raw materials and power, reduced availability of water, increasingly stringent laws for pollution control, labour problems, operational disturbance due to occasional power failures, etc.

It is therefore imperative that a close look is taken at the capital investment requirement for procuring equipment. Purchase of high-capacity units may not be the right choice in certain cases due to many practical difficulties in procurement and the additional (*hidden*) costs involved.

These can be due to incorrect specifications, long delivery schedules, non-availability of some critical components or spares in time, delays in erection or commissioning, difficulties faced during operation and maintenance, and the need for occasionally inviting outside experts.

Such problems ultimately result in cost overruns of the project. The accumulating interest burden due to delayed commissioning of the project results in lower rate of earnings from the industry.

The situation can get aggravated further in case the production run is not stabilised soon or the finished product is not as per required *marketable* specifications. It becomes necessary to store the off-spec product till the time the product meets the specifications given by customers. The lower grade product will have to be sold at a much lesser price (sometimes even at a loss) or reworked upon to improve the quality (if possible by recycling or other means) or disposed of in some other way acceptable to statutory authorities.

In many industries, the old plant and machinery are allowed to run as such and decisions for procurement of new plant, machinery, know-how and technology are postponed "to save" capital investment. However, this can only temporarily save the outgo of funds while the inefficient operations of the old equipment continue to cause losses.

An attempt is therefore made to present some guidelines to the management of chemical industries for taking decisions in the matter of procurement of process

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know-how, technology, better equipment and other related items. These guidelines can be used for obtaining offers/quotations correctly and quickly in order to shortlist the vendors. These can reduce likely delays in equipment procurement, erection and commissioning.

Hopefully the decision makers will find them useful and apart from preventing (or minimising) cost overruns and project delays they will also help in achieving safer, more efficient and economical operation of the process plants.

1.2 Procurement of an Entire Manufacturing Facility or Technology

Situations when it becomes necessary to procure an entirely new plant or replace most of the equipment or install additional new equipment are:

a. Revamping (major modifications) of the old plant has become necessary.
   - When the existing plant is not able to produce at the required rate, as per quality at a reasonable cost or is causing environmental pollution
   - When a better product is available in the market at a lower price
   - When the existing unit has become old and breakdowns are frequent
   - When it is unsafe to run the present plant

b. A common situation could be that the old plant is lying idle for some time due to some of the following reasons:
   - The cost of production was high
   - It was unsafe to operate
   - Some critical spares were no longer available
   - There were labour problems
   - Consumption of raw materials and power was high
   - It was generating more effluents and thus causing pollution
   - It was running batchwise and hence production rate was low
   - There were frequent breakdowns
   - The quality of product was poor

Management shall consider the programme for procurement of new units after the below revival steps are carefully discussed with plant engineers and purchase and sales officers.

- Investigate all the reasons before deciding to go for new equipment
- Analyse cost of production
- Make all equipment safe to operate
- Critically examine designs of all important equipment and develop new designs for important spares—*this may not be possible always*
- Negotiate with labour
- Carry out energy audit and take appropriate steps
- Check catalyst activity and residual life; check Effluent Treatment Plant

- Convert to continuous operation
- Implement regular condition monitoring and preventive maintenance programme
- Implement process control programme at every step of production (analysis of raw material, reactor operation, calibration of instruments, replacement of catalyst, filtration of raw material/product streams, purification steps for final product, etc.)

1.3 Options to Be Considered

a. Procuring an entire plant on "turnkey basis" (including detailed know-how)
b. Obtaining an old plant in either idle or working condition and revamping it (carrying out the necessary changes as per need) —the required know-how may or may not be obtained from outside
c. Obtaining process know-how (operating conditions), technology (detailed engineering design) and only certain key equipment. Balance facilities to be created by modifying existing equipment or fabricated in-house by purchaser's own technicians

Options for procurement from an outside party (*outsourcing the plant equipment with services to run and maintain—either fully or partially*)

- BOT: Build, operate (till performance guarantee terms are met) and then transfer immediately to purchaser
- BOOT: Build, own, operate and transfer to purchaser as per agreed schedule
- BOM: Build, operate and maintain on behalf of the purchaser, who agrees to pay some fees or shares the profit generated. The vendor recovers the cost from this. The ownership is transferred to purchaser after the vendor has recovered his costs fully along with profit. The purchaser does not invest funds initially but gets the benefits—at reduced rates
- BOOM: Build, own, operate and maintain for some years for an agreed fees as per agreement between purchaser and external vendor
- BOMT: Build, operate, maintain and transfer to purchaser as per agreed schedule

1.3.1 Procurement of an Entire Plant on "Turnkey Basis" Procuring an old plant and Revamping it

Important Selection Criteria and Steps
The purchasers will have to do some important jobs themselves:

- Obtaining all statutory permissions to establish and operate and arranging land, power, water supply and all necessary infrastructure.
- Disaster management plan report and environmental impact assessment should be ready before setting up a new project along with all the above statutory permissions.

- The selected process technology should be the latest and should suit the purchaser's local conditions and availability of raw materials, power, water and skilled workforce. The manpower available with the purchaser should be able to easily understand the process technology and operate and maintain it.
- It should be safe to operate the plant in the local climatic (ambient temperatures, rainfall, etc.) and geographical area where it will be located, along with the quality and quantity of water locally available.
- The process design and technology should be such that locally available raw materials (if cheaper) can be used as far as possible.
- Generally, an operating range of 70–130 % of the capacity shall be available, i.e., it shall be possible to operate the plant efficiently and safely even in underload conditions (up to 70 % when the demand for products is less, raw materials or utilities are not available) or in overload conditions (up to 130 %) of rated capacity when higher demand for product is to be met urgently.
- Consumption of raw materials, power, steam and water should be lowest or comparable with the best in industry. Specific consumption of all inputs per unit of output should be economical over all operating capacity ranges.
- The breakeven point (BEP) should be reached at the lowest capacity possible. Otherwise, one has to operate the plant at higher capacity just to break even.
  - *In case, there is not much demand in the market due to some reason, it may become necessary to sell the product at a reduced price. The other option of not selling at a reduced price causes build-up of unsold products, which have, however, already consumed resources.*
- A rule of thumb is that the cost of raw materials and utilities should not exceed 50 % of the selling price if a reasonable return on investment (ROI) is desired. Hence, while procuring a new production plant and technology, one must use this rule of thumb.
- The quality of final product should be easily marketable and meet the specifications (domestic and international) at the minimum and maximum production rates, i.e., when the plant is running at a lower or higher capacity than the rated one—within limits of operating range.
- The possibility of sudden or frequent interruptions in the power supply should be considered informed to the vendor, who should incorporate warning alarms, safety devices and interconnections in the designs. Vendor should demonstrate satisfactory working of all such systems prior to handing over the plant to purchaser.
- *These arrangements will have to be done by the management themselves if the revamping is being done.*
- It should be possible to recycle or purify the off-spec product (if produced during plant upsets) in the process plant and convert it to marketable-grade product once again, without causing any process disturbance or maintenance problems.
- The plant should not cause any environmental pollution. If the plant produces certain pollutants, there should be an in-built mechanism for effluent treatment. Cost of operation of the ETP and rendering the effluents harmless for meeting the

pollution control norms should be minimum. Vendor shall be asked to include the ETP also in the scope of his offer.

- It should be possible to run the plant on a continuous basis (instead of frequent stoppages due to changeover or resetting of the machines) with minimum manpower requirement for both operation and maintenance.
- In case of batch production units, the time, energy, manpower, etc. required to restart and bring up the reactors to optimum process conditions should be minimum (e.g. time required to empty, wash and recharge the reactor for the next batch should be minimum).
- It should be possible to carry out maintenance jobs while the plant is running. Critical pieces of plant and machinery should have standby units installed at the right locations so that they can be immediately used. Quick changeover should be possible, with minimum stoppage, while the plant is running. *Alternatively, process bypass routes (ducts or piping) should be available to enable taking out such units for cleaning or for maintenance work.*
  - Spares for two years smooth operation should be procured when the plant and machinery is being ordered from abroad. Performance guarantee conditions must include a clause for technical guidance/supply of spares for at least one year for all items purchased.
  - As far as possible, a satisfactorily running unit based on similar process and technology should be visited before finalising the purchase of the entire plant or any critical item.
- Vendors should provide free training to purchaser's technicians for operation and maintenance as well as handling emergency situations for all items purchased.
- At many locations, steady power supply may not be always available. There should be no detrimental effect on the product's quality due to power tripping/short-duration power failures.
- Dangerous process conditions, which can jeopardise safety of men and machines and can cause environmental pollution, should not develop during power tripping/short-duration power failures (*no overflow of tanks/sudden release of gases into atmosphere/formation of explosive mixtures, etc. should occur*).
- Individual equipment and plant layout should be designed (by the vendor) while keeping this specific requirement in view, e.g. reserve tanks with chilled water should be available in the plant when highly volatile liquids are being condensed. In case of power failures, the reserve of chilled water will not allow temperature of the liquids to rise fast. Also, the condensers should have cooling jackets, which will remain full in case of pump stoppages during power failures. The above design considerations will prevent escape of volatile liquids.
- *Purchaser must consider the cost of providing diesel generating sets of adequate capacity to provide power, at least, for emergency needs.*
- *A word of caution: in spite of the provision of a diesel generator set it does take a few minutes to start supplying power from it and bring back the process operation to normal values by readjustment of the valves/pumps operation.*

- Purchaser should have free access to latest developments in technology. This can be ensured by separate agreements, which should also include clause for technology transfer in future.
- There should be no legal impediment for the purchase of the plant or transfer of the process know-how and technology from the government of the vendor's country.
- Any long-term payment of licensing or royalty fees shall be clearly indicated by the technology supplier.
- The purchaser (*who is buying designs and process technology know-how*) may carry out innovations by his own research and development efforts in the original items, designs and technology. In such cases it is advisable to have an agreement with the original plant supplier that such innovations shall be a joint intellectual property. It can then be sold to a third party with permission from the original plant supplier on reasonable terms.
- Such agreements should be made in the beginning itself to avoid misunderstanding later regarding sharing of profits from sale to third parties.

1.3.2 Purchase of Know-How

In certain situations it may be a better option to purchase the know-how instead of buying a complete set of equipment or a completely assembled plant. Some of these situations are as follows:

- When the existing machinery is consuming excessive power and raw materials, running at a lower production rate, producing more effluents (causing environmental pollution), the quality of products is not satisfactory, is becoming cumbersome to operate and/or maintain existing machinery and the revival steps taken in-house are not able to improve the conditions

OR

- A second-hand plant is available for an attractive price and it will be possible to recondition it and operate profitably if reliable know-how can be obtained for the revival. *The existing plant or many of its units may have to be disposed of in this case*
- The present technology has become obsolete and better machines are now available, which can run with less breakdowns and manpower and are more efficient
- When reliable vendors are not available
- Manufacturing shops of reliable vendors are too busy and will not be able to deliver the required items in a reasonable time
- Very high or unrealistic prices are being quoted by most of the vendors
- Vendor is reliable but does not possess the necessary facilities for manufacturing all the items/components required
- Commercial terms (high cost, long delivery period, improper performance guarantees) quoted by vendor are not acceptable

- Plant expansion or diversification is to be done but only limited funds are available
- Any further modifications of existing equipment with the available know-how in-house is not possible
- Obtain only know-how and the necessary equipment or machines. Balance facilities to be created by modifying existing equipment or fabricated in-house by purchaser's own technicians
- Purchaser is able to obtain services of experienced and reliable consultants, who have designed, fabricated and operated similar equipment with satisfactory results at lower cost. Purchaser can modify existing units in small incremental steps with assistance from such consultant
- The broad process to manufacture the product is known but certain specific details (e.g. exact pH/concentration/temperature to be maintained) are not known. These details can be obtained through consultants and the plant can be run accordingly on trial. The operating conditions, product quality, production rate and consumptions of raw materials, utilities, etc. can be observed. Based on these observations the plant management can then carry out the necessary modifications and upgradations in the existing plants or procure balance equipment as advised by consultants with appropriate inputs from his own engineers
- ***A word of caution:*** *purchaser is at a risk if the consultant wants to try his new unproven ideas. There is also risk of getting inefficient technology instead of a proven one*
- Purchaser has experienced and knowledgeable shop floor engineers with some in-house facilities for fabrication. They are confident that by making small changes or by providing additional features to existing machinery, the required performance can be obtained by small incremental investments. This can minimise additional capital required, maximise use of existing units and minimise the stoppage of the running plant (since major changes are not taken up all at one time). *However, this will take considerable time—even a few months*

1.3.3 Options for External Procurement

Procurement from an outside party: outsourcing the work fully or partially

The following options are to be considered for external procurement or minimising initial investment by the purchaser. Enquiries are to be floated and offers are to be obtained.

- BOT: Build, operate (till performance guarantee terms are met) and then transfer immediately to purchaser
- BOOT: Build, own, operate and transfer to purchaser after a certain agreed period
- BOM: Build, operate and maintain on behalf of the purchaser, who agrees to pay some fees or shares the profit generated. The vendor recovers the cost from this. The ownership is transferred to purchaser after the vendor has recovered his costs fully along with profit. The purchaser does not invest funds initially but gets the benefits—at reduced rates

- BOOM: Build, own, operate and maintain for some years for an agreed fee as per agreement between purchaser and external vendor
- BOMT: Build, operate, maintain and transfer to purchaser after a certain agreed period

Advantages to Purchaser This enables the purchaser to save initial investment as well as efforts of setting up the plant from initial stages till it achieves steady performance. It also enables the purchaser to pay attention to some other (important) jobs at hand.

Purchaser may only provide infrastructure at the site for constructing the plant and machinery, unskilled labour, liaison with statutory authorities, make available raw materials and utilities and arrange to sell the product *if it meets specifications given by customers*.

Vendor shall be responsible for erection, testing, commissioning, initial trial runs, plant stabilisation and reaching the guaranteed performance of the plant with respect to production rate, quality of product, consumption of raw materials and energy and environmental pollution control.

All equipment and plant assemblies should be handed over by the vendor to the purchaser at the end of the contracted period in perfect working order except normal wear and tear. This must be however agreed upon in the initial contract itself. Vendor may be asked to replace worn-out components or spares by buying from the equipment manufacturer or their authorised sales agencies only.

Operation of the facilities is to be strictly done as per guidelines given by the purchaser. Maintenance of the facilities should be carried out as directed by purchaser/ as per standard maintenance guidelines given by original equipment manufacturer.

Advantage to Vendor He gets an opportunity to undertake trials of some new process or designs developed by him. He can develop some new business without the risk of marketing his products since his products are already being tried out at the purchaser's plant.

The vendor can also be assured of reasonable profit by such an arrangement.

Risk to Purchaser When the vendor is asked to supply some critical part of the plant, there is a possibility of loss of production or goodwill, product not meeting the specifications required by clients, timely delivery not being done by the main production plant if satisfactory work is not done by vendor or there are deficiencies in his equipment.

There is also a chance that movement of vendors' personnel in the purchaser premises can cause safety issues or leaking out of certain know-how from the main plant.

The vendor will not generally have ultimate ownership of the equipment and therefore may not operate and maintain very carefully unless penalties are specified in the agreement.

However, the responsibility for mishaps, compliance with statutory regulations, labour problems, loss of goodwill in the market, etc. ultimately rests with the purchaser while most of the operational control is with the vendor—at least during the contractual period.

Agreements are generally made for payment to the vendors on some of the following bases. These are not exhaustive—different options can be mutually worked out after a very careful study of all technical and commercial aspects while entering into such agreements:

- Leasing of equipment by making payment to vendor in instalments
- Profit-sharing from the marketable output from the plant
- A lump sum amount every year

Some Words of Caution Vendors should not generally be given very important sections for procurement of plant and machinery, i.e., other regular activities or operations in the premises should not be disturbed as far as possible.

Purchasers should not heavily or entirely depend on vendor for operation of their business. Therefore, an additional vendor must be available to take over any inefficient operation by the first vendor.

Procurement of critical items of the plant and machinery through unreliable parties should be avoided as far as possible even if they are cheaper since they can affect export orders, supply to important customers, product quality and may cause environmental pollution.

1.4 History Cards

A history card is an important and useful record for taking a decision regarding procurement of new items/carrying out major repairs/carrying out modifications.

Usefulness of history card for the management: an analysis and discussion amongst senior engineers should be done on the following before deciding to procure new equipment as replacement of old ones:

- Whether standard operating conditions as given by original manufacturer followed or if the equipment was overloaded (were feed rates, equipment loading, etc. done as per original manufacturer's instructions)
- Whether careful conditioning monitoring programme was followed during running of the items and was preventive maintenance, including lubrication, was done
- Whether standard repair procedures were followed and whether the spares were always procured from authorised stockists/original manufacturer or reconditioned spares were used
- What was the actual running history of the machinery in question—whether it was continuously or intermittently run; whether the equipment was frequently started and stopped or was it run continuously for a long time and then kept idle?
- Where was the equipment actually installed (as per design or in a dusty, hot, outdoor location)?

- Was it run and maintained by qualified and trained technicians?

In case of all equipment, a history card shall be created for each item and, broadly, following information should be recorded

- Code number
- Name of unit and make
- Location in plant and identification mark
- Serial number, year of manufacture/procurement and date of commissioning
- Design duty conditions (flow, temperature, pH, pressure)
- Actual working conditions (ambient temperature/dusty surroundings, outdoor or indoor installation, etc.)
- Original general assembly drawing and battery limits specified
- List of spares and their drawings, code numbers
- Due date for next test/overhaul—and actual dates when this was done
- Dates and duration for which the unit was idle
- Reasons for the unit being idle (e.g. for minor maintenance/replacement of spare parts like bearing, shaft, impeller, etc. or for any other reason)
- Parts replaced and whom were they obtained from?
- Cost of replaced parts

The above data should be updated every month. An analysis of the data will enable the plant management to decide about replacement of particular equipment. However, one should closely look into the differences, if any, between the design duty conditions and the actual conditions in which the unit is operated. It may be possible to trace the reasons of equipment failure in these conditions. Hence, suitable changes may be made in the specifications while procuring replacements.

1.5 Need to Purchase New/Additional Equipment

In spite of maximum efforts to run the available plant and machinery very efficiently, it becomes necessary in certain situations to procure *some new (or additional) equipment.*

Some of these situations could be those given below:

- When it is not possible to purchase an entirely new plant
- When reliable in-house modifications are not possible
- To increase production in order to meet additional or urgent demand, to reduce requirement of manpower, to simplify present operating methods (for better quality and safety) so that overhead cost per unit of production can come down.
- To replace
  - Damaged equipment (e.g. heat exchangers are due for replacement)
  - Polluting equipment (inefficient demisters or absorbers)
  - Inefficient machinery (some existing machines are consuming more power)

- Equipment that are breaking down frequently and causing disruption of production
- Unsafe machinery and equipment (which can cause accidents)
- To diversify the production line since it may become possible to produce some additional products by addition of a few new equipment only
- To de-bottleneck existing production line, e.g. a mixer/filter that is of smaller capacity than required and thus either not able to take care of material fed to it or is starving the downstream equipment
- To comply with instructions given by statutory authorities like boiler inspector, electrical inspector, factory inspector and pollution control board inspector for changing old machines
- To meet agreements made with labour unions regarding installation of easier to handle/safer machinery

1.6 Deciding on New Purchase

Before taking a final decision to procure new equipment, a proper technical and commercial evaluation for *upgrading the current performance* of the existing equipment/machinery shall be carried out on the following lines:

- The performance level required, e.g. increased production rate, improvement in efficiency and safer working. This shall be clearly defined as expectation from the new machinery.

Meanwhile, an objective assessment of cost and time required for carrying out the best technical upgrade of existing equipment and facilities should be done. If necessary, outside experts may be employed for this purpose.

- The estimates prepared by the experts and own technical personnel shall be compared with budgetary estimates or quotations obtained from at least two or three reputed suppliers.
- A realistic cost estimate may then be made for upgrading the existing equipment to get the desired performance. Comparison with cost of new machines should be made.
- Production loss must be considered for the idle time of the unit (for modification work) and this should be taken into account.

External Procurement: Confirmation for Purchase

Many times it may not be advisable (or feasible) to carry out the necessary upgrading in-house due to various reasons, such as:

- Lack of facilities for major fabrication work involved
- Lack of expertise or manpower or both
- One is not sure whether higher performance levels will be reached even after carrying out all the modifications in-house
- One is sure that higher performance (e.g. increased production rate) will not be achieved even after carrying out maximum modifications because of inherent limitations of size, speed, heat transfer area, etc. (of existing equipment), which cannot be changed. However, one must consider the cost, time and efforts required for dismantling old equipment and ultimately replacing them by new ones.

1.7 Options to Be Considered for External Procurement

- Outright purchase of new equipment indigenously
- Outright purchase of second-hand equipment in working order/repairable condition
- In both the above cases, one must be sure that the required performance would be met
- Purchasing only fabrication drawings and designs from consultants in order to develop the units in-house. *There is a risk of getting "untried designs" from consultants*
- Procurement from abroad: a lot of initial correspondence is necessary to make the foreign supplier understand the exact requirements. Also, considerable difficulties could be encountered during final ordering, inspection, transport, erection, commissioning and operation, besides getting spares for maintenance
- Equipment leasing: this option needs a lot of homework since the ownership may remain with external agencies, while responsibility of operation and maintenance besides timely repayment rests with the plant management, e.g. getting a packaged boiler on hire instead of buying it
- Getting certain processing jobs done in other units on contract (making payment on per MT output) basis instead of installing equipment in own plant, e.g. evaporation of dilute solution/filtration of liquids/conversion of sulphur to sulphuric acid, etc.

1.8 Technical Specifications

- As described earlier, the need to replace/add new equipment is to be firmly established and an approximate budgetary provision may be made. Prima facie, the investment should have a reasonable payback period, *which is acceptable to the management* after a cost–benefit analysis is done (benefits expected and all costs required for operation and maintenance of the new equipment).

- Technical specifications are to be worked out by design engineers in consultation with the shop floor/operational staff. These shall also be examined by experts and management (while carefully considering the future marketing and production plans of the company, the actual working and climatic conditions, etc.).
- This is necessary if large investment is involved for the new equipment.
- Inquiries and further action for procurement should commence only after this, so that time, energy and money is not wasted in clarifying various doubts/queries raised by fabricators and suppliers.
- *Suitable alternative specifications should be worked out in advance so that in case equipment is not available as per original specifications (or may become available after only long delay), one can proceed to procure the next best machinery. This is only for making a compromise in some special situation—need to meet urgent demand for the product by a prestigious client, immediate replacement of a key machine, which has broken down.*
- However, care should be taken not to dilute the critical specifications too much, e.g. (i) use of mild steel (MS) instead of stainless steel (SS) or (ii) use of thinner gauge sheets, which can result in inefficient or unsafe (or both!) performance.

1.9 Financial Implications of Procurements

After deciding on the purchase of new equipment or machines, the management can proceed to examine the financial implications in following situations:

- Confirmation that in-house modification or fabrication is not possible.
- Discussions with consultants and getting convincing advice to go for new equipment.
- Specification sheets have been prepared by own engineers (in-house personnel), which clearly show that existing units will not be able to perform as per requirement.
- *Management shall convince themselves that these have been prepared only after a study of history cards, future requirements as projected by the management, and the definite need for replacement of old equipment has been established by proper reasoning*.
- Take a close look into schemes like BOOT, BOM, BOT, BOMT and BOOM, which can reduce the initial capital requirement. The payment for assets thus acquired through investment made by vendors or others are to be paid back from the profits generated.

The purchase order should be prepared only after considering all technical details as given earlier and the following expenses also (since funds are to be arranged accordingly). *Having taken into account all such matters,* the total cost of procurement *can be correctly calculated.*

ROI and payback period shall be estimated on the basis of expected revenues/savings and final decision to be taken for release of purchase order.

- Ex-works price of equipment
- Advance payment requested by vendor for commencing fabrication if order will be placed with him. This is generally done for purchasing steel items, bought out components, etc. Big reputed parties, however, are resourceful and do not ask for such advance payment. Purchaser shall look into the credentials of the vendor
- Credit may be offered by vendor—this should be explored, if possible, as it can ease the cash flow required by the purchaser
- Taxes and levies applicable
- Packing and forwarding charges
- Inspection (including stagewise inspection) charges and expenses involved in sending representative to fabrication workshops (especially foreign workshops)
- Loading and unloading charges
- Insurance costs for transit
- Performance trial run costs
- Bank charges, interest on loan, initial margin money deposit and any other applicable fees
- Consultant's fees
- Contingency requirement (can be 5–10 % of estimated costs)
- Expenses on correspondence, documentation, etc.
- Licence fees and permissions to be obtained from various statutory agencies for installing and commissioning equipment if operating at higher pressures than before or if old pressure vessels are replaced completely
- Agreements with labour unions if they have some apprehensions about the new machines
- **Cost of dismantling existing equipment—*see below***
- Production loss due to idle time of plant
- Cost of modifying/augmenting auxiliary facilities and connections for new or modified equipment
- Excessive consumption (wastage) of raw materials, power and water may take place during initial plant runs that are stabilised
- The products produced in the initial few days after commissioning may contain dirt, moisture or may not be as per specifications till the plant operations involving new equipment are stabilised
- This product cannot be sold in the market at the expected price and hence it will have to be stored separately and either purified or recycled into the plant
- If this is not possible, then the product will have to be sold at a low price to some customers who may be able to accept it
- Environmental pollution load will also be more till the plant is fully stabilised
- Cost of maintaining supplies to customers during the period when one's own plant is stopped due to modification work

Dismantling of old running equipment to make way for installation of new equipment should not be done in a hurry because it can bring the entire production activities to a halt. It is advisable to install and commission a new piece of equipment and watch the performance for a few weeks before the old one is dismantled.

It is imperative that the finished product must meet all the specifications of the customers when the new units are running. Consumption of raw materials and utilities must be as per guaranteed figures and there shall be no pollution. All safety devices and interconnections must be in working order.

- Cost is incurred for floating enquiries, shortlisting of vendors and placing orders. (Add cost of *visiting actual working installations if a new or complicated technology is involved*)
- New foundations, sheds, support structures and electrical cables required for installation. It may be possible to use old cables if the new equipment has almost the same electrical load and existing cables are in reasonably good condition.

Money is spent for erecting, testing, preheating and curing (if required), commissioning and starting up. Items like fuel, water, steam and start-up lubricants and chemicals are also required when a fresh piece of equipment is being commissioned.

Extra manpower is also required even though engineers and technicians are sent by vendor for the erection and commissioning work.

Training must be given to operators and maintenance crew of the purchaser to make them familiar with the new machinery. The vendor may be asked to provide this training for which additional fees are generally demanded.

Financial incentives: n some countries the government gives certain incentives in the form of increased depreciation allowance or tax concessions on amounts spent on equipment installed for higher energy recovery/efficiency, pollution control, etc. The purchaser shall find out if these incentives are still available and applicable to the new equipment.

2 Classification of Equipment, Inquiry Document and Instructions to Vendors

As described earlier, the need to replace/add new equipment should be firmly established and an approximate budgetary provision should be made. Prima facie, the investment should have a reasonable payback period, *which is acceptable to the management* after a cost–benefit analysis is done (benefits expected and costs involved for the operation and maintenance of the new equipment.)

Technical specifications should be worked out by design engineers in consultation with the shop floor/operational staff. These should also be examined by experts and the management (while carefully considering the future marketing and production plans of the company, the actual working and climatic conditions, etc.).

This is necessary if large investment is involved for the new equipment.

Inquiries and further action for procurement should commence only after this, so that time, energy and money is not wasted in clarifying various doubts/queries raised by fabricators and suppliers.

Suitable alternative specifications should be worked out in advance so that in case equipment is not available as per original specifications (or would become available after delay), one can proceed to procure the next best machinery. This is only for making a compromise in some special situation—the need to meet urgent demand for the product by a prestigious client or immediate replacement of a key machine, which has broken down.

However, care should be taken not to dilute the critical specifications too much, e.g. (i) use of mild steel (MS) instead of stainless steel (SS) or (ii) use of thinner gauge sheets, which can result in inefficient or unsafe (or both) performance.

The following pages present the guidelines for procuring process plant equipment by considerations of important specifications. The following broad classification of the equipment is done in order to analyse the expenses on main production units, utilities, auxiliary services, etc. The expenses can be booked under the heads of new projects, major revamping/modernisation, annual maintenance shutdown jobs and regular maintenance.

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The classification is thus as follows:

- Facilities for feeding of raw materials
- Reactors and main process equipment (e.g. heat exchangers, filters, etc.)
- Heat recovery, steam generation and utilisation equipment
- Auxiliary equipment
- Material handling equipment
- Utilities and heating systems
- Instrumentation and process control
- Laboratory facilities
- Protective linings, insulations and cladding
- Effluent treatment plant, scrubbing systems, waste disposal
- General equipment
- Product dispatch
- Maintenance facilities
- Fire fighting system
- Personal safety items

2.1 Instructions to Vendor

Data sheets and inquiry document should be prepared by mentioning specific details for the items to be procured as per broad classifications given.

The purchaser should instruct the vendor to send the offer documents, which should fully comply with data sheets, general conditions mentioned and instructions given in the inquiry document.

The offers can be compared on this basis and shortlisting of vendors can be done.

The data sheets must specify full details of the following:

- Required performance during normal operation *along with lower and upper limits,* i.e. in case of a pump, the lowest and highest capacity and discharge pressures required can be given in the data sheet. Likewise, the operating temperatures, concentrations, etc. under normal condition as well as minimum and maximum values can also be specified.
- *The vendor shall also provide complete performance data of equipment offered (e.g. capacity–head–power–speed curves for pumps).*
- **Material of construction (MOC)** of all parts should be suitable for site and process conditions as given by purchaser.
- The inquiry document must clearly define the performance guarantee terms with respect to all outputs from the equipment and the consumption of all inputs such as power, water, steam, raw materials, etc.
- Test certificates for all MOC and all bought-out components should be given by the vendor.

A general arrangement drawing showing the battery limits of scope of supply must accompany the offer. It should also show preliminary layout, overall dimensions, weights, maintenance clearances, and maximum erection and maintenance weight for main components.

- The space required for installation of the unit and for maintenance activities later on should be clearly indicated in the offer. This may include cleaning and replacement of internal tubes, tower packing, impellers of blower, replacement of belt drive pulleys, etc.
- Instrumentation of the equipment should be offered in a calibrated and fully tested condition.

The vendor can also offer an alternative arrangement (if he has supplied it earlier) for the complete assembly; but without additional cost to the purchaser. The vendor should give at least two references where this alternative arrangement has been working satisfactorily for at least 2 years (or 16,000 h running).

- The design and fabrication must not violate any statutory regulations, and should be as per international industrial codes and standards (e.g. ASME Sec VIII, JIS, IBR, etc.) followed by latest amendments unless a different specification is mentioned in the relevant equipment specification data sheet. The offer shall be made on this basis.
- Good engineering practice and industry standards should be followed if no specifications are given in data sheets and no critical application or handling of dangerous, toxic or inflammable materials is involved. *However, as a matter of precaution, the purchaser should obtain approval from statutory authorities of such equipment before using them*.
- In case of any discrepancy/conflict between requisition and its associated specifications, data sheets and the codes, standards and regulations, the vendor should bring the matter to the purchaser's attention for resolution.
- The vendor should mention the thickness of vessels and corrosion allowance as well as test pressure.
- Suitability as per process flow diagrams and piping and instrumentation diagrams must be confirmed by providing all inlet and exit nozzles and their orientations. Overall dimensions and weight must not disturb other process unit and structural supports.

Noise Limit

- Unless specified otherwise in applicable standards, the sound level should not exceed 85 dB at 1 m from casing/surface and 1.5 m above the equipment base. The control of sound to meet this requirement shall be the sole responsibility of the vendor. Suitably designed silencers or acoustic enclosures should be provided by the vendor at no additional cost to purchaser.

The vendor should include all additional items that he deems necessary for proper completion and safe operation, in order to satisfactorily achieve the process and mechanical requirements even though such items may not be mentioned in the data sheets. The vendor should clearly state technical exceptions or deviations that may be considered by the purchaser. If no exceptions, exclusions, optional parts or separate prices are specified it will be assumed that the offer is completely in accordance with the requirements of the purchaser and applicable specifications, drawing, codes and standards will be followed. In case this is not possible, the vendor must give a list of exceptions and deviations in his offer.

2.1.1 Exclusion from Scope of Supply

- Items required by the purchaser in his requisition and their relevant applicable specifications but not included by the vendor in the offered *scope of supply* should be specifically listed in the offer under "exclusions."

The vendor shall also specifically mention all items that are necessary but will not be supplied. *These will have to be arranged by the purchaser at and will cost an additional amount*.

Additional equipment that are not a part of the equipment being offered but are necessary for the proper, safe and smooth functioning of the same can be clearly mentioned and offered by the vendor as an *optional extra supply* in the offer. Charges for these items should be mentioned separately.

2.1.2 General Conditions

An inquiry document should mention the following:

The following points should be easy:

- To flush out and clean the equipment before taking up a maintenance job. Complete draining out should be easy and safe. There should be minimum residual quantities of toxic or inflammable material in crevices or idle pockets.
- To open the equipment for inspection and replace damaged internal parts.
- Easy to understand the construction, operate and carry out maintenance.
- To carry out breakdown maintenance and replacement of internal parts.
- To vent out internal toxic or inflammable gases. (Provision of bolted manholes instead of welded manholes wherever possible—but not recommended for high pressure or units handling dangerous materials.)
- Safety devices and interconnections as required by the purchaser should be provided by the vendor to ensure safe and trouble-free working.
- The vendor must provide lifting lugs/eyes on the equipment and all special tools required to remove and re-install components.
- The vendor should supply sufficient spares for commissioning as well as ensure 2 years smooth operation considering normal wear and tear.
- The vendor may give his standard sub-vendors' list, but these shall be approved by purchaser.

- The equipment shall be fully assembled on a transportable base plate and delivered in the minimum number of sub-assemblies to minimize site activities.
- Parts of equipment or instrumentation shall be properly tested and packed. Each sub-assembly shall be complete in all respects at time of final inspections. They shall be tested as per standard methods/tests agreed.
- All items shall be packed in appropriate seaworthy/weather proof manner for safe transportation. Weights of items and dimensions of each container shall be clearly informed.
- The equipment shall be fully assembled on a transportable base plate and delivered in the minimum number of sub-assemblies to minimize site activities.
- First fill of all lubricants, greases, etc. to be given free of cost by vendor.
- *Equipment delivery*:
  The vendor should clearly mention the final delivery schedule of the equipment from date of (starting from commencement of the job) technically and commercially clear order.
  Schedules for stagewise inspection of different parts and tentative final inspection schedule of the equipment should also be given.
- The vendor should agree to provide drawings for civil foundation or for locating foundation bolts on placing order. If special foundations bolts are required then they should be supplied by the vendor.
- The vendor should agree to provide site assistance for erection and commissioning—either free or on a chargeable basis (*to be written in offer*).
- The vendor should give the details of site arrangements to be kept ready by the purchaser before the equipment is despatched from vendor workshop. This should include power, water, chilled water, steam, compressed air, fuel for initial heating, etc.

The vendor should offer the following items and services with separate quotation:

- Spares for smooth operation for 2 years which are necessary for replacement due to normal wear and tear.
- Training at vendor workshop or at a plant where similar equipment has been running satisfactorily for past 2 years and at site (lumpsum price). The training should be for at least two engineers, operators and maintenance technicians deputed by the purchaser. Generally, expenses for such training are paid by purchaser, but they can be shared with vendor also. The duration of training can be worked out mutually.
- The vendor should provide at least three copies each of the erection, commissioning, operation and maintenance manuals.

The vendor may be asked to offer an annual maintenance contract for the equipment offered by him. This can ensure proper servicing and replacement of worn out spares by Original Equipment Manufacturer (OEM). Besides, the equipment should be handled by trained technicians only.

While awaiting the offers, the purchaser may internally discuss with his own technical team about the possibility of reuse of some items from existing old units such as:

Supports and grids from filter, converters, trays from distillation columns, body or shells of units, some usable catalyst, active carbon, filter cloth, tower packings, lubricating oils, instrument cables, refractory waste, molecular sieves, etc.

2.2 Quality Assurance Plan (QAP)

The purchaser can ask for this while floating inquiries also (for costly, intricate, high-tech machinery or for bigger procurements like a complete plant).

However, the shortlisted vendors must be asked to send the QAP to enable final selection and negotiations.

2.2.1 The Vendor Should Include in the QAP

- Codes and standards followed by the vendor while designing and fabricating the items.
- How is the material tested? In house/outsourcing with test certificates
- Storage facilities at vendors' shop should be open for inspection
- Traceability of material—procured, stored and issued for fabrication—whether the same material (e.g. *boiler quality steel plates), which was tested earlier has been stored properly and is used for fabrication for the purchaser's order*.)
- Stage inspection during fabrication
- Final inspection and performance test—if possible at vendors' shop

2.2.2 Visit by Purchaser's Inspection Engineer to Vendors Works

- Visual inspection of the unit, to check accuracy of overall dimensions, calibration of tanks
- Ease of maintenance—to open, clean, flush, lubricate, replace parts and internals
- Fitment and alignment accuracy
- Physical and chemical test of MOC used
- Surface preparation and internal inspection report by contractor
- Hardness test
- Ultrasonic test for thickness
- Radiography test and dye penetration test—for welded joints
- Welder's qualification and weld procedure test—before starting fabrication of pressure vessels
- Post weld heat treatment
- Pressure test, Indian Boiler Regulations (IBR)/other statutory agencies' compliance certificate

- Balancing of impeller/moving/rotating parts
- Vibration test
- Performance test—capacity, head, power consumption
- NO load/free running test
- Load/overload test
- Measurement of speeds
- Acoustical test
- Manufacturer's test certificate for bought out items
- Spark test of lining for rubber, glass, Poly Tetra Flouro Ethylene (PTFE), fibre glass linings
- Load/deflection test of specimen

2.2.3 Documents to Be Included in the QAP

- Approved GA drawings and other reference drawings
- Stamped drawings, which will be released for fabrication/manufacture
- Relevant catalogues of bought out components
- Line/layout diagrams (*this is for confirmation of scope of supply*)
- Approved erection procedures will be given afterwards
- A copy of unpriced purchase order with specification and amendments, if any. *This is for confirmation of scope of supply (during visits for inspection) as reference only*
- Calibration certificate of all measuring instrument
- Guarantee certificate

3 Solid Material Feeding Equipments for Process Units

Solid material feeding needs one or more types of equipment given below:

- Electrical Overhead Travelling (EOT) cranes and hoists (in process areas, in warehouses)
- Belt conveyors
- Bucket elevators
- Screw conveyors
- Pneumatic conveyors

3.1 General Information to Be Given to Vendor

The following information should be provided to vendor in order to get satisfactory performance from the equipment.

- Material to be handled, its melting point, bulk density, average particle size/lump size, angle of repose, hygroscopic nature, etc.
- Tendency to form corrosive/explosive or inflammable dust during conveying. Some materials such as water sprinklers, electrical earth connection, nitrogen blanketing, may need special precautions.
- Whether the material is moist/dry (the blower, ducts, dampers, feed points, etc. of the feed system will have to be designed accordingly).
- Whether installation is outdoors/in a shed.
- Obstructions such as support columns, beams, major pipelines in the path of material transfer.

The expected running hours of the feeding units depend on the intermediate storages provided (a storage bunker/silo). If it can hold the raw materials sufficiently for

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4–6 h consumption in downstream units, one can attend minor breakdowns without interruption in production. If an intermediate storage is not provided, there is a possibility of the downstream process coming to a halt due to every stoppage in the feeding system.

3.2 Electrical Overhead Travelling EOT Cranes

These are generally used for lifting and transporting solid materials, bags, machinery, spare parts, etc. and for facilitating in situ maintenance work during major shutdowns (change of gear box, removal of electric motor). *These are used where a number of process units and reactors are installed in one common shed-like area.*

3.2.1 Procurement/Selection Criteria

- Purchaser should inform the following requirements to the vendor:
- Vertical speed to be measured in metre per second
- Horizontal travelling speed (with load) to be measured in metre per second
- Maximum lifting capacity to be measured in Metric Tonnes (MT)
- Time of operation each day: for very large warehouses, it is advisable to install more than one EOT crane (e.g. fertilizer bag storages)
- Maximum span (depends on the width and side clearances of the warehouse)
- Maximum length of travel (depends on length of warehouse)
- Whether operation on curved path (radius of path to be specified by purchaser) is required
- Avoid cantilever-type overhead rails (i.e. projecting rails outside the warehouse building is not advisable)
- Limit switches and guides for proper winding of wire rope on drum
- Need for pendant switches and controls for sideways, up/down and to-and-fro movements of lifting hook, control cubicle
- First charge of lubricants to be obtained from manufacturer
- Erection and commissioning assistance to be obtained from manufacturer
- Details of power supply available at site (voltage, phases and frequency)
- Whether any inflammable or explosive materials are being handled or will be present in the vicinity of the EOT crane (*motors should be flameproof in this case*)

3.2.2 Vendor to Give Details of

- Rating and speed of motors for vertical and horizontal travel.
- Maximum load carrying capacity of link chains and wire ropes used (*with test certificates*).

- Automatic brake to prevent the load going down in case of power failure.
- Rating of gear box and accessibility of gears for maintenance.
- Empty weight of the unit (but including control console)—*to enable selection of side rails.*
- Fully loaded weight.
- Size of wheels for movement of control console (trolley).
- Size of rails to be fixed along walls of warehouse.
- List of spares for two years of smooth operation.

3.3 Hoists

- Lifting capacity required and expected time of operation each day.
- Height from ground level to which the load is to be lifted.
- Height at which the hoist will be mounted.
- Provision of wire rope guide (for proper winding on the drum).The hoists should conform to IS: 3938 or its equivalent international standards for wire rope hoists with latest amendments.
- Vendor should be asked to give test certificates for wire rope lower pulley, lifting hook, hook pin and supply at least two extra lengths of the wire rope as spare.
- Lifting speed in metre per minute.
- Limit switch for preventing overhoisting.
- Whether pendant switch and fine control on the to and fro and up and down motion is required.
- Horizontal to-and-fro travel speed required in metre per minute.
- Weight of hoist alone and also with maximum load being lifted. This will enable design of side rails as well as the main rail on which the hoist will travel to and fro.
- Gear box should be easily separable from hoist and should have proper lubrication arrangement.
- The motor should be of high starting torque type. Vendor should specify HP, RPM, frame size, whether it is single or three phase. Flameproof motors and switches should be recommended for areas having inflammable materials.
- The motor should have proper weather protection as per international standards.
- Size of support rail for the hoist (to be informed by vendor).
- Load test certificate for the hoist should be provided by the vendor.
- Overload limit switch should be asked for.
- Clear headroom required at the top for maintenance work.

Although hoists are used for material handling, they can also be used for maintenance work (removal of shaft, lifting motor or gear box, etc.) and hence the load-lifting capacity should be specified accordingly.

3.4 Belt Conveyors

Belt conveyors can be used for carrying loose materials such as bauxite, coal, rock phosphate in lumps, or items packed in small boxes.

These are also used for transporting material in a straight line or to an elevated location (for feeding to a bin/silo). A diverter at the top of the conveyor can allow the material to be sent to the chosen silo/bin. Stores often have conveyor belts at the exit to move finished goods for loading on trucks for dispatch. Slope and linear speed of the conveyor should be such that there is no chance of spillage of material inside boxes.

3.4.1 Main Components of the System

- Multilayered continuous belt
- Driven and driving pulleys
- Gear box (as per design of the drive)
- Drive motor
- Charging hopper
- Belt weighing device/instrumentation
- Discharge chute and distributor at delivery end (if the material is to be fed to different silos)
- Idlers and support rollers
- Supporting structure
- Inspection walkway
- Rain protection cover shed

3.4.2 Properties of Materials to be Taken into Account

- Form in which material is to be transported: loose powder, lumps, small boxes
- Physical properties of material: density, angle of repose, inflammable or toxic nature, hygroscopic nature/effect of weather

3.4.3 Considerations for Selection

Options to be considered if material is in the form of loose powder:

- Pneumatic conveying through ducts by air pressure or under suction.
- Filling bags/containers and movement by overhead travelling cranes/small fork lift trucks.
- Filling trolleys and transport by movement on tracks.

Belt conveyors may be found to be the best option since it may not be possible to install overhead travelling crane system or to lay tracks for movement of trolleys.

The latter method is more cumbersome and may need operator attention continuously, while the belts can operate almost unattended.

3.4.4 System Design Considerations for Belt Conveyor

The angle of repose of the material should be considered while deciding the slope over which the belt should operate. In case of very steep slopes the lumps may slide/spill. The design should be such that loose material, small boxes or packets should not generally spill/slide during transport. The following points should be considered while designing a belt conveyor:

- Difference in elevation between the starting (loading) point and the end point (discharge point) and the distance over which the material is to be carried.
- Path of travel: inside a shed or outdoors.
- Obstructions in the planned travel path: could be support columns, pipes/ducts, buildings or structures, storage tanks, etc./disturbance, which may be created by the belt conveyor.

In some cases, it may become necessary to move the material in a different direction and not in a straight line. A smooth bend (long radius type) of the conveyor belt is recommended in such cases.

If it becomes necessary to have a 90° or close to 90° bend in the belt conveying system, two different belt conveyors may be employed, so that material from a belt conveyor falls on the other one below it.

Feed hopper: it is advisable to provide a hopper at the end of the first belt conveyor, which stores the material and feeds it to the belt conveyor operating below, (the bottom belt) whose speed is slightly more than that of the upper belt to avoid accumulation and possible overflow of the material from the hopper.

The hopper also allows for a short stoppage of the lower belt for a quick inspection or attending to a minor fault (e.g. a stuck-up idler, extra sideways motion).

In instances where two or more belt conveyors are employed, a longer breakdown in any one of the belt conveyors can bring the entire feeding system to a halt.

Pneumatic conveying can be considered for such situations, but belt conveyors may be found convenient in cases where the material is in the form of lumps (not very light or fluffy that it can be blown away by air).

Shop floor engineers should take into account the ease of operation, maintenance and power consumption.

System should be designed with protective shed or covers along the length so that the material should not get damaged due to exposure to weather (sunlight, rain and snowfall). The vendor may or may not offer this.

The total length of the belt should be considered. Sagging may occur (*see belt tightening*) if long belts are used.

Purchaser should inform vendor both minimum and maximum amount of material to be transported and the desirable speed range of the belt speed. A belt speed of more than 2 m/s may make observations somewhat difficult. Hence, a variable frequency drive control or a speed variation gear box should be included in the drive arrangement.

Carrying capacity: weight to be carried per hour by the system. This depends on physical load bearing strength of the material, speed of the belt and loading per metre of length.

All components of the drive mechanism should be designed for 150 % of the expected load due to fully loaded belt moving with maximum speed. Drive motor should be rated accordingly.

The support idlers as well as side idlers should operate with as low friction as possible.

A belt weighing device should be provided for a moving belt. This should be calibrated every 15 days by loading pre-weighed packets and then running the belt.

A feeding hopper should be provided to continuously load the belt along with a belt-weighing system. The chute can discharge at the end to the desired bin/silo when a divider is provided.

A screen with openings of 100/150 × 100/150 mm below the feed hopper should be provided to prevent big lumps from getting loaded on the belt as these can spill or cause erosion (can peel off upper layers of belt and damage it) due to their concentrated weight at one spot.

Hygroscopic materials may tend to stick to the belt and it may be necessary to provide a scraper edge at the discharge end. There is a possibility of incorrect reading by the belt's weighing instrument if stuck up material is not removed properly (for total quantity of material delivered by the system).

A collection trough may be provided below the belt for the spilled-over material or the area below the belt should be swept regularly to collect the material that has fallen down. The area below should be normally cordoned off if there is a chance of sharp lumps or boxes falling down. Warning signs should be displayed.

Material of Construction (MOC) of belt The belts generally consist of one or more layers of material. An underlayer of material such as PVC, rubber, polyester, nylon and cotton provides linear strength. The cover layer should be made from various materials suitable for the intended use of the belt.

Rubber or plastic compounds are also used as cover materials for unusual applications, to convey items with irregular bottom surfaces.

Purchaser should check the load-carrying capacity of the belt by supporting a test piece on two supports one metre apart and putting loads of the material. Test certificates may also be obtained from vendor.

The capacity of belt to convey objects that are regular or irregular-shaped, large or small, light or heavy should also be confirmed.

3.4.5 Safety Arrangements

Conveyors carrying inflammable materials (sulphur, charcoal) should be provided with sprinkler systems and switches for stopping the drive motor (movement of belt) to prevent spread of fire, which can happen if the belt keeps moving and the burning lumps fall all over the place.

A wire rope (trip cords) should be available along the entire length of the walkway by the side of the belt. It should trip the drive motor by activating appropriate switches when the string is pulled. This will allow workers to immediately shut down the conveyor when a problem arises.

Warning alarms should be provided to notify employees that a conveyor is about to be started (especially after shutdown for maintenance work). Code words may be sent over mobile telephones.

3.4.6 Tightening of Conveyor Belt

Belt tensioning arrangement should be provided by vendor to make it tight as per need (to maintain speed of movement).

Many variants of the design could be offered by vendors. The one easiest to use and maintain should be chosen after inspection by shop floor engineers.

During normal operations, the conveyor belt may get stretched and lose its tension; as a result it may slip on the drive pulley and it may/may not move forward at the required speed. In order to keep the belt under tension, it may be necessary to periodically shift the drive pulley a little forward over the (generally provided) adjustable slots. However, this needs a stoppage of the system and maintenance crew. Belt alignment on the pulleys can get also slightly disturbed.

An alternative is to use a hanging pulley system on the bottom side of the conveyor belt, which has weights on it, so that it can keep the belt under tension at all times. It should be ensured that the weight on the hanging pulley is not beyond the prescribed limit as it can damage the belt.

Provision of a walkway should be made along the length of the belt conveyor for monitoring movement and for maintenance should be designed, supplied and erected by the vendor.

3.5 Bucket Elevators

A bucket elevator can lift a variety of bulk materials from light to heavy and from fine to large lumps (most often bauxite, grain and fertilizer) vertically.

Some typical situations where employing bucket elevators should be considered are:

- If the material is not available in a suitable condition (e.g. as a light powder) and pneumatic conveying through ducts by air pressure or suction cannot be used.
- If filling bags/containers and movement by small fork lift trucks or hoists are cumbersome.
- If installation of EOT cranes is not possible in the premises due to space constraints. If required, additional manpower is not available.

3.5.1 Continuous Discharge Type

These are used when the material is to be taken vertically upwards. The buckets are very close to each other and they discharge by gravity. Their operating speed is generally lower than centrifugal discharge type. An increase in capacity can be obtained by using a large number of buckets and not by increasing the vertical speed (*which may increase wear and tear of chain and sprockets*).

3.5.2 Centrifugal Discharge Type

In case of centrifugal discharge type the load is thrown out of the buckets by centrifugal force as they pass over the upper wheel. These can be used for almost any material that can get freely discharged from the buckets.

High-capacity units run with centrifugal discharge. They have spaced buckets with rounded bottoms. The material from top bucket is discharged by the action of centrifugal force on the discharge chute. These elevators run at high speed and can have higher capacity than low-speed elevators.

For carrying certain materials—mostly dry lumps of 40–60 mm size (which can spill over)— the buckets can be triangular in cross section, with little clearance between them. This type of bucket elevator runs at a lower speed (not more than 0.4–0.6 m/s).

3.5.3 Properties of Materials to be Taken into Account

- Physical form in which the material is to be transported: loose powder, lumps, maximum lump size dimensions permissible should be discussed with vendor. The size of the material is generally less than 150 mm.
- Properties of the material: bulk density (high-density material can overload the buckets or can damage mechanical links at higher speeds), inflammable or toxic nature (chances of fire due to mechanical friction or buckets hitting the casing if the enclosure walls do not have sufficient clearance).
- If material needs protection from rain, dust and gases.

3.5.4 Main Components of the System

The Purchaser should discuss these with the vendor for intended use:

- Capacity of the buckets to contain the material. Purchaser should ask the carrying capacity of each bucket when it is about 50 % full. It is generally seen that the buckets may not get completely filled at the lower loading point due to many reasons: unavailability of enough material, repeated spilling out of big lumps, imprecise movement of bucket during loading, etc.

- Accessories for picking up the material and dumping at loading point for the buckets.
- A belt/chain to carry the buckets and transmit the pull (*speed of the belt/chain is important*).
- Means to drive the belt/chain and driving system for top pulley: gear box and electric motor. The system should be designed for at least 150–200 % of fully loaded condition at maximum speed.
- Safety enclosure for protecting the elevator (this is a must).
- Bins/silos for receiving the discharged material, availability of headroom at the top with provision of top cover for enclosure and for maintenance job on drive pulley, motor, discharge chute, etc. This will limit the maximum vertical travel and hence the number of buckets that can be fitted.
- Arrangement for maintaining the belt/chain tension.
- Work platform and inspection windows in the enclosure should be available at a convenient location.
- Material of construction: steel chain (small), steel buckets (for hard lumps) or rubber belt with plastic buckets (for lighter material) attached at short intervals.
- An adjustable diverter at the top of the elevator for sending the material to the chosen bin. The adjustment for diverter should be remote operated.
- Suitably located chutes for receiving the material in the bins/silos.
- Safety system: conveyors carrying inflammable materials need to be provided with sprinklers and easily accessible switches for stopping the drive motor (movement of chain) to prevent spread of fire.
- A wire rope (trip cords) should be available along the entire height by the side of the conveyor. It should trip the drive motor by activating appropriate switches when the string is pulled. This can allow the field staff to immediately stop the bucket conveyor in case of a problem. Overload tripping relay should be provided for the drive motor.
- Warning alarms should be provided to notify employees that the system is about to be started (especially after a shutdown for maintenance work). Code words may be sent over mobile telephones.
- High-capacity units run with centrifugal discharge. They have spaced buckets with rounded bottoms. The material from the top bucket is discharged by the action of centrifugal force on the discharge chute. These elevators run at high speed and have higher capacity than low-speed elevators.
- For carrying certain materials (which can spill over) the buckets can be triangular in cross section and with little clearance between them. This type of bucket elevator runs at slow speed, usually not more than 0.4–0.6 m/s.

3.5.5 Purchaser to Discuss with Vendor

- Convenient layout of the plant where the material is to be handled.
- Height from lower feed sump to upper storage hopper.
- Size, capacity and MOC of each bucket (any preference).

- Space available (length, breadth, and height) for the enclosure housing the buckets and drive chain.
- Feed rate of material in kilogram per hour (to be raised up).
- Motor HP, RPM and mounting position (by vendor).
- Gearbox and coupling arrangements with the system (by vendor).
- Lubrication and inspection doors should be provided at appropriate places for the gearbox, chain drive, buckets, etc. The doors should be big enough to enable replacement of damaged buckets, parts of attachment with drive chains, etc.
- If it will be possible to slightly overload the system by increasing speed of gearbox and providing bigger motor. (Purchaser should discuss this with the vendor, since it will be useful when plant production rate has to be increased.)
- Vendor to include tripping devices/switches for emergencies, e.g. fire, jamming, chain break.
- Provision of water sprinkler, DCP cylinders, CO_2 cylinders, etc. when inflammable materials are being handled; *may be done by purchaser in consultation with the vendor***.**
- Location of work platform for maintenance and inspections to be done by purchaser. This will, however, add to the cost of the system.

3.5.6 General—Vendor to Inform the Following

- Type of bearings and arrangement for their lubrication when the unit is running.
- MOC of upper and lower chain sprockets.
- MOC of chain.
- Arrangement to adjust position of motor for tightening the chain drives (since it may become loose after a few days). Slots should be available on the base plate on which the motor is fitted.

3.6 Screw Conveyors

Screw conveyors can be used for feeding solid powders at a controlled rate corresponding to the RPM of the shaft. The drive can be through a gear box and Variable Frequency Drive (VFD)-operated motor if there are chances of overloading the motor when material gets crushed or stuck in the fins. An instantaneous trip relay should also be provided for such condition.

These have helical fins fastened on a shaft that rotates in a trough. The material gets conveyed by continuous pushing action of the fins. However, it can get crushed and thoroughly mixed as it passes through the conveyor.

The MOC of the fin should be made of hard material (cast steel or having tips of manganese/vanadium steel) if abrasive material is to be handled.

The trough should be considerably larger than the fins so that the material rubs against itself rather than the trough. The diameter of trough, as a rule of thumb, may be about 12 times the size of the biggest lumps in the material. Screw materials can handle grain, crushed coal, sand, ash, gravel, etc.

Power requirements of screw conveyor can be estimated as:

Sum of power to run the equipment alone + power to overcome the friction of the material being moved + power required to lift the material to the given height.

Vendor should inform purchaser about drive motor HP, speed and speed control provided for the conveyor.

3.6.1 Purchaser Should Inform the Following

- Lump size of material
- Whether it is abrasive in nature
- Angle of inclination of the screw conveyor—*material may get further crushed if inclination is steep or may spill out*
- *Special heavy duty bearings should be provided for the shaft if angle of inclination is steep. Position of inlet and elevation of discharge chutes desired*
- *Length and inclination of path required*
- Intermediate hanging supports may be required for the central shaft if the length is more than 3 m
- Whether electrical interconnection is required with downstream or upstream equipment
- Type of cover (*powdered material can spill out if proper cover is not provided*)
- Inspection doors required
- Heating or cooling jacket required for the trough

3.7 Pneumatic Conveying System

- This is especially useful for carrying light materials, such as fluffy powders, over long distances through ducts that can be taken around obstacles or walls or support columns/beams, where it may be difficult to use overhead travelling cranes, belt conveyors or rail tracks (for carrying trolleys).
- Also useful for carrying such material that can spill or get wet if carried through belt conveyor or screw conveyor.
- Useful for carrying over a path where change of direction or elevation is required. (It could be difficult with screw or belt conveyor.)
- If carried in bags: the light material will have to be bagged at the supply end and then transported to the destination (reactors, silos and storage sheds). This method may become costly due to the cost of bags, transport machinery required (trolleys, fork lift trucks and overhead travelling cranes) and the cost of filling and then opening at the point of discharge.
- There can be considerable loss due to spillage and more manpower will be required if such methods are used.

3.7.1 Important System Components

- Covered feeding hopper and weighing arrangement
- Rotary air lock valve with speed control
- A high-capacity blower
- A well-designed path for the conveying duct

Vendor should give details of rotary valve for feeding at controlled rate (MOC, quantity per revolution, min/max RPM, speed control mechanism details—mechanical/electronic) and electrical alarm/interconnections for activating the system if the level in bins is low due to consumption by downstream units.

3.7.2 Limitations of the System

- Difficult to carry wet powder or explosive powder
- Very fine powders may be lost unless cyclone and bag filters are provided at the end of system, but these may add to power required by the blower
- Sharp 90° bends in the ducts tend to get choked due to the deposit of powder. The system works better with long radius ducts. Sufficient space should be available in the plant layout for this. *Provision of cleaning windows and work platforms near bend should be done. These add to the capital cost*
- Power consumption of the system can be more since considerable amount of air is also to be pushed through. It should be compared with power required to operate belt conveyor, EOT cranes, etc.

3.7.3 Considerations For Pneumatic Conveying Systems

- Material to be conveyed: is the material really fluffy? Or does it also contain hard heavy particles to some extent that may erode the blower parts or pipelines?
- Possibility of static electricity charge buildup during conveying of the particles
- Bulk density of the material
- Particle minimum/maximum
- Explosive/inflammable nature of powder
- Hygroscopic nature of particles: tendency to form lumps
- Distance over which material is to be conveyed
- Quantity to be conveyed per hour at various bins on the discharge side
- Planned operational hours per day. If the system is stopped, for, say one or two hours every day, it can be inspected and cleaned.
- Actual path of conveying the material—to be discussed with vendor
- Power consumption, blower capacity/pressure, etc.
- Duct diameter to be used and supports required for the entire length of the duct
- Vendor should be asked to provide a cyclone separator/bag filters at the discharge end (to prevent loss of very light particles)

- Inspection doors at bends should be provided. The ducts can be cleaned easily if the bends are flanged at both ends and proper supports are provided for ducts on both sides
- Manometers should be connected at appropriate places to detect choking in the duct/ bends
- Whether it is possible to use a straight pipe length from the feed point to the discharge point or a number of bends may be involved
- Vendor should be asked to specify the MOC of pipeline, blower, and the air pressure at which the system will operate. The blower capacity type and the power consumption of the motor should also be specified by the vendor
- Purchaser must compare the pneumatic conveying system with other modes of material transfer since the manpower required could be less and discharge to multiple points/bins can be made possible by opening appropriate valves in ducts for feeding at a controlled rate before taking the final decision

Equipments/Accessories for Handling of Fluids

4

4.1 Pumps

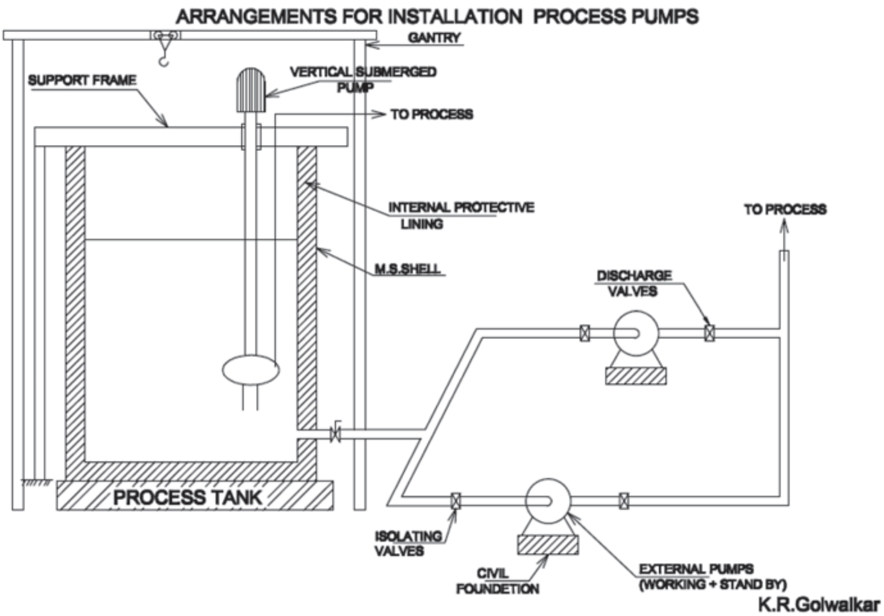
Use/Application *These are some of the most important equipment in a chemical process industry. They are required to pump out raw materials from storage tanks and feed process reactors, provide fuel to burners, provide cooling water to condensers, send product to storages, and fill tankers for dispatch.*

4.1.1 Considerations for Selection of Pumps

- Type of pump required
- Centrifugal: mono block, vertical submerged, multistage, with heating jacket
- Positive displacement: gear, reciprocating, metering type
- Special types like magnetic-driven (no direct contact with motor)
- Number of pumps required: running and numbers standby
- Liquid to be handled
- Temperature of liquid
- pH
- Density
- Viscosity
- Minimum and maximum capacity required in metre cube per hour or in litre per second
- Discharge pressure required: normal working and maximum
- Net positive suction head (+ve if available/−ve if not available)
- Whether liquid is clear or contains suspended solids (*This is an important consideration for selection of open/semiopen/closed impeller*)
- Suitably sized strainer should be provided at the suction of the pump to prevent erosion of the impeller due to the presence of abrasive particles in the liquid

K. Golwalkar, *Process Equipment Procurement in the Chemical and Related Industries,* DOI 10.1007/978-3-319-12078-2_4

- Installation and running conditions: whether the pump will be installed indoor or outdoor; minimum and maximum ambient temperature likely to be encountered
- Horizontal external mounting or vertical submerged mounting in a tank?
  - *Refer to the figure below. In case of horizontal mounting of another foundation, complete suction and discharge piping with valves can be kept ready for immediate changeover if the pump breaks down. But this will need more floor space, sets of valves, electrical cables, etc. For these pumps, external dyke walls are required in order to contain any toxic/corrosive liquid that may leak out from the pump and acid/alkali resistant tiles are also necessary. Mechanical seals are required for toxic/inflammable/corrosive fluids (oleums, chlorosulphonic acid) so as to prevent leakages*
  - *In case of vertical submerged pump, a gantry with a hoist or chain pulley block will have to be installed permanently for taking out the pump for maintenance and putting in another one. The spare pump may not be kept immersed all the time in the tank for changeover*



  - *Completely submerged pumps can also be used but only for water, since they can easily be damaged or suffer from corrosion in case of corrosive fluids like sulphuric acid and oleums. These pumps do not require gland packing and priming tanks. Net Positive Suction Head (NPSH) is always available since* *it is submerged in water. It, however, requires additional arrangements for support as well as its removal from the tank.*

- In case of horizontal pumps, it is preferable to have suction from two sides (balanced type). It should not become necessary to dismantle the suction and/or discharge pipelines for maintenance work on the pump
- Whether jacketed construction is required for keeping the liquid at optimum temperature. Heating/cooling medium to be used in the jacket
- Shaft sealing: whether ordinary gland packing is okay or water-cooled glands or special mechanical seals are required (for toxic, corrosive and inflammable fluids)
- Pump speed: high-speed pumps have more problems of maintenance though they may cost less due to their smaller size. Low-speed pumps run for longer periods without breakdowns due to less wear and tear, but initial costs and space required for installation could be more
- Vacuum pumps: free air delivery at standard/normal temperature and pressure conditions should be specified along with maximum vacuum to be created in mm Hg. The temperature of cooling water should be informed to the vendor, since these pumps do not perform properly in case the temperature of the cooling water is on the higher side (25 ºC)
- Material of construction of all wetted parts (e.g. impeller, shaft, impeller nut and volute)
- Any special bearing required
- Positive displacement pumps (reciprocating, gear): should have in-built safety/pressure relief valves, if possible. Otherwise, the vendor should be asked to supply dampening pot and pressure relief valve to be fitted on the delivery line along with installation details. A belt drive can also be considered as protection for the pump
  - An instantaneous electrical trip switch should also be provided to stop the drive motor if the pump gets jammed or the discharge is closed/throttled
- The pump should normally be complete with base plate, foundation bolts, coupling halves, etc.
- Drive motor should be preferably supplied by the vendor (unless a motor is available in-house) and assembled with the pump so that the unit comes ready for operation. Purchaser should ask for flameproof motor when inflammable liquids are to be handled
- Power consumption: the operating point of centrifugal pump should be chosen at the highest efficiency possible. Generally, the vendors/manufacturers offer a range of models, which cover the requirements of capacity, head, etc. However, the final selection should be done while keeping in mind the most likely (normal) condition in which the pump will be run. In case of positive displacement pumps the performance curves should be studied to select proper speed for the capacity and required head
- Special requirements (if any) should also be informed to the vendor (e.g. orientation of the discharge nozzle; any particular type of heavy duty bearings)

- Inspection and performance test: should be insisted on before despatch. Vendor should have the arrangement for running the pump at different flow rates, heads and speeds as required by the purchaser.
- Packing and forwarding: pump shaft should be properly supported and fixed on wooden planks in the packing case. Suction and discharge parts should be closed by wooden/mild steel (MS) blinds to prevent ingress of tramp material inside. These conditions should be laid down while ordering the pump.

4.1.2 Special Precautions for Boiler Feed Water Pumps

- Boiler feed water pumps must be suitable for handling water at high temperature since water will be at 95–100 °C due to the recycling of condensate/deaeration by steam.
- Instructions for levelling and tightly fixing the pumps on the foundations as well as for commissioning must be obtained from the manufacturer before they are used because slight movement is possible due to thermal expansion. Pump alignment with respect to motor must be carried out as per recommendations in the erection manual (preferably in the presence of manufacturer's representative).
- In case of misalignment as observed (by dial gauge) between pump and motor, thin brass sheets (shims) can be used for adjustment around the foundation bolts.
- The direction of rotation as marked on the pump must be checked with respect to the direction of rotation of the prime mover, otherwise pump will not deliver as per its rated capacity.
- Multi-stage Boiler Feed Water (BFW) pumps must have an Non Return Valve (NRV) between the pump discharge valve and the boiler/economiser water inlet valve so that any backflow of steam/high-pressure water does not take place when the pump stops.
- In order to keep the pump running and to avoid the possibility of churning, a minimum recirculation line back to the deaerator or feed tank should be provided. This is also required to maintain the feedwater temperature when the boiler is shut down for some time.

4.1.3 Metering Pumps

These are used to feed precise quantities of liquid for efficient operations. They also serve to minimise chances of excess feeding, which can lead to unsafe conditions (development of high temperatures or pressures in process unit). A typical example is feeding liquid sulphur to the furnace of a sulphuric acid plant for steady process operation.

It may be noted that centrifugal pumps can feed large amounts of water if the discharge valve opens more frequently or if there is less back pressure on the pump.

Metering pumps, however, can feed only at the rate set by the operator.

Purchaser should ask for the following information from vendor:

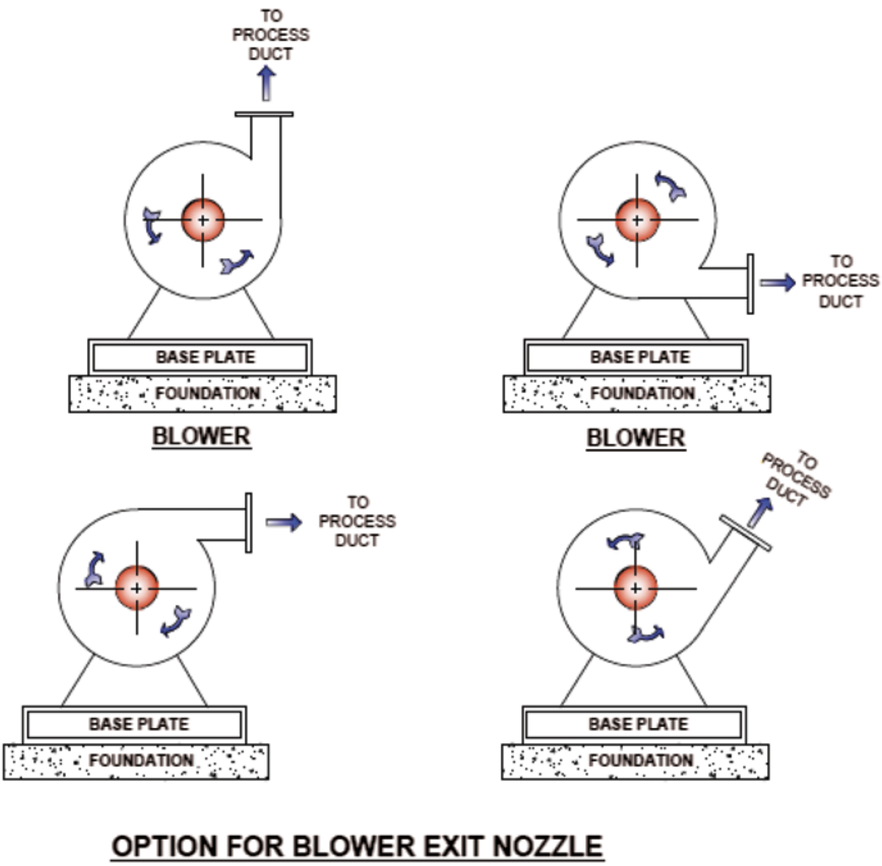
- Number of metering pumps required: running and on standby
- Liquid to be pumped
- Temperature of liquid: normal/maximum
- Melting and boiling point of the liquid
- Viscosity, density and pH
- Whether the metering pump should be jacketed for heating/cooling
- Preferred MOC of wetted parts
- Type of shaft sealing required (simple gland packing or mechanical sealing)
- Net positive suction head (NPSH) available or depth from which liquid is to be sucked
- Whether liquid contains suspended particles or it is clean (strainer will be required in suction line for proper functioning of the pump)
- Maximum discharge head required in kg/cm^2 or metres liquid column
- Maximum capacity required in l/h or l/min
- Details of the device provided for variation in capacity. The range of this device should be from 0 to 100 % of the rated capacity and it should be possible to lock it
- Whether capacity variation is done by varying the length of stroke (in case of reciprocating pump) or the speed (e.g. mechanical speed controller) or having a variable frequency drive for the motor
- Accessories offered by vendor should include bed plate, coupling halves, motor, safety valves for the pump, dampening pot for the discharge side (to smoothen out discharge pressure fluctuation)
- Purchaser may provide a bypass line on the discharge side to check the flow by measuring it separately before feeding in to the process unit
- Provision of Internal safety and rupture disc (on the discharge side) along with instantaneous trip for drive motor if excessive discharge head is encountered due to closed valves and choked lines (e.g. *solidified sulphur in pipes due to failure of steam traps)*
- Additional safety devices or interconnections provided

4.2 Blowers and Compressors

Selection criteria/details to be given to the vendors are:

- Intended location of the unit:
  - At sea level or at a height much above sea level.
  - In coastal areas where relative humidity and average rainfall are generally high or at a location where relative humidity and rainfall are less.
  - Whether installation is indoors (clean condition) or in dusty outdoor conditions (*may need filter at suction nozzle to prevent ingress of dust particles in the blower as they can cause erosion of the impeller and other internals*).

- Type of blower
  - Centrifugal/positive displacement type (twin lobe/triple lobe)
  - Gases to be handled
- Capacity to be measured in Nm^3/h
- Discharge head to be measured in mm water column or kg/cm^2
- Composition of gas mixture in mole % or volume %.
- Speed: in RPM for obtaining the rated capacity and head. High-speed machines may cost less due to their smaller size but are more prone to breakdowns. However, the maximum speed permitted by the manufacturer should be asked for
- Performance curves: capacity, head, power consumption, etc. at different speeds should be requested for. This will enable the purchaser to choose the most suitable model for his present as well as future needs.
- Operating temperature of gases measured in degree Celsius (normal, minimum and maximum should be specified) at suction side of the blower. Temperature at discharge side of the blower should be worked out by the manufacturer.
- Peripheral speed of the impeller: to be informed by the manufacturer (at high speeds, there is a possibility of the rubber lining coming off the impeller).
- Noise level (when operating at rated capacity): this should be below 70 dB at about 2 m from the blower. In case of higher noise, an acoustic enclosure will be required, which will add to the cost.
- Accessories offered: suction and discharge silencers, filters, bed plate, anti-vibration pads, pulleys/couplings, belts, belt guard, etc. Manufacturer should specify type of coupling, e.g. direct, flexible, fluid, etc.
- Protective devices: these will be very useful especially in case of jamming of lobes due to scaling, corrosion, dust, etc. The manufacturer should be asked to elaborate and give details of supply. *Electronic sensors for such jamming and for high bearing temperatures are generally available.*
- Type of drive: The manufacturer should be asked to supply the entire assembly of "blower-belt drive-motor"/blower-gear box-motor" "as a pre-assembled unit."
- The purchaser should, however, reserve the right of approval for the make and type of belts or gearbox, motor, etc. The gearbox should have proper lubrication arrangement. The first fill of oil and grease should be supplied by the vendor.
- The motor rating should be informed by the blower manufacturer so that Variable Frequency Drive (VFD) can be arranged accordingly.
- Orientation of suction and discharge nozzles: the purchaser should indicate his preference so that it becomes convenient to connect the nozzles to the process duct. This can reduce the cost of ducts as well as supports required for them. Refer to the figure.
- General assembly drawing showing blower+motor+gearbox/belt drive, etc.
- Total weight of the assembly and civil foundation details and drawings should be requested for.
- Safety devices should be available for preventing surging of the blower.



4.2.1 Compressors

- Type required: centrifugal/reciprocating/screw
  - Centrifugal compressors are used for medium flow to medium pressure applications
  - For high flows but lower heads, axial compressors may be asked for. The offer should be discussed by senior mechanical engineers with the vendor for the reliability, power consumption, space required, capacity control, etc.
- Capacity to be specified by buyer and measured in Nm^3/h at inlet
- Gas composition and properties
- Maximum and minimum ambient temperature of gas at inlet
- Maximum and minimum humidity at site
- Capacity control arrangement can be made by inlet guide vanes, speed control, with control valves to be specified by purchaser
- Discharge pressure to be specified by purchaser and measured in kg/cm^2

- Type of internal lining on the casing/impeller: Poly Tetra Flouro Ethylene (PTFE) lining may be found more suitable than rubber or Fibreglass Reinforced Plastic (FRP) lining for many applications since it is smooth and not affected by most of the corrosive chemicals. However, it can be costlier and hence it should be discussed with the vendor
- Purchaser must also ask for protection against surge (any valve or controller provided by the vendor). Depending on operating point and type of model, this requirement can be discussed
- Shaft sealing system for centrifugal compressor can be dry gas seals—but not for inflammable gases. Water-cooled seals should be discussed with vendor
- Speed measured in RPM to be specified by vendor (high-speed machines have more chances of breakdowns, vibrations, noise)
- Type of drive: directly coupled/through gearbox/belt-driven
- A big pulley is used for the unit and it works as a fly wheel too (*is this offered by vendor*?)
- Prime mover to be considered for drive: electric motor-driven, with/without a gearbox (both with increasing or decreasing speed), steam turbine and gas turbine.

Belt drives may be used for 150 kW and below. They may be offered for safety of the unit in case of jamming or closed discharge side valve or unexpected high back pressure. However, they have problems of breakage or loosening (lower efficiency).

4.2.2 Positive Displacement Type (Roots Blower)

Application: generally used for getting steady fixed volume of gases at discharge, e.g. aeration of effluent water, maintaining steady production rate in a sulphuric acid plant

- Capacity measured in Nm^3/h
- Discharge head
- Gas properties
- Ambient conditions, etc. as before

The purchaser of the compressor has to clearly mark the point on the datasheet on which he wants the compressor vendor to guarantee the performance. Capacity, head, speed and power required should be discussed with vendor as the rated point can be different from normal operating point.

Manufacturers can offer belt drive for reciprocating compressors and lobe-type blowers. These are offered as reciprocating compressors and lobe-type blowers are low-speed machines. *Belt drives may be used for 150 kW and below.*

A large pulley on a reciprocating compressor helps to reduce the speed as well as acts as a flywheel. In both lobe-type blowers and dry screw compressors, timing gears are used to maintain clearance between the screws and to drive the female rotor via the male rotor.

Details of arrangement of timing gears, MOC of gears, clearances, etc. should be obtained and compared with offers of other vendors.General linings like PTFE are used where non-lubricated cylinders are used, such as oxygen compressors, air compressors or applications where the contamination of gas by even a slight amount of oil is intolerable.

4.2.3 Induced Draft Fans

Induced draft fans are generally used in plants to maintain negative pressure so that gases may not leak out. Air ingress can occur in the plant and this should be considered while handling inflammable gases.

The impellers of such fans are suitably coated or protected against corrosion. Problems such as high vibrations when wet ash or dust carried with the gas sticks to the impellers can occur. In such cases, in situ cleaning, washing (by provision of cleaning window, water wash connection, etc.) and balancing should be possible.

Such impellers are generally used for higher volumetric capacities (*induced draft fans for thermal power stations*) but less discharge pressures. Vendor may be asked to recommend the type of capacity control (e.g. throttling the suction, variable speed drive or by any other means) most suitable for the machine being supplied.

Reciprocating compressors (for air supply to air-dry a plant of small capacity): these are to be procured when substantially constant low volumetric capacity is required at higher discharge pressures. Vendor may be asked to indicate the type of capacity control being provided (variable frequency drive or by any other means) as well as pulsation suppression device for the discharge side. This may be in the form of dampening pots.

Lobe-type blowers (positive displacement type): three lobe-types give less pressure pulsations on discharge side than twin lobe-type.

Purchaser should note that a good strainer to remove all dust/liquid entrainment from the suction side should be provided for the reciprocating compressor since the clearances are very small. In case non-lubricated type compressor is required, more than one unit should be procured because these machines have more maintenance problems.

4.3 Vacuum Pumps and Exhausters, Steam Jet Ejectors

4.3.1 Vacuum Pumps

These are required for:

- Maintaining very low pressure (in the range of 5–100 mm of water gauge) in process vessels, reactors and small distillation vessels.
- For boiling heat-sensitive liquids (essential oils in perfume industry, delicate medicinal components in pharmaceuticals industry) at low temperatures so that they do not decompose

- For purification of organic liquids
- For removal of small quantities of dissolved gases/non-condensable gases present along with main condensing vapours, e.g. SO_2 gas from vapours of SO_3.
- For research and development work in process lab on a small scale

Selection criteria:

- Vacuum to be created
- Expected volume of vapours to be removed
- MOC of wetted parts
- Type of gland packing (mechanical seal to be used if high vacuum is required).
- The unit should be offered as a preassembled one on a common base plate for pump and motor

Vendor should also provide calibrated dual pressure gauge, which can indicate positive pressure as well as vacuum, i.e. pressure below atmospheric pressure.

Vendor should inform about motor required (flameproof/high safety/conventional).

Demister pads or candles should be provided in a vessel at suction side if corrosive mist comes with incoming gases or mist (purchaser's scope)

4.3.2 Industrial Exhausters

Use/Application These are required for continuous (or as per need) evacuation of big reactors, distillation columns, oil storage tanks to remove toxic, inflammable or corrosive gases and vapours for subsequent venting out through appropriate scrubbers or condensation if the material is to be recovered, especially for maintenance work inside the vessels.

Selection criteria

- Vacuum to be created
- Expected volume of vapours/air ingress to be removed
- MOC of wetted parts
- Location of the unit
- Whether non-sparking alloys required if there are chances of fire due to inflammable vapours being evacuated. The vapours should be released at a safe height away from sources of fire or high-temperature surfaces

Vendor should be asked to carefully consider the properties of vapours/gases being handled such as composition of gas mixture, corrosive nature, boiling point, flash point, toxic nature (threshold limits), products resulting after burning of the vapours and explosive limits. Material Safety Data Sheet (MSDS) and send the offer accordingly.

Vendor should submit QAP, list of spare parts required and inform the delivery period.

Proper shaft sealing is a must for all such exhausters.

- Capacity measured in Nm^3/h of free air delivery.
- Ultimate vacuum to be maintained in the vessel to be evacuated measured in mm Hg (this may be specified as mm Hg absolute pressure also).
- Properties of gases to be evacuated along with composition (in mole % or volume %) and temperature is to be clearly indicated. In case of corrosive gases (e.g. moist acidic vapours) the MOC of wetted parts of the exhauster will have to be chosen accordingly.

In case of any liquid droplets likely to be entrained in the gases, a suitable demister/separator should be placed ahead of the exhauster suction port. This will minimize damage to the moving parts.

For very low absolute pressures (high vacuums), steam ejectors of single or multiple stage designs with/without barometric condensers may be considered.

These should be compared with oil ring vacuum pumps regarding the initial cost and operating cost (especially cost of HP steam, which is required for the steam ejectors) before taking final decision.

4.3.3 Steam Jet Ejectors

These are required for continuous removal of gases entering in equipment and air from steam condensers in thermal power plants so that proper vacuum and the condensation rate can be maintained, crystallising out certain salts from their solutions (sodium sulphate crystals by cooling of concentrated solution), non-condensable gases from solutions being evaporated under vacuum conditions, etc.

Selection criteria:

- Vacuum to be created
- Volume of vapours/air ingress to be removed
- Whether gases will be released to atmosphere or to a barometric mixing condenser
- Mounting details, size of connecting pipes to the main equipment

Vendor should inform about steam pressure required at jet nozzle and flow rate of water in barometric condenser.

4.4 Valves, Pipelines, Gaskets and Flanges

4.4.1 Valves

These are essential for controlling rate of transfer of process fluids from one unit to another. Wrong selection can lead to breakdowns, unsafe operations, pollution, etc.

Selection criteria for valves are as follows:

- Fluid properties: whether liquid or gas, density, pH, corrosive/reactive nature, viscosity, melting/boiling points, etc.
- Operating conditions: these should be specified as normal, minimum and maximum.
- Pressure measured in kilogram per centimetre square, temperature in degree Celsius and flow rate in metre cube per hour
- Slurry concentration (if the liquid being handled is not clear) and abrasive nature of suspended solids, if any.
- Type of control required, e.g. On/Off or proportional adjustment or very fine flow control of the fluid.
- Installation position of valve: in horizontal ducts/vertical duct/at bottom of process reactor/at outlet of storage tank or whether for boilers or economisers (i.e. vessels covered by boiler regulations).
- End connection: flanged/screwed/welded to gas pipes at inlet and exit (to minimise chances of leak from flanged joints if hot corrosive gases are flowing)
- Gland sealing/glandless type (required MOC of gland packing)
- MOC of wetted parts: many options such as cast iron, stainless steel (AISI-316), PTFE lined, polypropylene, etc. are available. Suitability for operating conditions must be discussed with vendor especially if the valve is to be operated frequently.
- Will it be possible to replace some parts like plug without taking out the valve from the pipeline?
- Leakage through the valve: liquid line valves can be easily obtained in leak-proof construction/operation.
- Gas line valves: butterfly valves/dampers in gas lines are generally not leak-proof (up to 0.5–1.0 % leakage is possible). If totally leak proof valve is required, then specially fabricated valve seats are to be asked for. A clearance of 1.0–1.5 mm between flap and body at ambient temperature may be specified, if actual operating temperature is on higher side. For example, valves at gas inlet and outlet of oleum boiler, a bypass route can be provided to minimise flow of gases through the oleum boiler.
- Thickness of flaps (of butterfly valves) and diameter of shaft is very important. This is necessary for long life of the valve. Method of fixing the flap to the shaft may also be specified. Options available are shafts fixed to the flaps by stainless steel bolts or by direct welding. The suitability depends on a case-to-case basis. Other materials for construction may also be considered. External operating lever and indicating pointer (for flap position) should also be made available. Manufacturer of the butterfly valve should be asked to provide these as standard fitting.

Observation Windows Small (100–150 mm diameter) observation nozzles at an angle may be welded upstream/downstream the butterfly valves, along with pressure points. In case the flap gets warped/disconnected from the shaft, the external indicating pointer can misguide the operating personnel and hence this precaution is necessary.

4.4.2 PIPELINES

Pipelines are a very important part of chemical plants and are used for safe transportation of process fluids, gases from storages to reactors and from various process units to the next downstream unit.

The criteria for selection are as follows:

- Properties of fluid to be transported: pH, temperature, viscosity, presence of solids, etc.
- Flow rate (quantity measured in m^3/h) to be transported.
- Total length of pipeline required and the path of the pipeline.
- Carefully observe elevations of different portions of pipelines. Examine possibility of formation of idle pockets, U-seals (in sections of descending and rising pipe lengths). Provide suitable drain points with valves at appropriate locations for liquid lines. Collection tanks should be available.
- Vent valves should be provided at appropriate locations for gas lines. Vent lines for the gases should be taken to a safe point at a height and then released (through a seal pot with 10 % alkali solution/neutralising solution).
- Provision for injecting flushing water or nitrogen to remove all dangerous contents before carrying out any maintenance work or replacement.
- Calculate the expected linear expansion and contraction of the pipelines due to changes in operating temperatures or due to weather. *A stress analysis of the entire piping system should be done to check whether large mechanical stresses will be created, which can exceed the permissible stress in the pipes for the MOC and thickness used.* Need for expansion bellows to be decided in consultation with piping design experts.
- Operating pressure of the fluid and maximum pressure likely in the pipeline.
- Expected pressure drop in the pipeline of different sizes (e.g. 50, 80, 100 mm diameter)
- Cost of pumping is to be compared with investment required for different sizes.
- Requirement of thermal jacketing, insulation and cladding, etc. as per process conditions. This will be useful for designing the pipeline layout.
- Whether welded construction is preferred for the pipeline or should there be flanged joints at certain places/regular intervals. This will depend on individual plant design and layout.
- Support structures (i.e. fixed or roller) required for the piping layout.
- Standard lengths of pipes available in the market: use of these can significantly reduce the cost of piping.

4.4.3 Gaskets

The following should be considered before procuring gaskets:

- Composition of fluid and its reactive nature with gasket material
- pH
- Maximum operating temperature
- Minimum operating pressure
- Diameter of the pipe
- Whether the fluid is highly corrosive/dangerous/inflammable: use pure PTFE gaskets in such a case instead of PTFE enveloped compressed asbestos fibre gaskets, provided temperature is within limits (200 ºC).
- Gasket at flanged joints should preferably have a diameter equal to flange diameter. If the gasket diameter is less then there is a chance of leakage at higher pressures.

Important Avoid very thin gaskets. The thickness should be as per pipe/vessel opening diameter, maximum temperature and pressure likely to be present in the pipes/vessels. (Ref. *Chemical Engineers Handbook*)

Avoid PTFE-enveloped compressed asbestos fibre (CAF) gaskets as these are likely to leak in highly corrosive mediums like strong oleums. It is better to use pure PTFE gaskets of appropriate thickness instead.

4.4.4 Flanges

Purchaser should make sure that the flanges employed for closing the various nozzles/nipples on the vessels or for making piping joints should conform to pressure and temperature conditions of the fluids being handled. This aspect should be specifically looked into during procurement, as there is a tendency to save costs by using thinner flanges. Movable flanges may be used in certain exceptional situations, e.g. when there is a mismatch between the holes of adjacent flanged joints or to provide MS flanges on SS pipelines. Raised face and plain face flanges are also available and their suitability for the application (fluid handled, temperature, pressure, etc.) may be confirmed by referring to *Handbook for Chemical Engineers*.

4.4.5 Expansion Bellows

Gas pipelines subjected to considerable temperature changes (ambient at start, going up to a high temperature during operation and again cooling down to ambient during stoppage of plant) expand and contract appreciably. This results in stress if some freedom of movement between fixed supports is not possible. The pipelines also tend to get lifted from supports and cause mechanical stress on nozzles of connecting equipment.

Hence properly designed expansion bellows must be provided in such pipe lengths. The following data should be furnished to vendors for obtaining their offers:

- MOC of pipeline
- Straight horizontal and vertical lengths between fixed supports
- Diameter and thickness of the pipeline
- Maximum operating temperature/maximum expected temperature
- Gas pressure: normal and maximum
- Gas composition in mole%
- Expected expansions of the pipeline: linear/axial
- Position of expansion bellow: in vertical pipeline/horizontal pipelines
- Whether any corrosive condensate formation is likely to occur in the pipeline during operation/shutdown: this can trickle down and corrode the bellow. Hence, provide drain points at appropriate location in the pipeline
- The bellows should preferably be welded at both ends to the pipeline instead of using flanged connections
- *Stress analysis of the pipelines should also be referred to while placing order*

Procurement of Raw Materials and Catalysts

5

5.1 Raw Materials

The difference between raw materials and starting materials/intermediates is to be understood clearly by anyone concerned with procurement, transport and processing. Raw materials generally occur naturally. Considerable impurities are present in them, hence they cannot be charged into the process reactors without some purification and/or pretreatment. These operations may include magnetic separation, washing, crushing, grinding, filtration, calcination, etc., and considerable cost is incurred on them. Managements should carefully compare the cost of obtaining purified, ready-to-use raw materials with the cost of obtaining impure, cheap raw materials and purifying or treating them in-house by installing, operating and maintaining the necessary machinery.

5.1.1 Starting Materials

These are made available by other industries as their end products or by small-scale units or by traders. These are comparatively simple inorganic products (e.g. mineral acids, caustic soda, metal salts), organic chemicals and solvents (e.g. acetic acid, ethyl alcohol). The starting materials are charged into the process reactors (in a measured amount) in the first stage. Generally, little pretreatment (e.g. filtration, calcination) is required before the starting materials are charged into the reactors.

5.1.2 Intermediate Items

These are special items that are generally supplied by ancillary industries/other major industries. These items are usually added to the reactors at an appropriate stage in the production process. They are vital for producing the final product (when they

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form part of the chemical reactions) or as property modifiers (when used to improve viscosity, shelf life, light fastness).

5.1.3 Selection/Procurement Criteria

These depend on the intended use and hence the specifications of properties necessary for obtaining satisfactory marketable final product should not be diluted, i.e. compromise should not be made on these counts. However, certain specifications such as moisture percentage can be diluted, i.e. materials having higher moisture may be accepted when there is a possibility of the excess moisture evaporating due to exothermic reactions/heating during the process. However, due allowance should be made while charging the materials into the process reactors.

Shortage of reactants (due to higher moisture content) should be taken care of by charging a calculated additional quantity of materials.

In case of sufficiently reactive materials or those materials that are to be charged in solution/molten form, the size of lumps is not very critical. Certain sizes of lumps are, however, specified for ease of feeding to crushers/pulverisers/dissolvers.

5.1.4 Other Specifications

- Minimum percentage of purity required
- Maximum percentage of tolerable insolubles
- *Maximum permissible content of all impurities such as iron (which imparts an unacceptable yellow-brown colour to most products), chlorides (which corrode equipment, including SS-316), calcium salts (which increase concentration of insolubles)* should be clearly specified. It is important to clearly mention whether the presence of certain other impurities is allowed (even in traces), especially those likely to cause side reactions, contaminate the product or corrode equipment
- Melting point, boiling point
- Chemical stability to mechanical shock (during handling), rain, exposure to sun. Appropriate precautions for safe handling and storage

5.1.5 Types of Packing for Procurement

- If liquids are procured in returnable carboys, initial investment on storage tanks can be reduced, but these supplies may be costlier compared to purchases made in full tanker loads.
- For certain process plants, free-flowing solids are required for ease of feeding (by means of screw conveyors, rotary valves, etc.) and for satisfactory rate

of reaction. However, certain materials tend to form cakes due to absorption of moisture from the atmosphere, (e.g. ammonium nitrate) or become excessively wet (e.g. salt). Suppliers coat them with anticaking agents to maintain the free-flowing properties. One should ensure that these agents do not interfere with the reactions or corrode equipment. Certain materials (e.g. sulphur) are inflammable, hence, should not be transported by screw conveyors since the friction can cause fires. They are conveyed by bags, truckloads or railway wagons and should be unloaded carefully at the point of use.

5.1.6 Purchasing by Tanker loads

- It is essential to ensure that a particular tanker is always used for transporting a particular chemical. If it is used to transport other chemicals, then the tanker should be thoroughly cleaned and dried to prevent contamination. The MOC of tanker outlet valves should be compatible with the transported material, e.g. MS-rubber lined for hydrochloric acid, stainless steel for nitric/acetic acid. Sampling valves should be fixed on all compartments of the tanker.
- When weighing fully loaded or empty tanker, the driver, tool box and spare tyre should either be in place or removed during both times to know the correct weight of the material brought in.
- The tankers must have vents, pressure gauges, protection against lightening and a compressor to empty out the contents completely without which they should not be used for transportation, otherwise there will be a possibility of material remaining inside the tanker or high pressure developing inside the tanker during unloading under the sun.
- The tanker driver must have safety manuals with precautions to be taken in case of leak. The telephone number and address of supplier should also be painted on the tanker.

5.1.7 Solids/Powders

These may be supplied by vendors in mild steel drums, plastic-lined jute bags, big HDPE-lined bags, small cardboard drums or packing. Vendor's/manufacturer's instructions must be followed for unloading (e.g. "do not drop from a height"), storing ("store in closed space away from sunlight and high-humidity") and opening the packing.

Sharp tools may be used for opening the drums only if advised by the supplier. Only non-sparking type devices (wooden mallets) with proper earth connection to each container (especially for aluminium powder) should be used. *However, it is advisable to use alternative methods of production where such types of raw materials are not required.*

5.2 Catalysts

These chemicals increase the rate of desired reaction (increase yield of desired products) and enable operation of the plants at lower temperatures, pressures, etc. Proper choice of catalysts can reduce the cost of equipment, operation and maintenance.

Certain chemicals, however, act as "retardants" for reactions (which are considered as undesirable reactions). They are useful in preventing deterioration of products, formation of gel or for maintaining fluidity of liquid products.

5.2.1 Considerations for Procurement of Catalyst

- Specific activity for the required reactions, i.e., the catalyst should promote only the desired reactions and should not promote any undesirable side reactions because raw materials, energy, etc. may get wasted, besides contaminating the main products. This is especially relevant for biotechnological products.
- *Examples: For reactions such as oxidation of SO_2–SO_3, the yield is more while using caesium-activated catalyst instead of the conventional potassium-activated catalyst even while operating at lower temperatures. The catalyst must enable operation of the process in appreciably less drastic conditions, e.g. lower temperatures, pressures. Operation at lower temperature can increase overall equilibrium conversion in case of reversible exothermic reaction of oxidation of $SO_2 \rightarrow SO_3$.*
- The catalyst should be easily separable from the products so that it does not contaminate them. It should be also be possible to separate the catalyst from the unconverted reactants by simple means for reuse.

5.2.2 Fixed Bed of Catalyst

The geometry of the catalyst particles (diameter and length) should be such that resistance to flow of gaseous reactants should be minimum at the rated flow and at about 20% of overload. This will minimize power consumption for the flow of gases in the blower (hollow ring-type vanadium pentoxide-based catalyst is now used instead of solid cylindrical pellets used earlier in sulphuric acid plants).

5.2.3 Fluidised Bed of Catalyst

Density, active surface area and attrition during fluidisation should be taken into account. The additional energy required for fluidisation of the bed (as compared to fixed-bed catalyst reactors) is also an important factor. Catalyst particles, crumbling to fine powder, can be carried away with outgoing streams. Apart from the loss, these particles can choke downstream equipment and reduce heat transfer. Hence, the added advantage of higher production rates at more or less isothermal conditions must be weighed against the above factors.

5.2.4 Loss due to Attrition

Catalyst particles (pellets/spheres) should be hard enough to withstand their own weight, erosion during normal operations or slightly overloaded conditions (due to flow of gases) and friction with screening equipments during annual shutdowns. A certain minimum crushing strength may be specified to the vendor. Otherwise the crumbled catalyst particles can plug the lower portion of the bed or get deposited in downstream equipment.

5.2.5 Deactivation/Poisoning of Catalyst

It is possible that during process upsets or operation overloads (for meeting increased demand) the catalytic reactor is fed with reactants at higher temperature or higher loads of reactants (than the designed value). This situation can also arise during improper cooling of the process streams (or the reactor itself) due to various reasons, e.g. inadequate supply of cooling water, higher temperature of cooling water, fouled surfaces of heat exchangers, etc. The catalyst bed becomes particularly susceptible to damage (sintering of particles may take place) during exothermic reactions. Hence, a catalyst should be so selected that it does not get deactivated during "overload" conditions—at least for a few hours during operation. The chosen catalyst should also be able to sustain the bed performance in presence of certain common impurities likely to enter the reactor along with the process fluids, i.e. it should be resistant to "poisoning". Since this is not always possible, research and development are being done all over the world for developing better catalysts. One should always compare the various types of catalysts available in light of the above requirements before placing an order. If possible, actual operating data should be obtained from units where these catalysts are in use. Catalyst manufacturer should also be consulted regarding impurities likely to "poison" the catalyst. Impurities should never be allowed to get mixed up in the process streams fed to the catalyst beds.

5.2.6 Initial Cost and Royalty

Cost of catalyst and royalty (if any) should be reasonable. Patented catalyst should be procured from authorised sources only with proper billing and certification for use.

Technical services and guidance should always be available from the catalyst manufacturer regarding correct selection, installation, commissioning, operation, screening and replacement of the catalyst. Special instructions/precautions for pre-commissioning and commissioning, for a fresh load of catalyst, must be strictly followed. Technical literature should be obtained from the manufacturer of catalyst. Optimum loading of catalyst for a given production rate should be looked into. Greater quantity of catalyst will result in more initial cost, increased power consumption and higher replacement cost, though it may result in higher yield. Such conflicting factors should be taken into account before deciding.

5.2.7 Handling, Storage, etc.

Proper instructions should be obtained from the manufacturer regarding these very important matters. Certain catalysts are hygroscopic in nature. Catalyst particles may agglomerate if exposed to humid atmosphere. Fixed-bed catalyst converter may result in highpressure drop in that case.

5.2.8 Performance Guarantee

Performance guarantee should be obtained for improving production rate, product quality, expected pressure drop (through fixed catalyst beds), permissible minimum/maximum operating temperatures, maximum feed rates or concentration of reactants, attrition, kindling temperature, equilibrium conversion, etc.

This will enable the operator to run the plant with efficiency of production rates, consumption of raw materials and utilities and heat recovery from exit streams of reactors (in case of exothermic reactions).

Liquid/gaseous catalysts, e.g. concentrated sulphuric acid (for organic reactions), nitrogen oxides (for manufacture of sulphuric acid), get thoroughly mixed with the reactants. They should be carefully separated or regenerated for reuse. If they cannot be separated from the products, then they should not affect the product quality or the intended use of the product. Such liquid catalysts (retardants/stabilizers) should be active in very low concentrations, i.e. a few parts per million.

Conclusion

Certain catalysts that have high initial costs may also have high salvage value, which may partially offset the cost of replacement, e.g. use of platinized asbestos compared to vanadium pentoxide for the manufacture of sulphuric acid. However, the choice will depend on other factors also (as discussed above), besides impact on the cost of production by use of a particular catalyst. One should also consider the likely corrosion of equipment and wastage of raw materials due to incomplete conversion by use of cheap catalyst.

One should visit a plant (or request the manufacturer to arrange for a visit) where such catalyst has been in use for reasonable time. The claims made by the manufacturer should be verified against the performance data. In case of significant difference between the two, reasons such as different flow rates, temperature, concentration of feed to converter should be clearly understood before selecting a new catalyst.

Process Reactors

6

6.1 Chemical Reactors

Reactors are at the heart of a chemical process plant. They are to be designed, fabricated, tested, erected, commissioned, operated and maintained with utmost care so that the process plant can run efficiently and safely.

Some Common Types of Reactors are

- Fixed-bed type (with catalyst beds)
- Fluidised-bed type
- Stirred-tank type (with/without jackets)

Small-sized reactors are generally fabricated in vendor's workshop and then transported to the purchaser' site.

Large-sized reactors are sometimes fabricated and assembled on-site if it is difficult to transport the entire unit and then erect at site. Internal components such as brick lining, grid supports, heat exchange coils are then assembled or fabricated at the site.

Rubber, glass and Fibreglass Reinforced Plastic (FRP) lining can be provided in the fabrication shop itself or carried out in another workshop (sub-contracting by the main vendor). The lined reactor should be carefully transported to the site.

However, the purchaser should put the responsibility of the entire job on one party only (the main vendor) to avoid controversy (e.g., if the lining fails). Protective brick lining is, however, done at site only when (i) the reactor may become too heavy to transport or (ii) there is possibility of the lining getting disturbed during transport.

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The following should be considered while ordering site fabrication:

6.1.1 Fixed-Bed Reactors (Catalytic)

The fabrication drawings should be approved by all concerned (consultants, shop floor personnel, technical authorities, project engineers, government inspectors, etc.) and should include details such as MOC of shell, thickness of plates, operating conditions, e.g., temperature, pressure, flow rate of gas, required grid supports for loading of catalyst, positions and orientations of nozzles for all incoming and outgoing gas streams, total weight (with lining and internals). *A typical example of a fixed-bed catalytic reactor is the converter used for the manufacture of sulphuric acid by the contact process.*

- Civil foundation should be ready and cured to necessary strength before starting site erection (placing load on it)
- Adequate working space on all sides should be available for erecting scaffoldings and temporary structures
- Clearance should be there on all sides and at ground level for inspection and maintenance of the unit and fittings
- Permanent staircase/ladder and work platform for maintenance of thermocouple, nozzles, etc. should be erected around the reactor
- Internals such as support beams, grids, S.S. Plates should be procured and should reach site in time for final assembly
- Inspection is an important condition and must be included in the work order. It should be done during various stages of manufacture
- Final inspection and testing of the entire assembly: the overall dimensions, provision and orientations of various nozzles and internals should be checked
- Similar procedure may be followed for site fabrication of other process reactors
- Nozzles for feeding material, fitting of internals, incoming and outgoing gas/liquid streams, sampling valves, vents, drain valves should be provided and their orientations checked. Proper earth connection of the reactor must be ensured especially when inflammable materials are handled. Suitable connecting lugs should be provided by the fabricator for this purpose.

6.1.2 Fluidised-Bed Reactors

These are generally big empty vessels with or without linings of refractory or acid resistant materials with various nozzles for (i) entry of reactants and fluidising media (could be high volume of air), (ii) exit of products, (iii) draining the reactor,

(iv) temperature measurement (v) pressure measurement, (vi) venting gases and vapours from the reactor, (vii) sampling points and (viii) manholes for maintenance and inspection.

Provision for demisters, separators for catalyst particles and arresting escape of un-reacted particles should be made.

Reinforcements should be made at all nozzles by adequately sized pad plates, gussets, etc. Pad plates with vent holes to be welded for side supports.

6.1.3 Stirred-Tank Reactors

Typically used for dyes and organic chemicals

The following should be considered while ordering the reactor vessel:

- Is it classified as a pressure vessel? (Please refer to chapter on pressure vessels for more details, safety devices, etc.)
- Lined (lining by hard rubber, glass, AR bricks, etc.) or unlined?
- Jacketed (e.g., for manufacture of fortified rosin) or without jacket?
- With internal cooling or heating coils?
- With external limpet coils (or jackets)?
- Properties of the reaction mass inside
- Type and number of baffles (width, height, thickness, method of fixing, MOC, number of holes and diameter, spacing between baffles). *Removable type baffles can be considered for improving the performance of the reactor. The figure shows different designs of baffles, which can be fitted as per need.*
- *The drain valve at the bottom should be the non-clogging type Y-valve. The plug goes into the vertical pipe and is flush with the bottom of vessel when the valve is closed. This prevents the deposit of any sludge in the pipe and prevents clogging. The reactor can be easily drained by opening the Y-valve rather than using a rod to remove the sludge deposit when a usual plug type valve is used* please refer to Fig. 6.1 and Fig. 6.2
- Heat evolved due to the reaction inside or the need for heating the reaction mass
- Total volume of the vessel
- Actual maximum volume of the reactants (maximum operating volume)
- Type of agitator/turbine/propeller. The actual design of agitator will depend on the speed of agitator
- Whether gearbox is required

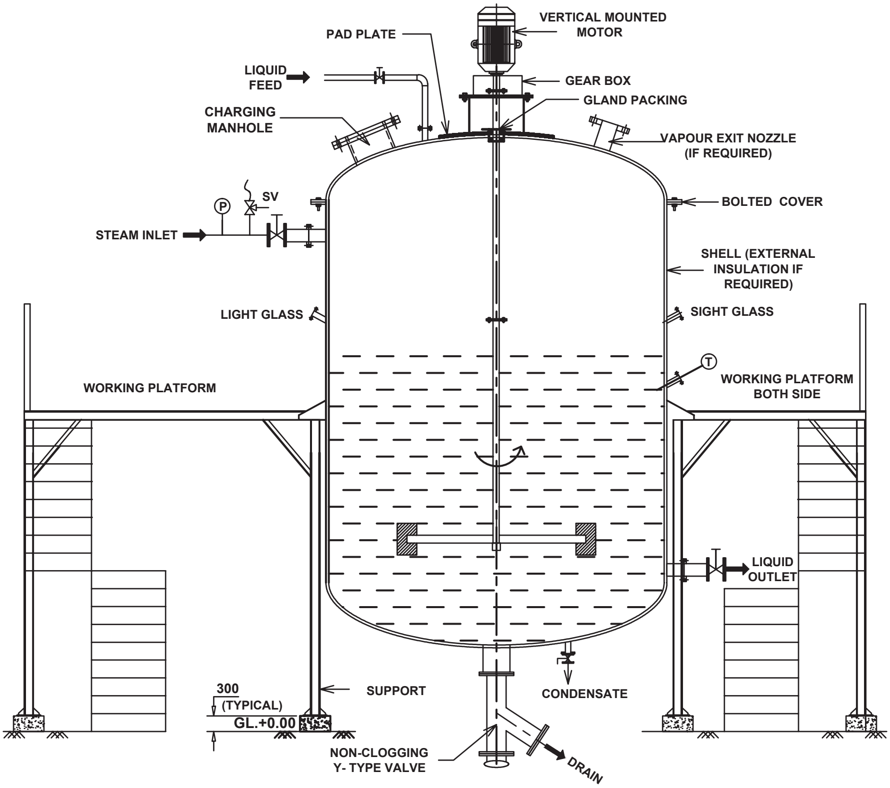


Fig. 6.1 Reactor with agitator

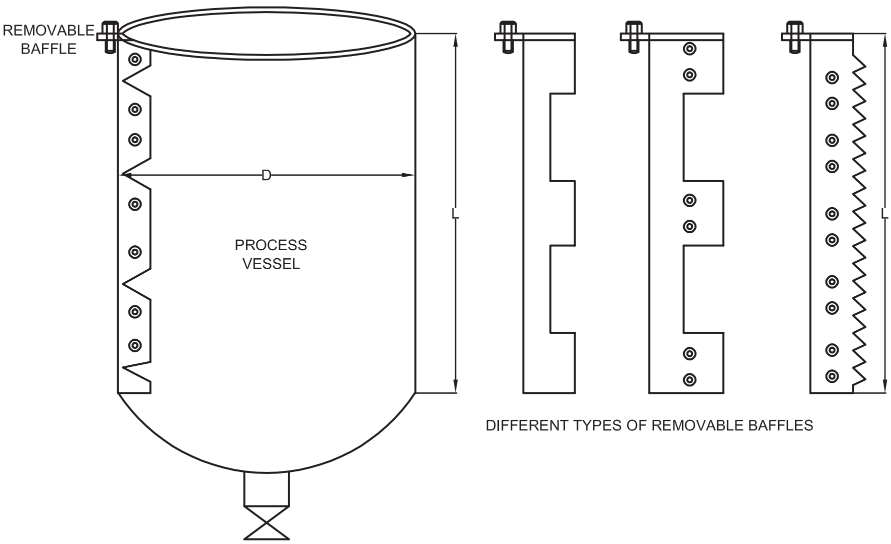


Fig. 6.2 Process vessel with removable baffles

6.1.4 Gas Induction Reactors

- The gas induction reactor (refer to figure given below) has a hollow shaft instead of a gas injection sparger. The shaft has holes above the operating liquid level and three or four perforated pipes at the bottom at 120° or 90° to the shaft. During rotation of the shaft, the reactant gas is sucked from the holes in the hollow shaft and is discharged from bottom perforated pipes. An intense mixing occurs due to the fine bubbles produced (reference-Omega-Kemix).

Advantages

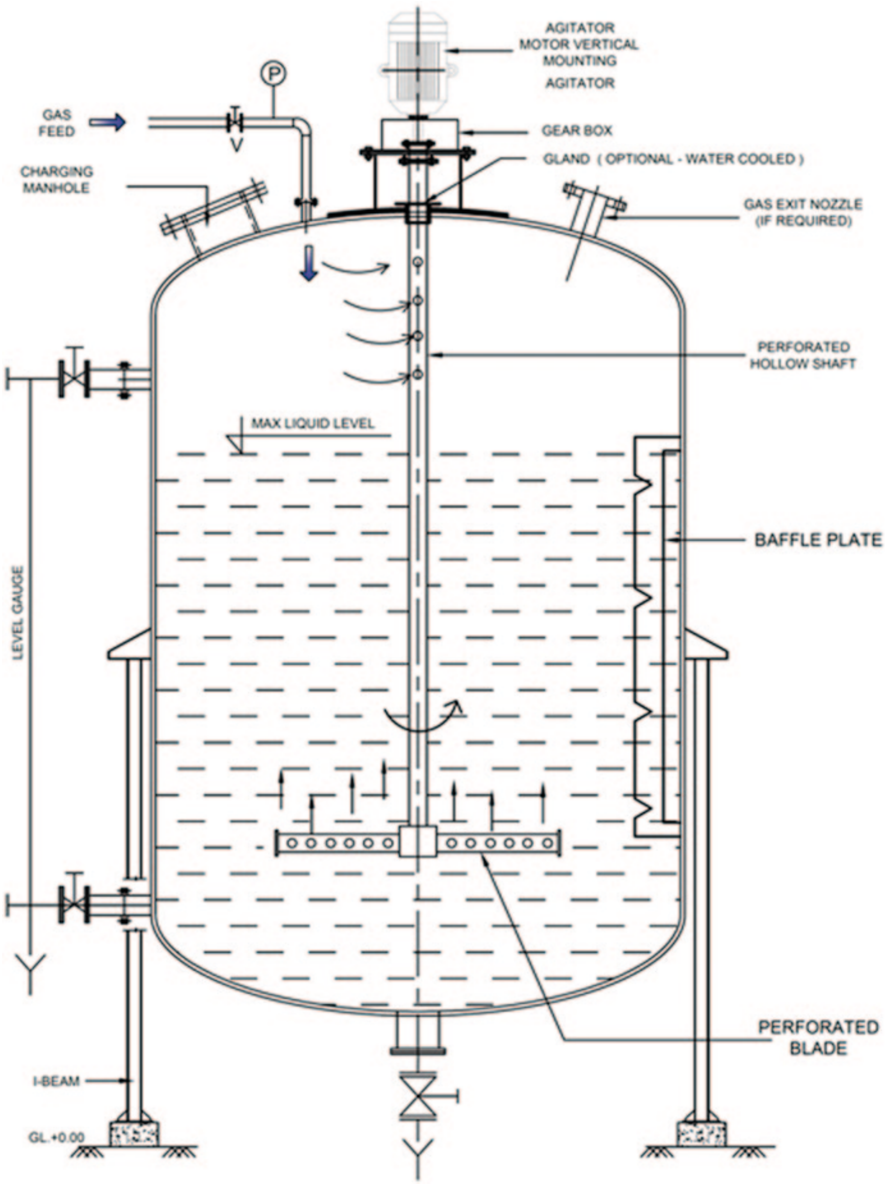
- Complete and vigorous mixing of gas and liquid
- Uniform suspension of catalyst (if used) throughout reaction mixture
- Large gas–liquid contact area, can be 100–150 m^2 per m^3 of operating volume
- Enhanced rate of mass transfer
- Better utilisation of reactant gas—less residual gas will be found when reactor cover is opened (for inspection of internals or for repairs)
- Reduced reaction time
- High pressure in gas supply line to reactor not necessary
- Higher heat transfer co-efficient
- Better batch-to-batch repeatability
- Heat transfer area not a constraint—heat transfer area can be provided by internal coil as well as external heat exchanger

Selection Criteria

- Reactions to be carried out and heat evolved, catalyst/particulate matter to be intimately mixed, their density, gas pressure available, heating or cooling to be done, mountings required as per standard requirements.

Spare sets of removable pipes with holes of different diameters should be supplied by the vendor. Spare shaft should also be kept ready.

Test certificates required for MOC used for reactor shell, agitator shaft and lower perforated pipes.



6.1.5 Selection of Agitators

Intended use: for reactor, dissolver, mixer, melter, etc.

Factors to be considered for selection of agitator:

- Composition of medium to be agitated—the proportion of liquid and solid
- Properties of liquid—density and viscosity at different temperatures, vapour pressure, corrosive and toxic nature, boiling point, melting point and inflammable nature of vapour, tendency for foaming
- Properties of solid—density, solubility, melting point, abrasive nature, corrosive and toxic nature
- Rate of addition of liquid and solid to the vessel
- Rate of withdrawal from the vessel—continuous or after every batch or intermittent
- Point of withdrawal from the vessel—from bottom or from overflow nozzle
- Point of addition of liquid and solid to the vessel—at top of liquid surface or through a pipe dipping in the liquid along wall of vessel or in centre of vessel
- Level of liquid to be maintained inside the vessel
- Whether there is tendency for deposition of solids or crystal on the agitator
- Whether there is tendency for settling at the bottom of vessel
- Total depth of vessel
- Total length of agitator required—an intermediate coupling will be required for more than 3000 mm-long shaft. It can have maintenance problems
- Type of agitator blades required
- Whether baffles are provided in the vessel—refer to drawings attached
- Speed of agitation required—depends on the above factors
- Whether continuous agitation is required or intermittent agitation is enough.
- Can existing motor and gearbox be used with new agitator
- Whether vessel has external heating or cooling jacket or if there is an internal coil in the vessel (it can interfere in the agitation)

6.1.6 Standard Fittings and Mountings to Be Considered

- Thermowell for temperature Sensor/RTD
- Manhole size should be not less than 600 mm diameter
- Nozzles for level indicator, pressure measurement instrument sampling
- Drain valve (Y-type), i.e., non-clogging type
- Steam jacketed drain nozzles/drain valves/outlet valves
- Light glass and sight glass
- Motor and gearbox rating to be provided by vendor
- Safety valves and rupture disc
- Bearing housing and gearbox mounting (if these are required, then it may be preferable to have dished top for the reactor for mechanical strength)
- Separate steam connections to be provided for jacket and drain/outlet nozzles due to the following reasons:
  in case of steam leakage (i) it is easier to trace source of leakage and (ii) on stopping steam supply, vacuum is created and materials may get sucked in the

jacket. If materials get sucked into drain valve and solidify, further maintenance work can become extremely difficult. However, this does not occur generally when separate steam connections to drain valve, drain nozzle and reactor jackets are provided
- Anchors for fixing hot/cold insulation (glass wool pads, polyurethane pads, etc.)
- Shaft sealing glands (conventional, i.e., without water cooling) or with water-cooling
- Mechanical seals for shafts if toxic/inflammable vapours are likely to escape
- Additional nozzles, if required, on top cover for vent lines, vapour outlet to reflux
- Condenser and entry of condensed liquid, etc.
- *Top cover*: This may be bolted or welded. In the former type, flanges should be thick enough (28 mm onwards) and bolts should be minimum 24 mm in diameter with high strength
- Gaskets should be CAF/AR/PTFE of minimum 6 mm thickness. (Bolted cover facilitates easy maintenance/replacement of agitator, baffles, etc.)
- Welded covers should have sufficiently big manhole so that it is not necessary to cut the cover to open it every time maintenance work is undertaken
- Lifting lugs and supports: purchaser should consider plant layout and the elevation at which the reactor is to be installed. Position of the supports can then be informed to the fabricator
- It should be possible to rotate the shaft by using a long handle pipe wrench in case it gets stuck. Once it comes unstuck it can be run by an electric motor. This is to save the motor from high load at the start in such situations (sufficient space should be available for introducing the pipe wrench)

6.2 Properties of Reaction Mass and Process Conditions

- Density, Viscosity, pH, melting point, boiling point
- Free acidity or alkalinity in reaction mass
- Operating maximum/minimum temperature
- Operating maximum/minimum pressure
- Corrosive properties of the reaction mass
- Explosive/inflammable nature
- Presence of suspended solids (crystals) or grit/silica from un-reacted portion of reactants
- Heat evolved during exothermic reaction
- Maximum rate of heat evolution in kilocalories per hour
- Possibility of runaway reaction if temperature or feed rate of any reactant is not controlled. A safety valve and rupture disc must be provided in such cases
- Heating required (if any) for carrying out the reaction
- Tendency of reactants to form thick viscous gel due to reasons such as overheating/overcooling/power failures/addition of excess reactants, etc. The gearbox, coupling and motor must be designed accordingly

6.3 Electric Furnaces

Certain processes (*e.g., manufacture of chemical products such as calcium carbide, carbon disulphide, by heating the reaction mass in a refractory lined furnace. Also, some important industrial operations such as controlled heat treatment of metallic components are carried out in electrically heated furnaces*) not only need heating of reaction mass to a high temperature but also need protective refractory lining for the reaction vessel. Heating by means of external source of heat is not efficient due to poor thermal conductivity of the refractory lining. It is also not possible to install internal burners as the flue gases and the air can burn and destroy the reaction mass or products. Hence, electrical heating is used for creating high temperatures by having the source of heat inside. In such cases it may be more efficient and economical to heat the reaction mass internally by electrical heating. In certain other cases where the reaction mass could get contaminated from direct heating of flue gases or oil firing, electrical heating could be the better option.

This mode of heating is preferred since the heat is generated in-situ (internally) and in absence of air—which can oxidise the chemicals/metal parts, etc.

6.3.1 Installation/Ordering an Electric Furnace

- Total heating load (Kcal/h) for heating raw materials and carrying out the reaction, which will be the sum of the heat required to bring up the temperature of the furnace from a cold start and heat required for processing (heat treatment operations in the furnace). This will not be required if the furnace is having long continuous runs.
- Power required (KW/hr): this will depend on the heat losses through the furnace walls, the temperature of incoming and outgoing material and resistance of electrodes.
- Batch time/cycle time (if a production cycle lasts many days).
- Frequency of opening and closing of furnace doors. This causes heat losses (try to minimise).
- Types of refractory and insulating linings provided. Temperature of external surface should normally not exceed 50–60 °C in order to minimise heat loss. However, the temperature of furnace shell should not be more than 70 °C. This can be done by using insulating bricks of adequate thickness inside the furnace shell. Suitable insulation can be provided externally through mineral wool/glass wool, etc. along with aluminium cladding or other sealing compounds, if ambient temperatures are very low.
- Arrangements for feeding raw materials (items to be heated) and taking out products should be such that escape of heat, hot gases, etc. from the furnace is minimised. Ingress of cold/ambient air should be minimised during loading or unloading of the furnace. Double door/special charging boxes should be used for the purpose (with inlet and discharge dampers).

Specially designed charcoal feeding boxes and inlet nozzles are provided for CS2 furnaces.

- The system should work automatically with a pusher ram and an (optional) arrangement for injection of nitrogen gas or steam. This arrangement prevents furnace gases from coming out (when the furnace is operating above atmospheric pressure) or ingress of atmospheric air (when the furnace is operating below atmospheric pressure) during raw material charging.

6.3.2 Instrumentation to Be Provided

- Thermocouples/optical pyrometers/dial thermometers at appropriate places, e.g. on furnace shell, outgoing gas ducts, back surface of refractory bricks
- Pressure gauges for monitoring internal pressure/pressure of inert gases if fed to the furnace
- Electrical instruments for monitoring voltage, current, power (KW), energy (KWH), etc. The resistance across electrodes or the furnace bed can be used as guides for adjusting the position of electrodes for optimum value
- MOC of electrodes and expected consumption of electrodes per unit output or per operating cycle. This would depend on operating conditions and internal geometry of the furnace

6.3.3 Whether Water-Cooling of the Electrodes Is Required

One should normally avoid an electric furnace where water-cooled electrodes are required. In addition to wastage of power (due to water cooling) there is always a chance of sudden development of high pressure and accidents due to leakage of water from these electrodes.

If water cooling cannot be avoided, the cooling water flow should not be pressurised, but preferably under negative pressure i.e. use a siphon for water flow. Provide an alarm for disruptions in water flow.

6.3.4 Furnace Accessories to Be Supplied by Vendor

- Exhaust hood or fume extraction arrangement
- Safety devices such as safety valves (should be automatic) and rupture discs—nozzles connected with furnace should be as short as possible to minimise chances of choking due to dust particles or solidification of vapours
- Instruments for temperature and pressure measurement
- Overhead arrangement for taking out damaged electrodes or adding more electrode pieces to the furnace. This can be as a gantry at the top of furnace. Pur-

chaser can buy the lifting hoist himself or ask the vendor to provide it at extra cost

- Spare set of electrodes with coupler pieces (for joining existing electrodes)
- Suitable glands at the nozzles for inserting the electrodes. These glands could be water cooled and packed with ceramic paper to prevent escape of gases or ingress of air
- Inspection manholes for access to the inside of furnace during shutdown
- Tap holes for taking out molten product mass and slag. Fitting refractory plugs should always be available for closing the tap holes after the molten mass is taken out
- Electrical control circuits, metering panel with appropriate meters for voltage, current, power and total energy consumption
- Suitably designed nozzles for removing gaseous products, if any, with provisions to connect to downstream process units

6.4 Electrolytic Cells

Certain processes are carried out through the electrolytic route, e.g. production of caustic soda by electrolysis of sodium chloride solution, production of aluminium by electrolysis of aluminium fluoride.

6.4.1 Selection of Electrolytic Cells

- Production rate and quality of the product required
- Flow rate of the electrolyte, change of concentration during the process, operating temperature, pH of the electrolyte, etc.
- Electrolyte composition required for efficient operation (whether special additives are required for lowering the operating resistance)
- MOC of electrodes and their corrosion resistance
- Current-carrying capacity of the electrodes (depends on the conductivity and cross section)
  Graphite is a common electrode material due to good electrical conductivity and high thermal and corrosion resistance, but the threaded pieces and couplers are delicate and need to be carefully handled.
- Maximum current carrying capacity expressed as Maximum Current Density permissible–amps/cm^2 of cross sectional area of electrodes
- Corrosion resistance of the walls of the cell
- Resistance of all electrical contacts (electrodes with cables, bus bars)
- Gas evolution, if any, during electrolysis. In case of toxic gases it is advisable to operate the cell under slight suction (manufacture of caustic soda)

- Actual operating voltage of the cell as compared to the theoretical voltage for carrying out the electrolysis. This is a very important parameter and depends on the cell geometry, distance between anode and cathode, electrolyte concentration, operating temperature, additives to the electrolyte, etc. Power consumption of the cell per MT of the product depends on this. Since these cells generally operate at a few hundred to a few thousand amperes, even a small reduction in the voltage drop can result in substantial saving of power
- MOC of bus bars: copper or aluminium may be used, depending on the corrosive gases present near the cell. Hence, vendor should be asked to give details of the incoming bus bars, electrical contacts with the electrodes and insulating materials used for supporting/fixing

6.4.2 Instrumentation Provided

- Voltmeters and ammeters for the system: both HT and LT sides of the rectiformer and across the electrodes
- Energy meter and KW meter
- Rotameter, pH meter (where required) and thermometer for the electrolyte
- Manometer for the cell when there is evolution of gases

6.4.3 Cell Grouping

A number of cells are put in parallel, and such groups of cells are put in series. This will depend on the maximum current-carrying capacity and the operating voltage of the rectifier.

Arrangement for automatically adjusting the distance between the electrodes to minimise the resistance should be provided by vendor.

6.5 Rectifier

This is vital equipment for supplying electrical energy to electrolytic cells. Some important criteria for procurement are as follows:

- DC power required for production
- Whether installation is indoor or outdoor. Provide protection against rain, sun, etc. as per recommendation of manufacturer
- Overall efficiency: this is the ratio of DC power delivered to the AC power absorbed. Vendor should be asked to give this figure during various operating conditions of plant
- Cooling arrangement: natural or fan cooled
- Incoming supply of voltage

- Maximum outgoing voltage and current permitted
- Maximum rise in temperature allowed above the ambient temperature
- Details of outgoing connections at the LT side for feeding the cells
- Overall space required for installation and total weight of the unit
- Overall weight of the unit
- Provision for electrical switching. Metering panel to keep track of power drawn from mains and power used in electrolytic cells

7 Pressure Vessels, Glass Vessels and Glass-lined Vessels

Pressure vessels are very important process equipment. Their typical applications include the manufacture of ammonia, liquid sulphur trioxide (by boiling of oleums), nitrogen and oxygen (cryogenic, PSA and membrane processes), processing of petroleum, waste heat recovery boilers, etc.

Incorrect specifications can lead to serious accidents. Hence, the following information should be given to and discussed with designer and fabricator before ordering procurement.

7.1 Considerations for Procurement of Pressure Vessels

- Intended use: reactor, condenser, heat exchanger, boiler, air receiver
- Intermittent or continuous use
- Volumetric capacity (working volume and some empty space at the top)
- Normal operating weight of the vessel: up to the overflow nozzle
- Maximum weight when completely filled
- Agitated/un-agitated
- Will the vessel be a fired or an unfired one? This is extremely important for statutory regulations. The purchaser should treat (from safety point of view) any process unit likely to develop pressure due to heating, reaction, choking of exit gas pipes, closure of valves of outlet pipes, failure of cooling medium, etc. as a fired pressure vessel. All precautions regarding designing, MOC, construction, testing, erection, commissioning, operation and maintenance should be taken
- Properties and composition of material to be handled: *toxic/inflammable/explosion limits/boiling point/density/viscosity/erosive/corrosive*
- pH, density, melting and boiling points of material to be handled
- Reactions, heat evolution, rise in pressure when reactants are added at a normal rate. However, the maximum rate of additions should also be considered for design
- Corrosive/inflammable/explosive nature of material

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- Possibility of condensation of reactants into solids at low temperature, this may choke inlet/outlet nozzles
- Operating pressures: normal and maximum; future increases
- Operating temperatures: minimum, maximum and possible shock loads due to sudden development of higher rates of reactions, which may cause high temperatures
- Frequency of pressurisation/depressurisation during use of the vessel
- Is the vessel stationary or transported regularly during use (product tanker)?
- Installation location: indoor/outdoor, height from the ground
- Installation position: horizontal/vertical
- Will the pressure vessel be heated or cooled (internally/externally)?

7.1.1 Arrangements

- Safety valves and rupture discs
- Nozzles for vent, safety valves, pressure and temperature indicators
- For heating/cooling (*to be decided by the design engineer appointed by purchaser*): whether jacket or external limpet coils (for external reinforcement) or internal coils (difficult to clean and replace) are required
- Nozzles for level indicator, sight and light glasses, sampling points, inlet of reactants and exit of products, entry for agitator shaft, thermo wells for temperature indicators
- Connecting pipes to nozzles and their orientations for incoming and outgoing materials; draining out the vessel. External pipes can cause bending of loads or mechanical stress if not supported independently outside
- Manholes for inspection and maintenance (whether bolted or welded cover plates are to be used is decided by the design engineer as per maximum pressure inside vessels)

7.1.2 External Fittings

- Earth connection
- Lifting lugs and support legs
- External heating/cooling jacket or limpet coils
- Drain valves, vent valve and pressure taps
- Anchors/cleats for external insulation
- Shaft seals: whether ordinary glands, water-cooled glands (for lower pressure only) or mechanical seals to be used—depends on operating conditions, nature of material inside the vessel (inflammable or toxic)

7.1.3 Factors for Deciding Wall Thickness of Pressure Vessels

- Radius of the vessel
- Internal/external pressure
- Vacuum (can cause inward collapse of vessel walls)
- Expected weight—empty/full vessel (*due to choked exit/closed valves*)
- Additional loads possible due to fittings, valves, connected pipes, shock loads from compressors, wind loads, etc.
- Additional safety margin and corrosion allowance for material of vessel
- Allowance (*as safety margins*) for corrosion, severity of operating conditions and nature of fluid (dangerous/inflammable)

7.1.4 Heads for Pressure Vessels

Purchaser should obtain approval for the pressure vessels' design, welding joints, electrodes, etc. from a statutory authority before placing fabricationorder to vendor

- Flat head for low pressures, up to 5 kg/cm^2
- Torispherical head for pressures up to 15 kg/cm^2
- Ellipsoidal head generally for pressures 15–25 kg/cm^2
- Hemispherical head generally used above 25 kg/cm^2

7.1.5 General Considerations for Design and Fabrication

- Various design and fabrication codes such as American Society of Mech Engineers (ASME) Sec. VIII Div. I and II, Tubular Exchangers Manf. Association (TEMA), American Society of Testing Materials (ASTM), ASME Sec. II A/B/C/D, Indian Boiler Regulations (IBR), Indian Standards (IS) should generally be followed. Any deviation from standards/codes must be with a mutual written agreement between fabricator and purchaser
- Approval for design, drawing, fabrication methods, welder's qualification, etc. should be obtained from a statutory authority before purchaser places order for fabrication to vendor
- Approval for all drawings should be obtained by the purchaser or his consultant before fabrication commences
- Radiography (100 %) of all welded joints
- MOC of welding rods used for fabrication

No statutory provision must be violated.

- Actual corrosion allowance should never be less than the design value in the final drawing for fabrication
- Supporting pad plates (weep holes for pad plates) and position/details of lifting lugs

- External insulation and painting should be done only after completion of all tests at vendor's shop and re-tests at site (after erection)
- External reinforcement in the form of flats or angle irons
- External enclosures (to prevent flying off of debris in case of explosions) may be erected at site. The vessel should preferably be installed away from human activity
- Welding by direct current sets only
- Connected pipelines with expansion bellows so that no stress is created on the nozzles due to expansion and contraction of pressure vessels due to temperature changes or any other reason

7.1.6 Materials of Construction

General considerations

- Certification for tensile strength
- Corrosion resistance at conditions against chemicals handled
- MOC: should not be adversely affected during fabrication, cutting/welding
- High-impact resistance, especially for vessels in low temperatures
- Pressure vessels should be fabricated from standard-sized sheets available in market as virgin material. They should not be fabricated from recovered material (used for some other vessels earlier or obtained from ship-breaking yards)
- Purchaser should specify MOC for reactants and products under maximum pressure and temperature

MOC Ordinary mild steel (e.g. I.S.2062 or its international equivalent) *should not be allowed.* Certification for MOC must be obtained. *Samples of MOC must be tested in approved laboratories.*

Some common MOCs

- Carbon steel: IS 2002 Grade A, ASTM A 560, SA-516, A-179
- Carbon–manganese steel
- Carbon–molybdenum steel
- Chromium–molybdenum steel
- Chromium–molybdenum–vanadium steel
- Chromium–nickel stainless steel
- Duplex steel, super duplex steel
- Non-ferrous alloys of Ni, Cu, Al, Ti

Temperature limitations of materials of construction

- Carbon steel for non-corrosive service: up to 500 °C
- Stainless steel (*18–25 % Cr; 8–20 % Ni; 0.05–0.2 % C*): corrosive conditions, up to 650 °C. *Also, 0.03 % low carbon stainless steel*
- Clad steel (carbon steel *with cladding of stainless steel*)

- Nickel alloys: Monel for marine/organic service
- Inconel: for dairy/food processing service
- Brass: up to 200 °C
- Carbon–molybdenum steel: up to 550 °C
- Chromium–molybdenum steel: up to 650 °C

MOC that can be used after test of corrosion resistance

- SS-304: 18 % Cr, 8 % Ni
- SS-316: 16–18 % Cr, 11–14 % Ni, 2 % Mo
- SS-317: 3 % Mo min
- SS-316 L and SS-317 L: carbon should be less than 0.03 %
- SS-321 has added Ti

7.1.7 Fabrication Drawings

- General arrangement drawing and installation in key plan
- Completion of mechanical design as per codes: thickness of wall, flanges and nozzles, selection of proper material of construction
- Preliminary drawings should show shell thickness, tie rods, reinforcements at nozzles, corrosion allowance, details of welded joints, design and test pressure, radiography/electrode specifications
- Should be reviewed by all concerned along with comments, suggestions
- Fabrication drawings should contain comments by consultants and shop floor senior engineers for suggested changes or waiving off of requirements (some fittings or nozzles may not be required)
- Permission should be obtained from statutory authorities for these changes. The *final approved fabrication drawings* must have signatures of all concerned parties
- Generally, six hard copies may be prepared of the original: a master copy and copies for designer, plant head, fabricator, statutory authorities

7.1.8 Steps for Ordering and Procurement

- Discuss fabrication drawings for any last minute changes (*only minor changes not requiring statutory approvals*); finalise for negotiations with vendor
- Prepare purchase/work order on basis of above technical and commercial terms and conditions
- Obtain quality assurance plan from vendor
- Prepare procurement, erection and commissioning schedules
- Prepare cash flow plan in consultation with finance department
- Release order to vendor after all terms and conditions have been agreed upon
- Pay advance

7.1.9 Quality Assurance Plan

- Vendor must possess valid certificates for fabrication of pressure vessels (required by statutory authorities)

Vendor to specify codes and standards for fabrication

- ASME Sec I: boiler and pressure vessel code
- ASME Section VIII: rules for construction of pressure vessels
- ASME Sec I: welding and brazing qualifications
- Pressure equipment directive (PED)
- Japanese industrial standard (JIS)
- Indian Boiler Regulations IBR 1950 with latest amendments
- German pressure vessel codes (DIN)
- IS 2825-1969 for unfired pressure vessels (these are Indian codes, equivalent international codes can also be used)

Compliance with gas cylinder rules (with their latest amendments) and all relevant codes of design, fabrication and testing is a must. Stage inspection clause should be put in work order. Final test must be carried out in the presence of the purchaser's representative and should be as per statutory requirements. It is better to test the vessel again after installation as per standard procedures.

IS 2825–1969 for unfired pressure vessels provides the following classification of vessels:

- *Class I:* carrying lethal/toxic substances—full radiography is mandatory. Generally, double welded butt joints are used. Structural steels such as *IS 226/2062 are not allowed. Only IS 2002 Gr A (boiler quality steel) is allowed for construction*.
- *Class II: Many vessels used in chemical processing industries are classified under this class. All longitudinal and circumferential joints should be radiographed.*
- *Class III:* Used for light duties. Pressure should not be more than 7.5 Kg/cm^2 and maximum temperature should not be more than 250 °C. *Not to be used below 0 °C.* Local statutory authorities should be consulted for radiography test.

Weld efficiency factors should be between 0.55–0.60 only.

- Safety margin, corrosion allowance
- Testing and certification of all materials by approved labs/procurement from reputed vendors (including electrodes, fluxes). *Certification results must be preserved.*
- Traceability of material (stampings on plates, original purchase bills for bought items, store records with receipts of incoming material and material used for fabrication)

- Welding process
- Welding electrodes
- Records of post weld heat treatment for stress relieving
- Stage and final inspection

Full reports for dye penetration and radiography (exposed films) should be produced when asked for by purchaser.

7.1.10 Visit to Vendors Shop

- Stage inspection: storage facilities for electrodes, plates, bought components, thickness and composition of plates, cutting diagrams and cut plates, weld-groove preparation
- Assembly of vessel *with only tack welding* prior to final welding, root run of welding
- Final visual Inspection: overall dimensions, pad plates and vent holes, lifting lugs, safety vents/valves, provision for rupture disc, drain points, sample points, thickness of flanges and holes, gussets for nozzles, ovality check
- Nozzle *orientations must match the final layout of plant. Orientations to be considered while fabrication drawings are made—without any violation of statutory instructions*

Purchaser should ask for Post Weld Heat Treatment (PWHT) before accepting the pressure vessel

Why PWHT is necessary:

- *To relieve stress introduced during manufacture*
- *To improve corrosion resistance*
- *To improve strength and toughness*

The PWHT is mandatory when vessel thickness is >38 mm, when lethal fluid is handled, when used below $-10\,°C$, when minimum $95\,°C$ preheat is not applied (as per IS standards or equivalent international standards should be followed)

- Required temperature for PWHT: as per ASME Sec VIII guidelines for HP vessels will be as per Mn, Mo, Cr content from $590\,°C$ onwards.
- No change involving cutting/welding is permitted after PWHT. Even accidental striking by hammer is not permitted.

Vendor arrangements for PWHT:

- A furnace with heating systems (oil firing/gas firing/electrical heating, etc.) and corresponding facilities
- *Calibrated thermocouples*

- *Automatic temperature control*
- *Proper loading and unloading facilities*
- *Non Destructive Tests (NDT) facilities*
- General method: load the PV, heat at controlled rate (e.g. 100–120 °C/h) till desired temperature is reached. It may take up to 4–6 hrs, followed by soaking for minimum of 2 h, then controlled cooling till about 150 °C and then natural cooling. Then take out from furnace.
- Inspection after PWHT—visual checks for welded joints, deformation of nozzles

Non-destructive tests: to be done in the presence of purchaser's representative

- Visual checks of all dimensions, nozzle orientations, fittings, etc.
- Ovality checks (refers to maximum diameter minus minimum diameter)
- The pressure vessel may be de-rated if the ovality is beyond acceptable limits (as given by designer)
- Dye penetration/magnetic particle tests: to detect cracks in welded joints
- Hydraulic pressure test: vent out all internal gases from the topmost point of the vessel; fill the vessel completely with water. Blank all openings and provide calibrated test pressure gauge. Pressurise slowly to the specified test pressure and close inlet valves
- Maintain constant temperature
- Observe pressure loss after 2–12 h
- Use chloride-free demineralised water for the test
- Calibration test records for the pressure gauges (used during NDT) should be available to purchaser as well as statutory authorities
- Final drying should be done by hot dry air/nitrogen purging after hydraulic pressure test is over since any leftover moisture in vessel can cause corrosion or problems

Testing of pressure vessels for transport and storage of gases is important as they can explode under pressure

- *Treat with $AgNO_3$ to remove chlorides (a white precipitate indicates the presence of chlorides, which could be corrosive). Wash again by demineralised water and check*
- *Dry completely after test to remove all traces of moisture. No water should be allowed to remain in crevices, nozzles or drain points as this can react with acidic gases to form corrosive products*

Radiography of welded joints

- Radiographic Test (RT) method is used for detecting hidden flaws. This method uses the ability of short-wavelength electromagnetic radiation (high-energy photons) to penetrate materials
- The radiation source can either be an X-ray machine or a radioactive source (Ir-192, Co-60 or in rare cases Cs-137)

7.1.11 Statutory Documents Required

These documents are required in many countries for obtaining permission to erect and hydro test chemical plants (also useful for future reference/records of the purchaser).

- Order copy with intended use/service conditions
- General Arrangement (GA) and approved fabrication drawings with inlet and exit nozzles, their orientations, nozzles for safety valves, vents, level and temperature indicators, light and sight glass, drain point, etc.
- Pad plates for reinforcements, details of welded joints, lifting lugs, support lugs, *electrode materials*
- PWHT (stress relieving): heating and cooling curve records
- Radiography and hydro-test records
- Test and guarantee documents for bought components: safety valves, sight glass, level indicators, light glass, rupture discs
- Quality assurance plan verifications

7.1.12 Safety Valves

Safety valves are generally bought. Vendor should furnish test certificates whenever required by purchaser.

- Purchaser should confirm the values for designing, working and test pressures from design engineer and statutory authorities (factory inspector, government inspection agency, etc.). *Setting of safety valves should be done as directed by statutory authorities*
- Should open in case of increase beyond set pressure
- Prevent further pressure rise: the valves should be suitably sized
- Close after pressure is released
- Should not leak as this can lead to loss of reactants
- At least two safety valves should be provided
- To reinforce the nozzles for mounting the SV with due consideration for bending moment during blow off
- Markings on safety valves
- Name of manufacturer
- Date of test
- Smallest flow diameter upstream (should be >20 mm)
- Code: vapour/fluid
- Set pressure values above normal

Malfunctioning of safety valves

Purchaser should keep the following possibilities in mind. Purchaser should discuss with vendor and make suitable provision during fabrication/before taking delivery of the vessel.

- Malfunctioning may occur if the safety valve is connected to the vessel via a long pipeline or if pressure drops suddenly or if it gets choked due to deposition of solids
- Bends should be avoided in the connecting pipeline
- Release port must be of adequate size or greater than the required size
- Sudden pressure drops due to choking in exit or inlet pipes (e.g. *solidified sulphur deposits, salt deposits from boiling chemicals)*
- Distortion of valve body due to weight of blow-off pipe, over tightening of bolts
- Too much blow off can create bending moment on nozzle. *Proper supports and clamping required*
- Corrosion of seat: continuous blow off or a leak leading to loss of material
- Jammed spring due to corrosion
- Counter weight not fixed properly
- Hence, two safety valves are provided in most countries

Practical hints

- Do not depend on one safety device alone. Provide rupture disc in addition to safety valves
- The valves should be tamperproof. Spring-loaded valves should have protective covers on the springs so they do not get jammed due to corrosion, rain, dust, etc.

7.2 Glass Equipment/Glass-lined Equipment

Advantages

- Product contamination is least when proper grade of glass is chosen. Such glass can be used in manufacture of high-purity chemicals, pharmaceutical industries, research laboratories, etc.
- Process is visible and can be studied easily

Disadvantages

- Poor mechanical and thermal shock resistance
- Susceptible to mechanical vibrations, presence of abrasive or hard solids
- Can get affected due to fluorides (specially in the presence of acids)
- Can handle limited volumes only

7.2.1 Special Precautions

- Special PTFE bellows and gaskets should be used for connecting pipes
- Very firm, anti-vibration supports are necessary to prevent damage to glass-lined vessels and connecting pipes. Rubber pads can be used at support lugs.

Borosilicate glass items have better thermal/shock resistance and they should be treated with care

- Glass-lined equipment should be located away from vibrating machinery (such as compressors, crushers, pulverisers, etc.), sources of heat (high-temperature furnaces), exposure to high wind and rain, etc.
- Should be possible to easily erect, repair and dismantle the GL equipment and connected pipes, fittings, etc. Sufficient clearance should be provided on all sides of GL equipment for movement of men, materials and maintenance
- Raw materials with fluorides, HF, abrasive particles can damage lining
- Strainers should be provided in inlet lines to the vessel
- No raw material (solid or liquid) should be added rapidly; it should be slowly introduced without hitting the GL shaft or agitator
- Most of the precautions to be taken for GL equipment are applicable to glass equipment also—with the added danger that the contents of the vessel can spill suddenly. Therefore, enclosures should be provided to arrest spillages (e.g. dyke walls, collection basin with AR tile lining) to prevent harm to personnel

7.2.2 Details To Be Given to the Vendor

The following details should be given to the vendor:

- Operating pressure, temperature, composition of the reaction mass (concentration of various chemicals), viscosity, density, heat evolved during reaction
- Heating, cooling and washing time cycles during every batch
- Tendency of the reaction mass to solidify in case of power failure or interruption in heating fluid supply to jacket
- Special shaft sealing system and pulling arrangement for the shaft seal
- Liners at clamps for pipe fittings and for alignment and dip pipes should be made of Teflon
- Vent for the jacket for removal of vapours to improve heat transfer
- Provision for controlling speed of the agitator. Electronic speed governor is preferable since it does not add weight to the vessel
- Provision of Y-type drain valve which does not allow the drain nozzle to get choked
- Fabrication and spark test: purchaser should check the internals and surface preparation of the vessel before glass lining is done. Total thickness of the lining should generally not be less than 2 mm at any point. Higher thickness may be specified where external cooling or heating is not required
- Vendor should be asked to carry out spark test at 5000 V at least for checking all the glass-lined portions of the equipment
- The lined vessel should be given heat treatment in a special furnace by slow heating for 24–48 h, followed by slow cooling to relieve any residual stress. The rate of heating/cooling and period of soaking should be discussed with consultant experts in glass-lining jobs. Temperature readings should be preserved. Direct flame should not come in contact with the lining during the testing

- Vendor should be informed about the temperature of heating fluid in the jacket and temperature of the reaction mass in the glass-lined vessel. Similarly, when the reaction mass is being cooled, the temperature of the reaction mass and the cooling liquid in the jacket should be informed to the vendor. If temperature differences are high, there is the possibility of the glass lining cracking. Vendor should be consulted in such situation. The size of GL equipment should be finalised only after consultation
- Vendor should be consulted for the rate of heating and cooling to be followed: very rapid rates can damage the lining. Also, the maximum temperature allowed in the heating jacket and tolerated by the glass-lined agitator should be confirmed
- High-speed agitators are not advisable as the glass lining can get damaged
- Vendor should be consulted for special precautions to be taken during storage, transport, erection and commissioning
- Vendor should provide composition of the glass lining and information about corrosion resistance to the reaction mass as certain types of linings do not withstand phosphoric acid as it may contain fluorine compounds as impurities. Test results of glass-lined pieces may be obtained from the vendor. The equipment should be tested independently in the purchaser's own laboratory

8 Mechanical Screening and Filtration Equipment

8.1 Vibratory Screens

These are used for screening of fines from lumps of raw material (limestone) or finished product (dried salt from wet lumps) and removal of fines from catalyst pellets (screening of catalyst during annual shutdown of a sulphuric acid plant).

The following criteria should be kept in mind while selecting a vibratory screen:

- Material to be screened, its density, moisture content, tendency to get crushed by itself during screening (can increase fines)
- Size distribution in feed
- Particle size distribution required for product
- Material of Construction (MOC) of screen; thickness of wires/metal parts
- Angle of inclination
- *Size and shape of openings in screen (circular, square holes are available. Do not select screen with diamond-shaped holes since the openings do not have uniform size)*
- Method of vibration: by electromagnets, by cams actuated by links (operated by motors)
- Spring supports provided: MOC, load-bearing capacity
- Stroke lengths (distance through which the screen moves to and fro and also up and down) shall be adjustable
- Dust collection hood, exhaust blower, dust separator shall be available to cover the screen, fines collection etc.
- Feeding chute/discharge chute shall be at manageable height for ease of feeding the inputs and collecting the screened material
- A bagging and weighing machine shall be available

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8.2 Rotary Screens

Considerations for purchase of this equipment are:

- Materials to be screened
- Size distribution in feed
- Particle size distribution required for product.
- MOC of screens; thickness of wires/metal part.
- H.P. and speed (RPM) of motor, gear box.
- Type of drive can be an internal rotating shaft with three blades attached. The shaft extends outside and can have a driven pulley. It generally has a sprocket and chain drive, a gear box or a VFD motor. *External girth gear drive can also be provided to the rotary screen if there are more than one concentric screens for separation of two-or three-sized particles. This will depend on length and diameter of each screen; and may not always be possible.*
- Speed variation device: electronic variable frequency drive/gear box
- Angle of inclination (not more than 10 °)
- Type of roller supports (Thrust rollers are must)
- Feed hopper capacity and feed arrangement (A controlled feed through a rotary valve is desirable)
- Diameter of screens
- More tumbling and crushing of sensitive, brittle materials to be avoided by proper choice of diameter, size of flight and RPM. Send a sample of material to be screened to vendor for trials if necessary
- Dust collection hood over rotary screen with exhaust blower and scrubber/cyclone separator
- In certain designs, there are two or three concentric screens for separation of materials having openings of different sizes. The exit ends of these screens are of different lengths. The innermost retains the biggest particles while the outermost screen allows the fines material to pass through. This arrangement is used to screen out catalyst dust, catalyst pellets themselves and the catalyst bed support. The attrition loss can be reduced by slow rotation of the screens.

8.3 Filters

These are some of the most important equipments in a chemical process plant. Generally, they are used to purify the final product. However, the following important applications of filters and strainers make them an invaluable tool for the chemical industry:

- Purification of raw materials and intermediate process streams (both liquids and gases) before feeding to the reactors by separating tramp materials, undesirable impurities, pipe scales, sludge etc.

- Preventing masking of active surface of catalysts in a fixed-bed reactor by filtering the incoming gas streams containing dust particles. This also minimizes pressure drop in catalyst beds and frequent shutdown of the catalytic reactor for screening of the bed is not required.
- Separation and recovery of catalyst (for subsequent reuse) from process streams from outlet of fluidized-bed reactors in case carryover of catalyst particles is taking place.
- Providing protection to pumps, agitators (lined with anti-corrosive coatings of FRP, lead etc.) from hard abrasive solids in the process fluids.
- Preventing fouling of heat transfer surfaces, plugging of heat exchanger tubes etc.
- To remove insoluble particles from final liquid products to meet stringent specifications e.g. from inks, paints etc.
- To prevent plugging of spray nozzles of burners, spray towers etc.
- To recover valuable components from waste liquors.
- To recover valuable liquids from process streams by separating the solid waste.
- The specifications and information to be given to the vendor/fabricator of the filter thus depends on the intended application.

Solid–liquid separation can be done by settling (where difference in density of liquid and solids is more), where rate of settling can be increased by adding flocculating agents like alum, poly-aluminium chloride, $FeSO_4$ etc). Where this is not easily possible, various types of strainers, filters, centrifuges can be employed which carry out the separation. Pressure or centrifugal force is used for increasing the rate of filtration.

8.3.1 Important Considerations for Procurement

Type of filter required:

- Horizontal bed (for liquids and for gases)
- Pressure leaf type
- Rotary vacuum
- Cartridge (Removable)
- Small strainers (generally on-line and of quick discharge type)

Fluid to be filtered, its properties and duty conditions for the filter:

- Viscosity, pH, density in kg/lit at different temperatures
- Operating temperature: normal, minimum and maximum values to be specified for deciding MOC of wetted parts
- Freezing point of liquid which is to be filtered
- Melting point of solid particles. These will have to be looked into and heating/cooling jackets may be provided as per need

- Operating pressure at which the fluid is normally available
- Flow rate of impure dirty fluid in m^3/h
- Concentration of impurities (particles to be removed) mg/m^3
- Particle size
- Any caking tendency of the solid particles, i.e. sticky nature to be checked.
  - Purchaser may inform if any specific filter media is required, e.g. S.S.-316 wire cloth of a particular weave or mesh, polypropylene cloth of a particular mesh, etc. Also if any special back up wire mesh screens are required to support the main filter screen.
  - Any special mountings/fittings required, e.g. drain valves, vent valves; internal distributor for distribution of incoming dirty fluid over the filter media.
  - Vendor shall be asked to give information on cleaning the filter (removal of accumulated sludge/solids) and procedure for changing filter media (filter leaf, filter cloth, sand bed etc.) since this will decide the downtime of the unit and manpower required for cleaning and maintenance. Vendor may offer manual or automatic mechanism for removal of sludge.
  - Certain designs of filters are also available wherein a wire brush can be rotated (either manually or by an electric motor) over a vertical cylindrical filter cartridge screen to remove the deposited cake. Care is required in design of the brush as it shall not scrape away the deposit of filter aid, made not be too harsh on the filter screen. The dirty liquid enters the outer surface of the screen and deposits the cake. Clean liquid passes through and goes out from the filter through a bottom side nozzle. This type of filter can run for long time without need for opening because the cake is removed almost continuously.
  - A guarantee may be obtained (if possible) regarding dryness of filter cake/product quality.
  - *A dry product means less loss of (valuable) solvent carried away with the cake/less load on evaporator or dryers provided downstream.*
  - In case of pressure leaf filter, it should be possible to drain out all the liquid from the filter before opening it for cleaning. Arrangement may be made for injecting compressed air/nitrogen/steam into the filter for this purpose. This will minimize loss of valuable liquor during removal of sludge.

8.3.2 Rotary Vacuum Filter Procurement

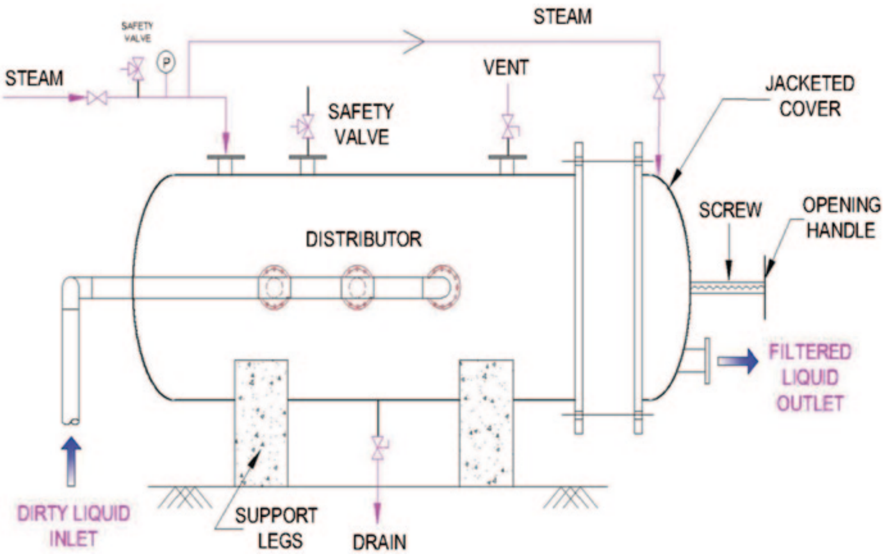
- Vacuum (during normal operations)
- Washing spray arrangement for cake deposited on filter screen
- Required adjustment for cutter knife for continuous removal of cake
- Lower liquid trough volume
- RPM of drum shall be adjustable
- Power consumption
- Thickness and protective lining on end plates
- Diameter of main shaft

8.3.3 Pressure Leaf Filter

Pressure leaf filters are generally employed where fine suspended impurities are to be removed. This operation is made easier by addition of suitable filter aids, e.g. Hyflo-Super-Cel, a diatomaceous inert powder which makes the filter cake porous, and filtration can be continued for longer time till the cake holding capacity is properly utilised. The following need to be considered for the procurement of this type of filter:

- Liquid to be filtered
- Temperature, pH, viscosity, density of the liquid
- Concentration of (suspended) impurities in the liquid
- Particle size of impurities
- Quantity of liquid to be filtered per hour or per day
- Cake holding capacity of the filter. This will determine the total run time of the unit between two shutdowns for cleaning
- Quality of filtrate required, i.e. maximum concentration of particles permitted and size thereof (e.g. not more than 50 ppm of all particles above 0.2 mm)

Example–The figure below shows a typical pressure leaf steam jacketed filter for liquid sulphur. It is used to filter molten sulphur at 130 C before feeding to the burner of a sulphuric acid plant. The filtration ensures steady plant operation and minimises deposit of ash on catalyst bed.



Vendor should inform the following (for the approval of the purchaser):

- Area of filtration
- MOC of filter leaves, maximum size of openings in leaves and heating jacket (if required)
- Internal liquid distributor
- Mechanism for taking out the carriage on which the filter leaves are mounted
- Insulation and cladding
- Accessories provided
- Details of the civil foundation required
- Space required on all sides for opening, cleaning and maintenance
- Any advice regarding suitable filter aid to be used.

For Batch Filtration One should specify a complete cycle time (time of operation and cleaning), i.e. time for which the filter is expected to be "on line" and time required to clean and restart (off line).

- Total quantity of throughput of fluid desired per cycle
- Cake holding capacity of filter
- Specifications of filtered fluid, separation efficiency for impurities of various particle sizes (e.g. 99.5 % separation for all particles above 10 µm is required during filtration of liquid sulphur)
- "Clarity" of filtered liquid/gas desired
- Pressure drop in filters, which are supposed to work "online" continuously, shall be specified
- This is important for certain chemical plants where in a stoppage cannot be taken to clean the filter; and it is not possible to install a standby filter
- Accessories and facilities required to operate the filter: foundation, pumps, steam supply, compressed air, pre-coat chamber, etc.

8.3.4 Filter Press

When the filter cake itself is the product to be recovered or in case of sticky impurities (even addition of filter aid may not be of much use) filter press is to be employed. Information to be given by the purchaser regarding the liquid and solid particles is almost same as in the case of pressure leaf filter. The following shall specifically be informed: slurry temperature and viscosity, nature of the cake solid and any preference for the filter medium.

However, the Vendor may be asked to give details of the following in his offer:

- Total area of filtration
- Size of individual plates and frames
- MOC of plates, frames and filter cloth (polypropylene, filter cloth of 200–400 mesh is common for dye industries)

- Size of passages for entry of liquid
- Arrangement to collect and transfer the filtrate
- Maximum safe operating pressure permitted at inlet. *It is useful to employ compressed air for flushing out the liquid from the filter cake. This helps for easier removal and also for quicker subsequent drying of the filter cake due to reduced moisture content. Vendor shall be asked to supply the compressor, air receiver tank, safety valves, drive motor etc.*
- Length of operating screw and whether a few more plates and frames could be added in future for increasing the filtration area
- Size of foundation required
- Cake holding capacity (this is more for recessed plates, but the utility will depend on filtration characteristics of the liquid and compressibility of the filter cake)

Purchaser may send a sample of the liquid to be filtered to the manufacturer of filter press for trials before procuring the unit and should inform the maximum percentage moisture allowed in the filter cake.

8.3.5 Centrifuge

These are used for quick solid–liquid separation, generally for easily separable crystals/suspended solids. However, difficulties have been experienced in use of centrifuge in case of sticky pastes for which press leaf filter may be used with appropriate additions of filter aid powders.

Information to be given to the vendor while floating enquiry for a centrifuge is as follows:

- Quantity of slurry to be filtered in m^3/h
- Concentration of solids in the slurry in % by weight
- Density of slurry and mother liquor
- Temperature, viscosity, pH of slurry/free acidity, if any
- Particle size of solids in the slurry
- Whether batch type operation is desired (capacity of basket desired)
- Can the vendor offer a continuous centrifuge to process the slurry continuously as well as removal of solid cake? Purchaser shall compare the capital cost of this unit with the batch type unit along with operation and maintenance
- MOC of wetted parts: any special requirement shall be indicated.

Information to be asked to the vendor

- RPM of centrifuge basket (also, type of bearings and drive mechanism used)
- Details of support springs and support legs
- Driven pulley (size) and number of belts
- HP and speed (RPM) of the motor (In case of inflammable materials, flame proof motor shall be asked for)

- Drain nozzle size and location
- Closing arrangement for the basket (bolted/clamped/others)
- Arrangement for continuous removal of cake from the centrifuge
- Total weight when empty and when full
- Foundation drawing/details of foundation to be made

8.4 Filters for Gases

Uses-for ensuring steady plant operation, to minimise deposit of ash on heat transfer surfaces/active catalyst surface etc.

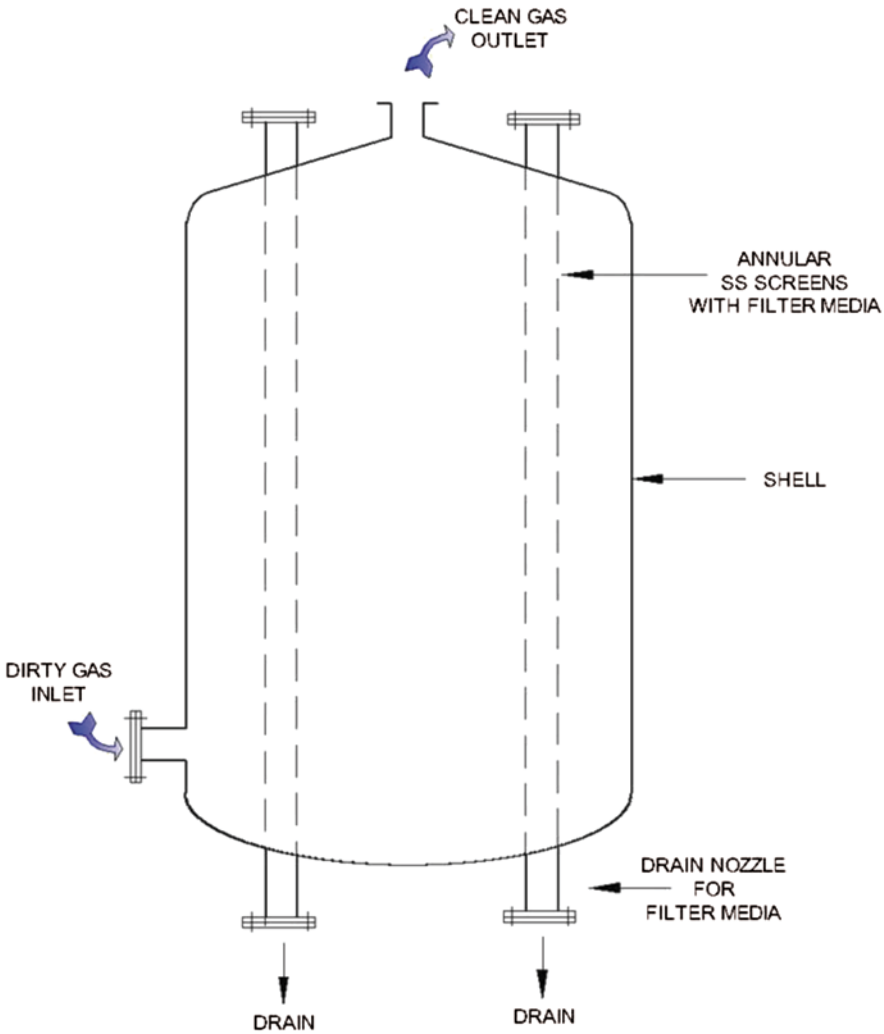
Considerations for selection:

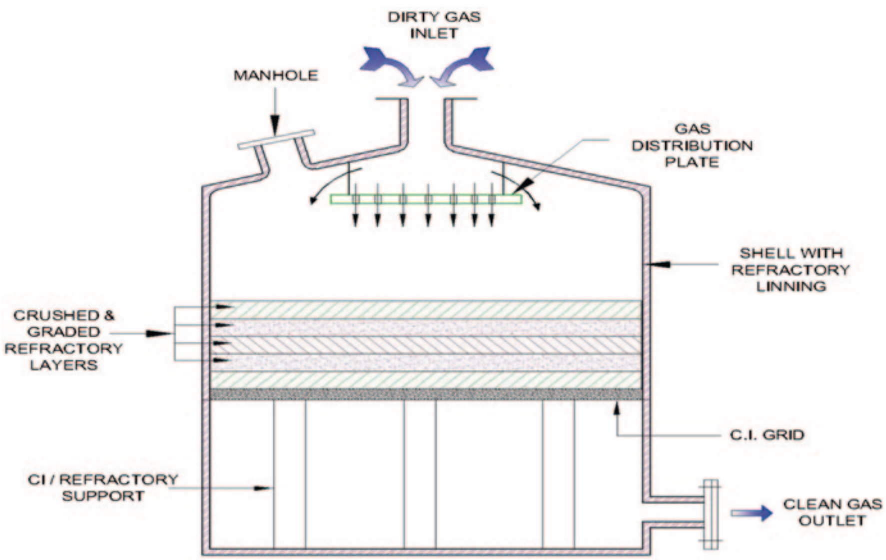
- Gases to be handled
- Flow rate of gases
- Maximum and minimum temperature of gases
- Maximum and minimum pressure of gases
- Composition on volume percentage basis
- Suspended particles: their concentration mgs/nm^3, size distribution, (minimum and maximum size) *attrition loss of filter media during cleaning must be minimum*
- Whether they have acidic or oily or sticky nature of gas mixture: whether it contains toxic, inflammable or explosive gases
- Separation efficiency required for the solid particles (especially when they are of high value or can choke downstream equipments
- Moisture content: this can corrode filter media, supports, and internals
- Presence of acidic particles
- Dew point of gas mixture
- Orientation of entry, exit nozzles and inspection-cum-charging manhole desired
- Pressure drop permitted in the gas filter by purchaser after consideration of existing units in process plant
- Capacities of existing ID or FD fans (for passing/sucking gases through the filter mass)
- Overall dimensions: length × breadth × height, space available in plant
- Cleaning manhole/facility provided for cleaning/removal of the filtration media
- Cleaning frequency necessary (depends on holding capacity for particles): once a week or a month or during annual shut down
- Cleaning method: manual or automatic, intermittent or continuous
- Automatic continuous removal of dust means a shut down for cleaning may not be required frequently
- Total space required for installation including space for incoming/outgoing gas ducts and cleaning of filtration media

8.4.1 Quick Discharge Type Filter (Case study—please see the two figures given below for comparison of these filters)

The filter media made from crushed fire bricks or quartz pieces is filled in the two concentric stainless steel screens (annular space between the screens). Dust particles are filtered and the clean gas goes out from the top outlet nozzle. When the pressure drop increase to a predetermined limit, it can be drained out quickly, and restarted again by filling in fresh filter media kept ready beforehand. *This needs only a small stoppage of the plant gas flow*.

However, the media can have pieces of only one size because the filter bed is vertical. It is not possible to remove fines of different sizes by such bed. If the bed is filled with very fine particles, the pressure drop can be high. There is also the possibility of warping of the screens, and some sinking of the media with time. This can reduce the efficiency of filtration (*due to uneven thickness of filter media*).





8.4.2 Filter with Horizontal Beds of Filter Media

The above shown filter has horizontal beds of graded crushed cleaned fire bricks. The lowest and uppermost layers are of a size 20–22 mm. Second and fourth layers from top are of 12–15 mm and the middle layer (which is the main filtration layer) can be of 6–8 mm only. The efficiency of filtration is very high. However, as it can take more time to take out the material after the pressure drop has increased, it is advisable to keep another identical unit ready as standby for a quick change over. This can increase the floor space required as well as capital cost. *In modern sulphuric acid plants, the liquid sulphur is thoroughly filtered and only one gas filter is provided (it is cleaned during annual overhaul only rather than every 5 to 6 months)*

Some typical filter media for gases are as follows: (select for use after taking trials in own lab or by vendor in his lab)

- Porous candles used only for small flow-rates
- Pads made from glass fibre—*for removal of acid mist*
- Pads made from stainless steel—*for removal of acid mist*
- Layers of crushed fire bricks—*for removal of ash particles*
- Crushed coke piece (temp. not above 200 °C)

8.4.3 Supports for Filter Media

- Cast iron columns
- Stainless steel 316
- MSRL (Mild steel rubber lined)
- MSBL (Mild steel brick lined)

8.4.4 General Features to be Provided

- Sampling points at inlet and exit
- Sight glass and light glass nozzles for internal observation (optional)
- Refractory or acid resistant lining required
- External insulation and cladding required (optional)

Important—Distribution Plate with perforations shall be provided for ensuring proper distribution of gas inside and to prevent disturbance of filtration media due to flow of incoming gases.

9 Heat Exchangers

Heat exchangers are one of the most important pieces of equipment in a chemical plant. They are used for heating/cooling of process fluids as per process requirement.

They should be procured with utmost care (e.g., it is generally very difficult to increase the heat transfer area by adding more tubes later on to a shell and tube heat exchanger).

9.1 Criteria for Selection of Heat Exchangers

The criteria for the selection of heat exchangers are:

- Duty conditions: for example, to cool "X" Nm^3/h of hot gasses from T_1 to T_2 °C, or to heat "Y" kg/h of cold liquid from T_3 to T_4 °C, etc.
- Composition in terms of mole fraction or percentage should be given for the gas streams (for each of the components).
- In case of liquids, the quantities of the streams should be mentioned in terms of kg/h.
- Properties of gas mixture: Mean C_p, viscosity, molecular weight of gas mixture; properties of liquid to be heated or cooled should be given.
- Fluids with suspended particles or a tendency for scale formation should be put on the tube side for ease of cleaning.
- Clean fluids should be put on the shell side.
- Material of Construction (MOC) of shell: Mild steel (Indian Standard 2062) or *its international equivalent* is may be considered. It is most common.
- Tubes: A-179 boiler quality or equivalent grade for high-temperature service. Other tube materials (BS 3059 CDS, A-106) can also be considered and appropriate one for the given application should be chosen.

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- Tube sheets: M.S. (I.S. 2002 Gr. “A”) boiler quality or equivalent grade.
- Special MOC is to be used as per compatibility with the fluids at the operating conditions. e.g. Hastelloy C-276 for strong sulphuric acid/oleum, etc.
- A protective layer of acid- or heat-resistant bricks may be put on the tube sheets, bottom plates if there are chances of condensation of acid.
- Ceramic/stainless steel AISI-304/stainless steel AISI-316 ferrules may be put in tubes and fixed by fire- /acid-resistant cement.

9.2 Allowable Pressure Drop

The allowable pressure drop during operation should be such that the cost of pumping liquids/blowing gasses should be as low as possible. If too-low values of pressure drop are specified, there will be need for more cross section. This can result in low fluid velocities, causing low Reynolds number (consequently low heat transfer coefficient and larger heat exchanger size). Hence reasonable pressure drops should be specified after ensuring that satisfactory heat transfer coefficients should be there.

9.3 Expansion Bellows

Shall be provided on the shell side (when operating temperature is more).

9.4 Floating Tube Bundle

This design will take care of the expansion of tubes when temperature variation is greater for the fluids on tube side than on the shell side.

9.5 Margin for Fouling of Heat Transfer Surfaces

Adequate fouling factors should be considered (depending on fluid properties, operating condition, etc.).

Orientation of inlet and outlet nozzles should be very carefully decided, especially on the shell side. The possibility of short-circuiting (when inlet and outlet nozzles are on the same side of the axis of a single-pass heat exchanger) is always there. In the case of multiple-pass heat exchangers (on shell side), there is a possibility of idle pockets at corners of baffles.

A typical example is the gas-to-gas heat exchanger used in a sulphuric acid plant for reheating the return gasses from intermediate absorption tower before admitting into next converter stage.

9.6 Tie Rods

Tie rods should be provided for maintaining the internal strength of the unit. Similarly, support columns may be provided for thick tube sheets for large-diameter vertical units.

9.7 Segmental Baffles

Generally 70–75 % cut baffles are used. Higher cut baffles provide less area of cross section for fluid flow in shell side, while providing good cross flow across tubes. The disc-and-donut-type baffle design has become more popular (see *below*). The pressure drop on the shell side is lower in this design. Drain nozzles, pressure points, cleaning manholes, reinforcements of appropriate places (cross bars on top cover plate, pad plates, etc.) and lifting lugs are the other important features that should not be missed while procuring/ordering a heat exchanger.

The corrosion allowance should be as per severity of operating conditions; that is, the pressure of corrosive fluids inside or atmosphere outside, high temperature and/or pressure, etc.

9.8 Radiography

100 % radiography for welded joints should be asked for when the heat exchanger is to be used for high-pressure, high-temperature or dangerous fluids. (e.g., *petroleum processing)*.

9.9 Pressure Test

This can be hydraulic or pneumatic. However, it is better to test the unit pneumatically especially for a gas-to-gas heat exchanger if the traces of moisture remaining inside (after a hydraulic test) can cause problems like corrosion of the shell or contamination of products.

9.10 Heat Exchangers with Disc-and-Donut-Type Baffles

In conventional heat exchangers with segmental baffles, there are chances of

- Higher pressure drop on shell side due to flow reversal.
- Formation of idle pockets where gas distribution may not be proper (hence, heat transfer areas may not be fully utilised).

- Bypassing of gasses may occur on the shell side if the gas inlet and exit nozzles are not properly oriented (ideally, they should be at 180°, but this is not always possible in a plant due to the positions of other process units, support columns, etc.) Hence, while fabricating a new heat exchanger in an existing plant these nozzles are fixed at 120° or at 135° some times. This can cause some bypassing of the gasses. If one were to fabricate a heat exchanger with nozzles at 180° then the ducts will have to be adjusted by taking longer paths (perhaps with additional bends too)—which is difficult again.

In the case of disc-and-donut-type heat exchangers, the baffles are in the shape of a disc-and-donut. Because of the shape of the baffles, gas distribution is almost uniform on the shell side in spite of any orientation of gas inlet and outlet nozzles (not very critical unlike segmental baffle-type heat exchangers).

Bypassing of gasses on the shell side does not generally occur, pressure drop is less and heat transfer area of tubes is fully utilised.

(*Case study*—The author had advised replacement of an existing shell- and tube-type heat exchanger in a sulphuric acid plant by a disc-and-donut-type heat exchanger. The above advantages were noticed immediately on its commissioning).

9.11 Plate Heat Exchangers (PHEs)

Plate heat exchangers (PHEs) have become very popular for the heating/cooling of liquids due to their very compact size. Also, the heat transfer area can be increased by adding a few more plates to the unit without increasing the overall size or disturbing the inlet/outlet piping. Criteria for procurement should include the following information:

- Properties of liquid to be heated/cooled; for example, density, specific heat, viscosity, thermal conductivity, pH, free acid/alkali concentration, etc.
- Heating/cooling load in kcal/hour.
- Properties of the service liquid (e.g., cooling water) available at site—TDS, pH, temperature, suspended solids, dissolved gasses if any.
- Temperature at which cooling water will be available.
- If heat recovery is desired, then the temperature up to which it is desired to heat up the cooling water.
- Thickness and MOC of the plates desired.
- MOC and method of fixing gaskets e.g. viton gaskets for Sulphuric acid service.

9.11.1 Information Required from Manufacturer

- Pressure drop which can occur for both fluids.
- Empty weight and weight when full of liquid.
- Foundation details.
- Total space required for installation and clearance to be kept on sides for operation and maintenance. Size of inlet and outlet nozzles for hot and cold liquids.

Important Since the PHE have very narrow passages to produce high liquid velocity inside, these can get choked due to suspended solids/impurities in the liquids. Hence, it is a good practice to install on-line cartridge type filters/strainers for the liquids. (*Example—strainers for ensuring proper cooling water flow for cooling hot oleums in an oleum plant.*)

Also, the pipelines should be so arranged and valves provided that it should be possible to backwash the PHE without dismantling it.

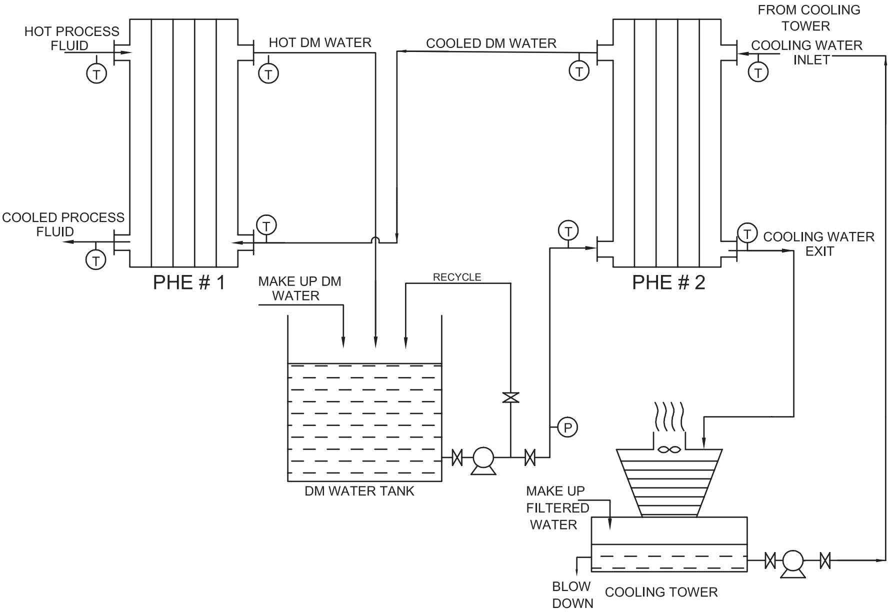
It is also advisable to install flow meters and thermometers/RTD to measure the performance of the unit. This will help keep a track of the actual heat recovery by the unit.

9.11.2 PHE-Based Heat Recovery System

It is difficult to get the cooling water heated up to a high temperature very close to the temperature (at which the hot process fluid enters the cooling system) when shell and tube heat exchangers are used because about 10–15 °C temperature difference is required for good heat transfer.

However, when PHEs are used it is possible to approach very closely the temperature of hot fluid at inlet because high heat transfer coefficients are possible, and a small temperature difference driving force can be enough.

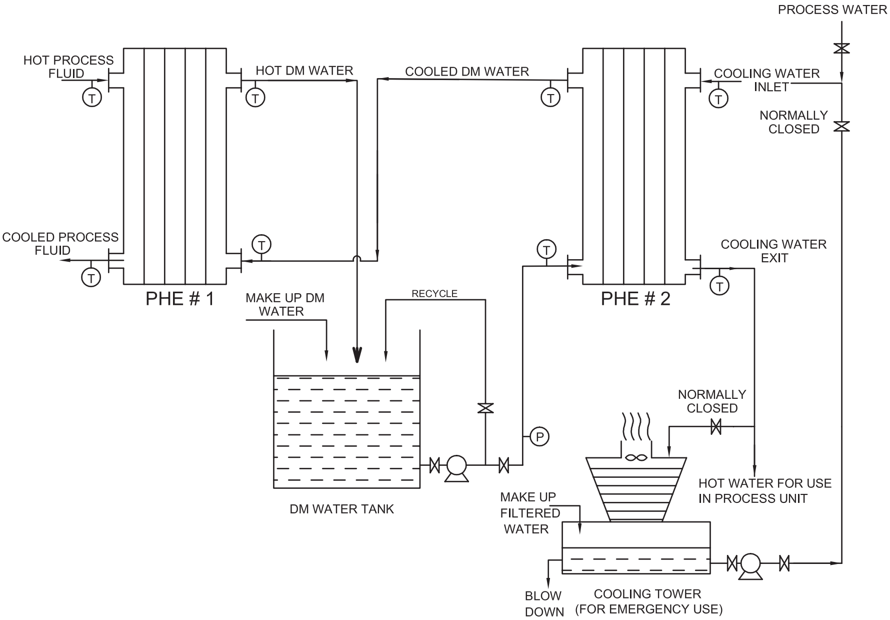
Option 1. Cooling of Hot Process Fluid Without Heat Recovery Example—Hot sulphuric acid can be cooled from 75 °C to 65 °Cby using a PHE supplied with water from a cooling tower at 30 °C. The water gets heated to about 40 °Cand is sent to cooling tower for cooling to 30 °C again. *The entire heat from hot acid is lost as evaporative cooling takes place.* The PHE may need cleaning frequently if cooling water quality is not maintained perfectly.



Option 2. Cooling of hot process Fluid Without Heat Recovery (please refer to above figure) The acid can be cooled from 75 to 65 °C by using PHE #1 with circulating DM water. The DM water can be heated to 68–70 °C and used elsewhere instead of sending to cooling tower. There may be a chance of an acid leak which can make the water acidic and hence it should not be attempted to use it as boiler feed water. Hence in this system the DM water is cooled by water from cooling tower. *Heat is not recovered here*. However the PHE #1 for acid cooling works satisfactorily.

The cooling tower water is to be well treated to maintain efficient working of the PHE #2.

However, heat can be recovered from hot acid by heating process water as illustrated below.



Option 3. Cooling of Hot Process Fluid with Heat Recovery—(please refer to figure above) The acid is cooled from 75 to 65 °C by using demineralised water as the cooling medium in the PHE #1. It is circulated in a closed loop and is cooled by filtered process water by PHE #2. The DM water can be heated to 68–70 °C and allows the PHE #1 to function efficiently.

The PHE # 2 exchanges heat with DM water and the process water can get heated to 63–65 °C for use elsewhere *instead of sending it to cooling tower*. The cooling tower can be used in case there is interruption in supply of process water.

There should be requirement for hot process water in the plant elsewhere. There are practically almost no chances of contamination of downstream process by acidic leaks.

Considerations for implementing such a system are—

- Properties of hot fluid–flow rate, corrosive nature, specific heat, density, viscosity, inlet and exit temperatures.
- Requirement of hot water elsewhere: volume, quality, temperature at which it is required and present method for generating it. A steady requirement suits this system.
- Cost of both PHE and power required for circulation pumps.
- Steam/fuel/electricity saved when hot water becomes available as above.
- Power saved by *not using* cooling tower during normal operations.

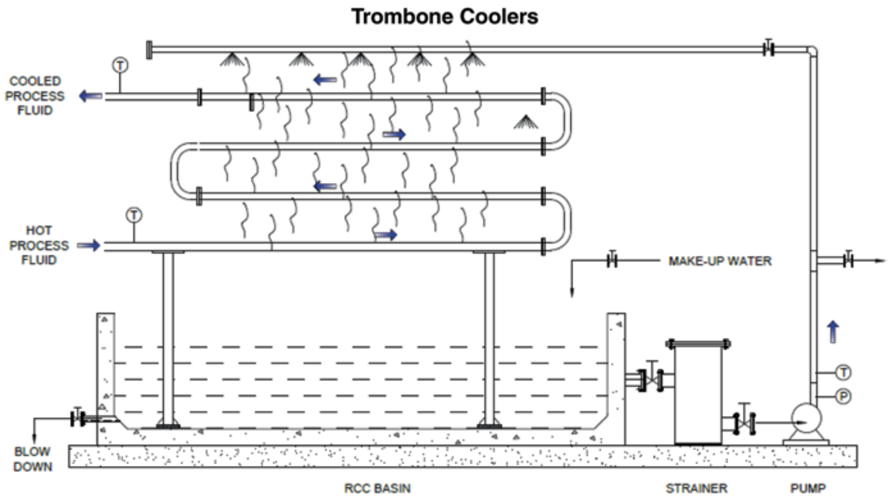
Case Study It was possible to get 24 m^3/h of process water at 60 °C for washing fibres when heat was recovered while cooling 120 m^3/h of 98.3 % sulphuric acid from 78 to 68 °C by the above scheme. This could save about 1300 kg/h of steam *which was being consumed earlier*.

9.12 Other Types of Heat Exchangers

9.12.1 Trombone Coolers

Banks of pipes over which cooling water is sprayed. There is a basin below the bank of pipes and has a pump for circulating water. The unit acts like a cooling tower—but without a fan—and any leaking pipe can be easily seen and attended. But it should have enclosure sheets all around to prevent any accident due to such leaks. The basin is supplied with fresh make-up water, and is purged out if TDS increases beyond 4000 ppm to reduce scale formation on the pipes. Cost of power required for ID fan is saved.

It occupies more space—both on floor and vertically. They were used for sulphuric acid plants earlier, but are now replaced by PHE or shell and tube heat exchangers.



9.12.2 Atmospheric Cooling Loops

Atmospheric cooling loops were used in earlier designs to cool gasses. They had bypass ducts also to prevent excessive cooling. They were easy to fabricate, and there was no cooling blower used. Heat recovery was not done and more space was occupied. These are mostly replaced by air pre-heaters or economisers wherever possible.

9.12.3 Finned Tube Banks and Radiators

For better heat transfer rates for gas/liquid cooling by air or for preheating air by steam or hot gasses inside the tubes. The area required for heat transfer can be less if gasses are clean. Dirty, corrosive, dust-laden gasses should not be put on the fin-side as they can get deposited between the fins and advantage of additional area is lost.

Their design and application is generally tailor made for a specific plant.

9.13 Condensers

The units are to be designed as per required rate of condensation while taking into account properties of the vapour and liquid, cooling medium, presence of noncondensable gasses (which need to be vented out), corrosive vapour, tendency for formation of scales, etc.

In case the liquid has a high vapour pressure/is costly/inflammable/toxic, etc., then subcooling of the condensed liquid is to be done by providing additional cooling area for the liquid, and cooling can be considered by incoming cooling medium or by using chilled brine. *This type of units are used for carbon disulphide.*

Dangerous vapours under pressure should be put on the tube side of a condenser, and a cooling medium like water should be put on shell side. In case of a leak, only water will come out and the accident will not occur (e.g., condenser for ammonia or sulphur dioxide under pressure).

In cases where water should not come into contact with the vapours being condensed, the shell side may be operated at negative pressure, that is, under siphon. In case of a tube leak, the condensing vapour will get mixed with water and get carried away from the condenser due to the siphon. An on-line pH meter can indicate the leak if the vapour is acidic. Some other detector, for example, conductivity meters, can also be used. *For example, Condenser for Liquid* SO_3.

Steam condensers (after turbo generator sets) are used to maintain the low pressure of turbine exhausts as well as to recover condensate for recycle to the boiler feedwater tank. Here it is necessary not to subcool the condensed liquid, so that the maximum heat recovery can be done (by obtaining condensate at as high a temperature as possible. The configuration of steam inlet nozzle and cooling water inlet/outlet nozzles etc should be designed accordingly.

9.13.1 Pressure Test

Condensers handling dangerous fluids must be subjected to hydraulic tests, even after carrying out radiography for welded joints. Outlet nozzles for condensed liquids should have gussets for reinforcement and heating/jackets or steam-tracing pipes if the melting point is near ambient temperature. Also, conical bottoms with flanged connection for drain valves will be found to be a very useful design.

Nozzles should be available for:

- Venting out vapours/noncondensibles
- Provision for purging out residual (toxic or dangerous) vapours by nitrogen gas
- Draining out condensate as well as cooling liquid from the tube side and shell side completely (required for maintenance work)
- Inserting thermo wells for RTD, thermometers, etc.
- Connecting taps for pressure measurement

9.13.2 External Reinforcement for the Shell

When there is a possibility of development of high vacuum due to rapid condensation in the shell, it can collapse inwards. Reinforcing flats, angle irons or "C" channels should be welded along the circumference for reducing the L/D ratio. The shells should be fabricated of thicker plates for added strength.

In case of the possibility of the choking of the tubes due to scales/dust carried with the vapours, provision of a cleaning nozzle should be available to insert wire brush in the tubes and remove the sludge from bottom. This will enable unit to be cleaned without dismantling.

9.14 Evaporators

These are used for evaporation of dilute liquors for concentration as such or before feeding to crystallisers, for producing distilled water, etc. and are of following types.

9.14.1 Open Type

Typical use is for manufacture of alum from dilute solution of alum.

Steam heating coils are installed in open vessels (the unit operates at atmospheric pressure) for evaporation of the dilute liquor. The operation can be batch type (production of alum from dilute solution). The vapours should be removed by an exhaust hood, scrubbed and connected to a chimney through a demister to control pollution. An ID fan is to be used for this.

While the observation of the inside of the open pan could be easy; the latent heat of evaporation is not recovered.

Samples of liquor are taken out to check completion of evaporation by observing specific gravity and solid concentration.

Considerations for Procurement

- MOC of the vessel and the lining material (can be with lead, AR bricks) as well as that of the coils which can be made from SS 316, or mild steel coils lined with lead if acidic liquor is to be handled.
- Some free space should be left at the top to prevent spilling out the boiling liquid.
- Quantity of dilute solution which will be taken for evaporation per batch and the dissolved solid content, pH, specific gravity before charging and in the concentrated product solution at the end of a batch should be looked into.
- Steam consumption can be found out by collecting the condensate and measuring it.

The steam coils should be tested by hydraulic pressure 1.5 times the working pressure and the steam traps should be provided for rapid removal of the condensate—as soon as it is formed—to maintain rate of evaporation. Thermodynamic traps should be used and the hot condensate should be recovered for use as boiler feed water ***after testing its acidity****.*

9.14.2 Closed Type

The operation could be at normal atmospheric pressure or under vacuum. The evaporators are single effect units or multiple effect types, which operate under progressively increasing vacuum. If the evaporating liquor starts boiling violently, or acidic mist is thrown out, or excessive frothing may result, then a closed-type evaporator is preferable. It should be provided with a scrubber, an entrainment separator (stainless steel pad or glass fibre demister as per need) and an ID fan. Liquid droplets scrubbed and arrested by demister should be recycled to process if possible.

9.14.3 Multiple Effect Evaporators

Used in sugar industry for concentrating dilute juice, for concentrating weak spin bath solution prior to recovery of sodium sulphate by crystallisation in rayon industry.

The above evaporators do not recover the latent heat of vaporization while a multiple effect evaporator can recover this latent heat. This can reduce the steam consumption for the same evaporation duty for concentrating the dilute solution.

Boiling Points

The boiling point of the solution depends on the operating pressures (vacuum). The dilute solution is concentrated by boiling it under progressively more and more vacuum. The vapour from the first effect is used to heat up the solution in the second effect which is boiling under lower pressure and hence at a lower temperature too. Likewise, vapours from second effect are used for heating the solution in the third effect and so on. This may be repeated three or four times (up to six to eight times also in some plants).

However, sufficient temperature difference driving force will be required in every effect, and the operating pressures should be selected accordingly. It is also important that the vapours generated in an effect should be *fully utilised in the next effect*. The area provided for heating thus depends above factors. Arrangement for sucking out the gasses evolved should also be provided for every effect for maintaining vacuum to ensure system efficiency. *This should be discussed with the vendor.*

The condensate from last stage (which is operating at maximum vacuum) can be used to preheat the incoming dilute feed liquor. Condensate from other stages can also be collected and recycled to boiler feed water tank/other process units as per need after confirming that there is no acidity/contamination during operations. *Appropriate type of steam traps (bucket type are generally used) for removal of condensate from every effect should be provided.*

9.14.4 Separate Measurement of Condensate

Separate measurement of condensate from the first stage gives the quantity of steam consumed, while the total of all condensates will give total evaporation. The ratio of the two is the steam economy. This should be confirmed by the vendor. *This is to be mentioned in the performance guarantee terms of the inquiry document prominently.*

Information to be included in the inquiry document:

- Feed rate of dilute incoming solution—during normal operation and maximum required in future
- Concentration of dissolved solids in dilute solution (normal and lowest)
- Suspended particles content—whether they are abrasive and can erode or foul the heating tubes
- Inlet temperature of dilute stream
- Desired concentration of solids (normally required and minimum acceptable) in outgoing concentrated solution

Vendor should guarantee the flow rates and concentrations of outgoing solution at normal operation and when most dilute solution is fed to the unit.

- The exit temperature will depend on the design of the evaporator.
- Chances of precipitation in heating tubes.
- Specific gravity, viscosity, boiling points, and specific heat of the solutions at different concentrations and temperatures.
- Solubility of solute at different temperatures.

- Evolution of dissolved gasses and dissolved air which may come out during evaporation/boiling. The boiling can be violent if gas quantity is more.
- Which gasses are likely to come out? In the case of toxic gasses, scrubbers may be required at the last stage/at all vapour exit points—when vacuum pumps are used.
- Chances of fouling of heating transfer surface.
- pH and corrosiveness.
- Foaming tendency of solution.
- Space and head room available in the premises.
- Local climate (for outdoor installation sites).
- Location of site—height above mean sea level.
- Annual operating hours required—this depends on maximum time permitted for annual shutdown and stoppages during the year for various maintenance jobs. Generally 90 % availability should be assured. The evaporation capacity should be specified accordingly on per hour and per annum basis.
- Properties of product if it is heat sensitive and likely to decompose or deteriorate at higher temperatures… *Forward feed is to be used in such cases. Here the dilute solution is first heated by incoming steam and as the concentration increases, it is boiled under greater vacuum. The boiling point is less under higher vacuum and hence the heat sensitive product is not damaged in subsequent effects.*
- Some heat-sensitive products (in pharmaceutical industries) may need further cooling after coming out of the evaporator. In this case the last effect should be operated at maximum vacuum possible and a product cooler may be provided.
- If product is heat sensitive, what is the maximum temperature it can withstand?
- The vendor should be asked to give detailed specifications and consumptions per MT of evaporation of the utilities required for operation of the units— steam, cooling water (for last stage barometric mixing condenser), electric power for circulation pumps, cleaning agents, need for vacuum pump or ejectors for removal of gasses and dissolved air evolving during boiling.
- The vendor should include the barometric mixing condenser in his scope of supply.
- The purchaser should check the actually available steam pressure and quantity (whether it will be taken from exhaust of a steam turbine or from a boiler directly).
- Cooling water available at site—its analysis, temperature and quantity.
- Whether cooling tower should be supplied by vendor if it is not there at site.
- *Materials of construction* of heating tubes and main body of evaporator should suit the corrosive solutions and should have good thermal conductivity, erosion and corrosion resistance to liquor and suspended solids.
- *Circulation pump*: capacity, head, impeller design (should be semi-open type if more suspended solids or crystals will be present in the solution), power consumption, shaft seals to be informed by vendor. This will depend on the length of the tubes, flow velocity, density of the solution and whether boiling will be allowed or not allowed in the tubes.
- Drain points and cleaning manholes for the tubes and main body (flash chamber).
- *Selection of a Forced Circulation Type Evaporator—*

(i) Heating surface provided by vertical heating tubes—when the product has a strong tendency to foul the heating surfaces (due to either suspended solids or precipitating out during evaporation). Pumps should be provided for a rather high rate of recirculation through the tubes (3–5 m/s linear velocity) and should have semi-open impellers. This consumes more power but it is necessary to get the required rate of heat transfer.

- There should be a separate heat exchanger with vertical tubes where the heating tubes should project about 150 mm in to vapour head. This can result in fast *disengagement of vapours as the circulating liquid exits from the tubes.*
- The liquid level should be kept slightly below tube sheet. *Check the assembly drawing before the placing order.*
- The advantages of a separate heating surface from vapour liquid separation zone, solids remaining in suspension and hence heat transfer surface remaining clean should be carefully weighed against need for more headroom required and higher power consumption by the circulation pump while selecting this design of evaporator.

(ii) Heater surfaces provided by horizontal heating tubes—this does not need more head room. *The tubes can be cleaned and replaced more easily*.

- High heat transfer coefficients possible if boiling is allowed in tubes.
- Suitable for liquors which do not form deposits or scales on surfaces.
- Not suited where deposits of salt can occur on tube surfaces due to boiling.
- Disadvantages—high power consumption, possibility of erosion of heat transfer surfaces due to high velocity of liquid.

Selection of Submerged Tubes Forced Circulation

- This may be offered for solids with lower solubility even at higher temperatures. The boiling may be prevented in tubes by placing heating element below liquid level in flash chamber *to get an effect of hydrostatic head (which increases the boiling point).*
- While it can result in minimum deposition in tubes (since saturation of liquor is not reached), the heat is transferred to the liquor at higher temperature of liquid. Hence less temperature difference driving force available.
- As a result more surface area will be needed (thus increasing capital cost), and the need for higher velocity through tubes will consume more for circulation (increasing operating cost).

Consideration for Falling Film Evaporator

- Used for a product which is heat sensitive.
- Both liquid and vapours move downwards while maintaining a thin film on the vertical tubes.
- It is very important to ensure proper wetting rate on the tubes. This is necessary to prevent local boiling; otherwise, the rate of heat transfer can reduce at tubes

where flow is more, while the rate of scaling on the heat transfer surface will increase where flow of liquid is less.

- *A properly designed liquid distributor to ensure uniform flow in all tubes is necessary. This is to be confirmed by the vendor.*
- Not suitable for viscous liquids or low flow rates as thick film may form on surfaces which can result in local overheating.

Properties of vapours leaving the evaporators should also be considered for construction of vapour space and internal entrainment separator of the evaporator.

- Temperature of vapours, specific volume per kg at operating conditions.
- Any carryover of liquid particles (as these can go to heating surfaces in next effect and adversely affect heat transfer due to deposit of solid particles). There will be need for entrainment separators in such cases.
- Toxicity (if any) of the vapours (will need scrubbing system at the exit).
- Whether the vapours are to be recovered (if they are of high value). This will need condensing/absorbing/adsorbing system.
- Options for heating—steam/hot oil/hot gasses, etc.
- Construction options desired for heating section/or available: jacketed shell/external limpet coil/internal coil/external heat exchanger.
- The external heat exchanger is sometimes used to augment the heat transfer area and helps to limit the size of the main vessel of evaporation.
- MOC: The MOC of all internals, mist separators, heat exchange surfaces must be compatible with the liquor being handled.

Instrumentation

- RTD or dial thermometers at all incoming and outgoing solution streams before and after every effect so that any overheating of solution can be monitored. This is necessary to keep control on heat-sensitive products.
- Steam pressure gauge at inlet and vacuum gauges on all stages.
- On-line pH/conductivity meters on all condensate lines (optional). Provide sampling points for all such lines to detect any leak of tubes. Manual check of pH every half an hour should be done.
- Flow meters for incoming dilute and outgoing concentrated liquor lines.
- Pressure gauges on incoming liquor/outgoing liquor line (optional).
- On-line hydrometers for continuous indication of the specific gravity of the incoming and outing liquors will give a good idea of performance of the unit.

In case the last stage is operated on barometric condenser (or by using a steam ejector for removing the *dissolved gasses* which are evolved during boiling), the water temperature and pressure at the inlet of the condenser should be monitored continuously as well as the electrical current drawn by the water pump for supplying water to the condenser.

In case of appreciable changes in the properties of the concentrated liquor, the instrumentation sensors should be located so as to avoid idle pockets. Suitably designed sample coolers should be provided wherever necessary.

Note Purchaser should inform the manufacturer about the solubility of the (dissolved) solid in the circulating liquor at different temperatures; tendency to crystallise out and abrasive nature of the crystals. This is very important for selecting the MOC and size of the tubes in the calendria and the type of impellers of the circulation pump.

Sufficient space should be available at the site to clean the tubes. It should also be possible to take out any tube for replacement. This should be checked if the vendor offers an evaporator with long tubes.

Air Pollution Control Equipment 10

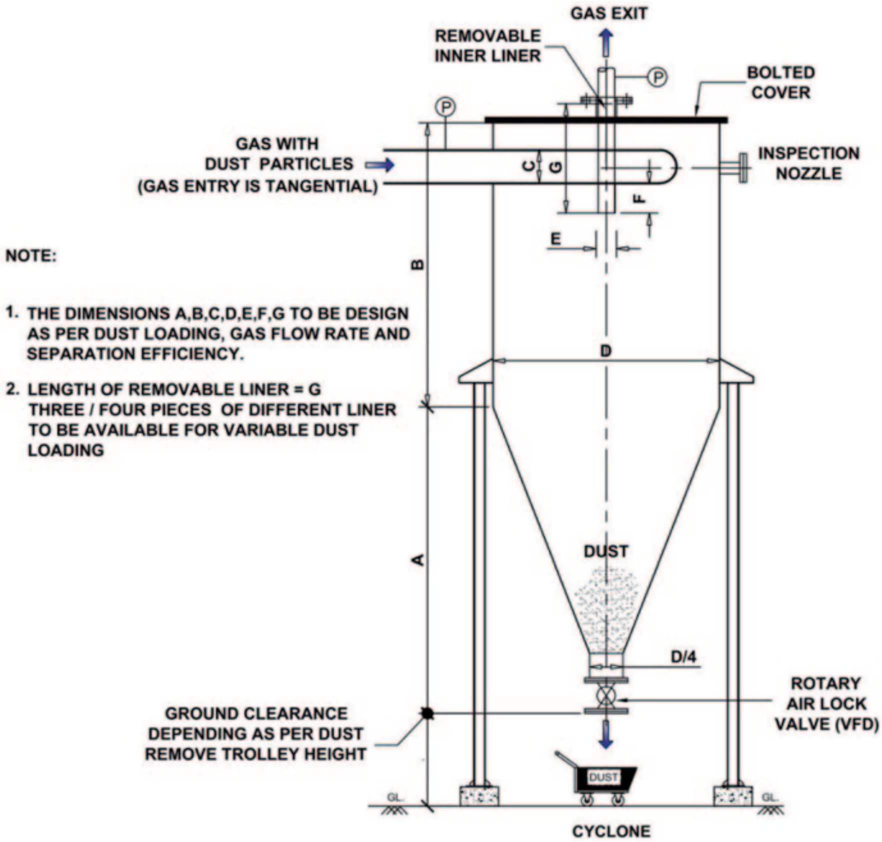
10.1 Cyclone Separators

These are generally used for pollution control, separation of dust particles from gas streams for recovery of solids after grinding operations, after pneumatic conveying. Separation of the suspended fine particles takes place due to vortex motion of the gas stream.

Selection Criteria/Information To Be Given by the Purchaser

- Gas flow rate: in nm^3/h (min/max/normal).
- Gas composition (volumetric percentage of each component).
- Gas pressure at inlet of cyclone (min/max/normal).
- Operating temperature (maximum and normal).
- Particle size distribution.
- Density of suspended particles and gas mixture.
- Properties of these solid particles (whether acidic/hygroscopic/explosive).
- Presence of moisture in the gas.
- Size of incoming gas ducts (gases should enter tangentially).
- Size of outgoing gas duct.
- Maximum pressure drop permitted in the cyclone.
- Desirable: A set of removable exit liners (pipes) of different lengths and diameters (fitted in the cyclone) should be asked to be included in the scope of supply. These can be useful if there is considerable variation in operating conditions.
- Length of lower conical portion can be longer than minimum calculated value (as much as practicable at site). This portion should be bolted and easily removable.

K. Golwalkar, *Process Equipment Procurement in the Chemical and Related Industries,* DOI 10.1007/978-3-319-12078-2_10



Vendor to Indicate the Following

- General arrangement (GA) drawings showing gas entry and exit nozzles and arrangement for discharging solid particles, position of support legs, etc.
- Overall dimensions, empty weight and filled up weight (with dust). Design the support legs for maximum weight.
- Material of Construction (MOC) of the unit and thickness of various parts.
- Location and orientation of cleaning/inspection manholes.
- Reinforcing ribs/flats provided externally.
- Temperature and pressure measurement points.
- Maximum pressure drop at rated operating conditions of flow rate, temperature, pressure, etc.
- Particle separation guaranteed for different particle sizes and loading in the incoming gas stream.
- In case of wet cyclones, the vendor should indicate position of liquid injection nozzles, flow rate required, etc.
- External insulation and cladding, if required as per process conditions.

- Provision of rotary air lock valve at bottom for continuous removal of dust. This should have a Variable Frequency Drive (VFD) motor with a chain drive. In case of jamming by the dust, the motor should have an instantaneous tripping arrangement.

10.2 Bag Filters

Bag filters are generally used for the control of fine dust and are provided after cyclones and pad-type filters.

Mention the following in the inquiry document:

Inlet Conditions

- Gas volume to be treated (nm^3/h).
- Particulate matter concentration expected (mg/nm^3)
- Size distribution of particulate matter in incoming gas stream.
- Temperature and pressure of gas.
- Presence of corrosive gases and moisture (these can damage the cotton fabric bags. One may have to use costly PTFE bags in such cases. Higher moisture content can choke the bags if condensation occurs inside—hence, operation should be above dew point of the moist acidic gases)
- *Bags of most materials can get damaged if the gases enter at above 210–220° C.*

Exit Conditions (Required by Purchaser)

- Separation efficiency desired for particles of different sizes (1–3, 3–5, 5–10 µm, etc.)
- Gas volume to be handled at present and in future
- Particulate matter concentration (mg/nm^3)
- Size distribution of particulate matter
- Temperature and pressure of gas
- Recovery of collected dust if possible

To be looked into the offers given by vendor

- Maximum temperature permitted (generally less than 100° C; it can be more if permitted by the vendor).
- Pressure drop in clean bags system and when the bags are due for cleaning.
- Number of bags fitted, diameter length and material of bags, reinforcing ribs on the bags.
- Sampling points provided at entry and exit of bag filter.
- Ease of replacement of bags.

- Arrangement offered for cleaning of bags (is it by reverse pulse air pressure?); simple shaking may not properly clean the bags, though cost of this arrangement can be lower.
- Air compressor, air receiver, adjustable timer and control valves should be supplied by vendor.
- Provision of air lock rotary valve at bottom discharge nozzle for continuous removal of dust collected inside. Overall size of the unit—length × breadth × height.
- It should be possible to install the bag filter in a satisfactory manner in the available space. There should be enough space around to install air compressor, air receiver tank, electrical control panel and for maintenance activities.
- Orientations of gas inlet and exit nozzles should be as per locations of process units in the plant.
- *Can the unit be kept running while bags are being cleaned?*
- *Can the existing ID fan suck the gases through the bag filter offered?*
- *Will the existing motor of ID fan be able to take the additional load or a bigger motor be required?*

10.3 Absorption Equipment for Pollution Control

10.3.1 Inquiry for Gas Scrubbing Systems

The following should be mentioned clearly in the inquiry floated for procuring a gas scrubbing system:

Gas Stream To Be Treated

- Flow rate (nm^3/h)
- Components present and their concentrations on volumetric (mole fraction) basis
- Presence of acidic, toxic and inflammable gases and moisture content
- Dew point for the gas mixture
- Temperature and pressure at which the gas mixture will enter the scrubbing system
- Concentration and size distribution of acidic or dust particles

Efficiency of Treatment Desired

- Maximum permissible concentrations of individual pollutant; for example, acid mist, SO_2, HCl, NO_x, dust and dust particles in gases going out from the scrubber.
- Temperature and pressure of gases at exit of the system.
- Chemicals used in scrubbing liquor and their concentrations in the liquor.
- Cost of these chemicals.
- Minimum concentrations of chemicals required for efficient scrubbing.

- Products which are likely to be found in the spent scrubbing liquor.
- Possibility of formation of suspended particles during scrubbing.
- Chances of choking the spray nozzles during operation.
- Whether the spent liquor can be reused in the plant or can be sold?
- If not, can it be regenerated and reused for scrubbing?
- Chemicals, water and power consumption per cubic nanometre of gases to be treated, that is, operating cost.

A combination of various scrubbing equipment may be offered. The purchaser should consider all offers by a cost-benefit analysis.

10.3.2 Venturi Scrubber

Venturi scrubbers are generally used for removal of particulate matter, acid mists and similar pollutants. The efficiency is greater when a very good contact between atomized scrubbing liquor and gases is made. It may cause a pressure drop of 400–500 mm water column and needs 1.5–2.0 L of scrubbing liquor/m^3 of gas flow.

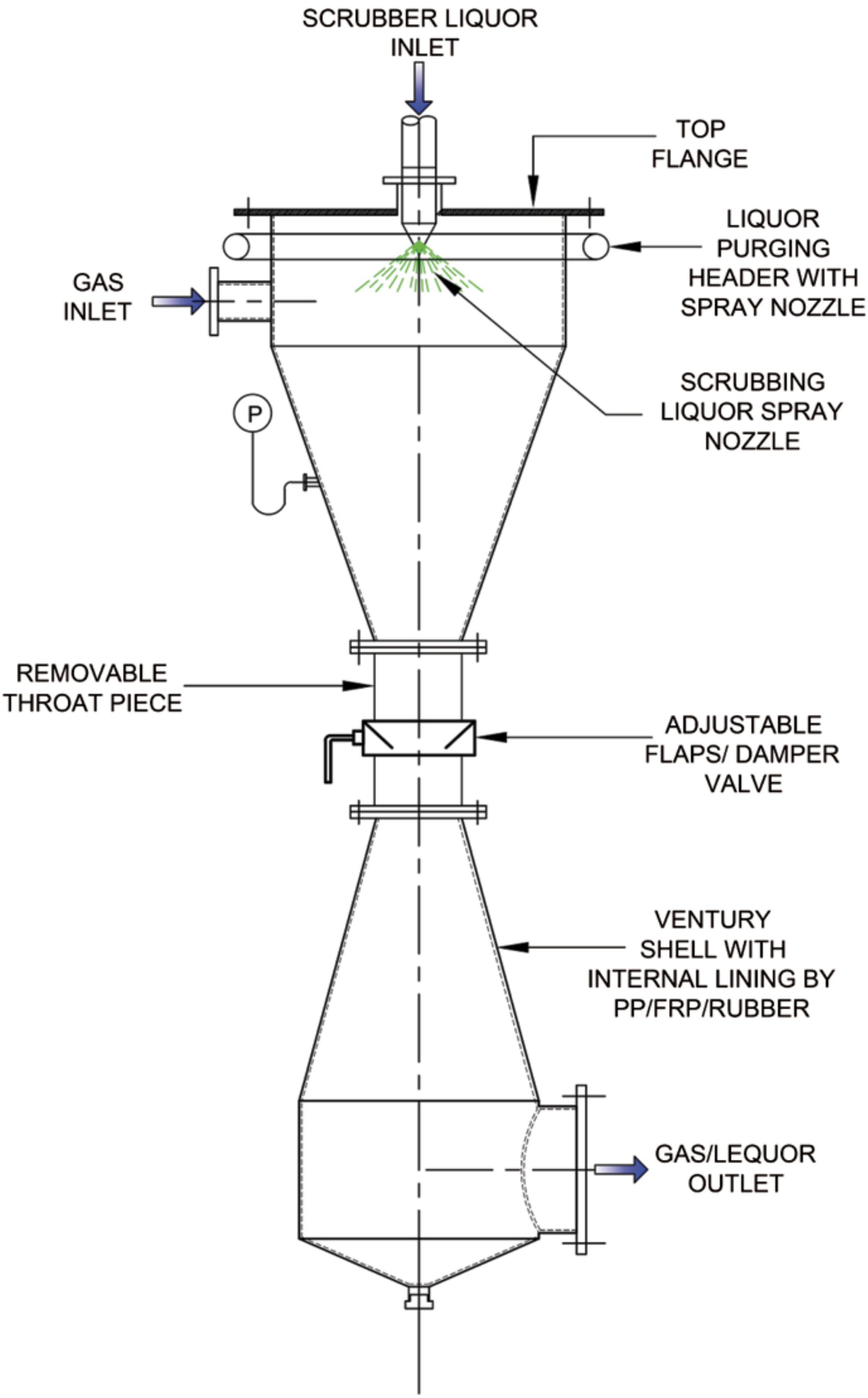
The converging section, throat and diverging sections should be fitted together by flanged (bolted) connections so that they can be removed, if required.

It should be possible to introduce liquid injection spray at centre and in tangential positions for which suitable nozzles should be fitted on the venturi shell.

It should be possible to clean the nozzles in situ or to take out the injection pipes completely.

The MOC of spray pipes and nozzles should suit process conditions of pH, temperature and erosive nature of particles present, if any.

- The removable throat piece should have an adjustable valve/damper.
- Pressure drop allowed in the system will be decided by the purchaser. This will depend on the process units connected, overall gas duct layout, ID fan capacity, chimney height, etc.
- Connections should be available for pressure and temperature measurement.
- A separate scrubbing liquor circulation tank should be installed, on which the venturi scrubber can be mounted.
- If a completely separate tank is provided, it will need a U-seal for the gases which means some additional piping and separate civil foundations for the tank and venturi scrubber.
- Arrangement for adding make-up water, alkali solution or any other scrubbing liquid.
- Provision of two circulation pumps for scrubbing liquor.
- The pumps could be vertical submerged type or installed horizontally outside the circulation tank. In case of the former, a gantry will be required for taking out the pump for maintenance.



VENTURY SCRUBBER

10.3.3 Packed Towers

Used for further scrubbing after the venturi scrubber. Pressure drop is more than spray tower due to packing filled in.

- It should be possible to introduce liquid injection spray at centre through pipes inserted in nozzles and in tangential positions for which suitable nozzles should be already available on the unit shell.
- It should be possible to clean the spray pipes and nozzles in situ or to take them out completely.
- The MOC of spray pipes and nozzles should suit process conditions of pH, temperature, erosive nature of particles present, if any.
- Liquid inlet distributor can be tray type (needs hangar bolts or side supports) or as a number of perforated pipes.
- Arrangement to clean the pipes in situ or to take them out completely.
- Nozzles for pressure and temperature measurement.
- Type of packing used (MOC, surface area m^2/m^3 of volume) and void space.
- Crushing strength of packing.
- Self-cleaning packing: polypropylene hollow balls, which are very light, are sometimes used as tower packing. They are kept in motion by the gas/liquid flow and are self cleaning. The efficiency of scrubbing can be maintained even when there is tendency for deposition of salts from the liquor. The pressure drop also remains on lower side. The limitation is strong acidic solutions or higher temperatures of gases (more than 100 °C) in certain industries.
- Support for packing: two to three layers of 100–150 mm size partition rings at bottom.
- The bottom manhole should be available to remove packings for cleaning.
- The top manhole should be available to add more tower packings, to inspect internals, etc.
- The bottom portion of the spray tower/packed tower can work as circulation tank on which the tower will be mounted (this saves the footprint and a U-seal required at the liquid outlet of the tower).

10.3.4 Jet Scrubber/Ejector Scrubber

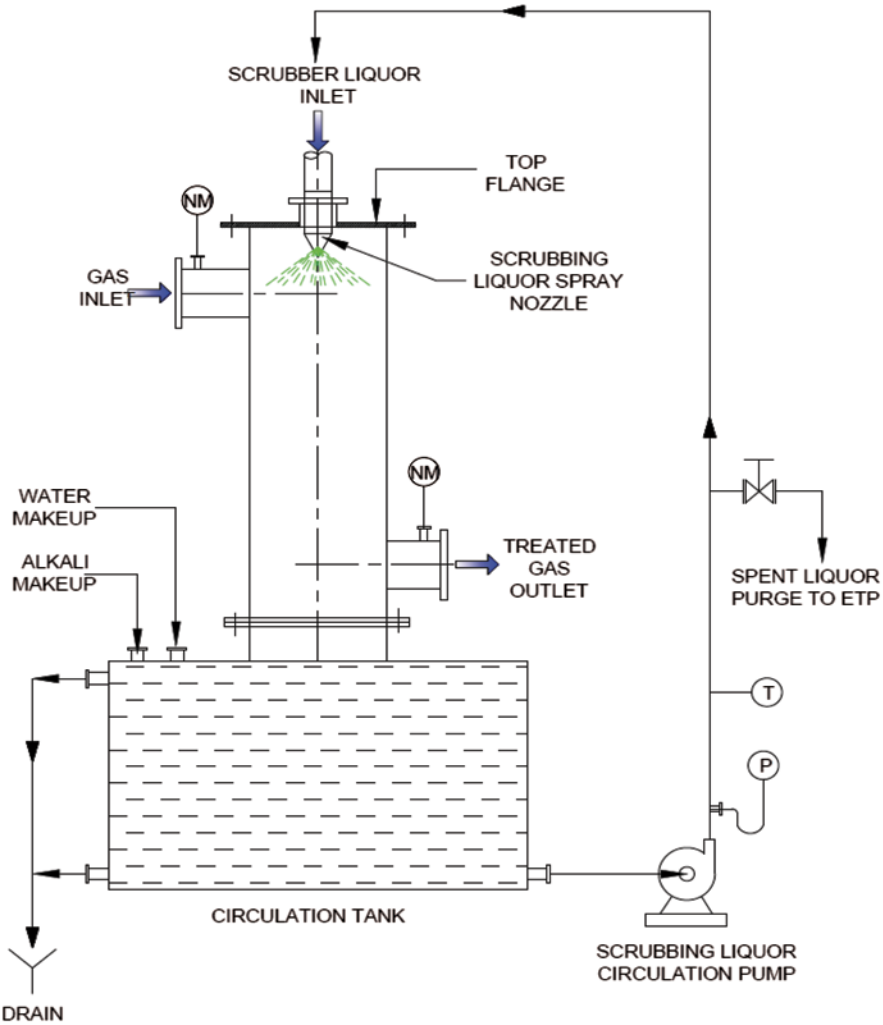
This is able to create a draught for the incoming gases due to the spray of scrubbing liquor. This will be useful for the flow of gases.

However, liquid–gas contact is not as good as venturi because the mixing is not as intense. It is useful where concentration of particulate matter is lower.

The unit is mounted on the circulation tank and thus saves separate liquid exit piping (with U-seal). The MOC can be an FRP-lined steel tank.

The vendor should be asked to supply a spray nozzle with a 120–135 ° spray angle so that the cross section is properly covered. The scrubbing liquor pump should have a capacity of at least 2.5–3.0 L/nm^3 of gas. Maintain a pH of at least 8.5 at the inlet of the tower for scrubbing acidic gases.

The DynaWave Wet Gas Scrubber is an efficient gas scrubbing system designed by Monsanto Envirochem Systems and may be considered by the purchaser.



JET SCRUBBER / EJECTOR SCRUBBER

10.3.5 Spray Tower

The inquiry should be similar to the one above with a small difference in that the tower does not have any packing, but has multiple spray pipes at top. The spray should cover the entire cross section of the tower. Pressure drop should not exceed 40–50 mm water gauge.

10.3.6 Tangential Scrubbing Tower

It is similar to the spray tower, but has many spray pipes or nozzles installed tangentially at more than one level, generally at intervals of 1000–1500 mm in vertical height. There are four nozzles at 90° at every level for spraying liquor. The tangential sprays clean the tower inner walls continuously and do not allow build up of layers of salt deposits.

These are used in phosphatic fertiliser industries where silica/other particulate matter tend to deposit on the walls of the tower. The vendor should specify the number of nozzles, flow rate through each, circulation pump capacity (it should have semi-open impeller) and MOC of pipes, valves, etc.

Polypropylene and HDPE can be considered as MOCs. The pipes and valves should be pressure tested before installation.

10.4 Tower Packing Items

These are used to increase the contact area of absorber liquid and the gases. Various types of tower packing items are available from suppliers, for example, plain Raschig rings, single partition, double partition, with outside corrugations, with or without glazed surfaces, etc. Also available are Tellerette packing, Pall rings, etc.

The packing items are generally washed thoroughly before placing in the towers for the first time or during an annual shutdown.

Those *without* glazing tend to absorb considerable amount of moisture; or dust can become deposited on the surface which gets mixed with circulating liquid.

Hence, one should prefer glazed packing which can cause minimum contamination of the product/circulating liquid.

10.4.1 Loading Pattern in the Towers

At lowest portion of the towers Single or double partition rings (150–200 mm diameter) with adequate crushing strength are to be used. Openings in the rings should not allow upper rings to pass through.

Middle portion Use 50–80 mm size partition rings/ordinary Raschig rings/INTALOX saddles/Berl saddles, etc. These will provide good liquid/gas contact interface.

Uppermost Portion Smaller-sized packings may be used as they help in separation of mist.

Other Criteria for Selection

- Chemical resistance to fluids being handled (since tower packings are available in a variety of materials) at the actual operating conditions and at maximum temperature, concentration, etc.
- Surface area per unit volume of packing.
- Void fraction when the packings are dumped at random in the towers.
- The expected pressure drops on gas side (though depending on the clear internal diameter of the tower for given flow rates of gas and liquid) it can vary with the type of packing filled in. This should be discussed with the manufacturer before procurement of the same.
- Weight of randomly packed random packings per unit volume.
- Crushing strength of the packings at operating temperature (This is important because the tower may get filled up with the liquid if the outlet nozzle gets choked due to pieces of broken packings). A certain minimum crushing strength corresponding to the expected height of packing in the tower must be specified and tested. This is to prevent crushing of the lower layers due to the own weight of packing filled up in the tower.
- Test Certificate should be obtained from manufacturer: Testing can be done in purchaser's own laboratory or in a standard approved laboratory acceptable to both the vendor and the purchaser.

10.4.2 Spray Nozzles

These are important internal fittings for cooling towers, absorbers, pollution control units, etc.

Selection criteria include the following:

- Properties of liquid to be sprayed: pH, density, boiling point, viscosity, etc.
- Flow rate minimum/maximum LPM per nozzle.
- Suspended solids concentration in liquid and their erosive nature, if any.
- Total number of nozzles required (this will depend on the liquid flow rate).
- Pressure of liquid (minimum required) at nozzle inlet. Consult vendor on this.
- Maximum and minimum temperature of the liquid to be sprayed.
- MOC of nozzles should be compatible with the liquid and the gases likely to be present in the vessel.
- Type of connection with scrubbing liquor inlet pipe–threaded (number of threads per centimeter; and total threaded length should be specified)/flanged or welded.
- While specifying the type of connection, one should keep in mind the convenience of replacement of the spray pipes and nozzles (Table 10.1).

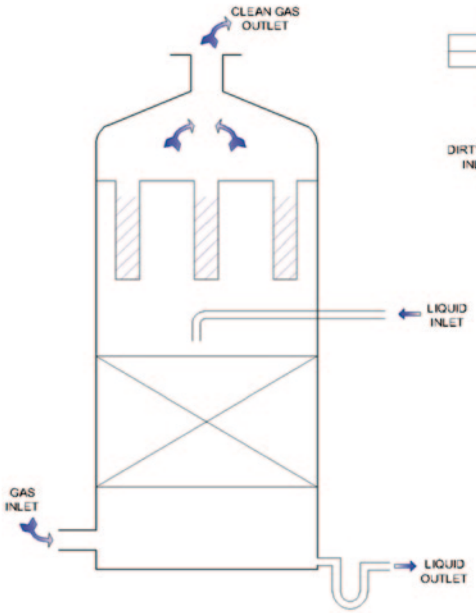
Table 10.1 Typical application of spray nozzles

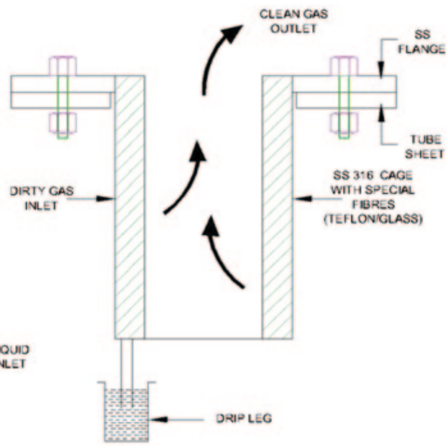
Serial number	Type	Typical application	Spray angle (°)	Remarks
1	Full jet	Cooling, quenching, dust suppression	30–130	Full spray pattern
2	Line jet	De-greasing, spray coating, coal washing	20–120	Flat jet spray
3	Circle jet	Air/gas washing, dust control	60–130	Hollow cone spray with most of the liquid at outer edge of the cone
4	Descaler	Descaling, high pressure cleaning	15–45	Uniform flat spray with knife-like cutting edge. High pressure of liquid required at nozzle inlet
5	Stream jet	Cleaning/jet cutting	0	Narrow concentrated stream jet with high impact force
6	Fog jet	Gas cooling/de-super heaters	130	Fine full cone spray from a cluster of nozzles
7	Atomiser	Humidification, atomising viscous fluids	15–90	Fine atomisation of liquid by mixing with air/gas

10.5 Candle Demisters and Entrainment Separators

Generally these are installed in exit gas streams of equipment like absorbers, condensers, evaporators, etc., for arresting the liquid droplets entrained in the gases. If the demisters are not installed, the liquid droplets can corrode or choke downstream equipment like heat exchanger tubes, damage tube sheets of heat exchangers, contaminate products (acid mist carryover from oleum boilers), cause atmospheric pollution (unabsorbed acid mist going out from chimneys).

The figure below shows installation of candle demister in an interpass absorption tower of sulphuric acid plant to protect downstream heat exchangers and catalyst in next passes of the converter).





Selection Criteria

- Gas/vapour flow rate (nm^3/h).
- Maximum temperature of gases (and liquid drops entrained).
- Pressure of gases at inlet of the separator (and liquid drops entrained) in mm WC or Kg/cm^2
- Gas stream composition as mol%.
- pH of liquid droplets/concentration in gas stream.
- Particle size of liquid mist droplets and their loading as mg/nm^3.
- Removal efficiency desired for various mist particles; for example, to specify 99 % for all particles above 3 µm, 99.9 % for all particles above 5 µm.
- The desired value should be indicated by the purchaser.
- Allowable pressure drop through the demister—*candle demisters have higher pressure drops* (*for the same gas flow*) *due to compact packing, but also have greater efficiency of separation.*
- MOC of fibres used for demister (common fibres are SS 316, special glass fibers). Old designs used quartz beds but their *efficiency of separation was very low for particles of size below* 10 µm.
- MOC of cage structure used for housing the fibres.

Pad-Type Demisters

- Pads are made from stainless steel wire mesh and are generally 100–150 mm thick and have an outer ring of SS 316L
- Diameter of the wires used for making the mesh should be 1.0–2.5 mm. Very thin wires can break easily as they can get corroded due to the presence of chlorides or dilute acid mist.
- The pressure drop on gas side should not exceed 20–30 mm WC. Vendor should make the weave accordingly and also provide reinforcing frame as well as outer ring.
- Separation efficiency for mist and particulate matter should be specified for these pads (e.g., 95 % for all particles of 5 µm; 99 % for all particles above 8 µm, etc.).
- Gas velocity through the pads should not exceed 1.5–2.0 m/s.
- Generally two pads are arranged about three pipe diameters apart in the gas stream.
- A separate vessel for housing such pads is required. It should have ring supports, a manhole for inspection and pressure monitoring taps.
- Bigger pads can be made in sections and introduced inside from the manhole.
- Direction of flow of gases (laden with mist) through the candle demisters, that is, whether outside-in or inside-out (should be specified by vendors. This will determine fitting of candles on tube sheet).*Outside→in offers more area for filtration as compared to inside→out, but the candles are generally to be hung upside down from tube sheet at upper portion of absorption tower.*
- MOC of tube sheet and gaskets: They should be fully resistant to the gases and mist particles at the maximum operating temperature.
- Arrangement (preferably a seal pot) for automatic and continuous removal of arrested mist (liquid) should be provided (inside the tower if possible).
- Diameter and length of individual candles (to be used as demisters) should be asked to the vendor. This will enable fabrication of the vessels for housing the candle(s). While more number of candles will reduce the operating pressure drop the size of the housing vessel will be more.

10.6 Electrostatic Precipitators (ESP)

These are installed for removing fine suspended particulate matter from gas streams which are otherwise difficult to remove by scrubbers, bag filters, dry and wet cyclone etc. Electrical power at high voltage is used for charging the particles which get attracted towards the collecting electrodes.

10.6.1 Dry ESP

Selection of these equipment should be based on the following considerations:

- Volume of gases (nm^3/h) which will be passed through the ESP.
- Temperature of gases–(°C).
- Pressure at which the gases will enter the unit.
- Pressure drip permissible in the ESP (should be as low as possible, say, of the order of 25–50 mm WG).
- Gas composition, especially concentration of corrosive gases like SO_2, HCl.
- Moisture content in gases (since this tends to form acid droplets).
- Total content of suspended particles (mg/nm^3).
- Size distribution of these particles. This data must be provided to the vendor, in the form of particle size (microns) and corresponding percentage (smaller the particle size, say 1–2 μm, it will be more and more difficult to separate them out from the gas stream.
- Material of construction of charging and collecting electrodes.
- Geometry/shape of individual electrodes, and their length, diameter, etc.
- Maximum corona power that can be supplied by each electrode (by vendor).
- Total Numbers of electrodes (by vendor) power consumption.
- Geometry of gas passages through the units by vendor.
- Director of flow of gas through the ESP (upward/downward).
- MOC of insulators and their rating (max voltage permissible).
- Arrangement for removal of settled/collected duct particles.
- Ease of replacement of non-functional electrodes.
- Collection efficiency for particles (below specially for particles micrometer size).
- Electrical power control mechanism and circuit provided.

10.7 Wet ESP

With considerable research and development in this field, improved version of ESP has been designed and commissioned at certain thermal power stations. Since the suspended particles in the gas stream have different conductivities depending on their composition, it is difficult to control the electrical power for charging all of them. This design incorporates a fine spray of water (fogging spray) at the gas inlet chamber which makes the particles heavy and equally conducting. The geometry of electrically discharging and conducting electrodes is such that a large number of star-shaped discs are provided at short intervals along the entire length. Since discs have many sharp points, they serve very effectively to supply corona power to the suspended particles which are then attracted towards the collecting electrode tubes, and remain stuck there (unlike dry ESP where in they may re-enter the gas stream).

Periodic washing of the collecting tubes is done to remove the deposited particles and thus the active surfaces are not masked.

These features make the wet ESP a device better than the dry ESP, and one may find the higher initial cost worth it due to the improved performance. The life of downstream equipment improves due to better removal of erosive, corrosive particulate matter lay the wet ESP.

Any electrode may be damaged if there is a chance of acidic particles with chloride content in the gas stream. In such cases, Hastelloy C-276 electrodes are used.

Water spray prevents build up of pressure drop on the gas side. A separate filtration arrangement (filter press) for the circulation water maintains the system clean and the collected dust particles can be removed easily as solid cake from the filter press. A continuous bleed of circulation water can also be done to control build-up of the TDS.

- MOC of casing: Gas entry nozzle, distributor, etc. it is advisable to get the internals (which can come in contact with wet gases) in rubber-lined/FRP-lined construction. Since the unit is likely to be quite big in size, and installed outdoors, one must consider the wind velocity generally prevailing at the site.
- Firm anchoring shall be provided as per civil load data of the unit when lower part of the vessel is filled up with circulating water.
- Power control: rectifier rating, location, instrumentation and overall consumption including circulation pumps to be asked.
- The unit should be well protected from heavy rains. The vendor should design all HT supply cables, power control, HT busbars, discharing and collecting electrodes accordingly.

10.8 Chimney

This is used for the final release of gases from the plant to the atmosphere. Smaller-sized chimneys are generally fabricated, tested (and occasionally assembled) at vendor's workshop. One has to make sure that it can be loaded on the transport vehicle and brought to the site without difficulty (due to traffic congestion, small bridges, difficult roads on the way, etc.).

Large diameter chimneys are site fabricated and assembled.

Following should be considered before ordering the fabrication of a chimney:

- Max gas flow rate (nm^3/h) through the chimney.
- Composition of gases (quantity of pollutants like SO_2, HCl in kg/h).
- Temperature, pressure of gases.
- Whether a self-supported chimney can be erected or would need guy rope supports. In better cases, suitable anchors for tying the ropes should be available on ground/permanent structures. The ropes should not obstruct the movement of trucks and equipment in the premises.

- Foundation bolts (the diameter should not be less than 25 mm) and they should be of high tensile strength. Test certificates should be obtained.
- Bottom plate and flanges: not less than 20 mm diameter
- Standard fittings and provisions: aviation warning lamps, lightening arresters (with copper conductors) safety ladders, gas sampling points, platforms and railings.
- Protective lining (AR bricks/rubber lining) at bottom chamber and along the vertical length.
- Chimneys can consist of flanged sections (thickness of plates used for chimney should be as per height, corrosion allowance, wind load). The flanges should not be less than 16 mm thick.

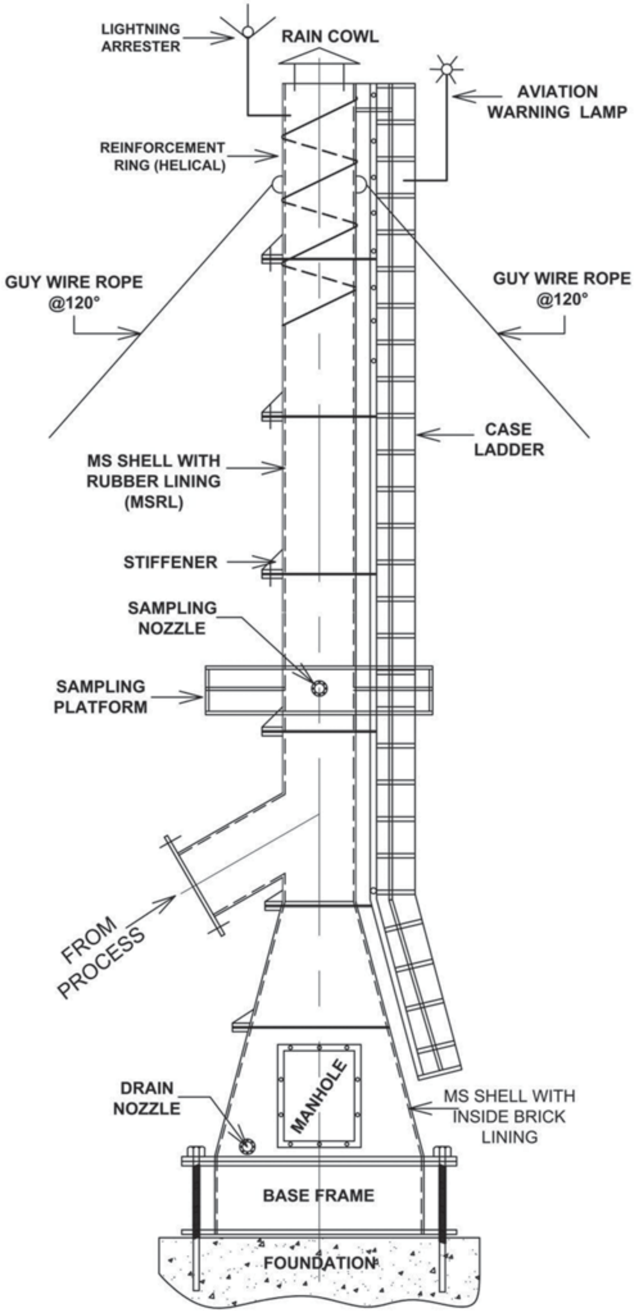
Final stack height is estimated by

$$H = 14\,(Q)0.3$$

Where H = stack height and Q = kg of SO_2 released per hour.

However, the final height should be decided after considering the following points:

- Location of plant and local climatic conditions.
- Populated areas, schools, hospitals, farms, airport nearby.
- Minimum and maximum ambient temperature, rainfall at site (minimum and maximum).
- Wind velocity and direction in all the months (consider maximum velocity at top).
- Maximum quantities of pollutants that may be released during plant upsets or during start-up.
- Area over which dispersion would occur.
- Ground-level concentration limits prescribed by WHO should never be exceeded (whether during normal plant operation or during process upsets).



SELF SUPPORTED CHIMNEY

11 Heat Recovery Equipments

Many exothermic reactions are carried out in the CPI and these result in raising the temperatures of the process fluids. Since the cost of energy is rising continuously, it has become imperative to maximise the heat recovery. The process design and plant layouts shall always be made in a manner to achieve this aim.

Incoming cold fluids should be (preheated and) brought to the required temperatures by means of heat exchange with hot outgoing fluids as much as possible. Not only will this recover heat, it can also reduce the cooling load due to the hot stream.

Attempts should be directed towards generating steam at as high a temperature and pressure as possible, because of the potential of this steam to generate electrical power. By correctly estimating the current and future needs of power and steam for process heating one can judiciously take a decision regarding the type(s) of steam turbine(s) to be installed.

Typically, these units are installed in sulphuric acid plants and nitric acid plants to recover heat from hot process gases and thus produce steam.

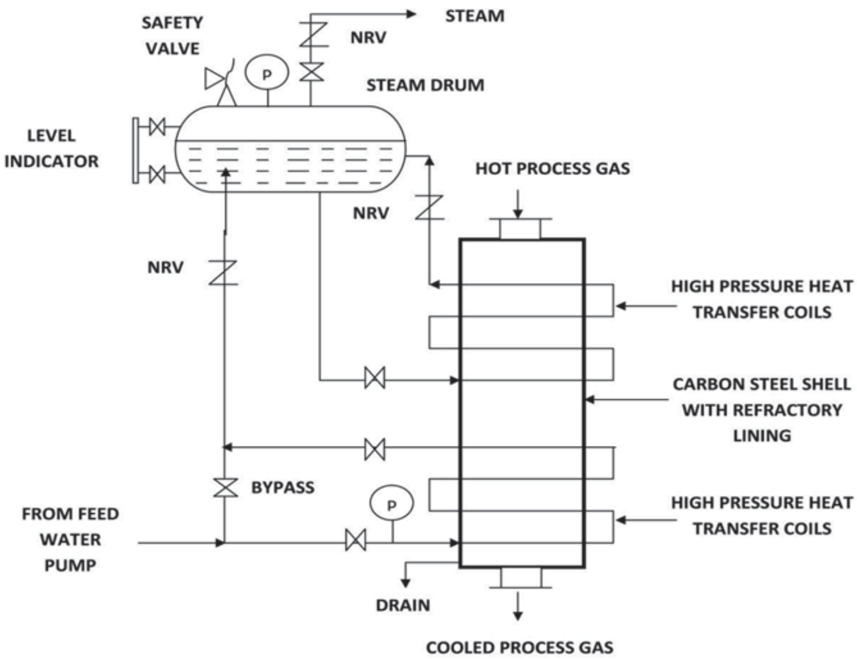
11.1 Selection of Waste Heat Boilers (WHB)

- Gases to be cooled (Gas consumption in Mole % or Volume %).
- Maximum temperature at inlet of the WHB.
- Temperature required at the outlet of the waste heat boilers (WHB; dew point of gas mix to be informed to the boiler manufacturer).
- Need to have a storage of steam in the plant, use pattern of steam in the plant.
- Whether the boiler required is of water-tube type or smoke-tube (fire tube) type.
  - *Fire-tube boilers* (*where the hot gases pass through the tubes and water is on the shell side*) *take a longer time to generate steam due to the higher hold-up of water; the cost is greater for the same capacity unit since the tubes and the shell are both subjected to steam pressure.*

K. Golwalkar, *Process Equipment Procurement in the Chemical and Related Industries,* DOI 10.1007/978-3-319-12078-2_11

  - *Water-tube boilers are generally operated at higher pressures than fire-tube boilers. The hot gases are on the shell side and water is inside the tubes. They can start steam generation much earlier due to the considerably lower volume of water in the tubes. The outer shell is not subjected to steam pressure. Only flue gases at low pressure pass through it and hence, the cost could be considerably lower.*
- Normal working pressure at which steam is to be generated.
- Working pressure (maximum) at which it will be operated.
- Maximum pressure drop allowed on the gas side.
- Number of passes on the gas side (more passes increase pressure drop on gas side).
- Pressure at which hot gases will be available at WHB inlet.
- Temperature at which feed water will be available and its quality (Vendor should confirm suitableness or give his specification for the feed water).
- Fittings and mountings required; for example, safety valves, feed check valves, nonreturn valves, blow down valve, pressure gauges, etc.
- Water level indicators and control being offered by vendor (There should be two level gauges with isolating valves, and alarms for low and very low water levels with auxiliary contacts for tripping the firing in case of the very low level).
- Gas inlet box and outlet box details.
- Gas side bypass valve-whether the WHB has any internal pass (this does not need external gas duct).
- The construction should be done as per Statutory Rules of Codes and Standards MOC and size of ferrules offered by vendor for protecting tube sheets (for the smoke-tube side).
- In the case of water-tube boilers, all welded joints at high pressure should be easily available for visual inspection and maintenance.
- Overall length × breadth × height.
- Locations and sizes of cleaning manholes.
- Space recommended all around for operation, cleaning and maintenance.
- Empty and full weight.
- External insulation and cladding offered by vendor.
- Structures, like saddle supports, work platforms, etc.—whether these have been included in scope of supply or not.

11.2 Steaming Economiser



OPERATION

1. FRESH FEED WATER IS PASSED THROUGH LOWER COILS AND FED TO UPPER DRUM.
2. WATER GETS HEATED BY CONVECTION CURRENTS THROUGH UPPER COILS AND IS FLASHED IN TO STEAM IN UPPER DRUM (THE STEAM IS USED IN THE PLANT.)
3. LEVEL IS CONTROLLED AUTOMATICALLY IN THE DRUM. BYPASS VALVE CAN BE OPENED TO QUICKLY MAKE UP LEVEL IF REQUIRED.
4. THE COILS ARE MADE OF BOILER QUALITY TUBES AND CAN BE PROVIDED WITH CAST IRON GILLS FOR PROTECTION AGAINST CORROSION.
5. SAFETY VALVES ARE PROVIDED ON THE COIL HEADER. (NOT SHOWN)

The conventional economiser is used to further recover heat from hot flue/process gases after they exit from boilers. The feed water is passed through the economiser for preheating and then fed in to the boiler. A large amount of hot water is frequently generated since the heat recovered is taken up as “sensible heat” of the water. If the existing boiler(s) are not able to evaporate the water, the excess hot water is wasted or the economiser may have to be bypassed from the gas side. This may upset temperatures in the downstream process equipment (when it is being used as a heat recovery unit), and hence this option may not be always possible.

Besides, the power consumed is high due to the large quantity of water circulated. Steaming economisers (special heat recovery boiler) take care of such a situation.

The hot water generated is flashed in a separate drum as steam and balance water are returned to the heating coils of the unit for reheating. The water circulation is established through risers and down comers by natural convection instead of a pump.

The feed water pump provides water only to maintain the water level in the unit, so that the pumping rate corresponds to the amount of water evaporated (and converted to steam). Hence, the power consumption is very low.

The steam can be directly put in the main steam header, if it is generated at the pressure in the header.

An NRV and a stop valve should be provided in the steam line at the outlet of the drum.

An example of such a unit can be seen in a sulphuric acid plant. The plant has two boilers generally (after the furnace for burning sulphur and after the first pass of converter) and an economiser after the last pass of the converter. This economiser can generate more hot water than the boilers can evaporate—especially when they are sometimes bypassed to adjust/bring up process temperatures.

Case Study Replacing the existing economiser with the modified design saved considerable power and also recovered more heat directly as steam. Also, no hot water was wasted.
(The existing water circulation pump was kept stopped and a much smaller feedwater pump was provided to maintain the level in the flash drum.)

11.2.1 Selection Criteria

- Potential for heat recovery is to be assessed; that is, the flow rate of gases (the lowest gas outlet temperature to be chosen depends on the dew point of the gas mixture if it is corrosive), temperature differential through which cooling is to be done, gas mixture composition and properties of the mixture—mean C_p, viscosity, density, etc.
- Allowable pressure drop through the unit on the gas side.
- Pressure at which steam is to be generated.
- Temperature at which feedwater will be available (from the feedwater tank).
- General arrangement of the unit, while showing gas inlet and outlet nozzles.
- Flash drum with level indicator.
- Gas cooling section having water tubes; total space requirement (Length × Breadth × Height).
- Possibility of adding more heat transfer tubes in future.
- Provision of cast iron gills; mild steel or stainless steel fins on the tubes (for protection fromcorrosion).

- The bends and welded joints should be easily accessible for maintenance; hence preferably should be located outside the gas enclosure.
- Total weight when empty and when full.
- Standard fittings and mountings (similar to those on a boiler); for example, safety valves, level indicator, vent valve, blow down valve and low level alarms.
- Gas inlet and exit boxes and internal fire/acid resistant linings.
- Drain nozzles on the gas inlet and outlet boxes for draining out any (acidic) condensate.

11.3 Air Preheater/Heat Recuperators/Other Devices for Heat Recovery

11.3.1 Selection Criteria for Air Preheaters

- When preheating of water/viscous liquid fuel is not feasible.
- Whether preheated air is desirable to improve furnace performance. The temperature of furnace exit gases can increase considerably.
- *Preheated air can improve combustion of pulverised coal in thermal power plants. It can minimise carryover of unburnt droplets of liquid sulphur in a sulphuric acid plant.*
- Availability of sufficient space for the air preheater and air ducts at incoming/outgoing nozzles of the unit.
- When the flue gases do not contain contaminants, suspended particles, ash, or corrosive gases like moist SO_2, acid mist (since these can foul the heat transfer surfaces of the air preheater).
- When the operation is generally continuous, at a steady state, and at known temperature and flow rates of the hot flue gases.
- Temperatures of hot gases should not be allowed to fall (below 150–160 °C generally) to dew point, especially when corrosive gases are present as a result of sulphur content in the fuel.
- Hot gases should be put on the tube side and air on the shell side. This can reduce heat loss also, since temperature will be lower on the shell side.
- Other considerations should be hot gas flow rates, temperature and volumetric composition and pressure drop on tube and shell side.
- Vendor should be asked to inform MOC and thickness of tubes, shell and tube sheet.

11.3.2 Recuperators

These units are generally constructed by refractory brickwork and used alternately. Flue gases are passed through a unit for some time for heating it, and after reaching the predetermined exit temperature (when rate of heat recovery drops), the hot gases are diverted to another unit.

Cold incoming air (used for the furnace for combustion of fuel) is passed through the first recuperator, while the other one is being heated.

Selection Criteria

- The temperature of preheated air that can be obtained-*heat recovery* (*calculated as fuel saved due to preheated air*) *should be weighed against initial investment and maintenance.*
- Some amount of flue gases remain in the unit and get mixed with incoming air, which can affect combustion. *Whether this will be acceptable*.
- Space available for installation: generally a large amount of space is required since two recuperators are required along with two sets of gas and air ducts (with valves).
- Heat storage capacity should be large so that frequent changeovers are not required.
- Bricks used for lining should have 40–45 % alumina.
- MOC of valves in hot gas inlet lines—this could be a major issue if the gas temperatures are 600 °C and above. Special alloy steel or ceramic lined dampers may be considered.

Practical difficulties for heat recovery from dusty gases by heat exchangers with metallic tubes: The heat transfer surfaces may not withstand the very high temperatures, and the dust deposits can hinder heat transfer are used.

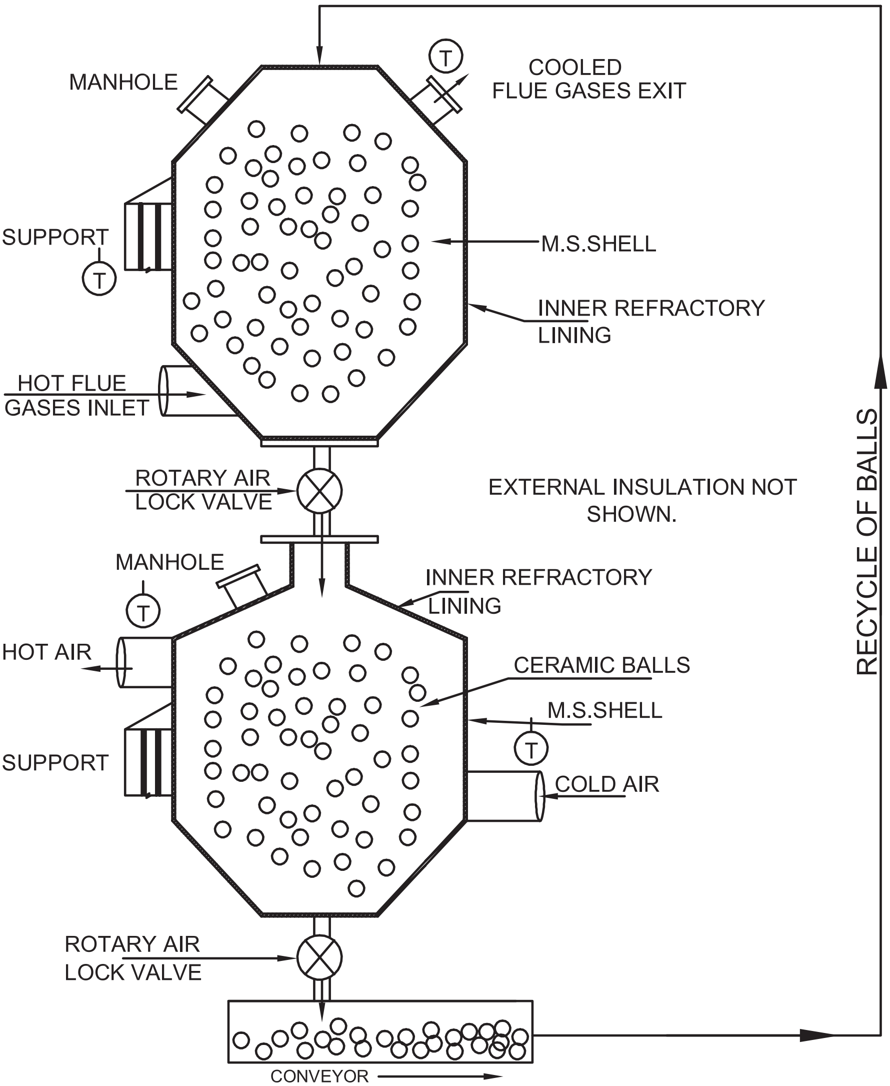
Recuperators with high alumina bricks: After the temperature of the exit air starts falling below a certain predetermined value, the unit is taken up for passing hot gases again, The hot gas and cold air streams are thus passed alternately by operating butterfly valves in the ducts which are switched over manually or automatically (can be by timers) as per temperature patterns desired.

It is seen that the inner flaps or the butterfly valves themselves can get warped due to the hot gases. The heat recovery is not very efficient; and the combustion also may suffer due to some recycle due to mixing of flue gases.

- *Heat recovery wheels* based on refractory materials are used in some power plants. Hot exit flue gases heat up the upper half of the slowly rotating wheels while incoming cold air is preheated by the lower half. Some mixing of air with flue gases may occur. These are generally not used in chemical industries.
- *Ceramic Ball Heat Recovery unit–please refer to the schematic drawing.* The reader may refer to more information available on the internet.

The upper refractory lined vessel is continuously fed with high-alumina balls which are heated up by the hot gases. They fall to the lower refractory-lined vessel where the cold air gets pre-heated by taking up heat from the hot material.

The alumina balls are discharged from the bottom and are again carried to the upper vessel.



Advantages

- Valves in hot gas and air ducts need not be operated frequently.
- Any damaged balls can be replaced easily by adding new ones while the unit is running. *It is difficult to maintain the recuperator internals when it is running.*
- Rotary valves are run by motors with VFD controls and their speeds can be adjusted as per need.
- Heat recovery is more efficient—less loss of heat through hot exit gases from upper unit since cold balls are continuously added at the top.
- Less footprint is required.

Considerations for Selection

- Flow rates, composition and temperature of hot gases.
- Flow rate and degree of preheat required for cold incoming air.
- VFD controls for all air lock rotary valves handling the alumina balls.
- The volumes of upper and lower vessels, their inner refractory and insulation lining. These should hold some of the excess balls since the rate of flow from the upper and lower vessels may not be the same always.
- Size, weight, specific heat and composition of alumina balls (should not be less than 90 % Al_2O_3). *Balls of other materials or metals can also be tried after due study and trials.*

The crushing strength of these balls is an important consideration since the attrition loss should be minimum (the height through which fall of the balls occurs in both vessels can be reduced by maintaining a higher level. This should be optimised because high level can increase pressure drop on the gas as well as the air side—thus increasing power consumption by fans).

Bucket elevators for carrying up the cold balls to upper vessel should be looked into as an important component of the system.

A screw conveyor may be examined for technical and economic feasibility in the given location.

11.4 Cogeneration of Power

Boilers are operated in many industries for generating steam, which is required for process heating of reactors, evaporators, distillation columns, etc. Generally, these units need steam at a pressure of 4–6 kg/cm^2. (*Only certain equipment like vacuum crystallisers, steam ejectors, etc. need higher steam pressure for operating them to produce the necessary vacuum*.)

However, the boilers are generally operated at 10–15 kg/cm^2 or even higher pressures. The pressure is then reduced by a pressure reducing valve. This causes loss of energy and hence cogeneration is to be seriously considered as an energy recovery method. The steam at higher pressure is to be first passed through a steam turbine for power generation or for driving a blower/pump. The exit steam is to be used for process heating.

Options Which Should Be Considered Are

- Back pressure turbine
- Extraction type turbine with/without reheat
- Condensing type turbine
- Steam-driven reciprocating engines (these have limited applications as their efficiency is low)

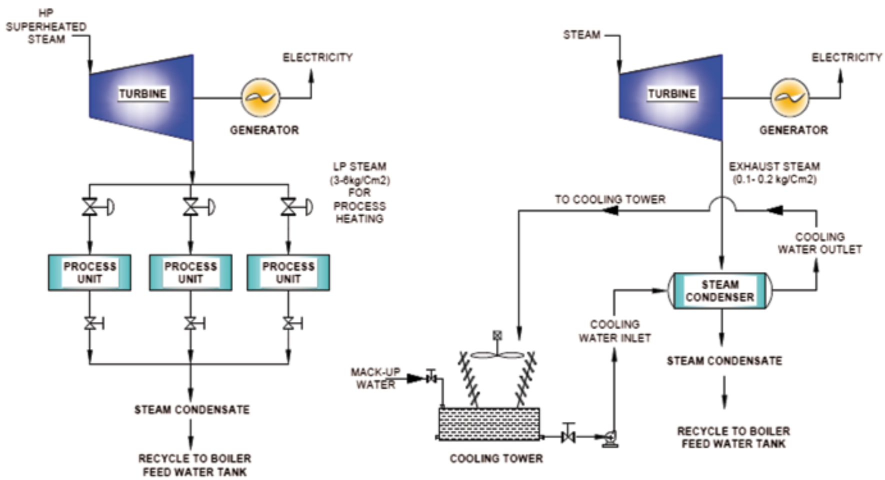
Back pressure steam turbines are to be used instead of PRV. The situation is ideal when all the steam can be passed through the turbine and then used for process heating.

When steam is required at the process plant at different pressures, the extraction-type steam turbine may be considered, wherein steam is extracted out from different stages, and the last stage exhausts at a pressure corresponding to the lowest pressure required in the plant. An accurate estimate of the consumption pattern of steam is necessary for procuring the turbine with the right design and to operate it efficiently.

It is not necessary that the extraction should be done at different pressures.

In a situation where there is a mismatch amongst boiler (main steam header) pressure, the quantity of steam generated and consumed by different equipment at different pressures, the choice becomes difficult and efficient operation even more difficult. Hence, a combination of small capacity turbines (extraction and back pressure type) may be considered. A condensing-type turbine can also be an economically viable option (depending on the plant operating conditions) in case of a large quantity of by-product steam available from waste heat recovery units, *since power costs are rising*.

11.4.1 Feasibility Study



STEAM UTILIZATION FOR CO-GENERATION / POWER GENERATION

11.4.2 Steam Turbines

Selection Criteria for Steam Turbines

- Steam pressure and temperature at the inlet and outlet of the turbine. Superheated steam at inlet will enable more efficient operation by the turbine.
- Steam consumption in kg/KWH (sometimes called "*steam rate*") and maximum permitted steam flow through the turbine.
- Speed (RPM) at normal operation.
- Speed governor provided (mechanical/electronic).
- Whether hand controls and emergency trips are provided.
- Type of gearbox and lubrication arrangement details.
- Type of coupling with gearbox–generator.
- Whether steam turbine, gearbox and generator are supplied as a pre-assembled unit on a common base plate or as separate units to be assembled at site. Alignment procedures and precautions should be asked for during procurement.
- MOC of all critical parts, for example, steam nozzles, turbine blades, shaft, gland packing, etc.
- Moisture separator with steam trap (required for saturated steam) for incoming steam.
- Instrumentation offered: Steam and lubricating oil pressure gauges, bearing temperature indicator, electrical panel instruments (voltmeter, ammeter, KW, KWH, frequency meter, etc.). Tachometer with digital remote indication, running time totaliser, vibration meters, safety trips.
- Generator speed and make (when generator and turbine speeds are low, both will have less wear and tear.)
- Type of excitation (induction/synchronous) for the generator.
- In case of a condensing turbine, the supplier should quote for complete package, that is, with condenser for exhaust steam, condensate extraction pump, vacuum pump/steam ejector, pressure and temperature gauges, control valves, and support structures. (This can be made locally as per drawings to be made available by vendors).
- Cooling load/duty conditions for cooling tower required.
- Overall dimensions and weight of the assembly and details of civil foundation required.
- Oil cooling arrangement.
- Oil pumps (directly turbine shaft driven or through separate motor). In any case, a stand-by should be provided and provision of auto start in case one pump trips should be included.
- Battery provided by vendor for emergency lubrication pump (or not).
- Battery charger provided (or not).
- The O&M manuals, spare parts list should be asked for during purchase.
- Lube oil accumulator provision should be studied before deciding the lube oil circuit. Also, the LO tank if required should be provided. Safety valves at the lube oil pump discharge should be duly calibrated by vendor and tested again at purchaser's site.

- Exclusions from scope of supply by vendor must be very clearly understood.
- *Another option for consideration is reheat turbines: HP steam turbine can exhaust medium pressure saturated steam, which can be reheated by hot process gases if available and more power can be generated.*

11.5 Steam Pressure Reducing Station

Selection/Ordering Criteria:

- Pressure at which steam is generated/available in the header.
  - (Normal/max./min.—Kg/cm^2).
- Pressure at which steam is required for consumption
  - (Normal/max./min.—Kg/cm^2).
- Line sizes incoming/main header.
- Quantity of steam required—Kg/hour (max).
- Accuracy of pressure regulation required can be within ± 0.1 Kg/cm^2 in downstream pressure at all steam consumption rates, up to rated value. This should be confirmed by measuring amount of steam condensate obtained in about 30 min.
- Fittings required
  - Main stop valve at inlet.
  - Strainer in steam line at inlet.
  - Pressure gauge with isolation valve (before PRS).
  - Steam trap before press controlling valve.
  - Pressure gauge with isolation valve (after PRS).
  - Connection for sensing downstream pressure.
  - Safety valve—downstream of PRS.
  - All piping, fittings, etc. should be flanged (and conforming to prevalent statutory boiler regulations).
- Insulation and aluminium cladding (to be provided after the PRS is installed).
- Complete assembly of PRS should be statutorily approved.
- Only superior grade gaskets or standard ready cut gaskets (with metallic reinforcement) suitable for the maximum header pressure should be used. Sample of gaskets used should be preserved for future reference.

11.6 Steam Superheaters

These are generally used for superheating of steam before it is admitted into the steam turbine for power generation. The superheating serves to increase the efficiency and power output of the turbine, besides minimizing the condensation of steam on the blades. In a process plant, the superheater is also employed to recover heat from hot gases. The following should be carefully considered for the selection of the super-heater:

- Pressure and temperature of the steam available/being generated.
- Maximum pressure drop allowed on steam side.
- Dryness fraction of the steam (after superheating this increases to 1.0)
- Temp of the steam required at the outlet of the superheater.
- Rate of flow of steam in kg/hr.
- Gas side, that is, hot side flow rate in nm^3/hour; temperature at the inlet; desired temp at the outlet, that is, temperature after cooling; gas composition as volume %; specific heat of the gas mixture, presence of any corrosive component in the gas mixture.
- Pressure at which the hot gases are available and the maximum pressure drops allowed on the gas side (in mm WG).
- Expected dew point of the gas mixture (if moisture is also present). This is the temperature at which the corrosive component might condense on the SH tubes. *It is to be understood that it can reduce the life of the SH tubes if the gases are allowed to get cooled to this temperature.*
- Diameter of gas ducts at inlet and outlet and their orientation.
- Total weight of the unit and the overall dimensions (length, breadth, height)
- Vendor should provide C.I. gills on the tubes for protection against corrosion
- Internal lining of Refractory/AR bricks.
- Drain nozzle for acidic condensate.
- Thermowells for temperature measurement at gas and steam side inlet/outlet.
- Steam inlet/outlet/bypass lines and valves.
- Gas inlet/outlet/bypass ducts and valves.
- Approval from the statutory authority for the unit and connecting lines.
- Vendor may be asked to keep a provision for the addition of a few more tubes in future.

11.7 Steam De-Superheaters

In certain situations (on very low load) there is a very small flow of steam through the super heaters and as a result, the steam can become overheated beyond permissible limits. The de-superheaters are employed for taking care of such situations.

(*While super heaters are used for more efficient working of the steam turbines, the steam sometimes rises to higher than the desired temperature* (*not suitable for admitting into the turbine*). *The temperature of the superheated steam can be controlled to the desired temperature by providing bypass routes for the hot gases.*)

The de-superheater can generate additional steam by spraying an optimum amount of water through specially designed nozzles in the superheated steam. Following points should be considered while procuring a steam de-superheater:

- Steam conditions at inlet: pressure, temperature, and specific volume.
- Steam flow rate: in kg/hr.

- Steam conditions desired at the outlet: pressure and temperature. The temperature should correspond to about 15–20 °C superheat to prevent condensation of steam till it reaches the steam turbine inlet.
- MOC of de-superheater body and water injection nozzles, their numbers and location; provision of control valve for feed water inlet (*only treated boiler feed water should be injected through automatic control valves*).
- Pressure rating of the unit (it should conform to prevailing statutory regulations).
- The length of the path from incoming to outgoing steam nozzle and location of water injection nozzle. A very short length may not be adequate for proper mixing of the water spray with the superheated steam and its subsequent evaporation may not take place.
- External reinforcements on the shell to prevent collapsing of the unit if excess water gets sprayed inside (creating vacuum) especially when steam supply is also stopped.
- Horizontal or vertical installation of the unit and orientation of all incoming and outgoing nozzles. This should be carefully looked into since all steam and water piping involved should be covered by statutory regulations. Hence try to avoid major alterations in existing steam piping while procuring a de-superheater.
- External insulation and cladding: This job can be done in-house after the erection, pressure testing and final approval of the unit by statutory authorities (boiler inspector).
- Instrumentation: Pressure and temperature gauges and automatic water flow control valve for spray injection of DM Water in the unit.
- In-built entrainment separator or an external strainer should also be procured to remove water droplets, if any, from the outgoing steam.

12 Instruments

12.1 Introduction

Accurate measurement, recording and controlling of a key process parameter are essential for efficiently running a chemical processing plant (CPP). They also help control pollution; reduce rejection rate (due to off-spec products) and power consumption and increase yield on raw materials. CPP operates safely due to proper control of temperature, pressure, etc. besides reducing equipment breakdowns.

Analysis of any malfunctioning of process equipment or suboptimal plant performance can be done easily by referring to past records of operating parameters and comparing with the present readings (which can be computerised and stored in memory). Hence, it is imperative to provide proper instrumentation, which ensures.

- Safety of human beings, plant and machinery
- Pollution control
- Conservation of energy (to minimise consumption)
- Maximum recovery of energy (cogeneration)
- Quality of the product quality as per specification
- Efficient operations to minimise cost of production and machinery breakdowns
  - Production rates to meet market demands
  - Research and development for new process and technology

12.1.1 For Safety of Personnel

- Detection and control of unsafe conditions, e.g. high pressure or temperature in process plant system
- High or low levels in overhead tanks, feedwater tanks and storage tanks
- Failure of cooling or chilled water systems
- Explosive conditions due to extinguished flame in furnace
- Concentration of toxic gases in working areas or closed vessels (to be detected before entry for internal inspection)

K. Golwalkar, *Process Equipment Procurement in the Chemical and Related Industries,* DOI 10.1007/978-3-319-12078-2_12

12.1.2 For Pollution Control

- Improvement of process control to minimise effluent generation
- Detection/measurement of pollutants in effluents, e.g. SO_2, acid mist, particulate matter, HCl in stack gases, acidic matter, suspended particles, pH of liquid effluents
- Automatic control/assistance for treatment of effluents to neutralise pollutants

12.1.3 For Energy Efficiency

- Minimise energy consumption by guidance/assistance to plant operator by accurate measurements of process abnormalities such as high-pressure drops, abnormal temperatures and high-energy consumption
- Monitor waste heat recovery units, air/water preheater performance, optimise cooling tower operation
- Monitor performance of multiple effect evaporators: *steam consumption, concentration of incoming dilute feed and outgoing concentrated solutions*

12.1.4 For Ensuring Quality of Product

- Ensure smooth process plant operations by quality/analysis checks at every stage of manufacture, e.g. analysis of raw materials at the time of procurement, progress of reaction, activity of catalysts, refinement of crude products into acceptable grade by controls on flow, temperature, concentration, etc.
- Reduce equipment breakdowns by better process control and timely alarms for abnormal situations

12.1.5 For Efficiency of Operations

- Minimise cost of production: procurement of proper raw materials as per specs. (Confirm by *checking with good lab instruments*)
- Monitor consumption of raw materials and utilities (measure levels and amounts in all storages to confirm quantities of material sent to process plant and confirm all incoming supplies)
- Detect abnormal conditions that can reduce catalyst activity, affect production rates, waste reactants through side reactions
- Detect and prevent overloading of reactors, catalyst, plant equipment

12.2 Selection Criteria for Procuring Instruments

- What is to be measured/recorded/controlled?
- Maximum and minimum values expected
- Desired accuracy for the particular application
- Location in plant/equipment: inside or outside
- Material of Construction (MOC) of sensor/wetted parts (*consider properties of fluid*)
- Length of probe (*avoid direct contact with flame*)
- Easy readability of dials/figures/pointer position
- Type of display required (digital or analogue)
- No part of the system should be affected by process fluids, dust and weather
- Recording and retrieval of data, as required
- Accuracy of measurement, quick response

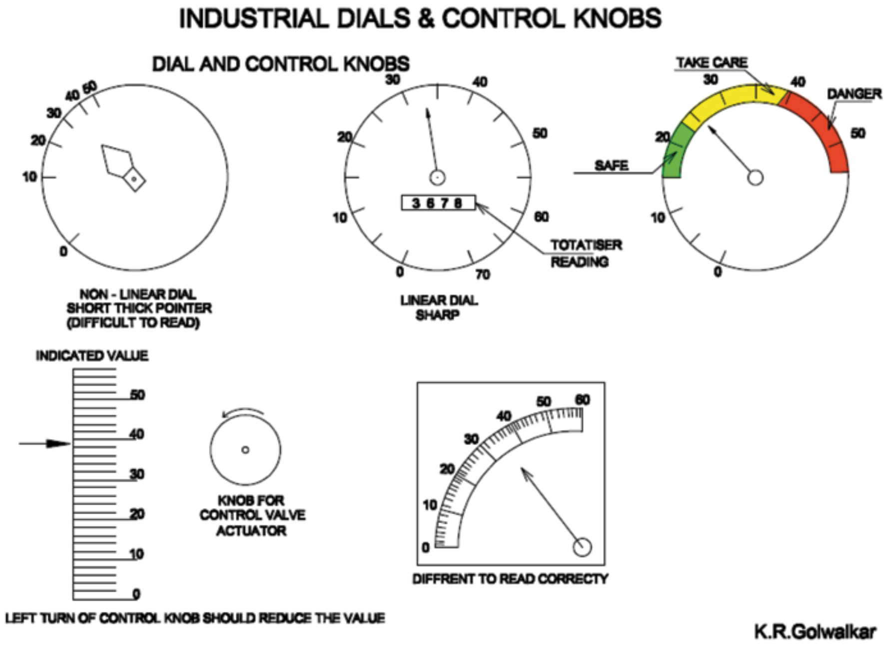
12.3 Dial Designs

- Easy-to-read circular or square dial with clearly marked danger zones
- Linear divisions with smallest divisions, as per need
- Long sharp pointers reaching up to scale
- Parameter control according to natural coordination with movement of control knobs. *In the figure, it will confuse the plant operator if left turn of control knob increases the parameter value instead of reducing it*
- Backlit dials (easy to read)
- Colour contrast of figures with face of dial
- Maximum value on dial should be about 100 % more than the normal values for ease of reading indicated values
  - *If normal value is about 3 kg/cm^2, then the maximum value on dial should be 6 kg/cm^2 (and not 20 or 50 kg/cm^2)*

12.4 Desirable Features of Dials on Instruments

- Size of dial: —should be preferably 150–200 mm diameter or more.
- The dial should have linear scale, i.e., if distance between any two divisions on the scale is same, the change in the value of the parameter being measured should also be same.
- The smallest division should be chosen so as to indicate change in the value of practical importance, e.g. when small changes in parameter are required to be measured in say 0.5 kg/cm^2, the smallest division should be able to read up to 0.1–0.2 kg/cm^2 at least (and not in terms of 2.0 kg/cm^2 or more)
- Dial size should be sufficiently big, so, the figures can be read easily even from a distance and in dim light (Therefore, LED displays in digital format are preferred).

- Length of pointer should touch/cover the smallest division by the sharp tip of the pointer
- Accuracy should be within a range of ± 0.1 %, on full-scale reading. Higher value means less accuracy. It should be possible to make the system tamperproof



12.5 General Considerations for the Instrumentation System

- Weatherproof construction/built-in protection available
- Minimum effect of nearby objects, heat, rain, gases
- Multi–functional:should detect, indicate, record, control and warn about dangerous situations
- Zero/minimum drift of set points, built-in auxiliary connections for data transfer

12.6 Accessories Required

Vendor should be asked to provide the following along with the instruments or give full specifications of accessories so that these can be arranged by the purchaser.

- Thermowells, connecting cables and cable trays; selector switches
- DC power arrangement/UPS for critical instruments

- Solenoid valves for emergency water supply
- Sample cooler/sample conditioner/sampling valves
- Strainer at inlets of certain instruments like flow meters for steam, online pH meters, acid concentration meters, etc.
- Calibration facilities such as:
  - Test bench
  - Standard weights
  - Standard thermocouples
  - Cylinders with known gas composition.
  - Substances with known melting and boiling points

12.7 Installation and Commissioning Assistance from Vendor

- Open packing and check all components after they have been received
- Confirm procedure is as per instruction manuals from vendor (if he is unable to come due to some reason). *Preserve guarantee cards*.
- Provide weatherproof, dustproof cover and corrosion resistant on the name plate.
- Check electrical continuity of all circuits.
- Voltage stabiliser, uninterrupted power supply arrangement, 24 V DC (or as per manufacturer's recommendation) supply to be arranged at the site
- Well-supported field mounting with comfortable work platform and good lighting
- Confirm that sensors/probes are made from correct MOC or have protective sheaths
- Connecting cables should not be too long, should not pass through hot areas, strong electrical or magnetic fields, directly below pipelines carrying corrosive chemicals. Proper support trays should be provided to lay the cables.
- Flush sampling lines thoroughly to cross-check instrument readings.
- Calibrate instruments by using standard solutions, items with known properties
- Install strainers to protect delicate sensors
- Provide bypass lines to continue operations when instrument is under repair
- Confirm probes are not subject to vibrations (except vibration monitors)
- Sample collection arrangement must give representative sample from process, from ETP discharge, from boiler feedwater tank, cooling tower, etc.
- Avoid long-sampling lines for solutions: these introduce process lag, and corrective actions can get delayed
- Provide sample coolers/conditioners as recommended
  - Facility to preserve/dispose off samples

12.8 Common Instruments

- Temperature, pressure and vacuum gauges (dial type, site mounted)
- RTD and thermocouples (for remote indication in control room)
- Flow meters, flow totalisers for liquids and gases
- pH meters
- Concentration analysers (e.g. for sulphuric acid at inlet of absorption towers)
- Gas composition analysers (stack gas analysers)
- Detectors for toxic/inflammable gases
- Level indicators and transmitters (process tanks, storage tanks)
- Tachometers (for important drives)
- Current, voltage, energy consumption indicators
- Recorders (The readings displayed by these instruments should be recorded for future reference and analysis)
- Steam flow meters
- Boiler level indicator and controller

12.9 Special Instruments

- Moisture analyser (hygrometer)
- Vibration monitors/analysers (for high-speed machines)
- Dial gauges for checking alignment (motors and blowers)
- Ultrasonic thickness testers for monitoring corrosion of process vessels and storage tanks, reactors handling dangerous materials.
- Hand-held temperature and pH indicators
- Density/specific gravity analysers (hydrometers)
- Flame monitoring device for furnaces
- Dissolved oxygen meter for boiler feedwater, treated effluent
- Conductivity meter for boiler feedwater

Digital/electronic instruments are preferable to those with mechanical moving parts since the former could be obtained in totally sealed construction and are less prone to damage by dust, vapours, vibrations, etc.

Following should be considered during floating enquiries, comparing quotations and while ordering the respective instrumentation.

12.10 Dial Gauges for Temperature

- Process of plant: place of installation should be convenient for keeping a watch even from a distance while moving around in the plant
- Range of measurement (e.g. 0–100 °C, 0–250 °C)

- Probe type: mercury in steel bulb/others
- Capillary type: length of capillary/length of probe
- Size of dial: 100 mm/150 mm/300 mm diameter
- Accuracy desired: as percentage of full-scale reading or as lowest fraction of a digit

12.11 Thermocouples

12.11.1 Types of Thermocouple

Typical application: Sensing of temperatures at different points of the process plant such as internals of furnaces, reactors, entry and exit points of reactants and products in gas ducts. Generally dial thermometers are not provided at such points as they are at remote locations or cannot be physically visited frequently by the plant operators.

Thermocouples are also used for ensuring safety in gas-fired (heated) appliances. They can sense high temperatures and can activate appropriate gas shut-off control valves to prevent overheating.

Selection Criteria to Be Considered for Thermocouples

- Normal operating temperature range of the unit
- Likely maximum and minimum temperatures
- Place of installation in the processing vessel/gas duct or liquid pipe (diameter of duct/pipe to be known where the thermocouple will be installed)
- Medium/fluid encountered
- Depth of insertion required for proper sensing
- Accuracy desired (as a percentage of full-scale reading or in absolute term as ±0.1 °C)
- *Possibility of erosion due to high velocity fluids/fluids containing abrasive particles; the damage to thermocouples can be prevented by using a thermowell* (*a sealed tube of metal or ceramic*) *and installing it in the stream of fluid. The thermocouple is kept inside the thermowell.*
- Whether corrosive atmosphere will be encountered by the thermocouple. In that case, protective sheath (SS-304, SS-316, SS-310, HRS or ceramic) is required. The response time of thermocouple installed in the ceramic sheath is lower, however.

Corrosion resistance can also be taken care of by a thermowell made from a suitable construction material. Generally a proper sealing, weather-resistant cover protection should be provided for the junction box of the thermowell, i.e., where cables are connected to the ends of the thermocouple wires (please see thermowells).

- Output in millivolts per °C or per 100 °C) and the repeatability of output
- Mechanical strength of individual wires used for making thermocouples
- Test certificates for calibration against standard instruments

Classifications of Thermocouple Pairings in Industry Parlance

1. The home body class: standard or commonly used metals
2. The upper crust class: all platinum combinations
3. The rarified class: refractory metals
4. The exotic class: usually special combinations of rare metals used for specified applications

Rarified and exotic thermocouples do not have special alpha codes assigned to them, because they are less frequently used.

Some standards governing types of thermocouple are as follows. (*Check the latest amendment, if any, at time of procurement*).

- British Standards Specification, BS 1041
- ASTM Standard E230 Specifications

Summary of Types of Thermocouple

Type	Conductor combination	Range (°C)
B	Platinum 30 % rhodium/platinum 6 % rhodium	1370–1700
E	Nickel-chromium/constantan	0–870
J	Iron/constantan	0–760
K	Nickel-chromium/nickel-aluminium	0–1260
R	Platinum 13 % rhodium/platinum	870–1450
S	Platinum 10 % rhodium/platinum	980–1450

Type B thermocouples can be used up to 1600 °C. They have a low electrical output, therefore are rarely used below 600 °C.

Type E thermocouples are often referred to as chromel–constantan thermocouples. They are regarded as more stable than Type K, therefore often used where a higher degree of accuracy is required.

Type J thermocouples degrade rapidly in oxidising atmospheres above 550 °C. The maximum permissible continuously operating temperature is around 750 °C, but are not used for this. They are generally not used below ambient temperature due to chance of condensation on the wires leading to rusting of the iron. *Note*: Constantan is a copper–nickel.

Type K is the most widely used thermocouples in the oil and gas and refining industries due to its wide range and low cost. This type occasionally referred to as chromel–alumel thermocouples. Oxidation can occur above 750 °C leading to inaccuracy and hence may need recalibration.

Type R: Pt 13%/Rh (+) *Pt* (−) thermocouples cover similar applications as Type S but have improved stability and are used at temperature values 850–1450 °C; also have a little increase in the range. Consequently, Type R tends to be used in preference to Type S.

Type S:*Pt 10%/Rh* (+) *Pt* (−) thermocouples can be used at temperatures up to 1450 °C. Range is 980–1450 °C. They need protection from high-temperature atmospheres to prevent damage to the tip resulting in reduction of EMF generated. Protection commonly offered is high-purity-recrystallised alumina sheath. For most industrial applications, thermocouples are housed in a thermowell.

Iron–Constantan

- For temperature up to 500 °C
- Accuracy: ± 1.0 %
- Main application: low-temperature process unit

Chromel–Alumel

- For temperature up to 1200 °C
- Accuracy: ± 1.0 %
- Main application: medium-temperature process unit

Platinum–Rhodium

- For temperature up to 1500 °C
- Accuracy: ± 1.0–1.5 %
- Main application: high-temperature furnaces

Optical Pyrometer

- For temperature up to 3000 °C
- Accuracy: ± 3.0–4.0 %
- Main application: high-temperature flames/furnaces

Resistance temperature detector (RTD) for temperatures up to 450 °C.

12.11.2 Multi-point Temperature Indicator

- Generally installed in control room
- The scanner should be specified as per the requirement of number of points. The scanning speed for various points and time for which (in seconds) each point is displayed should be adjustable.

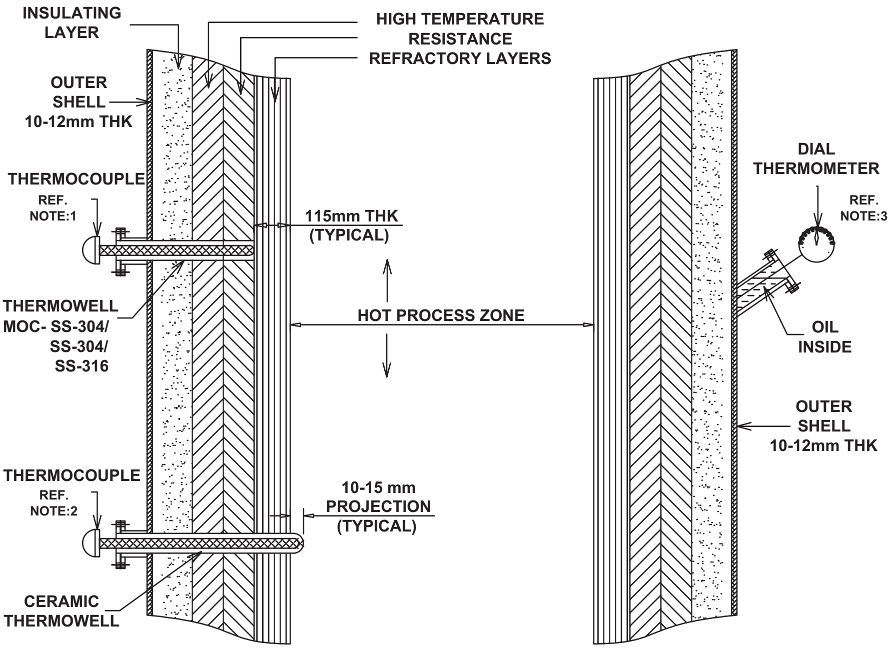
12.12 Thermowells

While purchasing thermowells, one should look in to the following:

- Required length for proper measurement of temperature: whether it should be just projecting inside the vessels or reach deep inside. *Refer to drawing*.
- Properties of medium that will be in contact with thermowells: temperature, pH of medium, concentration and abrasive nature of particles in suspension, presence of corrosive gases or liquids.
- Flow rate of medium: high-fluid velocities along with presence of abrasive particles can erode the thermowells and even puncture them. This can give erroneous readings. Hence, use stronger, thicker thermowells but this can increase response time.
- Whether there is a tendency for solidification and deposition on the thermowells.
- Response time and accuracy desired (will depend on thermal conductivity of the material of construction and thickness of thermowell).
- End connection: whether screwed or flanged to match nozzles provided on process vessel or fluid duct.
- The illustration shows different methods of installation of thermowells (with thermocouples inside) in a refractory brick-lined furnace. This is based on practical experience. It was seen that the thermowell projecting right inside up to the hot process material was getting damaged frequently. Hence, it was inserted only up to the back surface of the innermost refractory brick. Though it was not able to indicate the correct temperature of the hot process material, it could only indicate the trend for rise or fall of temperature and had more life.

The dial thermometer for the furnace shell was meant only to know trends of rise or fall of temperature of the brick-lining layers; and whether any damage of lining is taking place inside.

High cost of special thermowells was thus saved while satisfactory guess could be made regarding condition of the brick lining.



NOTE:
1) ABSOLUTE TEMPERATURE NOT DETECTED BUT LONGER LIFE.
2) FASTER RESPONSE BUT LESS LIFE
3) SLOW RESPONSE BUT LONGEST LIFE

12.13 Pressure Gauges (for Higher Range) and Manometers (for Lower Range)

- Range of pressure to be measured, e.g. 0–10 kgs/cm^2 or 0–2000 mms water column
- Size of dial (100 mm, 150 mm diameter, etc.)
- Connecting nipple size (1/2″–3/4″–1″, etc.) and thread specifications.
- Glycerine-filled pressure gauges for steam lines or hot fluids
- Vertical tube or inclined tube manometer (shows larger movement of the liquid and hence can be more accurately read for small pressure differences)
- Provision of (cooling) loop to be supplied by vendor before the pressure gauge to protect the instrument from high temperature.

Selector Switch for Temperature Measurement and Indicator in Control Room (Information to Be Given by Purchaser)

- Number of points required for selector switch
- Minimum/maximum value of temperature
- Power supply available at site: 230 V AC/110 V AC/24 V DC
- Space available in control panel for mounting the instrument
- Whether a moving pointer instrument is required or an LED display in digital form is required (the latter is preferable)

12.14 Flow Meters for Liquids

12.14.1 Rotameters

Typical designs are rising float in a tapered glass tube (for transparent fluids); rising float in a metal tube (for toxic/dangerous fluids). Inquiry sheet should mention the following:

- Pipeline size
- Percentage accuracy of full-scale reading
- Type of connection: flanged/threaded (flanged connections are preferable)
- Range of flow (in cubic meter per hour): Normal/minimum/maximum
- Pressure at inlet of the flow meter
- Temperature of fluid: normal/minimum/maximum
- Viscosity and density
- pH of fluid
- Presence of any suspended particulate matter/crystals, etc. (A strainer may be installed before the flow meter—but it should not affect the flow rate)
- 'Contactless' type flow meters (clamped on pipelines)—the output is in milliamperes, which is processed to get the actual reading.

12.15 pH Meter

A pH meter measures the potential difference, in (millivolt), between the reference electrode and the measuring pH electrode. It converts the difference to a display of pH. A pH meter is required to monitor the pH of process fluids, treated effluent, boiler feedwater. (since highly acidic fluids can corrode equipment and pipelines).

12.15.1 Considerations for Procurement

- Properties of medium: range of pH, operating temperature (normal and maximum) concentration of suspended solids, presence of erosive particles.
- Place of mounting required: on a pipe line, inside a reactor, in an open channel where liquid is flowing.
- The electrode should be preferably mounted vertically. In cases where the pipeline is vertical, a separate sample line may be required which will bleed a small quantity of the liquid into a container, into which the electrode may then be inserted. (this container can be drained in to a suitable process tank).
- Installation: Indoor or outdoor (will need protection from rains, sun, snow) weatherproof enclosure should be offered by vendor.
- Whether online measurement is required.
- Whether vibrations are expected in the pipelines or equipment where the electrodes are mounted. In this case, the glass electrode should not be used as they can break.
- Accuracy of measurement desired: +/−0.1 pH.
- Range of measurement desired: 1–12 (more common).
- Resolution desired: 0.1 pH.
- Type of display: the meter may have an analog or digital display. A digital display should be preferred with backlit dial for ease of reading even in dark.
- Automatic temperature compensator should be incorporated if there is variation in the temperature of the medium since the readings are generally affected by changes in temperature. Higher quality meters will have a provision for temperature correction.
- Vendor may supply a strainer in the sampling line if concentration of suspended solids is more.
- Standard calibration kit with three buffer solutions of known pH (generally 4, 7 and 10) and appropriate solutions for storing the electrode when the pH meter is not in use should be provided by the vendor.
- Handheld pH meters are also available. They also include DO and temperature sensors. These require batteries to operate.
- Length of the sensor to be informed by vendor. Purchaser should indicate if he needs a longer sensor. Spare sensors should also be supplied by vendor.
- Probes are available with glass or plastic bodies. The glass body electrode is most often used in laboratory applications. The glass body is preferred for highly corrosive materials and high-temperature applications. The plastic body is a good choice for applications where rough handling and breakage are likely.
- Power supply requirement (voltage stabiliser to be arranged by purchaser generally)
- Auxiliary contacts available for activating alarm/controllers, etc. (Purchaser should ask the vendor for these)

Connecting cable should be supplied by vendor in case the probe is installed outdoor and pH meter is installed in the control room. (Purchaser should inform approximate length of cable required. Avoid joints in cables as this will affect accuracy).

12.16 Humidity Meter (Hygrometer)

Hygrometer is used for monitoring the humidity in laboratories, storage areas and manufacturing plants where specific levels of humidity must be maintained. In sulphuric acid plants, moisture in combustion air can cause acid mist and damage boiler and heat exchanger tubes, catalyst in the converter besides causing emission of acid mist from chimney. Hence, it is advantageous to monitor the humidity in the air at inlet to drying tower itself.

Humidistat's (akin to *thermostats*) can be used to control humidifiers for regulating the humidity of the air in storages, warehouses to prevent growth of moulds in food-processing industries.

Mechanical hygrometer is based on animal or human hair whose length increases when the relative humidity increases and contracts when it decreases. The change in length actuates a lever, which turns the pointer on a dial. *This is not a very accurate device however*.

The wet-and-dry bulb hygrometer consists of two thermometers that are adjacent to each other. The dry-bulb thermometer measures the temperature of the air. The bulb of the other thermometer is kept wet by a wick dipped in water. As the water evaporates due to the air flowing across, the wet bulb is cooled.

Lower temperature is indicated by the wet bulb if the air is dry. The drop in the temperature depends on the dryness of the air.

The relative humidity is determined by comparing the readings of the two thermometers with standard psychrometric charts. The amount of water vapour in the air (mg/nm^3) can be calculated.

This instrument can indicate relative humidity at the present time. Change in humidity results in the change in the difference of the dry and the wet bulb temperatures in a short time.

Important A small dip pot should be supplied with the instrument to keep the wet bulb always wet. Fresh water should be filled in the pot every day.

Electrical hygrometers typically measure the electrical resistance of a substance, such as lithium chloride or of a semiconductor device which varies with the humidity. The change in resistance is indicated by the calibrated instrument. The response of such an instrument can be slow because the previously absorbed moisture should be completely replaced by the fresh incoming moist air. Also, regeneration of the saturated material may become necessary for fresh readings.

Dew-Point Hygrometer A smooth, shiny mirror-like surface is cooled until water vapour in the air begins to condense on it. The humidity is determined by comparing the temperature of the surface at which the condensation occurs (the dew point) with the temperature of the air read by another thermometer.

Limitation The shiny surface can be affected by dust, spillage of some liquid or chemical vapours from nearby reactors, and hence may not be very accurate.

Chemical hygrometers use an absorbent like $CaCl_2$, which absorbs moisture from a given volume of air. The increase in the weight of the substance before and after absorption indicates how much moisture was in the volume of air which was passed through it.

Limitation Takes more time to determine the humidity, replacement/regeneration of the absorbent becomes necessary after a few readings; the apparatus has many components like balance, aspirator, measuring cylinder/apparatus for determining volume of air making it complicated and time consuming.

Considerations for Selection

- Accuracy desired
- Readings should be indicated for present condition of air instead of a few hours back.
- Response should be fast: frequent regeneration or replacement of components or chemicals should not be required
- Should be possible to actuate a controller automatically as per humidity condition if food, pharmaceutical preservation are to be done.
- Construction should be robust and not affected by gases, dust or moisture present near the instrument. A dust-free enclosure should be available (with an access for air to come in) so that fresh sample is analysed without affecting the instrument.

12.17 Concentration Analysers

Resistance of the fluid is measured between two fixed points in a probe through which a continuous flow of the fluid is maintained. It is compared with the resistance of fluid of the known concentration.

- A strainer is to be provided before the probe for preventing damage to the sensing element.
- Temperature compensator must be provided so that the instrument indicates correct reading even when temperature of the fluid varies.
- The instrument should be panel mounted in a safe place in control room/site mounted.
- The output signal from the probe/concentration analyser should be such (e.g. in the 4–20 mA range) that it can be used to activate recorders/controllers/alarms, etc.

12.18 Contactless Instruments

- For measurement of flow rates (volumetric/mass) of gases and liquids
- Level measurement of solids in storage silos
- Piping and ducting layout required for installation
- Accuracy desired and actually available
- Range of instrument
- Size of pipelines/diameter and depth of vessels.
- Effect of surrounding gases, presence of dust, hot conditions, sunlight, rains and electrical cables in the vicinity of the instrument

12.18.1 Contactless Magnetic Flow Meters

These can be used for corrosive, dangerous liquids that can attack the sensor if placed directly in contact. A magnetic field is applied to the metering tube, which generates an electrical signal (potential difference) proportional to the flow velocity perpendicular to it. The potential difference is sensed by the electrodes fitted perpendicular to the flow and the applied magnetic field and converted to readings on the indicator.

The magnetic flow meter operates with a conducting fluid and a non-conducting pipe liner.

- There should not be strong magnetic or electrical fields or cables carrying high currents nearby as they can affect the accuracy.
- Connecting cables should not be too long, should not pass through hot areas, strong electrical or magnetic fields, or directly below pipelines carrying corrosive chemicals

12.18.2 Ultrasonic Level Indicators

A transducer (which has a piezoelectric crystal inside) converts an electrical signal to sound. It hits the level of material (target) and is a reflected back as sound. It is converted to an electrical signal and depth is calculated by the instrument from the time taken for the signal to travel.

Do Not Select in Following Situations When This Instrument May Not Indicate Correct Reading

- Dusty atmospheres may distort a return signal to the sensor
- High temperature of materials can change the speed of signals
- Sloped surfaces like ladders, material build-up, weld seams may cause indirect reflection leading to weak and/or split echoes

12.18.3 Level Indicators

- Float-actuated pointer on external scale (storage tanks for liquid)
- Rising float in transparent tubes (tanks with fuming liquids)
- Rising magnet in stainless steel tubes with external follower magnet for corrosive fluids with high vapour pressure, e.g. oleums
- Transparent external tube fitted to tanks with isolation valves (could close automatically if the tube is damaged)
- Internal scale for process tank with sight glass fitting(65 % oleum)
- Sound/radio waves reflection from surface (for deep tanks)
- Gamma ray projection and detector at other end (as above)

Purchaser Should Check That

- MOC of float is stainless steel or coated with PTFE or of HDPE or ceramic
- Strong multi-strand wire should be for connection to pointer moving over an external scale
- Spare float, tubes, magnets, etc. should be available

12.18.4 Level Controllers

- High level makes electrical circuit and low-level breaks electrical circuit through a limit switch contact or the process liquid itself. This actuates (or stops) the transfer control valves (pumps). *Should not be directly installed on tanks with inflammable fluids*.
- Probes should be protected from corrosion by ceramic, glass, PTFE coating.
- Used for conducting liquids or by providing limit switches (for non-conducting fluids)
- Liquid level should be steady for proper control. Hence do not install probe in a tube having incoming flow. The froth should not be allowed to shake the probe.
- The tube should be kept clean always; or a small flow can be diverted to this tube for continuous cleaning it by itself.
- Provision should be available to adjust the high- and low-level alarms or limit switches for actuation of the transfer control valve (transfer pump).
- *Connect overflow nozzles of tanks or provide another collection tank to prevent loss.*

12.19 Flow Meters for Liquids

12.19.1 Turbine Meters for Liquid-Flow Measurement

- Flowing fluid in a pipe causes a bladed rotor to rotate. This is used to move gears or a magnetic pick up. The speed of rotation is proportional to fluid flow

- Have lower pressure drop
- Simple installation, reasonably accurate

Accuracy of turbine meters can be affected:

- By bubbles in fluid (*rotor may not rotate properly*). *Hence the temperature of liquid should be much lower than boiling point during flow measurement.*
- Can be used only for measuring clean, steady, medium- to high-speed flow of low-viscosity fluids. (accuracy is also affected if fluid viscosity is high or flow is laminar)
- Install strainer upstream since suspended particles can interfere with rotor speed provided the strainer is large enough not to affect the total flow rate.
- Sensitive to changes in fluid viscosity: viscous thick fluids *affects rotor speed*

12.19.2 Vortex Meters for Liquid-Flow Measurement

- Working principle: an *obstacle* is placed perpendicular to the axis of pipe in which the fluid is flowing. Eddies are generated across the sides of the obstacle, which are detected by electronic sensor. Their frequency is proportional to the fluid flow.
- Pressure drop is less in these meters
- Generally not affected by fluid temperature or pressure

Not very suitable for low-flow rates (sufficiently measurable eddies may not be created)

Do not select in following situations when this instrument may not indicate correct reading

- Very low-flow velocity of fluid—less than 0.5 m/sec
- High-viscosity liquids
- Highly corrosive fluids which can corrode the *obstacle*
- Problem in electronic sensor or circuit may arise due to strong electric fields nearby

12.19.3 Gas Flow Meters

Considerations for selection are:

- Gases flowing: SO_2, HCl, CO_2, nitrogen, oxygen, etc.
- Composition of gas mixture flowing in the pipeline, average density and molecular weight, etc.
- Temperature and pressure of the gas

- Moisture content: normal, minimum and maximum
- Suspended particulate matter, acidic droplets in gas
- Operating pressures and temperatures: normal, minimum and maximum
- Diameter of pipeline and orientation
- Accuracy of measurement desired
- The installation could be outdoors and hence provide protective enclosure against weather
- The flow meter may consist of an *averaging-type pitot tube* inserted in the gas line. The MOC should be resistant to the gas mixture at the operating conditions. This causes a very little pressure drop in the gas flow
- There are a number of small holes, which can get choked by particles in the gas. It can affect the accuracy of the flow measurement. It should be fitted tightly at both ends, but should be easily removable for cleaning or replacement

The vendor should inform his requirement of straight lengths before and after the flow meter for correct readings.

Orifice meters measure the pressure before and after an orifice plate is placed in a pipeline. By measuring the pressure difference and using the coefficient for the meter, the flow rate can be calculated. Advantages of orifice meters include sturdiness, long-operating life and lack of moving parts. However, they increase the pressure drop in the pipeline (thus increasing the power consumption of the blower) and also require of straight pipeline equal to 5–8 diameter before and after their location in the pipeline. The orifice meters may not read very accurately if this condition is not met at the plant ducts.

12.20 Stack Gas Analysers

Online monitoring of stack gases is required by many statutory authorities. This requirement must be complied with.

12.20.1 High-Volume Sampler for Fine Particulate Matter in Gas

The sampler sucks sample of gas at a constant rate through sieves of different pore sizes to collect particles of size below 3 µm, between 3–6 µm and above 6 µm. The particles of different size collected in 8 h (or longer time as per instructions) are weighed. Since gas volume sucked in these 8 h is also known due to calibration of suction blower, the Suspended Particulate Matter (SPM)/nm^3 can be calculated. The sieve pore sizes should be selected as per need to analyse the gas sample.

The unit should have adjustment for increasing or decreasing the gas flow rate, provision of sieves of different sizes, manometer and temperature indicator.

The instrument can be installed outdoor by providing protective enclosure against weather and continuous power for running the suction blower.

12.20.2 Analyser for Gases

It works by comparison of thermal conductivities of gas stream with gas mixture of known strength **or** by chemical titration with standard solutions. Concentrations of SO_2, HCl, etc. can be seen on the digital indicator.

The range can be 0–1000 or 0–2500 ppm or higher, if required. Generally 0–500 ppm is used more because higher concentrations are not allowed in stack gases.

- *Accessories required: Suction pump, Sample conditioner, connecting tubes, digital display and recorder, UPS for the unit in the control room*
- *Should be calibrated at vendors shop by passing a gas mixture of known composition. Confirm by manually checking gas samples once a day/week as per need. Replace standard solution regularly*

Laboratory apparatus with an aspirator or vacuum pump, dust particle analysers should also be available.

12.21 Special Instrument Feeding

The device should be suitable whenever large quantities of bulk solids have to be measured downstream of mechanical conveyor systems and should be accurate even in case of large flows and high ambient temperatures. It should be possible to install the instrument on round pipes or ducts and should operate with the latest microprocessor technology. It should be dustproof and can be installed at an angle if required. The mass flow measurement should be independent of flow characteristics, and with no moving parts in the system, maintenance is not required.

12.22 Controllers

Vendors should be asked to give details of actuators for controllers, e.g. whether dry compressed air will be required for opening/closing control valves (say, for adding alkali for pH control) or whether the control valves would be actuated by some other means (e.g. solenoid valves).

Types of control action required: whether a smooth control action of the system is required or an ON/OFF action is ok? The latter is more drastic in nature, and the control action starts and stops only after the parameter values reach the upper and lower set points. The implications of this should be discussed with shop floor engineers before ordering the unit.

Other important considerations are:

- Constant set point (the set point should not drift by itself due to vibration/voltage fluctuations/due to any other reason); once adjusted it should remain constant till the plant personnel change it.

- Difference between actual value and set point value should be accurately sensed (and conveyed by the probe) and control action should commence after a predetermined short-time lapse. This time period should be adjustable. Initiation and continuation of the control action (e.g. regulation of fuel flow rate/addition of alkali) should be gradual, i.e. without sudden snap action.

It is necessary that a truly representative sample of the process parameter always reaches the instrument probe for correct control action. Purchaser should design the sampling lines accordingly and the flow through these lines should always be adequate.

12.22.1 Controller Types

Some typical controllers are ON/OFF, proportional integral derivative (PID).

Operation of Controllers Can Be Done by Following Means

- Electrical
- Electropneumatic
- Electronic

Information to Be Given by Purchaser

- Type of input signal that will be given to the controller
- Range of the signal
- Form of output signal required, e.g. as pneumatic pressure or as electrical current
- Power supply available at site: 230 V AC/110 V AC/24 V DC

12.23 Recorder Types

- Circular charts with day-time/night-time markings. This is generally one revolution per 24 h
- Strip chart
- Roll chart for recording and retrieving data for last-say-one week
- **Computerised recorders** have mostly replaced the old recording systems. These should be chosen to record values of the required number of variables, their individual totals for a week or month, trends for increase or decrease, highlighting instances when the values were above maximum permissible limits, etc. They should be connected to printers and to main computer, if required

Information to Be Given by Purchaser

- Type of input signal that will be given to the recorder
- Maximum range of the signal

- Power supply available at site: 230 V AC/110 V AC/24 V DC
- Whether past record will be reviewed every now and then or once in a week or so.
- Space available in control panel for mounting the recorder

12.24 Connecting Cables

The following should be taken into account before procurement of the cables:

- Signal generated by the sensor
- Maximum and minimum values of the signals expected
- Distance between sensor and measuring instrument
- Route to be followed for laying the cables. Avoid areas of high ambient temperatures (e.g. proximity to hot, bare pipelines) or where corrosive liquids may leak and damage the cables. Cables should have built-in protective sheaths and armoured construction if it does not interfere with the accuracy of readings
- Also, care shall be taken to see that the cables are laid away from areas having stray electrical signals due to heavy currents in the nearby equipment or strong magnetic fields. Usage of specially shielded cables for such locations is preferable. (shields of aluminium foils or metallic mesh in consultation with vendor)

12.25 Distributed Control System

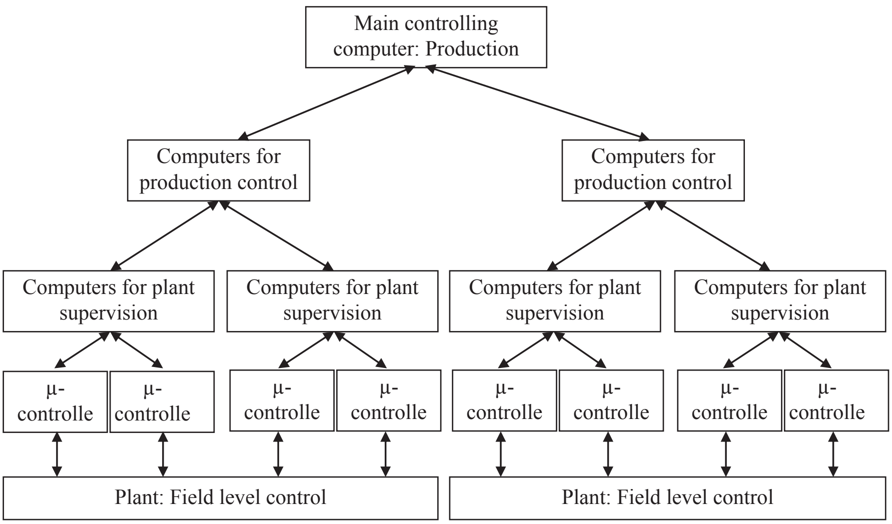
A chemical plant has many process units that should be operated safely, efficiently and without causing environmental pollution. Computerised process control systems are required where a large number of process parameters are to be controlled.

- Prepare a detailed process flow diagram and PID.
- Make a list of all important equipment and their operating conditions. These should include all incoming materials, their flow rates, temperatures, pH, pressures, concentrations, etc.; and likewise for all outgoing materials.
- Ideal (optimum) conditions should be specified for the equipment. These depend on the production rate, quality of products, pollution control level and energy recovery desired, etc. These should form a set of points for the process control.
- Deviations permissible from the set of points should be defined and explained to all operating personnel.
- Sensors for the appropriate instruments should be installed in the pipelines, reactors, storage, gas lines, etc. Field instruments and remote instruments should be installed in the plant. Sensors should send
- The operating personnel should check the readings and corrective actions initiated (if there is deviation from the set points), e.g. flow of fuel oil is reduced if temperature of flue gases from furnace is increasing more than the desired value.
- Many such microprocessor-based circuits are connected to a central-computerised system when the plant has a large number of process parameters to be controlled.

12.25.1 Considerations for Selection of a DCS

Following should be decided by the purchaser jointly with his consultants, shop floor and senior engineers and vendor of the distributed control system. A typical system is shown below in the figure.

- Confirmation of all critical parameters and their normal values.
- Selection and fixing of set points for all such critical parameters.
- Choice of the correct sensors and sensitive instruments for given conditions.
- Proper location of sensors so that they will be able to send accurate signals quickly.
- Route of connecting cables should not pass through strong magnetic or electrical fields or near high-temperature furnaces and ducts or below pipelines carrying corrosive acids or inflammable chemicals.
- Accuracy of instruments.
- Response time of controllers.
- Installation of additional sensors and instruments for critical parameters.
- Extra processors and control loops to increase the reliability of the system.
- It should have reliable instruments. All necessary auxiliary equipment (dry compressed instrument quality air, UPS, pneumatic and hydraulic system for actuators, solenoid valves) should always be in well-maintained condition.
- The system should be able to accept more number of signals, process them and take corrective actions (if desired for plant expansion in future).
- Warning signals and safety alarms should be activated by the system.
- All stored data should be available (retrievable) for analysis in future.



Utilities

13

13.1 Heating Arrangement for Chemical Plant

Many chemical industries need the heating of raw materials, reagents in the reactors or products for further processing. The heating arrangement based on combustion of fuels should be considered from points of view of not only the calorific value (*CV; Kcal of heat available per dollar spent on the fuel*) *but also safety, ease of handling* (*including storage arrangements at site*) *and operation, suitability for the plant, total cost of system, cost of operation and maintenance.*

13.1.1 Use of Gaseous Fuels

- Natural gas, coal gas, producer gas, water gas, propane, etc. are the most commonly used gaseous fuels. These can be convenient, clean and efficient options.
- The use of gaseous fuels is convenient and does not contaminate the product with ash deposits.
- Temperature control is accurate and easy. Combustion of gaseous fuel generally does not cause pollution unless it contains sulphurous compounds like H_2S.
- Higher temperatures can be achieved due to higher CV of the gas.
- Purchasers may install a gas processing plant themselves (for coal gas, water gas and producer gas) if cheap supplies of good quality coal are available and there is continuous demand for the gas.

The system can get supply of gas from an incoming pressurized gas line from external gas grid supply (available directly from oil fields at certain locations), from gas holders or from a bank of gas cylinders. The following should be carefully looked in to.

Accessories
The accessories required are:

- Pressure regulator
- Corrosion-resistant pipelines with nonreturn valves

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- Flow control valves for the fuel gases
- Flame arrester
- Pipelines capable of withstanding high pressure
- Flameproof motors and lighting in the vicinity of gas lines
- Flame arrestors in gas lines
- Nonreturn valves and shut-off valve
- Reliable gas flow measurement meters

Safety Precautions
Following safety precautions are recommended:

- Leakproof fittings
- Route of pipelines: must avoid electrical cables, heavy traffic, hot areas
- Detectors and warning devices for CO leak
- Flameproof fittings, photocell-actuated gas control valves
- Induced Draught (ID) fans and tail gas scrubbers (if the gases contain H_2S or other sulphurous compounds)
- Flare tower (optional)

Regular pressure testing of the gas lines and provision of safety valves (with release point being located faraway or to a specially designed flare tower) are important safety measures that should be implemented if gaseous fuels are being used.

13.1.2 Use of Liquid Fuels

Since oil (furnace oil, high speed diesel, light diesel oil (LDO), etc.) is a quite costly commodity, its use for heating purpose should be decided only after consideration of the following factors.

Arrangements and Accessories
Arrangements and accessories required are:

- Receiving fuel supplies by tankers (weighbridge and unloading facilities) or pipelines (metering of supply will be necessary); cost of transport, storage (in tanks).
- Storage tanks with level indicators and safety vents.
- Storage tank outlet: oil heater with thermostatic temperature control (electrical heater) or steam pressure regulator (if steam is available at site and is used for heating of oil) in case of viscous oils and a temperature gauge.
- Oil firing rate (L/h) required for the system, which depends on:
  - Total heat release capacity (measured in Kcal/h).
  - Calorific value per litre of oil per unit cost spent on oil as compared to coal or other fuels.
- Furnace temperature required to be achieved (oil firing can achieve 800 ºC or more).

- Accuracy of temperature control required (within 5 ºC is possible when it is being heated by oil firing). It is difficult with coal firing.
- Whether quick start/quick stoppage (within 2–5 min) of the heating is required.
- Loss of heat transfer efficiency due to ash deposit on heating surface takes place due to coal or husk firing. There is also the problem of ash disposal. These problems do not arise when oil firing is used.
- Good atomisation is necessary for proper combustion (to minimise soot deposition on downstream units). This will need fuel pump pressure regulator, oil filter at appropriate place in oil line and flow controllers.
- Centrifugal/gear-type oil pumps are used. Gear pump with in-built safety devices preferred for small constant flow of oil.
- Air blower: compressor (positive displacement type) preferred with silencer-cum-filter, dampers for primary (atomising) air, primary and secondary air piping, manometer, pressure regulators for air supply at burner inlet.
- Indicator/controller of CO_2 content in exit gas to ensure proper combustion.
- Photoelectric cell (to stop oil pump if the flame goes out).
- Oil pump trip if air pressure at furnace inlet is lesser than required.

13.1.3 Use of Solid Fuels

Common solid fuels are:

- Coal
- Waste wood or charcoal
- Refuse-derived fuels from municipal solid waste (in very limited cases)

Cost of solid fuels can be lower than liquid/gas fuels. The following points should be taken into account while selecting a solid fuel firing system.

Facilities
The facilities required are:

- Storage shed
- Storage hoppers
- A pulverizer is required for a coal-firing system along with other accessories such as screen for preventing entry of large lumps, conveying system (bucket/belt conveyors with arrangement for weighing the coal transported) and a screw feeder. This may result in considerable power consumption.

Considerations
- Solid fuel firing system generally requires more manpower than gaseous/liquid feeding system for unloading, storing and feeding the solid fuels.
- Quality of the fuel (coal, coke) available: ash content, gross calorific value, volatile matter content, size of lumps (not more than 150 mm).

- Fine temperature control is difficult to achieve.
- Possibility of the loss of (unburnt) fuel through grate.
- Ash removal system as well as arrangements for its disposal are necessary.

13.1.4 Heating Plant Units by Steam

Steam has high latent heat and can be transported to long distances by virtue of its pressure and is thus very useful in a chemical plant. It can be used for power generation also. (This is described elsewhere in this book.)

It can be generated by the use of different fuels given above or by waste heat recovery boilers (WHRB) from hot process gases which need cooling as per process requirement.

Steam generation by coal-fired boilers can be one of the cheapest options (if WHRB is not possible) as compared to use of other fuels.

Vendor Should Be Asked to Indicate the Following in the Offer for CFB

- Guaranteed steam generation Metric Tonne (MT) per Metric Tonne (per MT) of fuel consumption.
- Details of coal burning: moving grate/fluidised bed/others.
- Efficiency of combustion.
- Power consumption and motor details for ID fans, oil feed pump (for start only), etc. should also be given.
- Feeding arrangement for coal should be given in detail. This may include coal conveyors, crushers, elevators and screwfeeders along with their motor HP; electrical interlocks provided and power consumption per MT of steam generated at specified pressure and temperature.
- *It also needs more time to start firing and to reach required temperature and to stop and cool down.*
- *Regular removal of the ash from the furnace is required, which may pose disposal problems besides needing equipment for removal and handling.*
- Pollution control devices like electrostatic precipitator and flue gas desulphuriser are required if ash and sulphur content are more in the solid fuel (e.g. some varieties of coal, petroleum coke, etc.). *These are costly*.
- *In case of liquid or gaseous fuels, quick start and stop are generally possible, and they have less ash content. The coal-firing unit cannot have quick start to generate steam as soon as it is required. It also takes a long time to cool down. Hence, there is considerable loss of heat during starting and stopping.*

For the above reasons, coal firing should be used only when the plant is to be run continuously for days together.

13.1.5 Combustion Air for Firing Systems

- Air must be supplied for complete combustion—it should never be less than stoichoimetrically calculated amount for any type of fuel.
- Primary air is a must for a good degree of atomisation of liquid fuels.
- Secondary air is necessary for combustion and tertiary air for ensuring completion of combustion of any remaining oil droplets/fuel particles and for protecting furnace refractory lining.
- Preheated air is useful for complete combustion (minimising loss of unburnt oil).
- The air blowers must supply the necessary air.
- Positive displacement type blowers will be found useful (*if available in the required capacity at a reasonable cost*) for atomisation and for supplying required air in spite of high-pressure drop in downstream units.
- *Induced draught fans:* For sucking out the flue gases and discharging through a tall chimney. These fans should be fabricated from corrosion- and erosion-resistant MOC.

Important Considerations

- Effect of excess air: furnace temperature drops/flame can get extinguished due to blast of excess air if dampers in air line are opened too much.
- Deficient (less than stoichiometric) amount of air can cause explosive mixture inside furnace or deposits of unburnt fuel particles on downstream catalysts, heat exchanger tubes, etc.

Safety Devices to Be Supplied by Vendor of Firing System

- Electrical interlock of oil pump with air supply pressure at inlet of furnace should be made. The oil pump must stop if air pressure is too low due to any reason.
- Gaseous fuel supply valve should also have a similar interlock with low air pressure.
- Provision of photoelectric flame monitor with warning alarms and tripping system for fuel supply if the flame is extinguished for any reason.
- Combustion chamber should have appropriate refractory lining (insulating and refractory materials), safety vents, thermocouples for temperature monitoring, external insulation and a shed for protection against rain.

13.1.6 Factors to be Considered for Selection of Fuel

- Landed cost per unit of fuel at plant site.
- Physical form of fuel: solid, liquid or gas.
- Density of fuel kg/L for solid and liquids and kg/Nm^3 for gas.
- Net calorific value: heat available after complete combustion of the fuel per unit cost (local currency). This will depend on the efficiency of combustion system being considered.

Practical Considerations of Fuel Handling Facilities

- Inventory of fuel to be maintained at site (depends on rate of consumption and time required for arrival of fresh supplies).
- Provision of firefighting arrangements and safety enclosures, earth connections, lightning arresters and dyke walls around storage tanks.
- Ease of handling to receive and unload fresh supplies and use them as per need.
- Flash point.
- Autoignition point.
- Various liquid fuels: superior kerosene oil (SKO), kerosene, high speed diesel, naphtha, LDO, furnace oil, reclaimed oil (should meet statutory regulation).
- Some of these oils may need heaters for reducing their viscosity in order to pump them in extremely cold weather.
- Moisture and ash percentage in case of solid fuels like coal, coke.
- Ash percentage, and sulphur compounds percentage in case of liquid and gaseous fuels, can cause problems in downstream equipment due to deposits of ash.
- Possibility of air pollution due to SO_2 in stack gases and corrosion of gas ducts and induced draught fans since moisture is also present due to burning of hydrocarbons.
- Enclosure, lightning arrestors, individual earth connections for each storage tank and firefighting equipment are important safety considerations.
- Also, vehicle parking should not be permitted in the vicinity of fuel storage tanks.

13.1.7 Thermic Fluid System

Process heating can be done by hot flue gases produced by oil/coal firing, by electrical means, by high-pressure steam, etc.

Various Options as Below Should Be Closely Looked into

Electrical heating is easy to operate, has fine temperature control and is clean (no messy handling of oil, coal, etc.) but is very costly. *There is possibility of fire due to short circuit or malfunctioning of thermostat. This should always be considered if there are inflammable materials nearby.*

Heating by flue gases can achieve high temperatures. However, the heat transfer coefficients on gas side are low and can get affected by deposits of soot, ash, etc. A larger heat transfer area therefore becomes necessary. This mode of heating can achieve high temperatures due to direct use of flue gases but is not suitable for inflammable liquids/areas handling explosive dust, etc.

Heating by hot process gases is an attractive energy-saving option. This needs careful study of the process operating conditions for the heating and cooling loads, temperature profiles required (and available), etc. It may not be always possible to use this option, however. Also, nonavailability or inadequate availability of either hot gases or process fluid to be heated can affect operating conditions on both sides. (28 % oleum is boiled by hot gases in sulphuric acid plants to generate vapours of SO_3 in a gas-heated oleum boiler)

High-pressure steam as a heating medium is one of the most common options due to the high heat transfer coefficient of condensing steam and the large amount of heat (around 500 kcal/kg, depending on the pressure) available per kilogram of steam condensed, while also being pollution free.

When the heating is to be done for achieving 150 ºC and higher temperatures, the pressure of steam to be employed is more than 10 kg/cm^2. This needs thick-walled vessels, jackets, coils, pipelines, besides requiring approval of statutory authorities. *Superheated steam is better used for power generation rather than heating.*

Heat transfer oils (having high boiling points and thermal stability at higher temperatures) have been developed precisely for such situations. The oil is heated by the burning of furnace oil, LDO, etc. and is circulated through the jackets or heating coils of the process vessels to be heated. It is then led to a feed tank for recirculation by the pump. The fuel burner is used to heat the oil at the discharge side of the circulation pump. In this case, the process vessel and jacket are not operated at high pressure as in the case of HP steam.

Caution: Since the system works on circulating high-temperature oil, it *does* present a fire hazard and hence all relevant precautions must be taken; for example, motors, electrical fittings, lighting must be flameproof. Besides, the pipelines, valves, gaskets, shaft seals, etc. must be suitable for high temperature and pressure and should be tested and certified.

Selection Criteria/Information Necessary for Procurement

- Total heat load (Kcals/h).
- Whether process heating is required to be done batchwise or in a continuous manner.
- Time for which the heating is to be done.
- Temperature to be achieved in the process vessel. It may be noted that the thermic fluid will have to be at a temperature at least 20–30 ºC above the required temperature for maintaining a reasonable driving force for the transfer of heat. (The heat transfer coefficient is lower than in the case of condensing steam since the heat is transferred from the liquid oil only.) Vapour pressures of thermic oils are on the higher side beyond 200 ºC and this must be looked into carefully while heating the oil.
- Space available for installation:

The Important Components

The important components of this system are:

- Sufficient space should be available for installation of the fuel oil tank, fuel oil pump and burner, firing chamber, air blower, chimney for exhaust flue gases, hot oil circulation tank, pump, expansion tank, connecting pipelines and valves, control panel, etc. and around them for ease of maintenance.
- Capacity of the items (fuel oil tank, air blower, oil circulation pump, expansion tank, etc.) must be carefully calculated. Total volume of circulating oil required depends on volume of process vessel jackets, connecting pipelines, etc. The hot

oil expands considerably on heating (7–9 %) and this will have to be taken into account by the vendor. However, the volume of the expansion tank should be checked by the purchaser also. Suitable collection tank for overflow as well as vapour vents should be available for the expansion tank. The vendor should confirm the quality of the heat transfer oil (a sample may be independently tested by the purchaser also) regarding thermal stability; that is, there should be no formation of thick sludge-like deposits at the maximum operating temperature.

Purchaser should be very clear about the maximum operating temperature permitted by the vendor.

Parameters to Be Monitored and Controlled

i. Flame stability (through photo cell) if liquid fuel is used for heating the thermic fluid.
ii. Temperatures of hot thermic oil at the circulating pump discharge.
iii. Temperature of the hot oil at inlet and outlet of the process vessel.
iv. Pressure of the oil.
v. Level in expansion tank.
vi. Air blower discharge pressure, etc.

- Fuel to be used: LDO, furnace oil, high speed diesel (is costly). Fuels like coal, rice husk may be considered since they are cheaper, but temperature control is not easy.
- Safety devices incorporated (by the vendor): Flameproof motors and other essential electrical items (should also be flameproof), vent for expansion tank, guard for level indicators, mechanical seal for the oil circulation pump, high-temperature cut-out for stopping oil firing in case of high thermic fluid temperature, furnace oil supply cut-out if the burner flame gets extinguished or air supply gets disturbed (due to blower tripping, closing of valve in air lines, etc.).
- Refractory lining provided for heating chamber: type of lining, thickness of lining, alumina percentage of bricks used (should not be less than 45 %).
- External thickness of pad-type insulation on the hot oil piping, valves.
- MOC, wall thickness and diameter of coils/pipe used for thermic fluid. Only seamless pipes with tested quality for high-temperature and high-pressure service should be used. Test certificate for the pipes must be available.
- Whether the unit is available as a "skid-mounted unit" or the assembly is to be done on site.
- Instrumentation and control for thermic fluid temperature, air blower pressure, firing temperature of heating unit, flame stability, etc. must be included in the scope of supply of the vendor. Audiovisual alarms (hooter/siren/warning lamps) should be provided for drawing the operator's attention.
- Exclusions from supply of the vendor should be clearly known.
- Purchaser's obligation should be clearly discussed with the vendor and the impact on the total cost of the system should be compared with other options.

13.1.8 Air Drying Plant

Various types of air drying plant are available: (i) Electrically heated, (ii) Refrigerated-type, (iii) Using the heat of compression. While the first two consume electricity for regenerating the dryer, the third type uses a part of the compressed hot air.

13.1.9 Procurement

Considerations for procurement are:

- Volume of dry air required for process/instrumentation in NM^3/h.
- Dew point temperature/relative humidity value required in dry air (this is sometimes specified as −40 ºC for dry air to be used for instrumentation purpose). However, this should be confirmed from instrument vendor/engineer because −20 ºC dew point may be adequate for many instruments. A dry bulb temperature of – 40 ºC may not be required unless specifically insisted upon by the instrument manufacturer.
- Pressure at which dry air is required in kg/cm^2.
- Details of following units, which should be generally included in scope of supply by the vendor:
  - Air compressor and air filter, oil separator, active carbon filter.
  - Air cooler, or electric heater, solenoid valves, nonreturn valves, etc.
  - Air receiver (this should be a certified pressure vessel with a safety valve and a rupture disc. It should be inspected and permitted for use by the local factory inspector).
  - Automatic on/off switch for the air compressor as per pressure in the air receiver.
- Instrumentation provided: pressure and temperature gauges, RTD, electrical controls for heaters, high-temperature cut-outs.
- The refrigerated type is for higher volumes of dry air required. It cools the incoming air and removes the moisture by condensation. The vendor shuold indicate the maximum volume of moist air that can be handled by the unit and pressure drop on the air side.
- Refrigeration load TR.
- Cooling medium employed (chilled water or chilled brine): temperature and flow rate of the cooling medium required and details of moisture removal arrangement details.

13.2 PSA Nitrogen Plant

Nitrogen is a very inert and nontoxic gas easily available from atmospheric air.

It is used for the following purposes:

- Purging of process vessels to remove inflammable toxic vapours *before entry for internal cleaning/inspection or for taking up maintenance job*
- Blanketing of inflammable liquids
- Reduction of the chances of explosions of combustible dust
- Preservation of packed food, pharmaceuticals
- Protection of valuable chemicals from contamination

The buyer should decide the following and obtain quotations accordingly:

- Purpose for which nitrogen gas is required: blanketing of inflammable liquids
- Preservation of food stuff, purging of process vessels before welding or entering inside preservation of sensitive pharmaceutical chemicals, etc.
- Pressure at which it is required
- Whether required in cylinders or as a continuous flow for process use

Since obtaining nitrogen in highly pressurised cylinders from outside is cumbersome and costly, while handling liquid nitrogen could be dangerous, it can be made available by generating at site itself.

The two main processes used for on-site generation are:

1. Pressure swing adsorption and
2. Membrane separation.

These are convenient, safe and can supply nitrogen at much less cost.

Atmospheric air is filtered, compressed and cooled to remove dust, oil and moisture. The dry compressed air at 7–8 kg/cm^2 is sent to an air receiver. It is then passed through two PSA towers, which operate alternately. They have activated alumina bed (to remove moisture and CO_2) and carbon molecular sieve bed that adsorbs the oxygen gas at higher pressure. Nitrogen comes out as product and is sent to a surge tank.

If very pure nitrogen is required, the remaining oxygen is removed in de-oxo towers wherein hydrogen is injected. It combines in presence of palladium catalyst, producing water vapours. The gas is cooled and dried to remove water.

For very pure nitrogen gas (if hydrogen is not acceptable) twin tower de-oxo units with copper catalyst are used alternately where in copper combines with Oxygen to produce copper oxide (CuO).

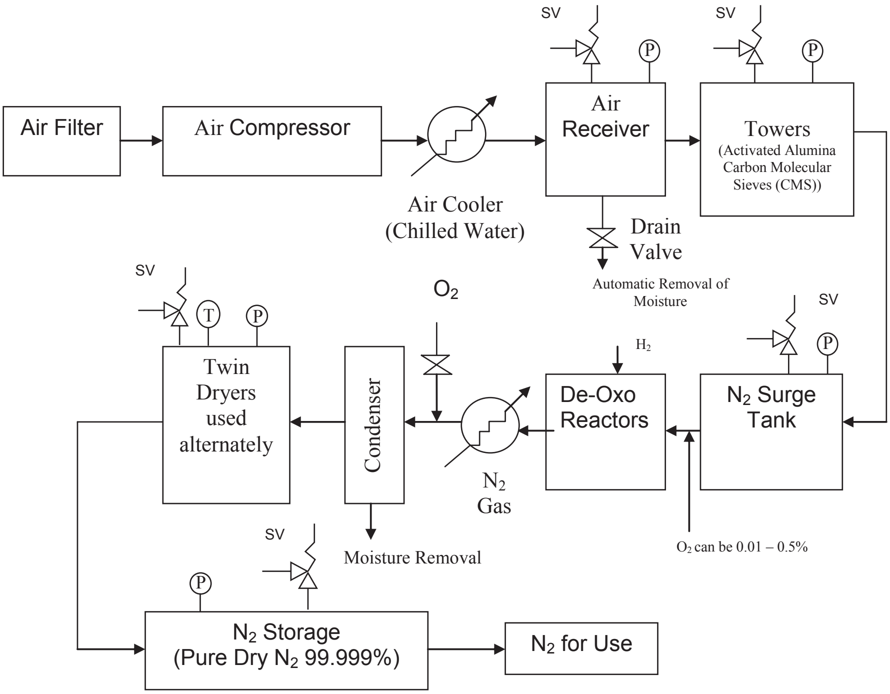
Exit gas is cooled and stored in a receiver vessel. Pure nitrogen is obtained as a product.

The copper catalyst is regenerated by reacting CuO with hydrogen. The gas is purged out during this operation.

System Components of a Nitrogen Plant Are (*Which Should Be Checked During Procurement*)

- Air compressor with filter at suction
- Refrigerated air cooler (chilled water will be required at 8–10 ºC)
- Air receiver with automatic moisture drain valve

- Pressure swing adsorption towers with activated alumina and carbon molecular sieve. These should be separate from each other and there should be separate manholes/nozzles for taking them out.
- Surge vessel for nitrogen gas (volume shuold be sufficient to take care of pressure fluctuations during pressurisation and de-pressurisation)
- De-oxo unit with palladium catalyst/copper catalyst (if hydrogen is not accepted)
- Hydrogen injection controller (hydrogen cylinders may be procured as per need)
- Gas cooler for exit gases (cold water will be required at 8–10ºC)
- Automatic moisture removal of condensed moisture
- Online oxygen analyser unit
- Pressure regulators
- Safety valves on all pressurised units
- Cooling water/chilled water supply
- Temperature and pressure gauges
- Automatic gas flow change over valves with adjustable timers for PSA and de-oxo towers



PSA Tower

– Carbon molecular sieve (CMS) can capture oxygen at higher pressure.
– Saturated CMS is regenerated by depressurization.

De-oxo Reactor

– Hydrogen is injected and it combines with the (remaining) oxygen in presence of palladium catalyst to produce water vapours. The reaction is exothermic and hence the exit gas is cooled and then condensate is removed.

Purity of product nitrogen can be:

O_2—up to 3 ppm
Hydrogen—0.5 %
Nitrogen—balance
Dew point ≥ −60 ºC

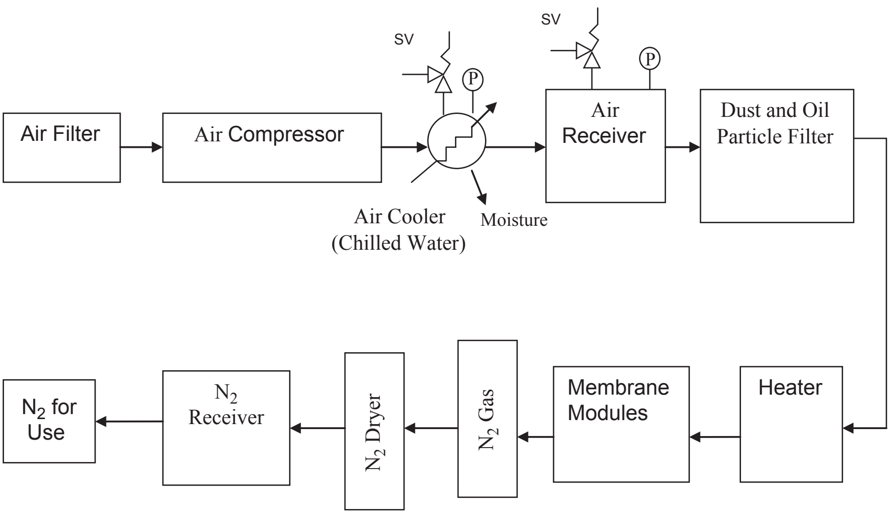
If hydrogen in the product exit gas is not acceptable, copper catalyst-based de-oxo units are used to remove the oxygen wherein oxygen combines with copper catalyst to produce CuO. The spent copper catalyst is regenerated by injecting hydrogen which reduces CuO to Cu and moisture is purged.

Purity of nitrogen gas produced:

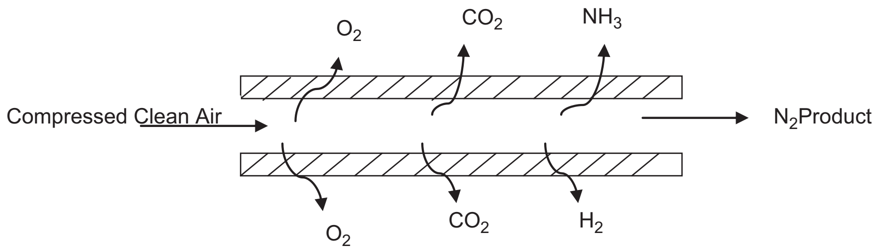
O_2—1 ppm
Hydrogen—nil
Nitrogen—balance (99.999 %)
Dew Point ≥− 60 ºC

13.3 Membrane Process for Nitrogen Gas

The membrane process for nitrogen gas depends on selective permeability rates of different gases through membranes, which are made from hollow polymeric fibres.



Gases like hydrogen, NH_3, CO_2, and oxygen are able to permeate through the membranes faster than nitrogen. Hence, these gases come out from sidewalls exit. A number of such hollow-fibre membrane modules are provided as per flow rate of nitrogen desired.



Purity of nitrogen coming out:

95.0–99.00 %
* Not suitable for critical application.
The purity required could be 95 % upwards.
PSA plant can generate nitrogen up to 99–99.999 % (for critical applications).
Membrane plant can generate nitrogen up to 95–99 %.
Oxygen and moisture analysers at exit of the process confirm product quality.

Steady power should be available at the site—if not, then an alternative arrangement for power supply may be required for a continuous flow of nitrogen gas to point of use. (Diesel generator set may be installed.)

13.3.1 Purchaser to Examine

- All pressure parts should be as designed and fabricated as per standard codes (ASME section VIII).
- Only tested/certified material of construction should be used for all pressure parts.
- Radiography should be done for all pressure parts, including all connecting piping between components and final discharge pipe (if nitrogen is to be taken out under pressure).
- Post-weld heat treatment should be done by fabricator for all welded parts and should be inspected by purchaser.
- Only tested/certified toughened sight glasses should be fitted on PSA towers.
- All units operating under pressure should be provided with separate certified safety valves; for example, air receiver, air dryer, PSA vessels, nitrogen receiver, etc.

- Air filter to remove dust should be provided at inlet of air compressor. The compressor should have automatic control as per pressure required downstream and filters for oil vapour and moisture should be fitted before PSA columns. It is better to have an oil-free compressor, which will ensure longer life for the carbon molecular sieves and improve performance of the plant.
- Gas coolers may be supplied with chilled water/brine for better removal of moisture, oil, etc., since presence of moisture can affect performance of the carbon molecular sieves.
- Gas purity analyser for product nitrogen gas.
- Carbon molecular sieves should be obtained from reputed sub-vendors and should be certified for selectivity foroxygen; CO_2; crushing strength; surface area in square or cubic metres of packed volume; density and tolerance for dust, oil vapour and moisture in the incoming compressed air.
- Supplier should guarantee how many times it can be regenerated and reused—before rejection.
- A higher than minimum required volume of CMS should be loaded in the PSA Towers provided it does not cause excessive pressure drop.
- The vent lines from PSA towers and safety valves should have release points above roof/away from working area

13.4 Electrical Transformers

- Present running load in each phase (if single phase loads are also present).
- Total installed load in each phase.
- Whether these loads are balanced.
- Future planned total and running load in each phase.
- Incoming supply voltage: normal/maximum.
- Outgoing voltage desired: at normal operating conditions.
- Maximum voltage/current/power KW available on secondary (L.T.) side in case of step down transformer (which is being purchased) at various output voltages.
- Maximum current permissible (on H.T. side) on primary side at various power outputs as above.
- Whether the output voltage can be varied "on load" or the unit will have to be switched off (off-load type) before changing taps. (In case of heavy electrical loads, any frequent switching on/off causes voltage fluctuations on supply side, which may not be permitted by the local electrical authority.)
- Whether any adjustment is desired for increasing or decreasing the output voltage.
- Installation: outdoor/indoor.
- Maximum temperature rise permitted above ambient temperature in summer at the location where the transformer will be installed.and whether temperature indicator is provided with alarm for high oil temperature.
- Cooling arrangement: natural/fan cooled/oil cooled.
- Quantity of oil filled in.

- Dielectric strength of oil/chemical composition and moisture content (test certificate for oil should be obtained from a standard laboratory).
- Breather provided and drying agent (indicating the type of silica gel) filled in.
- Junction box (incoming) leads/contact: rated capacity for maximum current/voltage.
- Outgoing (cable) connection junction box/contacts: rated capacity for maximum current/voltage.
- Transformer winding, hysteresis losses as percentage of output power at normal and maximum rating.
- MOC of primary and secondary windings.
- MOC of magnetic laminates.
- MOC of gasket for oil enclosure (to prevent escape of oil vapours, which can lead to fires or explosions).
- Insulation tests—resistance between windings and shell of the unit.
- Area of cross-section of winding wires.
- Total space required all around.
- Volume/dimensions of oil drain pit required.
- Total weight after oil has been filled in.
- Lifting hooks required for lifting the unit as a whole and for internal windings.
- Rating of insulations provided at high-temperature points for the whole unit as such.
- Any instructions from electrical inspector/SEB for installing the new transformer (especially when capacity is being increased).
- Earth connections and separate earth pits should be provided to the transformer body and incoming neutral.

13.5 Electrical Power Distribution in the Plant

- To examine total electrical load installed and actually running.
- Total future electrical load to be installed and to be run.
- Classification of load:
  - Inductive (e.g., electrical motors) or resistive (e.g., furnaces)
  - Single phase or three phase.
- Total load on each phase
- Any DC load:
  - High-torque motors—for heavy loads with high inertia.
  - Electrolytic load—for deciding ratings of rectifiers.
- Operating timing of all electrical loads. (High-power consumption items may be shifted to the timings when tariff could be less in certain countries.)
- Cable routes
  - To avoid areas handling inflammable/corrosive materials.
  - Should withstand heavy currents during switching on/off of big motors (since they can take up heavy current at start if VFD or soft starters are not provided).
- Capacitor banks:

  - Incoming voltage.
  - Electrical load.
  - Power factor must be greater than 0.99 for efficient use of power.
- Bus bars: Copper bus bars preferred, but may not be used in corrosive sulphurous gases atmosphere.
- Maximum demand: To be carefully worked out and, about 20 % margin added and then sanction obtained. Otherwise heavy fines are imposed by state electricity authorities/power supply grid authorities if the MD exceeds the sanctioned figure.
- Starters, push button stations, flame proof fittings, motors, earth connections, etc.: as per good engineering practice and approval to be obtained from electrical inspector.
- Lighting:
  - Important operational areas, valves, level indicators, pressure/temperature gauges, etc. to be provided with good lighting.
  - Areas having inflammable vapours etc. should have flameproof lighting.
  - High-power lamps to be provided at a safe distance in such areas only after statutory approval is obtained.
  - Automatic switching on/off to be arranged by incorporating photocell(s) in the lighting circuit.
  - Alternate lights to be provided with alternate feeders so that in case of failure of a feeder, the area will not be in total darkness.
  - Fluorescent paint for easy visibility in night.
- Separate energy meters to be provided for
  - Process units like reactors, mixers, circulation pumps.
  - Auxiliaries.
  - Utilities.
  - Lighting. (Important areas must have emergency lighting fixtures, which must also be procured in sufficient numbers. Important valves, instruments, control panels should have sufficient shadowless light.)
  - Offices and rest rooms.
  - Maintenance shop, store room.
  - Effluent treatment plant (as per law in some countries).

If incoming supply is at 11 kV/33 kV etc. instead of 440 V, then a suitable transformer, oil circuit breaker (OCB), main panel, etc. will be required.

13.6 Electrical Motors

These are the most important drivers for all equipments and machineries and need to be procured by consideration of the following criteria:

- List of all equipments/machineries which need a drive.

- Actual load conditions at present.
- Expected load condition in future. (A motor with higher HP may be required.)
- Need for any high starting torque motor (e.g., stirred tank reactors where agitators need heavy starting power, loaded conveyer belt drives, hoists, etc.).

To Carefully Consider Areas in the Plant Where the Motors Would Be Installed

- Indoors/outdoors.
- In areas of high ambient temperature.
- Dusty areas.
- High humidity, vapours of chemical, etc.
- In the presence of inflammable or explosive materials.
- Whether coupled directly/through gearbox/through hydraulic coupling.
- If the equipment to be driven has high inertia provide VFD.
- Is speed control required? Will it be step-less type or a geared motor will be okay?
- Mounting: whether vertical or horizontal.
- Frame size: In the case of a replacement being procured for a damaged motor the frame size must be mentioned.
- Electrical specifications: HP, frequency, voltage, phases (single phase or three phase) (*supply frequency is not same in all countries-it is 50 Hz or 60 Hz and the speed RPM will depend on it).*
- Vendor to specify maximum allowable current and temperature rise above ambient temperature and the winding connections.
- Type of insulation (purchaser to specify the place of installation of the motor; e.g., in dusty conditions or outdoors or in places where inflammable/explosive vapours are likely to be present).
- MOC of cooling fan, shaft and coupling half.
- Type of bearings. (Purchasers should insist on heavy duty bearings and should ask for the make.)
- Junction box: this should be of sufficiently large size with leads from windings brought to the junction box and connected to properly sized contactors. Junction box cover and the cable inlet point should have suitable gland packing/gasket to prevent ingress of dust, gases and moisture.

13.7 Diesel Generator Set

Managements Should Carefully Consider the Installation of a Diesel Generators (s) in the Following Situations

- When the plant is a continuously operating one.
- If there is a possibility of development of unsafe conditions; for example, pressure rise in reactor or chances of runaway exothermic reactions taking place

due to cooling water/brine supply interruption due to power failure, When local power supply is erratic (frequent stoppages/low voltage, etc.).
- When it is urgently required to maintain production; to run a refrigeration facility; to maintain water level in boilers.
- To maintain lighting.
- If certain equipments may get jammed due to formation of some thick slurry or solidification of reaction mass in case of a power failure even for a short time.
- To prevent pollution by providing immediate power supply to essential units, scrubbers, etc.

Selection Criteria for DG Set

- Total load to be run on DG set
  - Process plant load
  - Emergency load
  - Utility services
  - Lighting requirements, etc.

The power rating of the DG set should be enough to provide power for all essential units continuously. *Decide the order of importance of various loads*.

- Voltage, amps, frequency, maximum kilowatts required.
- Net electrical energy available at generator terminals as kilowatt-hours per litres of fuel consumed (i.e., fuel efficiency).
  (i) Is it necessary to run the heavy machinery on full load, or can it be run on partial load?
  (ii) Are soft starters/Variable Frequency Drive (VFD) provided for such load? *If these are not provided, there could be sudden heavy load on the DG set and it can trip*.
- Engine speed RPM.
- Generator: Make, speed, maximum current and voltage, temperature rise above ambient.
- Gear Box: Input/output speeds, type of gears installed and lubrication system provided.
- Type of coupling: Is the entire assembly (engine—gear box—generator) available as a pre-aligned, skid-mounted unit?
- Engine cooling arrangement and whether water filter and softener are provided by manufacturer or not.
- Accessories which vendor should include in scope of supply for the DG Set: Engine speed/generator tachometer, engine temperature, fuel oil tank level, lubrication pump pressure, kilowatts, voltage, ammeter, kilowatt-hour meter, frequency meter, engine running time totaliser, start-up batteries and battery charger.
- Fuel oil tank and strainer.
- Exhaust gas manifold and silencer.

- Maximum current/starting load the DG set can take—to match with emergency loads planned by purchaser for his plant.
- Guarantees offered by the manufacturer. Whether any annual service contract is also possible?
- Noise level at full load operation should be less than 60 dB. Otherwise a separate acoustic enclosure as per statutory instructions will be required.
- Is automatic change over to DG set possible in case of power failure?
- Cost of electrical switchgear (isolation switches, connecting cables, metering panels, etc.) required for use of the DG set should also be considered.
- To estimate emergency and important loads–
  - (i) Is it necessary to run the heavy machinery on full load? Or can it be run on partial load?
  - (ii) Are soft starters/fluid couplings provided for such load.
  - (iii) Arrangement for automatic load sharing should be available when more than one DG Sets are provided at the plant premises. Initially only one set should start, and when more loads are being added, another set should start automatically when the load on first set reaches 70–80 % of its capacity.
- Total space required for installation for DG set and its accessories.
- Possibility of installing heat recovery steam generator/air heater from exhaust gases of large DG sets.
- Total cost of power generation to be calculated by taking into account the following:
  - (i) Cost of fuel and lubricants.
  - (ii) Operator's salary and other payments.
  - (iii) Interest paid on investment in DG set installation (DG set, accessories, separate shed, electrical switchgear, etc.)
  - (iv) Statutory levies, fees, etc.
  - (v) Annual maintenance costs.

One should compare the total cost of power generation by DG set with the cost of obtaining power from the state electricity board/external grid/other means.

13.8 Refrigeration Systems

These are required to operate the process plants at low temperatures, production of ice, crystallization at low temperatures (separation of crystals from concentrated solutions), condensation of volatile solvents etc.

13.8.1 Working of a Conventional Refrigeration Plant

A conventional refrigeration plant circulates cooled chilled water (at about 5–8 ºC) through process units and where it gets heated to about 10–12 ºC. It is then cooled again by the refrigeration plants by passing it through an evaporator (having refrigerant like freon, ammonia, etc).

The liquid refrigerant evaporates (by taking up heat from the circulating chilled water) and the vapour is then compressed by a compressor. It is now condensed by a condenser to a liquid and is collected in a liquid receiver from which it is fed *at a controlled rate* to the evaporator.

The sensible heat of the compressed incoming refrigerant vapours as well as the latent heat of condensation is ultimately removed by cooling water flowing through the condenser. A cooling tower is used to maintain the temperature of the cooling water for proper condensation.

These units consume considerable power, have many components operating at higher pressure and may need more maintenance.

13.8.2 Criteria for Selection/Procurement

- Temperature up to which process fluid is to be cooled (temperature of the cooling water/brine required at the inlet of the process equipment).
- Whether different process fluids are to be cooled at different temperatures.
- Cooling load in Kcals/Hr at different temperature conditions:
  (i) As per present requirement (purchaser to work out cooling loads for winter and summer separately).
  (ii) In future when the production capacity of the plant may be expanded (winter and summer loads).
- Total expected volume of chilled water/brine in circulation in the system is to be calculated for deciding volume of circulation tank.
- Is space available for a bigger capacity single refrigeration plant? It is advisable to install two units of lower capacity (say 100 TR each) when a total capacity of 150 TR is required, rather than one single unit of 150 TR. It will be found useful in case of any breakdowns since the process plant will still continue to get refrigeration—*though at a lower rate.*
- Power consumption per tonne of refrigeration loads, at specified operating conditions (of chilled water or brine whichever is used) of the inlet and outlet temperatures. *These figures should be very closely looked into.*
- Use the most efficient compressor and the details of the same should be looked into.
- Cooling water requirements for the unit: temperature and flow of cooling water required in m^3/hour.; when the refrigeration unit is running with a water cooled condenser for the working fluid (e.g., ammonia/freon)
- Whether certain banned fluorocarbons are being charged in the system. Since these refrigerants will be phased out in the next few years, the system should employ other gases.
- It may be noted that refrigeration systems operating on high-pressure ammonia are not advisable due to possibility of an accident.
- Compressor used should be oil-free type (otherwise an efficient oil separator is required).
- Capacity control facility to run the compressor at lower load if required.
- The compressor should be driven through a belt drive (if it is a positive displacement type compressor).

- Vendor may supply a screw compressor with inbuilt safety devices for tripping the motor in case of jamming/high discharge pressure for any reason.
- Instrumentation and safety devices provided: temperature gauges and cut-outs for chilled water/brine) at inlet and outlet of evaporator, for interruption in cooling water flow at inlet of condenser, for temperature of gas at inlet to condenser and in Receiver (for liquid refrigerant).
- Pressure gauges for compressor inlet and outlet, condenser inlet, liquid receiver inlet, evaporator inlet, lubrication oil pressure gauge
- Level gauge and level controller for flow of liquid refrigerants to evaporator.
- Provision to evacuate the unit by reversing suction/discharge sides.
- First charge of refrigerant and lubricant to be supplied by vendor.

13.9 Producing Chilled Water by Using Low Pressure Steam (Thermax System)

In this method water is used as a refrigerant instead of Ammonia, Freon etc. It is taken from a vessel (which is at a very high vacuum at which the water can boil at about 5–7 ºC.) and sprayed on coils through which the *chilled water to be cooled* is flowing. These coils are located inside the Refrigeration unit.

The water sprayed on the coils boils (under *vacuum in the unit*) due to heat taken from the circulating chilled water. The vapours produced by boiling/evaporation are absorbed in a strong solution of lithium bromide (LiBr) and thus the vacuum is maintained in the unit.

The LiBr solution gets diluted due to absorption of the water vapours. It is re-concentrated by heating in an evaporator (generator) by using low-pressure steam.

A heat exchanger preheats the dilute solution by exchanging heat with hot strong LiBr solution (which is reused for absorbing water vapours) which, in turn, is cooled before absorption of water vapours.

Water vapours produced during this concentration are sent to a condenser, which is supplied with cooling water from a cooling tower.

Latent heat of condensation as well as heat transferred (taken from) from chilled water is removed here.

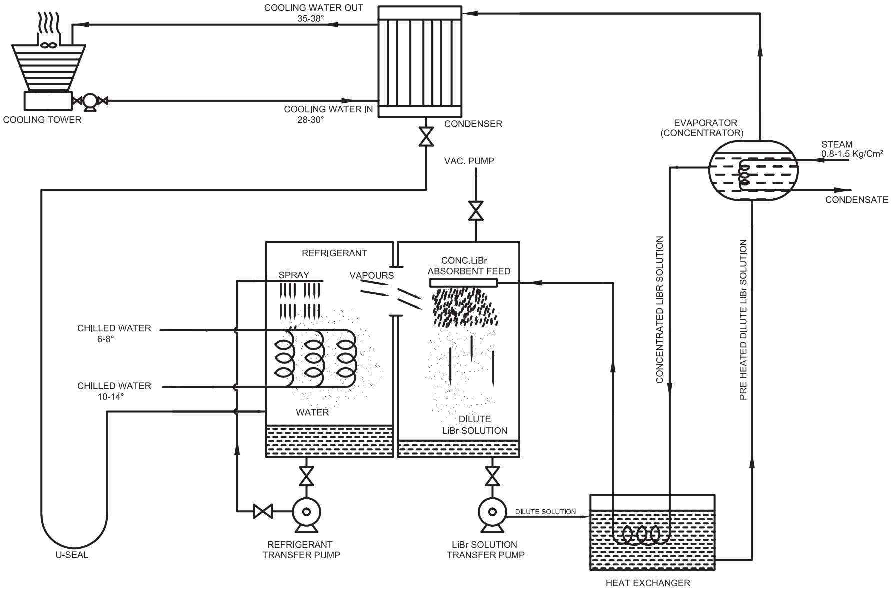
The condensed vapours are returned to the refrigerant storage vessel operating at very high vacuum.

The power consumption of such a unit is low as no compression of refrigerant vapours is required.

13.9.1 Main Components of the System Are

- Vessel for refrigerant water—operating under high vacuum
- Feed pump for refrigerant water
- Feed pump for dilute LiBr solution to evaporator (generator)
- First charge of LiBr

- Circulation pumps (one working + one stand by) for chilled water
- Circulation pumps (one working + one stand by) for cooling water
- Cooling tower
- Steam supply line with safety valve and pressure controller.
- Internal steam coil in the evaporator for concentrating dilute LiBr solution
- A vacuum pump/ejector for removing any ingress of air
- Vacuum gauges, temperature Indicators, RTD or dial thermometers for all fluid streams at inlet and exit
- Concentration monitors for LiBr solutions
- Ammeters for circulation pumps
- Steam pressure gauge
- Steam trap and arrangement to recover condensate



13.9.2 Selection of this Unit Is Based on Following Considerations

- Temperature of chilled water coming from exit of process plant (10–14 ºC generally)
- Temperature of chilled water to be maintained at inlet of process plant (6–8 ºCgenerally)
- The required cooling system will be thus used to cool the circulating chilled water from 10–14 to 6–8 ºC
- Total flow rate of chilled water coming from process plant i.e. refrigeration/cooling load on the chilled water system

- Pressure and quantity of waste steam available. (It could be from exhaust of steam turbines or from low-pressure heat recovery boilers)
- Total space required
- Space available in plant
- Capacity of cooling tower required to handle the refrigeration load (there is a slight increase due to addition of heat by the steam
- Vendor should perform the leak tests as per standard practice for all components which should operate under high vacuum—main vessel, evaporator and absorber (helium leak test may be asked for), etc.
- *Performance guarantee* terms for the unit should clearly specify the refrigeration effect for the flow rate and temperatures (both inlet and outlet) of the chilled water, steam consumption (at specified pressure as saturated condition), cooling water circulation rate and temperatures required from the cooling tower and power consumption per TR.
- All pumps, valves and piping handling should be resistant to the LiBr solutions (both dilute and concentrated at the operating temperatures). Mechanical seals/leak proof gland sealing for pumps should be used.
  - Use appropriate MOC for the tubes and add corrosion inhibitor to the LiBr solution
  - Purchaser should inform the analysis of cooling water available at site so that vendor will use proper materials for the condenser tubes etc. If the purchaser is desirous of using sea water the vendor must be informed accordingly.
  - External thermal insulation and cladding should be done after satisfactory result is observed for the leak tests. Vendor may be asked to repeat these tests after erection at site.

13.10 Another Method to Produce Chilled Water

It is also possible to produce chilled water by using strong NaOH solution (instead of LiBr solution) as absorbent. The water vapours from the evaporator are led to an absorber wherein a strong solution (about 42–46 %) is sprayed down. It absorbs the vapours and thus maintains a high vacuum. The water used as refrigerant can boil at about 6–8 ºC under this condition.

13.10.1 Another Method to Produce Chilled Water

Fresh make-up of water is added to the system to maintain level in the vessel.

Incoming chilled water at 10–14 ºC is passed through coils kept immersed in the vessel where refrigerant water is boiling at 6–8 ºC under high vacuum. Heat is taken from the chilled water and it is cooled to 7–8 ºC depending on the flow rate.

In another design, no coils are kept immersed in the vessel. Instead, the refrigerant water itself is taken out to other process plant and fresh make up is added.

A vacuum pump or a steam ejector is used to suck out any ingressed air or evolved gases.

A cooling tower serves to maintain the temperature of the circulating NaOH solution.

13.10.2 Selection Depends on Certain Specific Situations

- ***Where chilled water is required at about 6–8 ºC***
- ***Where dilute caustic soda solution is required in other nearby plants/in same premises.***

It may please be noted that NaOH solutions are not so corrosive as LiBr solutions; nor there are chances of choking of valves and pipelines. Since the refrigerant water is cooled and taken out from the system, no condensation is carried out. This can reduce load on cooling tower.

13.11 Cooling Towers

13.11.1 Selection Criteria

- Duty conditions: To cool…. m^3/hr of water from T_1 to T_2 ºC.
- Site Location: Geographic location data for minimum and max relative humidity, height above mean sea level and wet bulb temperature (design value) in different seasons of the year to be given by the purchaser. Maximum ambient temperature should also be informed.
- Location for installation in plant—on ground floor or on roof. The latter needs a strong roof, but can serve as a storage of cooled water for emergency use in process plant.
- Type of cooling tower draught required: natural/forced/induced (induced draught type is preferable).
- MOC of cooling tower preferred: wooden planks (treated wood only to be used/ fibreglass reinforced plastic).
- Fill and nozzles for spray: PVC fill is preferable. Spray nozzles should be able to wet the entire fill.
- Loss due to wind blowing across should be as less as possible (not more than 2.5 %)
- Power consumption of fan: To be specified by manufacture (fan with FRP blades and speed-reduction gearbox is preferred).
- Natural draught cooling towers do not need a fan, but their initial cost is high.
- Basin and support structure: If FRP basin and support structure are indicated, then these should be supplied by the manufacturer, along with ladder for climb-

ing up to the top-induced fan–gearbox–motor assembly. The fan and drive shaft should be provided with protective grille to prevent entry of foreign matter from top (branches of nearby trees, birds, etc.). RCC basins can be made on site and the vendor should supplycivil drawings for this in detail.

- Vibration monitor for fan–gearbox–motor assembly for larger cooling towers.
- Indication lamp for fan and a coloured ribbon to be tied at top. The ribbon flutters vertically when the fan is running.
- Thermostat for switching off/on the fan during low ambient temperature. This will reduce power consumption.
- A blow-down valve should be provided for draining the basin.
- Float-operated valve for makeup water to maintain the water level in the basin. Only treated water should be used to minimise fouling of heat transfer surfaces in equipment like condensers, cooling coils, and jackets. Suitable chemical treatment should be done to prevent growth of moss, algae in the water.
- Certain manufacturers provide rotating arms for distribution of warm water (coming from process equipments) over the fill. However, this needs the water at a certain pressure in order to rotate the arm and hence increases power consumption.
- Cooled water outlet nozzles: To be connected to water circulation pump for supply to process plant.

14 Effluent Treatment Plants

14.1 Thickeners

Thickeners are generally used for water treatment, effluent treatment, clarifying process liquors before evaporation by settling of sludge, etc.

14.1.1 Selection/Discussions with Vendor for the Following

- Incoming effluent/feed liquor
  - Flow rate as m^3/hpH
  - Temperature in °C
  - Density
  - Concentration of suspended solids
  - Settling rate of the suspended solids

A Sample of feed liquor may be given to vendor for designing the unit. Purchaser may indicate a preferred flocculating agent.

- Total dissolved solids in the feed liquor
- Feed liquor: residence time should be as per standard design value norms if the settling rate is known
- Feed liquor: actual residence time (as per construction of the unit)

In case of difference, vendor may be asked to explain the reasons for the same.

- MOC of wetted parts (AR bricks/stainless steel lining.)

K. Golwalkar, *Process Equipment Procurement in the Chemical and Related Industries,* DOI 10.1007/978-3-319-12078-2_14

14.1.2 Rake Mechanism Details

Vendor should be asked to give the following details:

- RPM of rake
- Gear box input and output speeds
- Motor HP and RPM
- Arrangement to lift up the rake in case of jamming by settled sludge.

Vendor should furnish above details for purchaser's approval.

14.1.3 Unit Geometry

- Diameter and depth of feed (incoming) well—should not disturb the settled sludge
- Outer and inner diameters of the unit
- Diameter of launder
- Weir height of launder
- Vertical height of cylindrical and conical portions
- Diameter of conical opening (at the bottom)

14.1.4 Outlet Liquor

- Clarity desired for the outgoing liquid
- Percentage efficiency for removal of suspended particles desired
- Maximum suspended particles allowed (PPM)
- Location and orientation of the outlet nozzle.
- Height of weirs should be adjustable in case of setting down of the thickener (there may be chance of a slight tilting after some months due to the weight of a large amount of liquor).

14.1.5 Civil Foundation

- Weight of the thickener (when empty)
- Weight of the thickener (when full)
- Soil data (load-bearing capacity MT/m^2 area): to be given by the purchaser for the site where the unit will be located (see above).

14.1.6 Removal of Sludge

- Quantity of sludge expected per day/per hour
- Holding capacity of bottom sludge chamber
- Sludge removal pump capacity, MOC and type provided
- Drain valve. Purchaser may ask for non-choking (Y-Type) valve to be provided by the vendor
- Whether hard grit/stones would be expected in the sludge?
- Select sludge removal pump with open impeller if necessary. Recycle (by-pass) line at sludge pump discharge to be provided in such a case.
- A large tank for storing the waste waters/raw water is required, if the existing thickener is to be cleaned or maintenance job is to be done as follows:
  - Major repair or replacement of rake mechanism
  - Internal cleaning of sludge
  - Repair to brick lining etc.
  - This can increase the capital investment required, if thickener is selected for the plant. It can, however, be used for storing water or process liquor (dilute alum solution in an alum plant). It may be possible to use the two tanks alternately, but this would increase the capital cost futher.

14.1.7 Estimation of Sludge Level Build-Up

A simple device as described below may be kept available.

A 10-mm diameter steel rod can be welded at right angle to a flat steel disc (about 500 mm diameter and 3 mm thick) at one end and can be slowly lowered vertically inside till it rests on the thick sludge accumulated at the bottom. A graduated scale should be attached to the rod with the bottom tip reading zero.

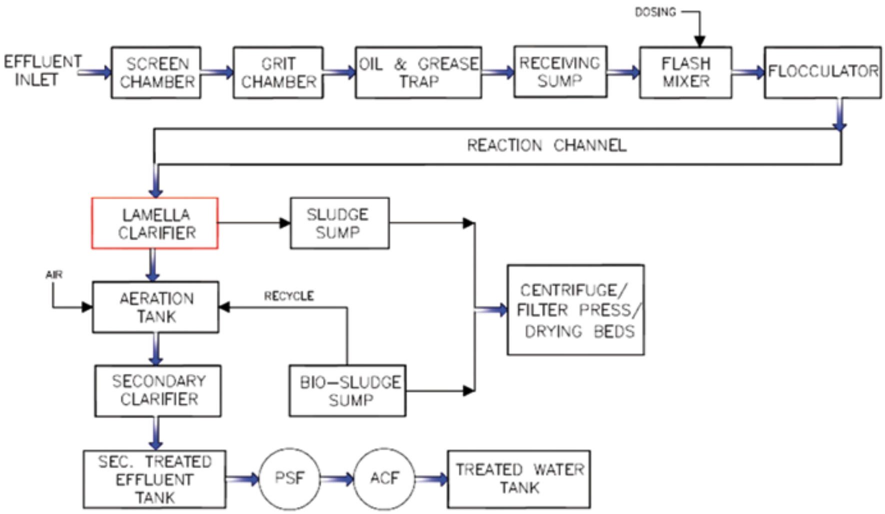
The depth to which the steel plate has gone in should be measured.

Then, measure the total depth of water by putting in another rod with a sharp end at the same spot till it touches the bottom. Then, the level of sludge should be estimated by calculating the difference.

Such readings should be taken at five or six places for confirmation.

Alternatively, the hydraulic pressure at the bottom may be measured by an instrument and subtract from it the pressure due to water column for estimating liquid and sludge levels. If a transducer is used, *Choked connecting nozzles in the instrument can give erroneous readings.*

Wrong estimates of sludge level can lead either to excess draining out of clear liquid from the bottom or some particulates/floc flowing in to the treated water from the overflow launder



14.2 Lamella Clarifier

14.2.1 Selection Criteria for Lamella Clarifiers

- Flow rate, pH, temperature, and free acidity of incoming waste water
- Concentration of suspended solids in waste water
- Particle size distribution ranges—consider the size range in which most of the particles are found
- Average particle size of the suspended solids: this will decide the plate spacing
- Chemical pretreatment of water by flocculating agents can increase the size of particles and assist the settling. The dose of such chemicals will have to be determined by taking trials on samples of waste water
- Desired pH of treated water (add alkali, if pH indicates acidity)
- Maximum permissible levels of suspended solids in outgoing treated water
- Space available in plant for installation
- Inclination of plates should be in the range of 55–60°, while the horizontal is usually suggested for self-cleaning of the plates
- Velocity of water through the plates: should be limited to the range of 0.04–0.05 m/min to ensure laminar flow conditions
- Material of construction of inclined plates: FRP/HDPE/UPVC plates are recommended. Stainless steel plates are not recommended because of their cost and weight, which makes them difficult to support and clean. Also, wastewater may contain chlorinated compounds or free chlorine which makes stainless steel plates incompatible for use
- Plate thickness: minimum 5 mm of plate thickness is suggested

- Spacing between adjacent plates: commonly used spacing between adjacent plates is 50 mm. However, the spacing may be increased up to 80 mm provided particles > 50 μm were removed in earlier treatment stages.
- Plate length: plate lengths are usually in the range of 1.5–2 m. The length of the plates should be chosen such that 120–130 mm of the plate length is above the water level. The plate length should also be sufficient for about 1–1.5 m of sludge zone at the base of the plate. Choose the basin depth accordingly
- Feed point: the feed point should be slightly above the base of the plates, so as not to disturb the settling zone at the bottom of the plate.
- Flow of incoming waste water should be uniformly distributed at the lower side of the plates for efficient working
- Sludge collection pocket should be provided at the bottom of the Lamella clarifier tank and the sludge level should be periodically monitored. One possible way of doing this would be to use a rod with a pointed end to reach the bottom of the tank and another one with a flat plate at its end which will rest on top of the sludge. The difference in the heights measured by the two rods will give a rough estimate of the height of the sludge in the tank.
- Level indicator for water
- Y-type drain valve for sludge removal
- Collection pit for collection of drained sludge.
- Sludge transfer pump for drying/disposal of sludge
- A drying bed may be required for the wet sludge

14.3 Tube Settler

In certain situations, difficulty is experienced in plate-type lamella clarifiers due to choking by algae/sticky sludge between the plates. It may become cumbersome to take out the plates, clean them and put back.

Tube settlers may be found as a more workable option for settling of sludge in such cases since the individual tube can be taken out, cleaned and put back.

The diameter of tubes can be chosen between 50 and 80 mm generally.

14.3.1 Shape and Inclination of Tubes

- Circular (close packing is difficult)
- Square tubes—close packing is possible and hence, can accommodate more number of tubes in a given cross section, but uniform flow pattern in a tube may be difficult.
- Hexagonal and octagonal tubes offer more internal surface area, can be packed closer, and flow pattern can be better than square tubes.
- Angle of inclination of tubes can be 60° as before

14.3.2 For Minimising Disturbance of Settled Sludge

- Tubes *should not be* installed in first (about) 30–40 % of the basin
- Velocity of liquid in basin should not exceed 0.9 m/min
- Velocity of rising liquid in tubes *should not* exceed 0.2 m/min
- The basin should have a V shaped bottom channel for better settling of the sludge.

14.3.3 Other Features

- MOC of Tubes: HDPE, UPVC pipes can be used. Stainless steel pipes are costly and should not be used when chlorinated compounds or dilute acids may be present in the waste water.
- Feed point: Feed should be introduced at least 200–300 mm above the bottom of the tubes to prevent disturbance of the settled sludge.
- A feed distributor should be available at bottom to uniformly feed all tubes from the bottom.

14.4 Dissolved Air Flotation

These systems are generally used for removal of suspended fine particles from raw water or effluents stream.

14.4.1 Working principle

Air is compressed and dissolved into water. The solubility of air is more under pressure. Water with dissolved air is mixed with the incoming waste stream and pressure is released.

The dissolved air comes out of solution, producing thousands of microscopic bubbles (similar to the froth from bottles of aerated drinks when the cork is opened).

These air bubbles attach to the suspended solids and increase their buoyancy making them float to the surface. A mechanical skimmer at the surface removes these solids. The incoming water is thus cleaned and discharged from the system.

An adjustable weir can facilitate efficient removal of floating particles/solids.

A small fraction of the clean treated effluent is recycled and again saturated with air, mixed with the wastewater influent and injected into the dissolved air floatation (DAF) separation chamber.

14.4.2 Main Components of the System

- Incoming waste water receiving tank, and chemical solution feeding tank
- Mixing (pre-treatment) tank for chemical dosing (optional)

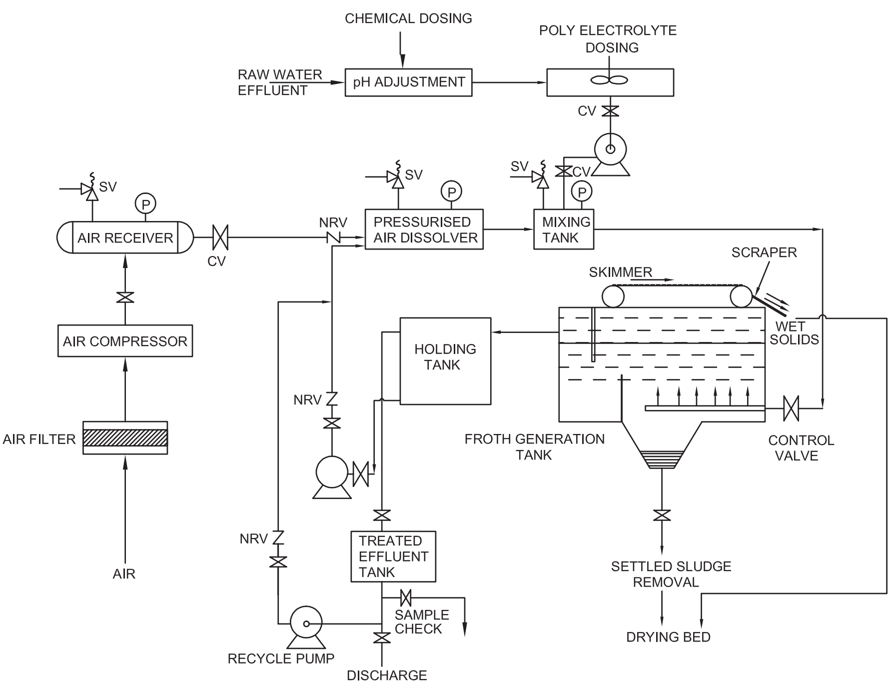
- Main froth producing tank (separation chamber) with mechanical skimmer
- Treated water/effluent discharge tank
- (*Option 1*) Pressurised air saturation tanks are provided (can work alternately—one being fed with pressurised air and other from which the water with pressurised air is being released)
- Recirculation pump
- Air compressor
- Piping and control valves
- Instrumentation—flow meters for treated water and recycled water, level indicators for all tanks and separation chamber, dissolved oxygen meter for treated effluent (for special applications), temperature indicators, electrical panel for air compressor, recirculation pump, pressure gauges for compressed air and for discharge lines of recirculation pump, etc.

14.4.3 Considerations for Selection

- Inlet conditions—flow rate and analysis of inlet stream (raw water/raw effluent), concentration of suspended solids, particle size, pH and temperature of inlet stream
- Outlet conditions desired—flow rate of exit stream, concentration of suspended solids, particle size, pH, dissolved oxygen and temperature
- Whether the vendor is able to guarantee required performance (flow rate and analysis which should meet specified norms by statutory authorities) without chemical pre-treatment
- Vendor should submit a process flow diagram with facilities if pre-treatment is included in his scope of supply
- *Continuous DAF system* (*Option 2*)*:* the air saturation tank is generally not included since the compressed air is injected in the recycle stream of the treated effluent. In this case, the control valve settings are done on the basis of an almost constant characteristic of incoming effluent. This will need a sufficiently large equalisation tank and possibly, chemical pre-treatment by dosing of ferrous sulphate, aluminium sulphate, polyelectrolyte (these are generally added in small dose of a few ppm to a few hundred ppm only) etc. in appropriate quantities. The cost of this dosing should be taken in to consideration. Lab scale trials may be carried out to determine dosage of these chemicals
- Vendor should furnish test certificates for all pressure vessels or the necessary tests should be carried out by purchaser before acceptance
- Circulation pump capacity and discharge pressure, and motor with appropriate rating should be checked
- Design basis for air required (kilograms of air per thousand litres of treated effluent going out)
- Equalisation tank at inlet of system should have a volume for 24 h hold-up at rated flow. Two tanks with 16–18 h hold-up capacity may be considered to reduce frequent changes in settings of control valve in recycle line and air pressure (*vendor to clarify this)*

- Linear velocity of flowing liquid at skimming section (this will depend on the cross section, i.e. width and depth of the main processing tank)
- Control valves and bypass valve in the recirculation line should be remote operated with provision for manual operation also
- Adjustable weir position for treated water outlet
- Skimmers for floating suspended particle: the depth of immersion in water should be adjustable
- Position of recycled water injection pipe should be adjustable if possible.
- Air compressor capacity and maximum discharge pressure should be sufficient to meet the requirement of dissolved air.
- All vessels, valve, pipes operating under pressure should meet statutory requirements. They should be provided with standard safety relief valves
- Position of compressed air injection point in to the recycled water (in the piping itself or in the air saturation tank through control valve operation)
- Power required KWH/m^3 of *treated stream* going out (should not include the volume which is recycled back in to the unit)
- Painting/coating by corrosion resistant paint for all vessels
- Instrumentation—flow meters and totalisers for the incoming, outgoing and recycle streams
- Temperature indicators for incoming and outgoing streams
- Level indicators for all tanks

Option 1



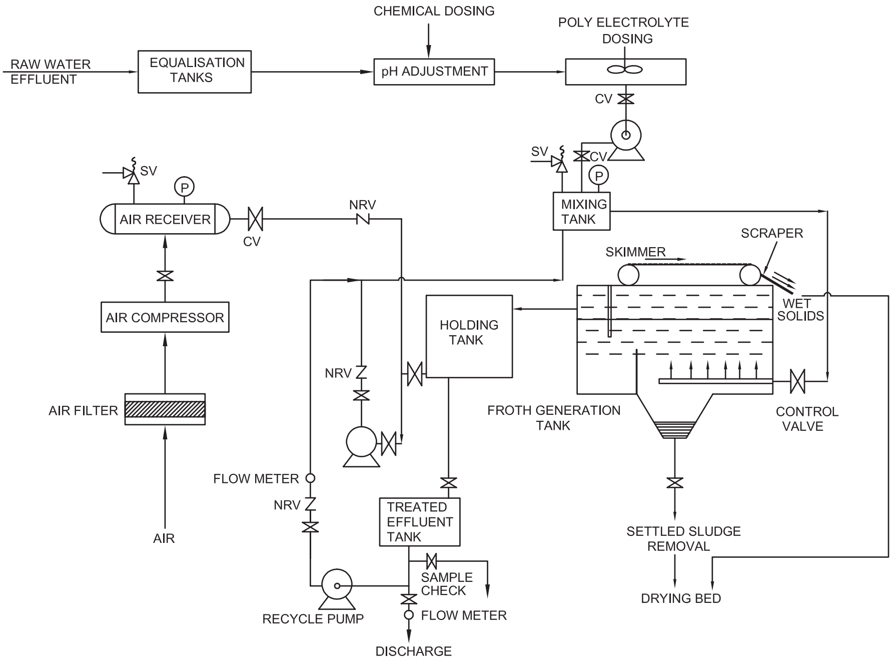
14.4.4 Disposal of Skimmed Out Material

This contains about 4–10% solids which are to be dewatered before disposal to reduce the sludge volume. This dewatering can be done by one of the following units/methods:

- Filter press
- Belt filter press
- Centrifuge
- Drying bed

Vendor may be asked to offer the most suitable equipment from the first three. Purchaser should consider disposal of the dried sludge in land fills or sale to other party, if possible.

Option 2



14.5 Sequential Batch Reactor Technology for Wastewater Treatment

All phases of the treatment process are done sequentially within the same tank.

14.5.1 Items Required Generally

These should be discussed with the vendor who have offered to install an SBR technology plant for the wastewater treatment

- A storage or equalization tank and a single SBR tank or a minimum of two tanks
- Screening and grit removal as preliminary treatment
- Primary sedimentation stage when the influent contains excessive suspended solids
- Reactor basin (hydraulic volume and depth)—see below
- Waste sludge draw-off mechanism (by special sludge handling pumps or actuated valves)
- Aeration equipment
- Effluent decanter
- Process control system
- Sludge dewatering method offered for its disposal

14.5.2 Aeration Equipment and Air Blowers

Aeration equipment and air blowers offered by vendor to provide aeration air for biological degradation of the organic components in the wastewater.

- The diffuser or membranes should not get choked when air supply is stopped during settling and decantation/removal of treated water
- Power consumption should be discussed for oxygen addition per KWH consumed
- Fine bubble aeration equipment should be removable to facilitate maintenance of the diffusers
- Vendor should also provide a dissolved oxygen probe within the basin for fine-tuning of the aeration system and controlling the aeration intensity with a variable speed blower (and hence the dissolved oxygen concentration).
- *Blower operation: for a two tank system there may be need for continuous blower operation for the total system, with each tank being provided with an aeration grid capable of taking the total airflow.*
- *Air flow control should be sent to the correct tank by motorized valves by carefully watching the periods of settling and decantation (no air supply during these)*
- Treated effluent can be removed from the SBR tank after the settling period. Enough time must be allowed during the settle phase to enable the solids interface

to reach a low enough position in the tank to avoid re-entrainment during the effluent decanting
- Basin depth (should be generally not less than about 6 m)

The top and bottom water level should be designed accordingly by vendor and the volume treated per batch or "hydraulic" volume should be confirmed (this should not be less than 30% of the volume between the designed bottom water level and top water level).

Inflow to the tank is normally interrupted during decantation and hence partitions may be made in the tank to continue the process and mixed liquor suspended solids should not be washed out with the treated effluent. As a result, the total process cycle time can be reduced.

14.5.3 Effluent Removal Systems

The most important aspect of the decanter design is to ensure that effluent is withdrawn uniformly from the tank. Options to be looked into are given below. The choice mostly depends on quality of effluent required, efficiency of aeration, top water level in reaction tank, etc.

- Fixed decanters including submerged outlet pipes with automated siphon control valves
- Moving devices, including weir troughs, floating weirs and pipes connected to flexible couplings, tilting weirs, and floating submersible pumps.
- Guards should be available to prevent scum and other floating material going out and causing deterioration in effluent quality.

Vendor should inform sizes of tanks and the civil structures required, total electrical load and pipe work for aeration.

15 Protective Linings

In many chemical plants the process vessels (e.g. reactors, furnaces, absorbers, heat exchangers etc.) are subjected to high temperatures, corrosive conditions and hence they are provided with protective linings.

The linings serve the following purpose:

- Protection of metallic shells against chemical corrosion and extreme heat.
- Prevention of contamination of products due to contact with metallic surface.
- Conservation of heat in the equipment.
- Reduction of breakdowns/leakages due to corrosion.

15.1 Types of Linings

- For thermal protection
- For protection against chemical corrosion
- To prevent contamination of products

15.2 General Methods

The most important prerequisite is proper *surface treatment* of the equipment to be lined. This includes cleaning by wire brush, acid wash, grinding of the welding seams etc. without which the protective lining would not hold properly.

Sand blasting of the surface may be permitted if sufficient personal protective devices and ventilation by Forced Draught (FD) fans, dust removal Induced Draught (ID) fans are used. However, workers should not enter the vessel when this is being done.

- Adding the layer of lining material
- Bonding the layer of protective sheets to base metal by alloying

K. Golwalkar, *Process Equipment Procurement in the Chemical and Related Industries*, DOI 10.1007/978-3-319-12078-2_15

- Fixing the protective layer to the equipment and curing it by suitable means, e.g. by autoclaving, pressure rolling over, wet curing, dry curing, baking and/or slow heating etc

15.3 Materials Used for Lining

- Insulating and fire brick
- Castable refractory with appropriate anchors of stainless steel. The grain size should generally not exceed 3–4 mms and should be able to withstand required service temperatures (1200 °C at least.). Twisted fibres of stainless steel 316 (of 2 mm diameter and 25–50 mm length) can be mixed with the castable refractory to the extent of 2–3 % for strength
- Acid/alkali resistant tiles and bricks
- Cladding of surface by 2.0–4.0 mm thick 316–stainless steel sheets
- Lead bonding with base metal is preferred to simple lining
- Glass lining of 2.0–3.0–4.0 mm thickness as per specific need
- Fibreglass reinforced plastics
- Neoprene rubber sheets of 3.0–4.0–5.0 mm thick as per specific need
- PTFE (Teflon) sheets of 2.0–3.0–4.0 mm thick as per specific need

15.4 Selection Criteria for Lining Materials

Brick-lining of equipment is to be done generally at site since the lining can get disturbed during transportation even over a short distance.

Selection criteria include:

- Operating temperature inside the equipment
- Material being handled and their compositions, corrosion properties etc. (chemical composition, acidic/basic nature)
- Melting point of materials and tendency to form hard deposits on solidification
- Whether heat is evolved during reaction. How much? (High local temperature may be caused if reaction is highly exothermic and results in thermal shocks to the lining if proper mixing of reactants is not done)
- If reaction is highly endothermic, it is very difficult to supply heat from outside the equipment, hence internal heating by oil firing, electrical heating may have to be done. In this case, (and when conducting slag may be formed) it is necessary to provide impervious and non-conducting lining. Mica sheets/ceramic paper sheets soaked in potassium silicate may be placed between the shell and the lining
- Electrical resistance of the lining must be specified to prevent electrical short circuiting, wastage of power and damage to the equipment due to electrical sparking during operation
- Outside surface temperature of shell of the equipment should not exceed 50–55 °C after lining is done inside. This is to minimise heat loss to surroundings.

This can be done by providing a layer of insulating bricks as backup to fire bricks
- Erosive properties of the reaction mass: Concentration of suspended solids, high relative velocity between lining material and the reactants should be considered as the lining can get peeled off during operation exposing the unlined surface

Tip speed of rubber lined/FRP lined gas blowers must be informed to the party lining them, since the pollution control system can come to a halt if the blower lining fails. (*At high tip speeds the rubber lining can come off exposing the blower to corrosive gases*).

- Need for expansion joints

15.4.1 Test Certificates

Test certificates for refractory bricks, cements, castable lining material and their properties and compositions should be checked for following:

- Alumina percentage (higher the percentage of Al_2O_3 means it will be able to withstand higher temperature)
- Porosity (not more than 20–22 % for fire bricks; however, insulating bricks can be 60–65 % porous)
- Density of insulating brick based on this data will be found to be less than 1.0 gm/cc
- Weight of a standard sized brick, and its dimensions (should be as per specifications given by purchaser)
- Thermal conductivity Kcal/m°C/h, and coefficient of thermal expansion
- Refractoriness under load RUL) in kg/cm^2 at … t °C
- Cold crushing strength in kg/cm^2
- Pyrometric cone equivalent (PCE) values
- Iron content (higher iron percentage can lower the RUL)
- Resistance to acid/alkali (percentage of loss in weight in 24 h when exposed to operating conditions. This should not exceed 1.0–1.5 %)

15.4.2 Typical Specifications for Bricks

Acid-Resistant Bricks

- As per IS:4860-1968 Class-I or equivalent international standards.
- Chemical analysis should be done of the brick samples.
- The length, breadth and width/radius of curvature should not differ by more than 1.5–2.0 mm from each other amongst the lot of bricks.
- Surfaces should be smooth (without scratches) and edges should not be broken or damaged. *Salt glazed surfaces are preferred*.

- Water absorption should be maximum 2.0 %.
- Compressive strength should be 700 kg/cm^2 (minimum).
- Resistance to acid (sulphuric 98 %), that is, loss in weight should not exceed 1.5 % in 24 h when in contact with 98 % sulphuric acid at 100 °C.

Iinsulating Bricks

- IS:2042-1972 type-2 bricks or equivalent international standards
- Pyrometric cone equivalent: 27 (ASTM)
- Bulk density (maximum): 0.9 gm/cm^3
- The length, breadth and width/radius of curvature should not differ by more than 1.5–2.0 mm from each other amongst the lot of bricks
- Apparent porosity (minimum): 60 %
- Cold crushing strength not less than 15 kg/cm^2
- The brick should be able to withstand 1250 °C temperature on continuous duty
- Each brick should be individually packed in paper and waterproof plastic sheet since they are somewhat delicate

15.5 High Alumina Bricks

- IS:8-1983 type-2 or equivalent international standards
- Should not contain less than 45 % Al_2O_3 and Fe_2O_3 content should not exceed 0.3 %
- Pyrometric cone equivalent (ASTM):32
- Refractoriness under load (RUL): 1400 °C
- Apparent porosity not more than: 20–22 %
- The length, breadth and width/radius of curvature should not differ by more than 1.5–2.0 mm from each other amongst the lot of bricks
- Permanent linear change not more than 1.0 % at 1250 °C

15.6 Ceramic Paper

An alumino–silicate ceramic uses high purity washed fibres as a non-woven fabric. It is made by a special paper-making process.

Main characteristics:

- White colour
- Generally uniform structure
- It is flexible and hence can be easily handled
- Resists temperature as high as 1150–1200 °C
- Non-flammable
- Low thermal conductivity
- Low specific heat

- Good dielectric strength
- Excellent corrosion resistance (it is resistant to most chemicals except hydrofluoric, phosphoric acids and concentrated alkalis)

15.6.1 Properties

- Density: 160 kg/m^3
- Chemical composition: Al_2O_3: 46–48 %; total Al_2O_3 and $SiO_2 > 97$ %; Fe_2O_3: < 0.5 %
- Tensile s;trength:1.5 kg/cm^2
- Working temperature: 900 °C
- Maximum exposure temperature should not exceed: 1200 °C

15.6.2 Typical Applications

Used in many industries such as: steel and metallurgy, petroleum industry, furnaces, converters operating at high temperature in chemical plants, automotive industries, etc.

- It is used as a thermal insulation layer, as gasket material for cover plates on nozzles.
- Ceramic papers when used as expansion joints in refractory brick lining can reduce the stresses created when the bricks expand as the temperature in the vessel is increased.
- It is used as a separator gasket on both sides of a blind inserted in high temperature ducts.
- It is used for fire and spark protection.
- It is used for insulation in ducts carrying high temperature gases: it can reduce required thickness of castable refractory layer and hence the weight of ducts.
- It is used for high temperature filtration.

Sizes in which it is generally available:

Thickness: 0.8, 1.6, 3, 5, 6 mm etc.
Width: 600 and 1200 mm.

Procurement for use in plant: This material should be considered as an insulating lining layer to back up fire brick layers in furnaces, high temperature converters and for ducts carrying high temperature process gases. A test piece may be obtained from vendor and tested by the purchaser for the intended application in his own laboratory or by keeping inside the furnace/duct for a few days at operating conditions. The loss in weight, breaking in to smaller pieces etc. should be observed.

If test facilities are not available in-house then the tests can be done in authorised material testing labs and certificates can be obtained.

Hence, for procurement, the bricks of proper specifications should be ordered.

About 10 % extra quantity may be purchased to take care of losses during transit and actual lining—where some bricks have to be cut to suit nozzle openings of the equipment.

Manufacturer should be consulted for the best cement for laying the bricks and precautions will be while laying the bricks as well as curing procedures.

Standard rectangular shaped bricks are generally available from ready stock while curved bricks—to suit the particular curvature of the vessel to be lined—are to be tailor made. This requires making of special patterns of moulds, making raw bricks and then baking them. This can delay the procurement period and also increase costs. (Because special batches of curved bricks are to be baked/fired separately and the cost of heating and cooling the furnace is distributed over less number of bricks)

Hence, the possibility of using standard bricks in place of curved ones may be looked into when the diameter of the vessel is large enough, i.e. when the curvature is less. If the standard bricks could be tightly laid in place, the cost can be reduced. This, however, depends on the skill of the masons and whether any leakage past the lining can harm the process vessels. The suitability of this method should be discussed with brick lining designer and engineers who are going to carry out the job at site for the particular application.

15.7 Work Order for Brick Lining Work at Site

The Work Order can be placed with/without material. In the latter case, contractors should be instructed to be very careful while handling the material supplied. However, close sampling and inspection of materials is required in the former case. In both cases, close supervision should be done on the method of working, laying of bricks and curing the lining.

All the bricks, cements, fire clay should be stored very carefully near the actual work place in a closed room (protected from rains, dust, spillage of some other materials being handled at site). Only a small quantity which can be used up, i.e. applied inside the concerned equipment should be taken out on that day.

If the equipment is to be provided with more than one layer of lining then each complete layer should be cured in appropriate manner, after allowing at least 24 h of *initial setting time*. Curing should be done after every layer before laying the next layer. The temporary supports provided (e.g. for arches, overhead lining etc.) should not be removed till the initial set has occurred/24 h whichever is later.

Water used for making cement/castable paste should be of clean, cold and of potable quality with TDS less than 100 ppm generally.

15.7.1 Vents

Vents should be provided for escape of moisture during curing/initial heating.

15.7.2 Curing

After the initial set has taken place, slow uniform heating of the lining should be done by using a good amount of hot air. This can be done by placing three or four oil firing burners at different locations and uniformly circulating the hot air. Instead of oil firing, gas firing or electrical heaters can also be used. The temperature rise in first 24 h should not exceed 150 °C, and then 250 °C in the next 24 h.

It can be taken up to 450 °C in next 24 h (i.e. 72 h since start of heating). Now the final heating is done up to 500–600 °C if required and maintained for 24 h. Moisture coming out from vents is observed. *This is called soaking period.*

These temperatures are only suggestive and can be a little different as per experts carrying out the job at site. The aim should be to remove moisture, and not to cause any thermal shock to the lining.

After the soaking, the unit is cooled slowly—not more than 150–200 °C drop in 24 h—till it reaches ambient temperature again. Oil/gas firing at slow controlled rate is necessary during this cooling period.

15.7.3 Important Precaution

The flame from the burner should never be allowed to impinge directly on the bricks as it can cause thermal shock due to local overheating.

Brick lining engineers should be entrusted with this job. Heating and cooling curve records should be preserved for reference.

In case of acid resistant lining, the curing should be done by the same (but diluted) acid to which the lining should be exposed during operation.

Safety precautions like exhaust fans, gas masks, should be used while curing the lining in closed vessels/confined spaces etc. since evolution of acidic gases can occur.

15.8 Rubber/Fibreglass Reinforced Linings

15.8.1 Important Considerations

- Hardness of lining material
- Whether the lining material conforms to local standards or equivalent international specifications
- Electrical spark test. The lining must withstand at least 5000 V. Choose suitable thickness of lining accordingly (but it should not be less than 5 mm for better life). Spark test indicates spots of weak lining or unlined surfaces

- Curing completion time: consult vendor before the lined equipment can be taken into use. *Purchaser should wait for one more day if possible and again thoroughly examine all lined surfaces, nozzles, flanges etc*
- Repairs to lining: specialised techniques are required for each type of lining
- Details should be obtained from concerned party. However, one must remember that glass linings cannot be generally repaired

15.8.2 Work Order for Rubber/Fibre Glass Lining

- Fluids being handled: especially presence of fluorine compounds—in the equipment (to be lined). PTFE lining will be required in this case
- Operating temperature (normal and maximum temperature) likely to be reached
- pH of fluid
- Suspended solids/crystals and their abrasive nature (if any). (Purchaser is advised to minimise presence of such particles by filtering the fluid/providing strainers at appropriate places)
- Liquid agitation: whether violently in motion or moving in a smooth rotary motion speed of agitators/stirrers should be looked in to
- Size of equipment, internal fittings, baffles, agitator etc. and nozzles for input outputs, sampling, drain etc
- Operating pressure/vacuum in the equipment (lining tends to get peeled off due to vacuum. Hence lining should be done with extra care)
- Thickness of FRP/RL/PP linings required
- Whether spark test is required? At what voltage? (Do not exceed 5000 V unless vendor is confident and offers to test at higher voltage)
- Whether very smooth surface is required after lining

15.8.3 Lining Contractor to Inform

- Type of lining material that will be used
- Whether single layer will be used or multi-layer construction will be done to get the required lining thickness
- Resins and hardeners being used and their shelf life so far
- Chemical resistance test should be done for resins and hardness
- A test piece should be made by the vendor and subjected to actual operating conditions for determining the suitability
- Curing method which will be used by the contractor
- Site facilities (steam, power, fuel etc.) required by vendor if the vessel is big and the job will be done at site only
- When can the process vessel/equipment be put into service?

15.8.4 Poly Tetra Flouro Ethylene (PTFE) Lining

This is most inert and hence not attacked by almost all chemicals in use. Generally a thickness of about 1.5–2.5 mm is used.

However, it is not recommended above 250 °C. It is quite costly, and heat transfer through PTFE lining is poor. It can be used where product contamination due to equipment/shafts/agitators etc. must be avoided. PTFE sleeves will be found very useful for drain nozzles, bottom outlet pipes, valves etc. in case of highly corrosive chemicals. Since the material is soft, it may not be used where the liquids may contain (abrasive) solids in suspension.

Weep Holes A small drain hole may be purposely made at bottom of the equipment shell to drain out any liquid (reactants) that may seep through cracks in the lining. The weep hole should be kept clean always. Any continuous flow of liquid through the weep hole indicates failure/cracks of the lining and thus a thorough inspection may be carried out, to see whether procurement of new equipment (or fresh lining of old equipment) is required. The weep hole will minimise chances of accumulation of the leaked material between the shell wall and the protective lining (as this can rapidly corrode the metallic shell).

15.9 Insulation and Cladding

15.9.1 Hot Insulation

Generally, the following types of equipment need to be insulated from outside to prevent heat loss to the surroundings/to minimise "heat pollution", i.e. to minimise working areas becoming uncomfortable.

1. Heat exchangers operating at a high shell temperature
2. Jacketed equipment being heated by steam/hot oils etc
3. Gas/fluid pipelines/steam lines having higher temperatures

After providing glass wool pads (50 mm thick for temperature up to 150 °C and 75 mm thick for temperature up to 200 °C) aluminium sheets (20 SWG generally) are to be put on to prevent peeling off the glass wool and to prevent rainwater wetting the insulation. *Thinner aluminium sheets can get damaged easily and moisture ingress may occur.*

Mineral wool insulation may be employed as higher thickness pads (80–100 mm) for temperatures exceeding 250 °C on the external surfaces of the equipment. The insulation is then covered by cemented chicken netting/aluminium sheets (20 SWG).

Vendor should be asked to bring his own anchors for providing insulation pads. It is preferable to weld these before lining inside and with as low current as possible. *This cannot be done on pressure vessels after Post Weld Heat Treatment (PWHT) and radiography has been done. This can be done only beforehand.*

However, furnaces lined with insulating and firebricks and operating at greater than 800–1000 °C, tend to have high shell temperatures. It is advisable to have more thickness of internal refractory than providing external insulation on the shell, because this can result in high shell temperatures (sometimes making it even red hot at isolated spots) and weakening it at such spots. Aluminium heat resistant paint may be put on outside to minimise heat loss. A shed to protect the furnace from heavy rains is quite useful.

Note: Using too much thickness of insulation may actually increase heat loss in due to increase of external surface area.

15.9.2 Cold Insulation

Polyurethane (thermocole—a popular name) calcium silicate foam preformed pads (as per pipe diameter) are fixed on chilled water/brine pipelines at low temperatures by bituminous adhesive. This should, however be avoided in areas handling inflammable vapours, since thermocole itself can burn.

15.9.3 Work Order

Equipment, pipe lines are to be insulated and clad at site after erection and testing for leakages. Hooks/cleats are to be *welded prior to start of insulation job*. This can be done in house also, but it is better to negotiate with experienced contractors and ask them to do the job with supply of material included in scope of work.

Rates should be obtained for straight length of pipelines, flanged joints, and fittings such as valves, bends etc. and for cylindrical and conical vessels separately. Joint measurement of surfaces to be insulated should be done by purchasers and contractors representative before start of work and recorded. This will avoid future controversies.

Samples of materials used for insulation, cementing, waterproofing of insulation and external cladding shouldl be preserved for future reference.

Appendices

Appendix A

A.1 Ball Mill

- Material to be ground and its properties, for example density, hardness, explosive/inflammable nature of dust, hygroscopic nature/cake-forming tendency, corrosive nature, feed size and distribution; how many are above 10, 20, 30 mm etc.
- Size of powdered material (screen analysis) and distribution required
- Quantity to be ground per hour
- Whether continuous feeding and discharge will be possible (with dust control hood and induced draft (ID) fan, bag filter to be supplied by vendor)
- Rotary speed of ball mill (any preference by the purchaser)
- Material of construction (MOC) of vessel of mill (scales of mill should not contaminate the product)
- "Flights"/lifting devices provided in the mill.
- Properties of "balls": MOC, size, density, surface hardness, individual weight—to be provided by vendor. Quantity of balls in the unit shall not exceed 35–40 % volume
- Hardened steel balls or other materials are to be checked for suitability
- Drive arrangement may include gearbox—belt drive etc.
- Motor horsepower and speed control mechanism to be specified by the vendor

A.2 Jaw Crusher

Jaw crusher is useful for crushing lumps of rock phosphate, lime stone required in fertiliser industries, waste treatment etc. They use compressive force between two

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jaws for breaking of lumps. A preliminary screen and a strong magnet shall be installed to prevent entry of very big pieces, tramp iron in to the crusher as these can damage the jaw plates.

One of the jaws is fixed while the other moves to and fro by a cam–flywheel mechanism which breaks the lumps.

The crushing is done by the strokes of the plates (the size reduction continued in every stroke). The force to crush the material is provided by a heavy flywheel that moves a shaft creating an eccentric motion which causes the closing of the gap between the jaws.

Jaw crushers have to carry out a heavy duty job. Hence, the frame is generally made of cast iron or steel with reinforcements to add strength and usually constructed in sections for ease of transportation. MOC of the jaws can be cast steel and shall have replaceable liners of alloy manganese steel or Ni–Cr alloy steel.

Options available for the swinging (moving) jaw could be:

- Fixed at the upper position
- The lower position
- An intermediate position

The space between the two jaws is called the crushing chamber which can get progressively smaller towards the discharge end.

If the jaws are farther apart at the top than at the bottom, forming a tapered chute, the material is crushed progressively smaller and smaller as it travels downwards until it is small enough to escape from the bottom opening.

If the jaw crusher has a variable feed area and a very small discharge area at the bottom, it can lead to choking of the crusher and cannot be used for heavy duty operations.

The swing jaw is suspended on the eccentric and undergoes two types of motion—swing motion towards the fixed jaw and vertical movement due the rotation of the eccentric. Both these motions combine to create an elliptical motion and help push the particles through the crushing chamber.

Advantage: Higher capacity

Disadvantage: Higher wear of the crushing jaws

This type of jaw crushers are preferred for the crushing of softer particles.

Consider the following during selection:

- Properties of material: hardness, inflammable or explosive nature of dust.
- Moisture content (higher moisture makes it sticky).
- Size of lumps in feed: provide a preliminary screen to remove very big lumps and tramp material, iron pieces by magnets. *Purchaser to discuss this with vendor*.
- Desired reduction in size: for example ratio 4:1 or 5:1, as per need and hardness of material.

- Quantity to be crushed per hour.
- Strong heavy flywheels with attached eccentric and cams to operate the moving jaw
- Provision of an emergency brake.
- Installation at ground floor is advisable. Feed chute shall be at a convenient height for ease of observation. If possible avoid installation on upper floors (since vibrations, generally created during crushing, can weaken the floor in the long run).
- Foundation details to be provided by vendor as this is a heavy duty unit generally.
- Discharge side: A conveyor may be operated to carry away the crushed material to process plant storage silo.
- Exhaust hood, cyclone/bag filter and an ID fan shall be provided for dust control.

A.3 Grinding Mill

There are certain similar considerations (like those for jaw crushers) for buying grinding mills (Fig. 1).

- Material to be ground and its properties such as density, hardness, explosive/inflammable nature of dust, hygroscopic nature/cake forming tendency, corrosive nature etc. should be explained to the vendor, and he should be asked to give details of the following:
- Preliminary screening arrangement: MOC, mesh, thickness and method of fixing.
- Product: quantity per hour, screen analysis and particle size required.
- ID fan capacity; "suction" generated (200 mmWG is preferable, since this will minimise dust pollution in operating area).
- Dust arrester balloon size, MOC; mesh size of cloth (for small amount of dust)
- A bag filter may be provided if large amount of dust is likely to be produced.
- Speed control and emergency brake for main drive.
- Heavy duty bearings should be provided.
- Details of grinder wheels/weights or any other method should be given by vendor.
- Spare parts of the grinding mechanism—these may need replacement every year.
- Discharge chute; arrangement to hang/fix bags for collecting the product.
- Manometer connecting points on ducts.
- Details of mechanical arrangement for feed screw/feed control damper.
- Overall dimensions.
- Empty and operating weight.
- Civil foundation required.

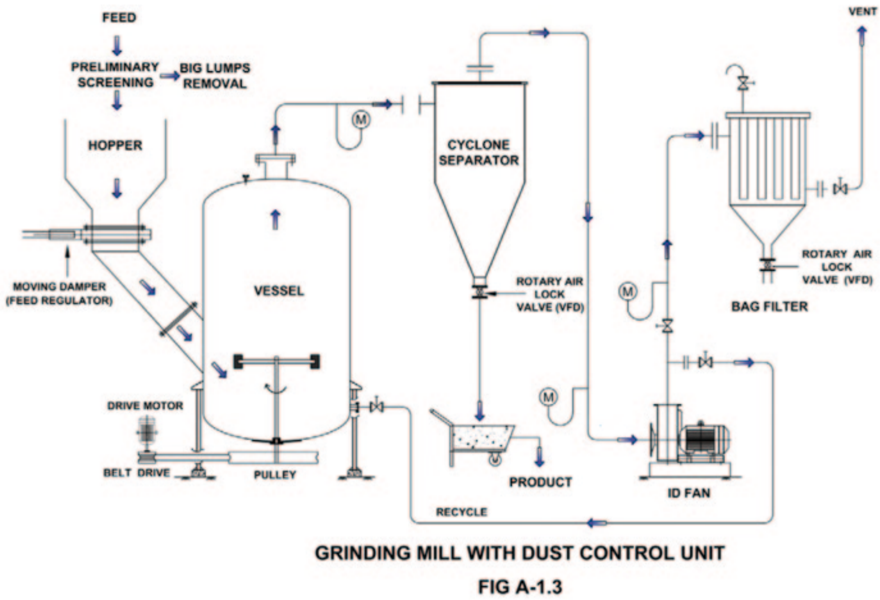


Fig. 1 Grinding mill with dust control unit

Appendix B: Safety-Related Equipment and Services

B.1 Elevated Storage Reservoir

Water is required in many Chemical Process Industries (CPI) for:

- Making solutions
- Boiler feeding
- Cooling of electrodes, reactor jackets condensers
- Scrubbing systems
- Fire fighting
- Safety showers, eye wash fountains

List of all such requirements should be made and their order of importance should be decided. The estimated requirements of the important ones for 20–30 min should be calculated. The individual volumes should be added up and an additional margin of about 15–20 % should be provided.

The volume of elevated storage reservoir (ESR) can be calculated from these figures, and the cost of tank plus support structure, water piping for filling and pump cost can be estimated. A convenient location for the tank in the premises should be decided. It should be as near as the important user points as possible.

The ESR bottom outlet main header should be connected to the plant distribution water lines through solenoid valves. These valves shall be closed when power supply is available and should be programmed to open automatically (manually) as per need when power supply fails. This will ensure that all emergency requirements of water are met till DG set is started for resuming water supply to important units. It will give the operators the vital 20–30 min to take necessary steps till the DG sets come on load.

B.2 Safety Valves

These are generally bought out items and are fitted on boilers, pressure vessels, air receivers etc.

Vendor should furnish test certificates whenever required by purchaser.

- Purchaser should confirm the correct values for design, working and test pressures from design engineer and inform statutory authorities for approval.
- Setting of safety valves should be done as directed by statutory authorities. It is done by boiler/factory inspector and sealed thereafter.
- Should open in case of increase beyond set pressure.
- Prevent further pressure rise when it is suitably sized.
- Close by itself after pressure is released.
- Should shut tightly during normal operations.
- The valves should have flanged connections.
- At least two safety valves are to be provided.
- Reinforce the nozzles for mounting the safety valve with due consideration for bending moment during blow off. Additional supports or clamps may be provided for the exit pipe with permission from inspecting authorities.

Markings on Safety Valves

- Name of manufacturer
- Date of test
- Smallest flow diameter upstream (should not be less than 20 mm)
- Code: vapour/fluid
- Set pressure values above normal working

Malfunctioning of Safety Valves Purchaser should keep the following in mind and discuss the following possibilities with the vendor of pressure vessels (who may provide the vessel with bought out safety valves).

- Release port is of smaller size than required.
- High pressure drop due to choke in exit or inlet pipe (e.g. solidified sulphur deposits). Hence, these pipes should be of short length and of sufficient diameter.
- Distortion of valve body due to weight of blow off pipe, over tightening of bolts.
- Corrosion of seat: continuous blow off or a leak leading to loss of material.
- Jammed spring due to corrosion: provide protective cover.

- Counterweight not fixed properly: provide locking arrangement.
- MOC of valve seat, stem and plug shall be chosen properly. These shall not get corroded due to continuous contact with the medium in the vessel.
- Hence, in most countries, number of safety valves recommended is two.
- The gases coming out during blow off should be released at a safe distance away from working areas, hot surfaces.
- Keep collection drums (with 10% alkali solution) if liquids are likely to come out.

B.3 Fire Fighting Systems

Managements must consider these as a very essential system of the plant. Following should be carefully looked into while installing a fire fighting system (FFS), as proper compliance can reduce the premium to be paid to the insurance company; besides meeting instructions from the statutory authorities like factory inspectors, electrical inspectors etc. *This investment is necessary for safety of personnel and plant.*

- Inventory of all chemicals in storage sheds, warehouses, storage tanks, gas cylinders, process vessels (condensers, distillation columns, reactors, big ducts, long pipe lines should be within maximum permissible limits.
- Flash point, vapour pressure, boiling point data for all chemicals handled should be available and prominently displayed.
- Make a list of all non-compatible chemicals and all inflammable items, and take precautions so that they should not come in contact even by mistake *if stored together*.
- Inflammable materials should be stored away from main plant units at isolated spots. No source of high electrical voltage (transformer, air circuit breaker, oil circuit breaker, main panels) or high temperature surfaces (furnaces, steam lines, hot gas ducts) should be nearby.
- Crushing, grinding operations which can produce inflammable dust should be carried out at isolated spots.
- Comply with requirements of insurance companies regarding fire fighting facilities to be provided on the premises, with detailed specifications if any (e.g. CI pipelines, separate water pumps, separate power supply/DG set, CO_2 cylinders, sand buckets, dry chemical powder type fire extinguishers, long hose reels etc.).
- Always implement instructions from factory inspectorate.
- The FFS must be as per approved disaster management plan.
- Installing automatically operated FFS with audiovisual alarms.
- Requirement of FFS system: storage of water (ground level/overhead tanks), standby power supply DG set, public address system, smoke detectors, sprinklers must be provided and inspected regularly.
- Whether it would be possible to change the plant layout for isolating certain areas more prone to fires.

- Conduct mock drills.
- Approved site evacuation plan and vehicles for carrying away personnel.
- Ambulance with necessary first aid facilities, oxygen breathing unit etc.
- Neighbourhood evacuation plan and vehicles.
- The following should be always available at locations prone to fires:
  - Long hose pipes wound on a reel, dry chemical powder cylinders and CO_2 cylinders.
  - Overhead emergency water storage dedicated tank—for supply to fire fighting pumps.
  - A network of fire hydrant piping
    - Water bodies like spray ponds may be helpful in emergency.
  - Fire tenders—These are tankers of 10,000–15,000 L capacity and with high pressure pumps, ladders, emergency lighting.
  - External cooling water spray on fuel tanks to prevent overheating due to some fire nearby.
  - Keep one tank always empty to transfer from leaking tank.
  - Warning siren.

While every care is taken to prevent the occurrence of unfortunate incidents such as fire, accidents do happen. In such a situation, the work personnel may become panicky, thus aggravating the case. This can certainly be avoided if the personnel concerned are properly trained in the use of fire fighting equipment and safety appliances and suits being purchased by carrying out regular drills.

B.4 Safety Equipment and Personal Safety Devices

It is advisable to have adequate safety equipment for ensuring an accident-free plant performance. While the actual requirements will depend on the site, the following must be available all the time in the plant. Personnel should be trained in their use and asked to wear them during operation and maintenance.

- Personnel protective equipment like gumboots (up to knees), acid resistant dress, face shields with transparent front, full-length rubber/asbestos gloves (up to elbows).
- Safety shoes with metallic plate inserts for protection of toes and fingers.
- Shoes with rubber soles to prevent sparking when working in presence of inflammable vapours/liquids with low flash points.
- Fountains for eye wash.
- Safety showers with an assured supply of water from dedicated overhead tank. This tank must be supplied water from a running source and an overflow must be ensured to confirm that it is full always. The capacity should be 1000 L at least. Many such systems should be installed in the plant for immediate availability near piping and units handling corrosive chemicals.

- 24 V lighting system, self contained breathing apparatus with oxygen (line or cylinder) supply for persons working inside closed vessels.
- Gas masks equipped with gas absorber canisters appropriate for the gases should be present in the plant.
- High temperature protection dress (reflective surface).
- Wooden planks to stand on (if vessel contains corrosive material).
- Rope ladder for quick escape.
- Air circulation fans.
- Portable fire extinguishers.
- Hand-operated warning bells.
- Mobile telephones/walkie talkie sets.
- Non-sparking tools for working in areas having presence of inflammable vapours or dust.

B.5 Structurals and Work Platforms

Structural designs with safety margins and overload considerations should be done on basis of all equipment (reactors, evaporators) provided with all fittings and mountings in completely filled up condition, and with the agitators running at full speed. This gives an indication of vibratory load. Consider wind loads and loads due to future expansion plans.

Vendor shall be asked to inform this maximum weight. Occasionally, workers tend to stack raw materials for next batch and/or finished products from previous batch on the work platforms attached to the reactors or on the top covers of certain equipment. Such additional weights must be considered.

Earthquake resistant structure should be made as a matter of abundant precaution.

Work Platforms These are necessary for safe and efficient working and should be procured with the purchased equipment or provided for:

- Operation of valves, close observation of pressure gauges and dial thermometers, sight glasses, safety valves.
- Taking out samples from sample points.
- Maintenance work on safety valves, thermocouples.
- Near cleaning and observation of manholes.
- Procure only anti-skid gratings, in removable section for making work platforms (to enable maintenance/replacement of equipment etc.). They should be obtained with coating of anti-corrosive paints. Rubber coating may be employed and workers instructed to use shoes with rubber soles to avoid sparking when explosive or inflammable vapours are present nearby.
- Earth connections should not interfere with work platforms.
- Work platforms can be fabricated/procured in standard sections.

- Railings should be of sufficient height and should be covered by anti-corrosive paint or cement encasings. It is advisable to fabricate the railings by using stainless steel pipes as they neither rust nor hurt the person holding them. The railings fabricated from pipes shall be closed at both the ends so that no corrosive gases, moisture can enter inside.
- Emergency exits, ladders, escape routes must be provided from all working areas/platforms. Adequate ventilation should always be available and workers must be desisted from storing spares, stacking bags of raw materials in the emergency exit routes.

B.2.5 Proposed Safe Handling System for Collection and Feeding Chemicals

This design was proposed by the author to one of his clients.

Figure 2 shows a safe arrangement for collecting and transporting of chemicals when the purchaser has to buy a chemical (from outside supplier) which needs very careful handling.

The tank can be fabricated of rubber lined mild steel, stainless steel, fibre-reinforced plastic (FRP) etc. (whichever is compatible with the chemical) and is mounted on a suitable transport vehicle. It will have arrangement to heat it if necessary. (MSRL/FRP tank will not be heated.)

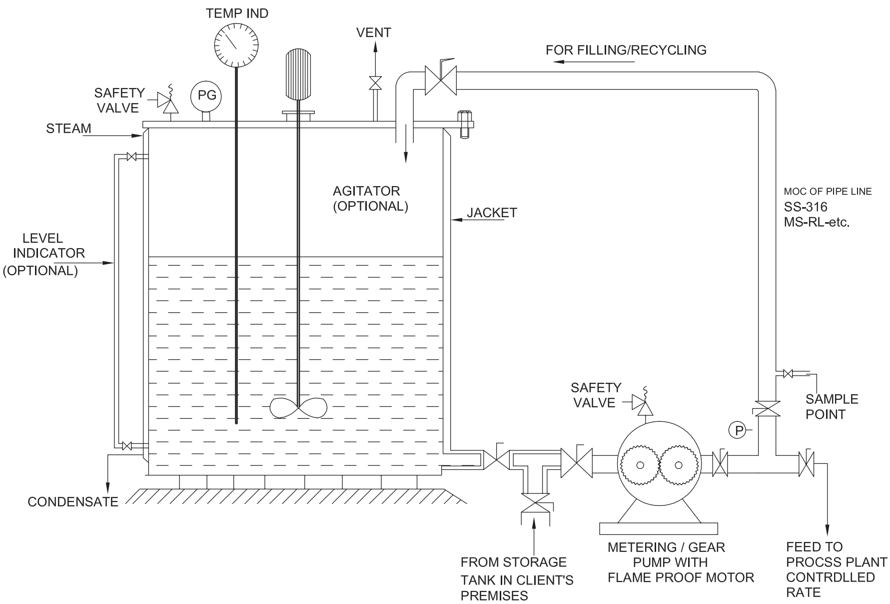


Fig. 2 Proposed safe handling system for collecting and feeding chemicals

The chemical loading point is connected to the suction line of the pump and it is run to fill up the tank through the filling-cum-recycle line. The tank is now brought at the purchaser's plant and the pump is run again through the recycle line.

After drawing a sample and testing it, the chemical can be fed to the process plant at a controlled rate.

The chemical can be kept hot or cold as per need by supply of steam or cold water. A safety valve can be provided to release the excess pressure if any.

A vent is also to be provided.

Capacity of the tank can be 1000–3000 L. Do not fabricate a tank of large capacity as it can be dangerous.

Appendix C: Solid Waste Disposal and Some More Effluent Treatment Facilities

C.1 Incineration Plants for Wastes

Chemical industries generating hazardous wastes (which are defined by statutory authorities) are required to destroy/dispose off such wastes by law as per prevalent guidelines issued by pollution control authorities/government agencies in the particular country.

Common facilities are also established by parties (who are authorised by the local government) for collection and transport to disposal/destruction facilities and licensed to operate the incinerators as well as secured landfill sites.

Advantages of incineration include:

- Reduction in volume of the wastes
- Detoxification of waste
- Ensuring regulatory compliance
- Energy recovery (if possible, depending on nature of the waste)

Some typical guidelines are given below. However, the plant management must take all due precautions to minimise generation of hazardous waste itself; and then duly pack in leak-proof containers for ultimate disposal by authorised parties.

If such parties are not available, then the plant management shall install such incinerators and downstream equipment as per Government guidelines and get them approved before operating their own production plants or else permission to operate the plant can be refused by statutory authorities.

Incineration system comprises of the following four main steps:

- Waste preparation and feeding-
  Plant operator should check the compatibility of wastes (mixed feed) before feeding for preventing dangerous reactions, formation and subsequent release of toxic compounds and concentration of pollutants (e.g. halogens, sulphurous compounds) in waste and feed rate should be controlled as per capacity of air pollution control facilities.

Plant Management Shall Inform the Vendor/Fabricator the Following Requirements While Obtaining an Incineration Plant

- The average calorific value and analysis of the waste (as above)
- The amount of waste which will be charged per hour
- Need for double door arrangement during charging
- Requirement of firing systems (with fuel tanks, feeding pumps, forced draft (FD) fan),
- Required running time per day/per month as well as other units as per guidelines generally given by statutory authorities as below

Construction of furnaces (stationary kiln) and secondary combustion chamber

- *Mild steel shells with high temperature-resistant lining capable of withstanding 1300 ºC, manual and automatic burners, thermocouples, view ports, pressure release valves (auto and manual) and air blowers for proper burning*
- Liquid waste feeding arrangement at controlled rate—separate spray injection nozzles
- Mechanism for ash removal
- Fuel used should be high speed diesel, LPG, furnace oil (coal or coke are generally not recommended)

Rotary kiln type furnace (if used)

- Vendor should inform the designed heat capacity of furnace (calorific value of waste kilocalories per kilogram × feed rate kilogram of feed per hour).
- MOC and thickness of shell.
- Refractory lining thickness.
- Furnace slope shall be about 3°.
- Rotational speed (about 10 revolutions/h) with suitable VFD mechanism.
- Residence time for solid waste (up to 10 h) to ensure incineration.
- High temperature resistant refractory lining (shall not be less than 45 % Al_2O_3).
- Inside operating temperature not less than 850 ºC at start of feeding.
- *Safe arrangement for feeding waste (double door hydraulic ram pusher) and removal of ash (from bottom manholes) must be provided. Gases should not leak out from these.*

Thermal oxidiser (secondary combustion chamber)

After the rotary kiln, a secondary combustion chamber should be provided. The refractory lining and shell should be capable of withstanding at least 1100 ºC, in order to ensure complete destruction of the waste. This includes complete oxidation of dioxins and furans as well as of any material left unburnt in the rotary kiln.

- MOC and thickness of plates—not less than 12 mm.
- Refractory thickness—to withstand 1100 ºC.
- Residence time shall be minimum of 2.0 s.

- Temperature sensors at three places at least.
- Photocell for flame monitoring.

Auxiliary Burners Incineration plant shall be equipped with at least one additional burner. This burner must be switched on automatically when the temperature of the gases after the last injection of combustion air falls below specified temperature. They shall have manual controls also.

The burners may be pressure-atomised type with approved certification from authorised party.

Air pollution control system to be provided with:

- Quencher for rapid quenching of exit gases from furnaces with temperatures up to 200 °C to prevent reformation of dioxin.
- Particulate matter removal by a cyclone or ESP.
- Venturi and packed bed scrubber for acidic gas removal.
- *Considerations for venturi, packed tower and demisters have been covered elsewhere in this book and the same are applicable for air pollution control system here also.*
- Demister (pads/candles).
- Active carbon bed.
- ID fan of adequate capacity with rubber/FRP lining (for wet acidic gases).
- Tall chimney (*MSRL preferred*, *minimum 30 m*) with sampling ports, corrosion resistant inner lining.
- Instruments for continuous monitoring of pressure, temperature, SO_2, CO, HCl etc.

General considerations:

- Provision of emergency water and power supply (DG set).
- Inventory of fuel for 5 days' consumption should be available always.
- Provide interlocking of feed system with exit gas analysis, flame control and *operating* pressure in system *(should be always negative to prevent escape of gases), tripping of scrubber circulation pump must stop ID fan and fresh feeding of waste. Vent release vale shall open if there is positive pressure in the system.*
- Heat recovery—to be tried if possible.

C.2 Some More Effluent Treatment Facilities

Chemical industries generate solid, liquid and/or gaseous effluents. It is imperative to see that they are rendered harmless to the environment before release. Plant managers shall look closely into all operations in their units and list out all the sources of effluents.

Following are suggested for taking care of the effluents:

1. Recycle as much effluent as possible back into the process if the product quality/equipment life are not affected.
2. Explore markets for untreated effluents. It is probable that some other industrial units may be able to use the effluent. (Alkaline effluent from paper mills may be used for neutralising acidic waste waters.)
3. Try to produce some saleable product from the effluent.

If the above is not possible the vendors of the ETP should be provided with the following information for satisfactory working of the same:

- Details of various effluents generated (quantities of individual streams, their composition, both normal and maximum pollutant contents, pH, temperature, suspended solids, oil and grease, colour intensity, biological and chemical oxygen demands, total dissolved solids, i.e. total dissolved solids (TDS) etc.).
- A sample of the effluent may be given to the vendor for trials.

(In case of gaseous effluents, well-designed and operated scrubbing systems are required. The selection criteria for the same are given in the book elsewhere.)

Vendor should be asked to give following details while quoting for the supply of ETP.

- Guarantees offered for quality of treated effluent. These guarantees must meet the norms laid down by State pollution control boards *always*.
- Equalisation tank and its hold-up volume should be adequate for storing effluent generated in 24 h at least so that shock loads are taken of.
- Process flow scheme for the treatment in general giving proposed pH adjustment, aerobic or anaerobic process employed, aeration unit, active carbon unit, sludge disposal unit.
- Residence time in each of the vessels employed. Purchaser must discuss this with the supplier of the ETP since very short residence times may result in improper treatment of the effluent streams.
- Power consumption per cubic metre of treated effluent.
- Generation of gases (especially if it contains H_2S, methane etc.) per cubic metre of treated effluent.
- Method employed to treat these gases since H_2S is very toxic. However, methane rich gases can be used for heating/steam generation/for running biogas engines. This can offset part of the cost of operating the ETP.
- MOC of all wetted parts.
- Instrumentation provided for monitoring process parameters during treatment of effluent and for the finally treated effluent.
- Amount of wet solid sludge generated in the end and method for disposal thereof.

C.3 Up Flow Anaerobic Sludge Blanket Reactor (UASB)

A common method is to introduce the effluent in to the reactor and distribute through the sludge blanket. Biological action by organisms in the sludge decompose the organic impurities and generate biogas. The mixture of sludge, liquid and gas rises to the top of the UASB reactor and is separated by a suitable separator.

The biogas is to be collected and treated before use. The suspended material settles down into the sludge and thus the bacteria are retained. The partially treated effluent goes out from overflow nozzle and is treated further.

The purchaser should carefully look in to the following items of the offer by a vendor:

- Details of the distributor for effluent at inlet (must ensure uniform distribution all over the cross section) and whether it can be cleaned easily without major dismantling.
- The solid–liquid–gas separator.
- Maximum COD load and flow rate of the effluent that can be treated.
- What will be the further treatment required for the exit liquid?
- Analysis of biogas that will be produced (methane, CO_2, moisture, inert if any).
- *Expected calorific value of the gas—vendor may not be able to comment here.*
- Volume of bio gas that will be generated every day and its pressure.
- Effect of ambient temperature on the working.
- Will the unit be able to run continuously for months without cleaning?
- Gas collection, treatment (if it will contain gases like H_2S) scheme and proposal for use—whether for heating purpose or for power generation by specially designed engines.
- Residence time of the liquor in the UASB reactor.
- The quality of treated effluent/reduction in the COD values.
- MOC of the reactor.
- Will it need addition of activated sludge periodically?

C.4 Producing Potable Water from Sea Water

It is cumbersome to carry a large stock of drinking water on the ship from the starting port. This can occupy considerable space on the ship and also add weight to the ship, thus reducing its cargo carrying capacity to that extent.

- *Process*: The big engines of the ship are cooled by circulating treated (*demineralised, DM*) water in their jackets which can get heated up to 75–80 ºC. Sea water is drawn in by suitable pumps (designed to handle salty water with high TDS and containing sodium chloride and other salts). This water is heated by plate heat exchangers of titanium/suitable MOC by taking up heat from hot circulating engine jacket DM water.

- The preheated sea water is boiled under vacuum of about 700 mmHg which lowers its boiling point. The vapours of pure water thus produced, are condensed and collected in a suitable vessel for potable water. Incoming cold sea water itself is used as cooling medium.
- The concentrated water from the vessel is drained out to the sea again.
- An online salinometer continuously analyses the salt content of the condensate. If it contains more than 50 ppm then it is rejected to sea again/used elsewhere on the ship. This can indicate some leak in the system which is investigated and attended immediately.
- All the metal parts (pump, hot piping, condenser tubes etc are made of Hastelloy C-276 or equivalent after testing the corrosion resistance) The valves and cold water piping could be made of polypropylene or high-density polyethylene.

Recovery of Water from Waste Waters in a Chemical Plant

- The above method may be used to recover usable water (as make up to cooling towers, for manufacture of chemicals, for washing reactors, for flushing etc) from *partially treated* effluents- if the quality is acceptable. *This can reduce consumption of fresh water in a chemical plant*.
- It is not necessary to have high pressure steam or high temperature gases for operating this arrangement. A source of waste heat at about 80–90 ºC will be able to run this recovery unit if sufficient flow of hot fluid is available in the plant.
- The benefits shall be weighed against cost of power for vacuum pump and operation of condensation system.
- Extensive study and pilot scale trials shall be carried out first before investing funds in such schemes.

Appendix D: Steam-Related Equipment and Water Treatment Plants

D.1 Packaged Boiler Selection

A) General

1. Capacity required ----- Kg/Hr(Also expressed as ….Kcals/Hour)
2. Maximum pressure Kg/Cm^2
3. Steam Temp. ----- ^{o}C Saturated /^{o}C Superheated

4. Operation continuous/ intermittent ----- Continuous (12 Hours/24 hours) Off: 3-4 hrs/Off 6-8 hrs)

5. i) Space available ----- Meter x Meter

   ii) Space required ----- Meter X Meter

6. Power connection: Available and actually required (for air blower, oil pump, coal feeder and feed water pumps)

7. Manpower available ----- Trained (Skilled)

8. Distance of Boiler from points of steam consumption

9. Local cost of fuel per MT (landed at site)

Coal (Ash content > 25%)	-	…….	$/MT
Furnace Oil	-	…….	$/KL
L.D.O.	-	…….	$/KL
Diesel	-	…….	$/KL

10. Time from Cold start to get steam (*Oil fired/water tube boilers take less time as compared to coal fired/smoke tube boilers*)

11. Fuel handling system: More convenient to handle oil as compared to coal.

12. Ash disposal system: Required for coal fired boilers. Not generally required for oil fired ones.

13. Stack height

14. ID fan and FD fan with provision of interlocks with fuel feeding system

15. ESP/Cyclone etc.: Required for coal fired boilers

16. No. of passes (gas side)

17. Pressure drop of gas side (max 50-60 mm)

18. Chimney with all statutory fittings.

19. Permission from statutory authorities must be obtained before commissioning.

B) Technical Details

1. Water quality available ------ pH, TDS, Total hardness

2. Possibility of Steam condensate recovery and recycle

3. Possibility of rain water collection and storage

4. Heat transfer area (based on pipe O.D.) ------ m^2

5. i) Diameters (ID & OD) of pipe used for civil
ii) Total hold up volume of coils > 22 Liters

6. Seamless or ERW?

7. Test Pressure of Coil ------ (Minimum 1.5 Times working pressure)

8. Air Blower

Capacity	------	nm^3/hr
Discharge Pressure	------	mmWG
Speed	------	RPM
Type of coupling	------	Directly coupled or belt drive
Base Plate	------	Common/Separate for Blower and Motor
Motor HP	------	
Type	------	TEFC, Single phase/Three phase

9. Air Line sizes provided or not ------ Primary, Secondary, Tertiary lines. Dampers

10. **Feed Water Pump**

	Capacity	------	Litres/hour (At least 2.0– 2.5times steam eneration)
	Discharge Pressure	------	Kg/hr (atleast 1.5 – 2.0 times working pressure)
	Type	------	Centrifugal (Multistage), Reciprocating
11.	Motor HP	------	
	Type	------	TEFC, Single phase/Three phase
	Insulation	------	External insulation necessary

12.	Fuel Oil tank	-----	overhead tank with internal heating coil and jacketed outlet nozzle, main stop valve,Basket strainer (top removable 120 mesh strainer)
	Temp. gauge	------	0 – 200°C on Oil Tank
	Oil Burner	------	with Y type, 200 mesh SS Strainer Refractory (Bricks & Castables) protection for shell

Flame monitoring arrangement is a must to stop oil supply in case the flame gets extinguished due to any reason. It should be possible to keep the air supply running in this case to drive off the un burnt oil vapours.

13. Oil Pump

Capacity	------	LPH (Type – Gear pump preferable)
Gland	------	water cooled/mechanical seal
Discharge Pressure	------	4 – 6 kg/cm^2
Internal Safety Valves	------	Spring loaded type

External cum recirculation oil line with control valve

14. Motor for Oil Pump --- Flame proof type; directly coupled, and common base plate with oil pump, Single phase, three phase

15. Oil Heater (on line) --- Electrical heater with earth connection, temperature Indicator and high temperature switch off.

16. Instrumentation offered--/Safety Devices (Separate Control panel to be provided)

- ☐ Steam Press Gauge
- ☐ Steam Temp.
- ☐ Safety Valves on steam coil & Economiser section
- ☐ Low oil press cut out switch at oil heater outlet
- ☐ High Oil Pressure (if burner nozzle gets choked) recirculation safety valves.
- ☐ Indication for oil burner flame 'on'
- ☐ "Flame out" indication and cut out switch
- ☐ Observation Mica/sight glass for Burner Flame

17. Economiser ------- Tubes ID & OD____________

MOC Boiler quality seamless tubes tested at at least 1.5 times working pressure of the unit.

Heat transfer area ----- m^2.... with provision for in-situ cleaning of tubes.

Finned tubes can be used for oil-fired boilers more efficiently.

D.2 Thermal Vapour Recompression

Low pressure vapours are evolved from evaporators, but they carry lot of heat as latent heat which should be recovered. This is not possible always; hence, as much portion of vapour as possible from either a single- or multiple-effect evaporator stage is mixed with (by *sucking out and then mixing*) higher pressure steam to yield steam at an intermediate temperature and pressure.

This can now be used as heating medium. This can improve the thermal efficiency of the system since the latent heat of the vapour is recovered.

The equipment shall be similar to a steam ejector.

Considerations for Using a Thermo Compressor

- Pressure, temperature and quantity of vapour which is to be reused.
- Pressure and temperature of available high pressure (HP) steam.
- Pressure controller shall be installed for getting HP steam as per need.
- Quantity of HP steam required per kilogram of low pressure (LP) vapour to be calculated.*This can be an appreciable quantity and will depend on above.*
- Resultant pressure and quantity of mixed steam shall be correctly assessed.
- There should be definite requirement for this quantity of the mixed steam. The quantity of LP vapours drawn from evaporator depend on this. This can enable recovery of the latent heat.
- *If there is not enough demand for the mixed steam, the quantity of LP vapours to be sucked out will be limited.*
- *If dissolved gases or air also are evolved, they can interfere with the heating operation. There can be wastage of HP steam in such cases. Presence of particulate matter, or mist carried along with LP vapour can also reduce effectiveness of the system.*

D.3 Mechanical Vapour Compression

If *HP steam is not available, then mechanical compressor* can be used to suck and compress the vapour to a higher pressure and then reheat it to a higher temperature if a source of heat is available (say, hot process gases) in the plant. This can reuse the entire LP vapour from the evaporator if there is requirement in the plant. This can be possible in more instances, since this method does not increase the quantity of LP steam (but only increases its heating potential).

The system needs a compressor, a heat exchanger, valves and piping. It does not need HP steam.

The benefit from recovery of latent heat shall be weighed against additional cost of power required and then decision is to be taken.

D.4 Selection of Steam Traps

Steam is used in many industries for evaporation of dilute solutions (sodium sulphate, sugar), melting of solids (sulphur), drying of wet solids, maintaining temperatures in process vessels and in pipelines where the viscosity of liquid may increase too much on cooling.

Steam supplies a large amount of heat (as it has a large latent heat of condensation) and can travel over long distances due to its pressure).

It is very important to use it efficiently by minimising loss of live steam during heating.

Steam traps should be able:

- To remove non condensable gases
- To remove the condensate formed
- Prevent escape of live steam

Considerations for selecting the right type of steam trap are as follows:

- Condensation load expected, at start and during operation, depends on the purpose of heating.
- Batchwise melting/evaporation—once the job is done, there is a drop in steam requirement.
- Only keeping the process unit pipeline hot—i.e. only maintain a particular temperature to prevent solidification, to maintain viscosity of the liquid inside. *Steam demand is less all the time*.
- Continuous melting or evaporation—steam demand is more all the time.
- Presence of other gases or non-condensibles in the steam.
- Whether condensate is to be allowed to cool down further (rather than immediately to be discharged as soon as it is formed)
- Steam pressure used for heating and corresponding saturation temperature. *In case of condensate discharged at high pressure it may flash into low pressure steam in the condensate exit line and create water hammer/back pressure on the trap.*
- In case of a condensate recovery system—if the condensate is carried over a long distance or raised over a height and collected in a tank it can also cause back pressure.

Various types of traps are manufactured as follows:

Mechanical traps (inverted bucket)

They have a float that rises and falls in relation to condensate level in the body of the trap. It has a mechanical linkage attached that opens and closes the condensate exit valve.

Can drain out condensate continuously.

Thermostatic steam traps

There are two types of the thermostatic steam trap, a bimetallic and a balanced pressure design. In a bimetallic trap, an oil filled element expands if it comes in contact with live steam and closes the condensate valve against a seat. It may be possible to adjust the discharge temperature of the trap—often between 60 and 100 ºC. Hence, these can hold back some condensate till it cools sufficiently to allow the valve to open. Though this can use the heat more efficiently, this may not be desirable as condensate needs to be removed as soon as it is formed in most applications.

However, this makes the thermostatic trap suitable to remove large quantities of air and cold condensate at the start-up condition, especially for batch wise processes.

Thermodynamic (TD) traps

As steam enters, static pressure above the disc pushes it against the valve seat. Since static pressure over a large area can overcome the inlet pressure of the steam, it does not allow live steam to escape. As the steam starts to condense, the pressure against the disc reduces and opens the valve allowing the condensate to go out. *It is thus able to remove condensate fast*.

D.5 Water Treatment Plants

It is not always possible to get good quality water for the industry from the local sources. The raw water may contain salts of calcium, magnesium, sodium etc. These can cause both temporary as well as permanent hardness. It may also contain floating impurities, dissolved solids, organic impurities like chlorides, sulphates, dissolved oxygen etc. This water needs to be treated before it can be used in the process or for cooling duties etc. Otherwise it can spoil the final product quality due to insoluble matter, cause corrosion of equipment, waste the fuel due to formation of scales in boilers, upset process conditions due to scales in the cooling jackets and so on. Hence, it is essential to procure a water treatment plant or create the facility in-house.

D.5.1 Following Points shall be Considered for This Purpose

1. Quality of raw water available locally—pH, turbidity, floating impurities, TDS, temperature and permanent hardness, concentration of chlorides, nitrates, sulphates, bicarbonates etc and presence of calcium, sodium, iron, magnesium shall be analysed by taking three samples at least at different times. If the TDS is 450—500 ppm or more, it shall be confirmed and in that case it is better to arrange for another source of raw water rather than try to treat such a bad quality as it may cost more. (Raw water shall not contain more than 100–125 ppm TDS).
2. Availability of water round the year and cost of procurement per cubic metre at site.
3. Requirement to be correctly estimated for various purposes, for example process water, cooling water, for boiler feed, domestic needs, gardening, reserve stock for fire fighting etc.

The raw water treatment plant shall have the following facilities:

- Main storage for raw water: This could be an underground tank or an overground tank supported on a suitable structure.
- Primary settling tank: If the water is muddy in rainy season.
- Pressure sand filter.

- Active carbon filter: for removal of organics, odours, colouration etc.
- Water softener: ion exchange-based. (This is normally regenerated by sodium chloride and thus the treated water contains sodium salts.)

D.5.2 Reverse Osmosis

This is suitable for treatment of water containing considerable amounts of dissolved solids. *The fraction of water rejected can be on the higher side (depends on the treated water quality desired) and one should check if there is any problem at site for disposal*. Permission shall be obtained for this from statutory bodies, State PCB etc. before procuring this type of plant. Also one shall look into the easy availability of the membrane being used and its life and the power consumption per cubic metre of treated water.

Note: The following items shall be included in the supply of reverse osmosis (RO) plant by the vendor:

Sand filter (one working + one standby)
Active carbon filter (one working + one standby)
Iron removal filter (one working + one standby)
Micron cartridge filter (one working + one standby)
Membrane blocks (maximum pressure allowed)
HP pumps shall not generate pressure which may damage the membrane
Rotameters, pH meter, conductivity meter
HP piping shall be of SS 316 L
LP piping shall be of Unplasticized Poly Vinyl Chloride (UPVC)/Chlorinated Poly Vinyl Chloride (CPVC) with test certificates.

Multiple effect evaporators can be considered as an option for producing DM quality water from the raw water if by-product steam is cheaply available from the process plant, for example from a sulphuric acid plant it is possible to get one MT of steam as by-product per MT of the sulphuric acid produced.

Hence, one shall correctly estimate the total expected demand (present and future) for the following and then arrive at the capacity of the water treatment plant required.

1. Boiler feed water for HP and LP boilers
2. Quantity of condensate likely to be recycled for the HP and LP boilers
3. Process water
4. Make up water for cooling towers
5. Make up water for refrigeration system (chilled water/chilled brine)
6. Water requirement for plant washings and domestic purposes.
   - Specifications of process water: Filtered, free from organic and suspended matter, pH = 7.0 – 7.5, TDS less than 100 ppm, hardness less than 50 ppm.
   - Soft water (for LP boilers) operating below 20 kg/cm^2: Hardness below 10 ppm, pH = 7.5 – 8.0, TDS below 10 ppm as far as possible to reduce blow downs.
   - DM water (for HP boilers) generally operating above 15 kg/cm^2: TDS less than 1.0 ppm, pH = 8.5 – 9.0, Hardness less than 0.2 ppm, Silica less than 0.1–0.2 ppm

Conductivity (mho): as specified by the boiler manufacturer.

- Total quantity per regeneration cycle in cubic metre.
- Number of regeneration cycles per day: Usually one per day. (This can be two or more to reduce the cost of plant.)
- Time required for regeneration and restart: 2 h (maximum). If more time is required there is a danger of the treated water tank getting emptied.
- Scope of supply: Vendor shall be asked to include the following items:
  - Sand filter.
  - Degasser.
  - Active carbon filter and iron removal unit.
  - Anion and cation resin columns.
  - Mixed bed polishing unit.
  - Acid and alkali tanks for regeneration.
  - Air blower with motor.
  - Acid and alkali pumps.
  - Deaerator for removing dissolved gases.
  - Oxygen scavenging (dosing tank and pump for chemical addition like hydrazine). *Consult boiler manufacturer if necessary*.
  - Pressure gauges.
  - Online conductivity meter with remote digital indication.

We would need to check whether the vendor can supply the whole unit as a skid-mounted type. If not, the vendor should inform the overall space required for the plant.

The purchaser shall work out total space required by including raw and treated water tanks and pumps, electrical MCC, control panel etc.

The final specifications for the water treatment plants including raw water storage, pumps for raw and treated water, treated water storage, piping layout shall be adequate for present and future needs.

The wastewater generated due to backwashing of sand filter, active carbon filter, resin beds etc. shall be sent to the effluent treatment plant or reused in the premises wherever possible.

Appendix E: General Process Equipment

E.1 Distillation Equipment

Considerations for procurement of simple distillation equipment: (These should be discussed with the vendor for these equipment.)

These guidelines are not for distillation of crude petroleum or very complex liquid mixtures at input. Experts in petroleum refineries should be consulted for such requirements.

- Feed composition, i.e. proportion of all components.
- Rate of feeding inputs—normal and maximum.
- Properties of all components in the feed, for example pH, vapour pressure, density, latent heat, dissolved solids which will precipitate out and maximum limits of impurities for which the unit has been designed.
- Properties of all fractions in the distillate, for example pH, vapour pressure at different temperatures, latent heats, viscosity, density, flash point etc.
- Arrangement to take out vapours of different fractions.
- Arrangement to condense the vapours and adjust the reflux ratio (balance will be product stream. Heat sensitivity of the product should be considered and condenser design should be done accordingly if further cooling of the liquid is desired).
- Operating pressures and temperatures: normal and maximum.
- Empty weight and filled up weight along with weight of fittings.
- Cooling and heating media required (to discuss with vendor and own senior engineers; check what is available already).
- Pressure and temperature of heating and cooling media (to check what is available).
- Cooling loads (for sensible heat as well as condensation loads).
- Is preheating of feed possible by condensing vapours? This will reduce heating load and, in turn, will reduce steam/fuel consumption.
- Possibility of formation of any solid residues, since these tend to spoil the heat transfer surfaces.
- Arrangement for safely removing the solid residues: provision of cleaning manholes, supply of tools made from non-sparking materials.
- Presence of non-condensable compounds in the feed or generation during the distillation operation? Can they be released to atmosphere as such or whether any treatment by suitably designed scrubbers/absorbers or by another method is required.
- Examine need for a vacuum pump or ejector for continuous removal of non-condensable gases. This is required for proper condensation of the vapours.
- Accessories required for separation of condensates if they form distinct separate layers (e.g. water and lemon grass oil).
- MOC of heating coils, distillation columns and internals.
- Treat the unit like a pressure vessel and take all precautions for fabrication, testing erection, commissioning, operation etc.
- Ease of removal of heating coils and internal parts for observation and maintenance.
- Insulation and cladding to be provided.
- Instrumentation for temperature control, feed control, safety, fire alarm, steam PRV.
- Any necessity for flameproof electric motors and cables.

E.2 Dissolvers for Solids

Consider the Following Solids to be dissolved and their properties especially the following:

- Solubility/reactivity with the liquid at different temperatures.
- Density with respect to the liquid (heavy lumps tend to settle down and will need suitably designed propeller type of agitator for proper dissolution).
- Heat of dissolution (heating/cooling jackets may be required).
- Whether any thick sticky paste formation will take place in case the agitator stops (due to power failure/mechanical breakdown etc.). This will need arrangement to take out agitator immediately or provision of emergency power supply.
- Size of lumps and abrasive nature of the solid particles/impurities present.
- pH and temperature of resultant solution and the likely effect on agitator blades, shaft seals, dissolver body, internal coils etc.
- Feed rates and method of feeding, for example by charging bags of material manually into the dissolver/by screw feeder/from overhead hopper by rotary valve at controlled rate.
- Generation of any unpleasant/toxic/inflammable gases during dissolution and whether a scrubber/rupture disc etc. would be required.
- Tendency to form foams in the solution, which may make correct measurement of levels difficult.
- Baffles/foam breakers required—if any.
- Whether separate nozzles for temperature measurement, sampling etc. are required.
- Any internal coils required for heating/cooling?
- Tendency to form thick bottom sludge (special Y-type drain valves will be required in this case).
- Earth connection and cover will be required if any inflammable solvent is being used.
- Type of shaft sealing (gland packing/mechanical seal) required.
- Maximum revolutions per minute (RPM) of agitator permitted. (To be specified by designer/vendor).
- Type of agitator preferred (turbine/propeller etc.) to be informed to the vendor of equipment. However, final choice of design may be given to the supplier, if the purchaser does not have experience or adequate data on the solids being dissolved.

In case the purchaser does not have previous experience or adequate data, a sample of the solid to be given along with the liquid to the vendor for testing the design. The cost of such a test may have to be borne by the purchaser. This matter can be mutually discussed and agreed upon between the vendor and the purchaser.

E.3 Tray Dryers

These are generally used for batch drying of solids. These could be delicate materials and should not be subject to tumbling action as in case of rotary dryers.

The selection criteria are as below:

- Total quantity of material to be dried per shift/per day/per hour.
- Initial and final moisture content of the solid. This gives total amount of water vapour to be removed per batch. The efficiency of drying can be determined by amount of moisture removed per kilogram of steam consumed. (Amount of steam condensate should be measured for this purpose.)
- Desired moisture removal (i.e. drying) rate in kilogram of moisture per hour.
- Temperature to be maintained in the dryer. (Since certain materials are susceptible to heat, they can get decomposed).
- In case of products not affected, higher temperature can be maintained. The heating medium could be steam, heat transfer oil, electricity etc.
- Ease of taking out or repairing the heating coils.
- In case of the product being affected by higher temperature, the drying operation can be done by using hot water as heating medium and operating the unit at vacuum up to 700 mmHg, or even more (i.e. absolute pressure can be 10 mmHg or even lower).
- Material to be dried per tray. (Capacity of each tray as dry material in kilogram.)
- MOC of trays and internals. In case of evolution of acidic vapours, the inside should have acid-resistant coating of fibre reinforced plastic or special anti corrosive paint.
- Instruments provided: temperature gauge, vacuum gauge, relative humidity gauge etc.
- Light glasses and sight glasses to observe condition of trays and materials.
- Exhaust fans (induced draught to suck out moist air) and air injection fans for ensuring proper hot air circulation inside.
- Details of heating area: (whether flat plates/steam coils/others) provided by vendor.
- Number of trolleys that can be loaded in (trays with moist material are generally arranged on slots provided on a trolley.)
- Door sealing arrangements.
- Scrubber for vapours coming out, if any. This depends on properties of the material.
- Control valves for heating medium circulation in different parts of the dryer.

E.4 Rotary Kiln with Girth Gear Drive

Heat-sensitive products are heated in a co-current manner. Burners/hot air supply nozzles are located at the feed end of the wet products. The dried material comes out at a lower temperature (Fig. 3).

If the product is not heat-sensitive, it can be heated in a counter-current manner. The dried material comes out at a higher temperature and arrangement for cooling is required. The refractory lining is done internally to protect the steel shell. The innermost layer can be of high alumina (45 % Al_2O_3 or even higher) bricks and the layer nearer to the shell is generally of insulating bricks. Ceramic paper of 3–6 mm thickness can be used between shell and insulating bricks for improving insulation.

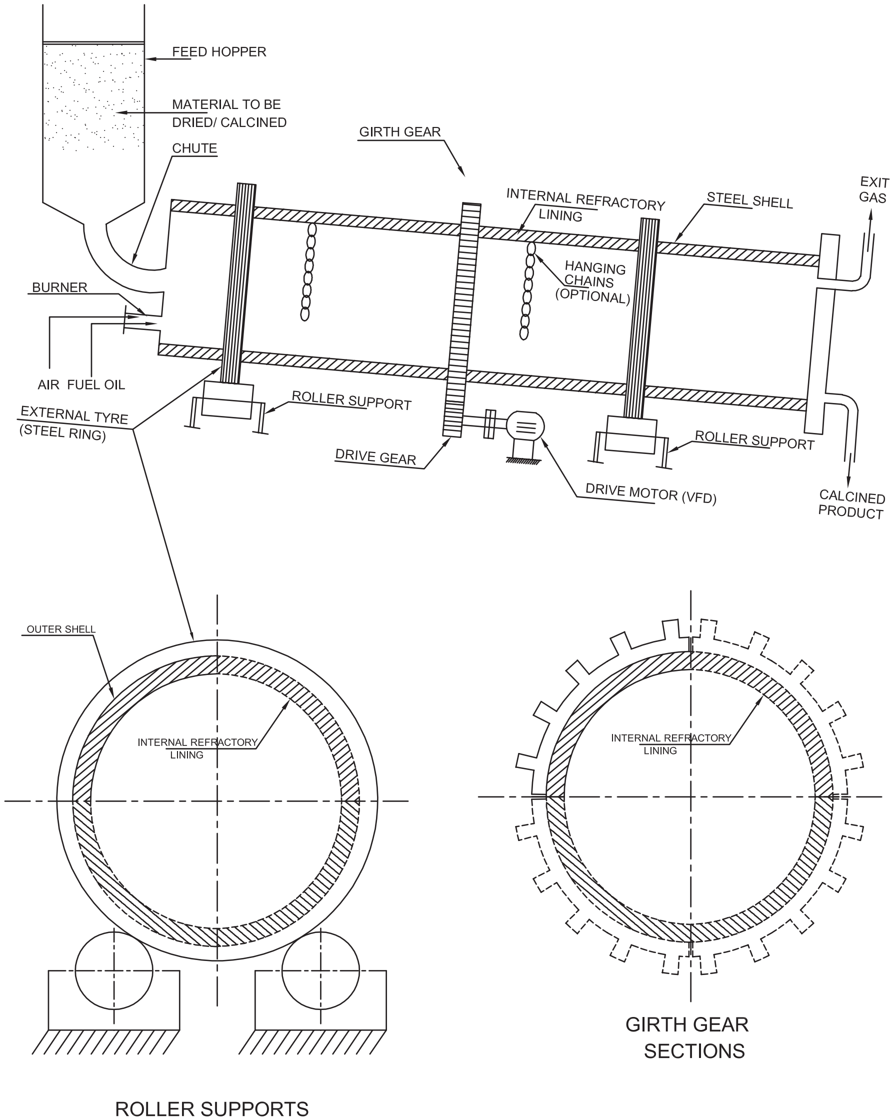


Fig. 3 Rotary kiln with girth gear drive

A long rotary kiln can be constructed from many sections for ease of replacements. These sections can be bolted together and can have ceramic paper as gasket material between two sections.

The slope is generally 3°–5° and the speed of rotation is adjusted by VFD so that the residence time of material is adjustable by varying the speed of rotation. *It is generally 2—12 h.*

Supporting rings for the rotary unit: These should be easily removable if they are made in sections and are bolted to cleats welded on the rotary unit. Position and number of roller supports for the rotating unit.

The girth gear is generally located suitably between the roller supports. Design of girth gear can be in sections *to enable quick replacement of any damaged portion* rather than removing the entire girth gear. All components of the drive mechanism should be designed by considering as if the entire rotary unit is full of material and is operating at maximum design speed. The gear box and motor should be rated at 150 % above full load.

Dial thermometers are to be provided at regular intervals of, say, 2 m each, on the outer steel shell to monitor heat loss. *Any abnormally high temperature can indicate damage to internal brick lining.*

Heavy chains are sometimes provided inside for better heat transfer from hot gases to the material. The steel chains should, however, be able to withstand the operating conditions of temperature and any possible chemical attack from the material being dried/calcined.

Scoops can be provided to lift up the material during the rotation and allowed to fall through the hot gases. Ring dams are also offered to increase the residence time of the material, *but there are chances of clinker formation if overheating occurs.*

Samples of feed material may be given to vendor for estimating the calcination/drying time required. Heat recovery is possible from the exit gases which can preheat the incoming wet feed material. The vapours released should be removed by ID fan. A cyclonic dust separator may be required at discharge end of flue gases with bag filters and ID fan as optional equipment to suck and clean the exit gases. A scrubber should be used if the exit gases contain pollutants like SO_2, HCl.

Heat recovery unit may be considered for the products coming out at high temperature during counter-current operation. It can cool the products also. If this is not possible, one may provide a water filled tank for collecting the hot product falling out from the rotary unit.

Information to be Given to Vendor

- Material to be dried (calcined) and its physical as well as chemical properties (size of particles, density, abrasive nature of the feed material, likely reactions at high temperature inside)
- Whether co-current drying is to be done or counter-current drying? (Those materials getting spoilt/deteriorated at high temperature should be dried in co-current fashion).

- Maximum operating temperature permissible inside so that product is dried as per requirement without getting decomposed/fused/spoilt in any manner.
- Analysis of product required at the exit end of the kiln.
- Purchaser must inform specifically the presence of inflammable material, presence of toxic compounds in the material to be fed.
- Initial moisture content of the wet feed.
- Final maximum moisture content (which should not exceed) in the dried product.
- Feed rate of moist material in kilogram per hour.
- Temperature at which material is fed in.
- Space available at site (length × breadth × height).
- Feed hopper will be installed or not? Capacity of feed hopper planned.
- Fuel to be used/any other heating method preferred for drying of material.
- Properties of material: any caking tendency, or particles getting crushed on tumbling.
- Any formation of fine dust from the dried materials which may need cyclone separator/bag filters.
- Generation/release of any dangerous, toxic, inflammable vapours: these will have to be scrubbed or condensed and recovered. Suitable arrangement like scrubber, ID fan or condenser should be required.

Vendor should Inform/Confirm the Following

- Diameter and length of the rotary shell.
- Thickness of shell should not be less than 12 mm. Boiler quality steel should be used since these units run at high internal temperature for long time continuously.
- Internal lining details (e.g. type of insulating and refractory bricks used, their alumina percentage, thickness of layer, castable refractory, expansion joints provided. (Vendor to submit copies of their test certificates giving chemical analysis, refractory properties, thermal conductivities if asked for by the purchaser. The expected maximum temperature at outer surface of the shell should not normally exceed 60—65 ºC.)
- Method of heating by oil firing, gas firing or by hot process gas. Accessories and safety devices included by vendor in his scope of supply for the method of heating.
- Position of burners and safety interlocks provided if flame gets extinguished or temperature goes very high.
- Capacity and discharge pressure of air blower.
- Drive system details, girth gear MOC, motor horsepower, speed variation arrangement (PIV or electronic speed controllers) provided.
- Feeding arrangement for the incoming moist material.
- Instrumentation provided for the kiln

E.5 Control Valves

Used for assisting the plant operator for safe operation of plant, minimize environmental pollution control, maintaining product quality and energy recovery.

- *Process control, i.e. temperature, pressure, flow rate, concentration etc. of the raw materials, reactor operation and products.*
- *Level control in process tanks by control of inputs and outputs.*

The following should be carefully considered while purchasing control valves for the plant:

- Which operating condition of temperature, pressure, pH, melting and boiling points, viscosity at minimum and maximum operating temperatures is to be controlled?
- At which point it is to be controlled (at reactor inlet, condenser exit, ETP exit etc.).
- *Highly viscous liquid can cause the control valve plug to get stuck up or will not move properly—thus delaying control action. More force will be required here to operate the valve and hence choose the actuator accordingly.*
- Composition of gas mixture whether it contains toxic, inflammable or explosive gases.
- Moisture content and acidic particles: These can corrode control valve internals.
- Suspended particles: concentration, size distribution, (minimum and maximum size in microns) acidic, oily or sticky or erosive nature.
- Dew point of gas mixture.

Control Action Required

- Whether the required process condition is to be controlled within a broad range or a narrow range of optimum value (set point). For example, a furnace temperature is to be controlled at 700 ºC by fuel feed control. If the broad range is 650–750 ºC, it can be maintained by switching on or off the valve in fuel supply line, i.e. either full open or full closed.
- If temperature is to be controlled within a narrow range (say 690–710 ºC)—here the valve is slowly operated as per signal received from temperature sensor. The control valve accordingly will function with a smooth action (for fuel oil supply to furnace) for flow adjustment by throttling—*this is fine control.*
- Fine control is also required if product quality depends on accurate control.

Operating Method Control valves can be operated either manually, electrically (motorised, solenoid), pneumatically or hydraulically. The method of operation depends on process requirement, location of control valve (at remote place, at a great height, in high temperature zone, in dangerous areas) and force required to operate the valve.

Types of Control Valves for Solid Feeding

- Dampers at bottom of bins: Manual/chain operated or through levers. These can open or close as per level inside the bin.
- Air lock rotary valve: Manual or motorised (with constant speed or with speed control). These are generally gas tight and feed solid powders into a unit operating under pressure or under vacuum. They can provide fine control action by the speed variation.

General

- Rising stem with external indicator pointer for the valve opening positioning.
- Butterfly valves with external indicator lever/pointer for the valve opening positioning. This can have locking arrangements also.
- End connection: flanged or screwed.
- Gland packing: rubber, polytetrafluoroethylene (PTFE), ceramic fibre etc.
- Glandless valve: internally operating stem

Important Consideration for Proper Functioning of Control Valves Sensors should be installed at appropriate locations in the process unit (raw material feed lines, in the reactors, or in the product lines) for sensing to detect the actual value of the parameter.

Signals: Signal is sent from the sensor to the measuring instrument by means of connecting cables or mechanical link or change in pneumatic/fluid pressure. The desired values of the process parameters are generally known or are designed in the beginning.

- Connecting links—the mechanical, hydraulic, electrical links which activate the valve plug through the connected stem.
- Set points are the lower and higher limits from the optimum value of the process parameter. It is expected that the control valve will function to maintain the process within these limits.

Error signal: The difference between the set point/desired value of the parameter and the actual value is compared and a corrective action is initiated. This can be done manually or automatically by the valves for automatic control.

- System capacity and delay/time required
- Action required—on/off or proportional to deviation
- Actuator operated by—power, hydraulic, mechanical link, springs, pneumatic

Main Components of the Control System Sensors: Signal is sent from the sensor to the measuring instrument by means of *connecting cables or mechanical link or change in pneumatic/fluid pressure.* The desired values of the process parameters are generally known or are designed in the beginning.

Actuators are generally of the following types:

- Electrical, (motorised or solenoid control)—avoid for inflammable material
- Pneumatic—all piping should be leak tested
- Hydraulic—all pipes should be leak tested
- Mechanical (operated by a link or by a spring)—should be very sturdy

Amongst these the hydraulic actuators can produce more forceful action compared to electrical actuator, because high pressure hydraulic oil can be made available in the plant. In case of a process plant where inflammable vapours are present the electrical controllers should be flameproof. However, hydraulic controllers can be used in such a situation.

The pump developing high pressure for the hydraulic oil can be located in a separate area where flame-proof electrical fittings may not be necessary. However this needs accessories like oil tank oil cooler and high pressure pump.

In case of spring actuated controllers there is a chance of the spring getting jammed or corroded and hence control action may not be as desired/quick.

They operate the control valve element (plug/diaphragm) to control the fluid pressure, flow etc. After this the change in value of the parameter is measured and again compared with desired value.

Indicator for movement of the plug in the valve should be available outside, e.g. a rising pointer on a scale attached to the valve should read zero when the valve is closed and 100 when it is fully open.

Selection of Control Valves Depends on the Following Considerations (A typical example is given below for fluid flow control)

- Accuracy desired for the value of controlled variable.
- Location of the valve: Presence of dusty atmosphere, corrosive gases nearby, high temperature area, outside installation etc.
- Speed of control depends on response time of sensor, location, time for transmission of error signal (i.e deviation from set point), force available to operate the valve plug.
- *Pneumatic actuator–High pressure air is made to act on the diaphragm in a control valve as per the error signal. Greater the error, more will be the pressure. The diaphragm will push the valve plug on the seat and try to close it. A spring is attached to open the valve plug. When the error signal reduces the valve will open again due to pull exerted by the spring. In case of hydraulic system, high pressure oil actuates the valve. The force is much more in this case and can be used for viscous fluids.*
- Effect of control action depends on the capacity of system, e.g. if the flow rate is being controlled at inlet, the change in system will depend on volume of the process unit.

- Feed back control: A small pilot line connects the discharge side pipe of a flow control valve to the actuator/diaphragm. Any increase in flow beyond the required flow is sensed and conveyed to the actuator which then throttles the valve plug to reduce the flow. This pilot line diameter should not be less than 10 % of diameter of main downstream line or else it will not convey the downstream conditions fast enough or may get choked.
- Similarly a higher pressure on the downstream side of the pressure control valve is sensed and conveyed to the actuator. It then throttles the valve plug to reduce the pressure till it reaches desired value.
- If the purchasers specify a narrow range of desired values then they should purchase a control valve with smooth continuous action by the actuator. However, if a broad range is specified then a on/off type control valve may be used.

End Connections of Valves Flanged type should be used in case of high pressure fluids or toxic material flowing through the control valve. It should be tested at 150 % of the working pressure. Screwed type connection can be used for low pressure service or where dangerous fluids are not being handled.

E.6. Product Despatch

Purchaser should install the following equipment so that the products can be despatched correctly in order to build up consumer confidence. Some common equipment for despatch of solid products are:

1. Feed conveyor
2. Storage hopper
3. Rotary star valve
4. Weighing and stitching machines
5. Conveyor for carrying away bags

These should be procured after taking into consideration the delivery schedules, if any special type of bags are desired by clients, or convenience for loading, capacity of the storage ware house, production rate, distance over which the material is to be moved, up to delivery stations. Inflammable, toxic, explosive nature of the solids must be kept in mind while procuring the above equipment. Suitable fire fighting arrangement should be installed at the loading point if required.

E.6.1 Solids

- MOC of bags containers, drums, boxes: Compatible with properties of solids (HDPE/with PE liner/jute/paper)
- Capacity: Generally 50 kg/bag; 20bags/MT.

- The solids can be filled in MS drums of larger capacity also.
- Accuracy of automatic bagging machines: +0.2 kg (desirable) and +0.3 kg max permissible.

E.6.2 Liquids

Containers should be made from material of construction compatible with the liquid.

Carbouys

- Capacity of the carbouys can be 20–50 kg. They should have tamper-proof seals. It is advisable not to carry corrosive or dangerous liquids manually in carbouys of more than 20 kg capacity each.

PP/HDPE Cans (5–10 L) can also be used.

Important: The carboys should be subjected to:

a. Stack test, i.e. stacking one above other 5–6 numbers
b. Drop test (dropping from a height of 3–4 m) before filling with the product. They should have strong handles. The bottom should have grooves, which will mesh on top of other carboys to enable their stacking vertically without tumbling easily. Wooden pallets/sand bed may be used for transporting by trucks.

Tankers It may be better to own a fleet of tankers rather than asking outside party to transport liquid products (because delivery schedules can be adhered, better maintenance can be carried out and safety can be ensured)

Following should be considered if tankers are to be purchased.

MOC can be mild steel MS, rubber-lined MS, stainless steel tankers and this should be compatible with the liquid. These may be having partitions (separate storage sections) as per need, to reduce excess vapour generation when tanker is moving.

Fittings like separate drain valve for each compartment, safety valves, earth connection by hanging chains/other approved means by statutory authorities, vent valves and arrangements with air compressors for completely emptying out the contents should be provided on the tankers.

Note: Tare weight, (empty container); loaded weight (full) container) and contents should be clearly mentioned along with *hazardous chemical classification* and precautionary measures on the tankers. A checklist should be prepared and should be available with the driver. Drain valves should have a blind fixed (at outlet) to prevent accidental draining. The operating spindles should be locked.

Insulated Tankers: These are used for maintaining temperature of the liquid inside. The insulation and cladding must be checked before filling the tankers.

Samples: must be drawn randomly from bags/each compartment of tankers and preserved as reference. Special sampling kits should be procured for drawing out samples of corrosive/toxic/inflammable/fuming liquids.

Weigh Bridge: For regular despatch of materials in truck or tanker loads. Computerised data of vehicle entry (date/vehicle No/Customer's name & address/destination/quantity and name of material despatched) should be recorded in the system and this data should be preserved. The weighbridge should have a capacity range 10–100 MT as per need and good approach roads should be made.

Space should be available around the weighbridge for movement of vehicles. Dewatering pumps should be installed at the weighbridges to eliminate water logging. Accuracy of weighbridge should be + 0.05 % of maximum capacity, i.e. an error of not more than 10 kg in 20 MTS. The load cells should be easily approachable for maintenance and replaceable.

Scrubber: Portable scrubber/permanent scrubbers should be procured and installed for taking care of fumes coming out from tankers or connecting pipes during loading of certain chemicals like HCl, oleums etc. The spent scrubbing liquor should be sent to ETP. Dry compressed air may be made available for flushing the connecting pipelines before and after filling of tankers.

Gaseous Products: Gases like Oxygen, Nitrogen are filled up under high pressure. All the fittings should be tested to be leak proof at up to 150–200 kg/cm^2 and approved by statutory authorities. Gas cylinders should be *procured from approved manufacturers only* and should have serial no, test pressure, date of discontinuation from service marked. Separate record should be kept for each of the gas cylinder procured. The valves should be tested prior to purchase. Only standard colour code should be followed, e.g. yellow for chlorine, black for oxygen etc. by the manufacturer.

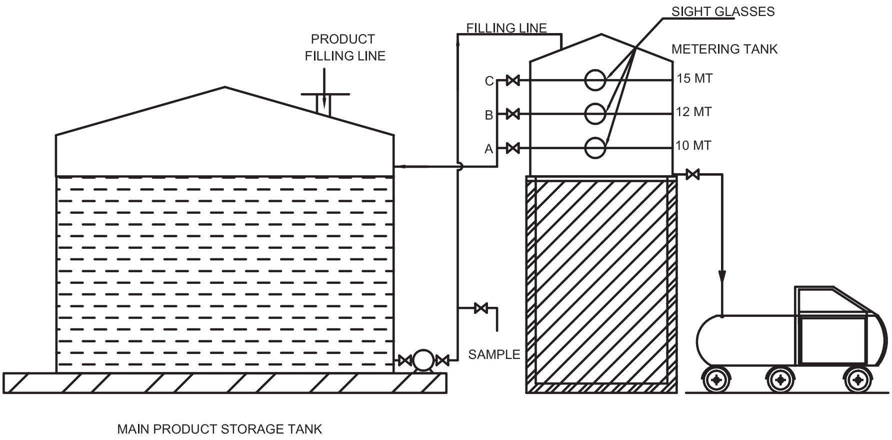
Rejected Material System: Separate storage tanks and pumping systems for receiving, transferring, recycling and purifying materials which may be sent back by customers due to off-spec quality should be in place. Such material should be carefully analysed and reasons determined for any deficiency.

Corrective action should be immediately initiated for either purifying it, building up concentration if necessary or recycling it back in to process plant.

If none of this is possible, it may be used by customers who may not specify very stringent specifications as they may consume it for some less important use. In some isolated cases a lower strength material can be combined with more concentrated material to meet the customer's specification. Such practices should not be resorted to as far as possible. Records should be maintained for such rejected materials.

E.6.3 Metering Tanks

In order to deliver correct quantity of the liquid every time into a tanker (so that there is no controversy regarding amount of liquid filled in), metering tanks having known and calibrated capacities may be erected at a convenient height. They are filled up every time up to the mark (with overflow connected back to the main storage tanks) and then filled up in road tankers. This system is costly but may be installed, as it is foolproof. *Please refer to Fig. 4 given below.*



VALVE POSTION	METERING TANK FILLED UPTO
A -VALVE OPEN	10 MT
A - VALVE CLOSED, B - VALVE OPEN	12 MT
A,B - VALVE CLOSED, C -VALVE OPEN	15 MT

Fig. 4 Metering Tanks

Appendix F: Other Essential Services and Facilities

F.1 Laboratory Facilities

Process control laboratory is very useful for safe, pollution-free operation of plants while minimising cost of production and ensuring product quality.

The Following Important Jobs Depend on the Lab

- Analysis of raw materials and assistance to purchase department.
- Analysis of finished products, and to confirm that product meets specifications given by customer and thus assistance to sales department.
- Analysis of materials after initial treatment (drying, calcination, filtration etc.) before feeding to process plant.
- Process control at every stage by checking all streams (all important parameters).
- Assistance during commissioning and plant stabilisation.
- Assistance during performance guarantee run.
- To assist plant operators for safe working (when they are processing dangerous/ toxic chemicals) by confirming the compositions of the reaction mass for every batch.
- To assist production engineers for trouble shooting problems in process or when unexplained consumptions of materials occur.
- Assistance for process yield estimation, material balance and cost of production.
- Determining reasons for abnormal corrosion of plant equipment.

- Effluent analysis (before and after treatment) for pollution control.
- Advice on materials of construction.
- Modification of present process.
- Development of new process/new products.
- To develop treatment schemes for any product which is not meeting specifications and should be recovered or disposed off properly.
- Analysis of raw materials and finished products.
- Assistance for process control during commissioning.
- Assistance during performance guarantee runs.
- Assistance for process yield estimation, material balance and cost of production.
- Determining reasons for improper product quality.
- Effluent analysis (before and after treatment).
- *Investment in laboratory apparatus/equipment* which give accurate results in the shortest time is a must. Since the laboratory apparatus/facilities required depend on the individual processing plants, these items should be procured in consultation with the shop floor personnel only. However it is suggested that *instruments for online process monitoring* should be installed as far as possible so that changes in process conditions can be immediately monitored and control actions initiated early. These instruments are helpful for automatic process control.

The cost of installation and maintenance of these instruments should be compared with delay due to collection of samples from the process units, bringing them to the laboratory for analysis and the initiating corrective actions.

However, calibration of instruments and cross checking of the readings show by instruments should be done by laboratory analysis regularly, and when in doubt.

Following is a general list for procuring the lab apparatus. This should be augmented as per need for the plant in consultation with plant engineers.

- Apparatus for qualitative and quantitative analysis
- Ovens and fume chambers
- General glass apparatus—flasks, pipettes, burettes (auto)
- High volume samplers aspirators, dryers, electronic balances, magnetic stirrers, sieves for screen analysis
- Soxhlet apparatus, condensers, distillation stills, filters
- Bomb calorimeters
- Analytical reagent (AR)-grade chemicals
- Plant for distilled water

It is also suggested to provide the power supply to sensitive instruments through voltage stabilisers only, with a backup battery.

F.2 Maintenance Facilities

“A stitch in time saves nine”—this very correctly sums up the importance of timely maintenance. Serious problems like equipment failure, fires, heavy environmental pollution, loss of life due to heavy leakages of chemicals etc can be prevented by carrying out condition monitoring and preventive maintenance. Since chemical industries are more likely to have equipment failures (mainly due to corrosion) it is very important to have in-house facilities for maintenance work.

Condition Monitoring and Preventive Maintenance The temperatures, pressures, flow rates, pH, current drawn by drive motors for the process units and machinery in the plant should be regularly checked. The observed values should be always compared with instructions from plant manager. These should be, however, within maximum limits given by manufacturer. In case of any doubt senior engineers should be immediately consulted.

High noise levels, vibrations, abnormal surface temperatures, strange smells should be looked into, the reasons investigated and corrective action taken to prevent any mishap, environmental pollution, deterioration in product quality and damage to plant equipment.

It is advisable to have instruments and devices for detecting conditions detrimental to equipment life and for carrying out preventive maintenance. Some of these are as follows:

- Ultrasonic thickness testers
- Vibration analysers for rotating machinery
- Dial gauges for checking alignments
- Tong testers for checking electrical load conditions
- Handheld (portable) infrared temperature detectors
- Thermographic imaging cameras
- Dial thermometers, standardised temperature measuring instruments
- Orsat apparatus (for gas composition analysis) for detecting malfunctions of scrubbers/process reactors etc.

Maintenance Facility It will be found very useful to carry out routine maintenance and minor corrective repairs to the equipment by own technicians. This will reduce down time and costs which may be incurred if such jobs are done by external parties.

Some examples of routine and minor maintenance activities are as below:

- Preventive maintenance of all equipment as per the planned schedule.
- Condition monitoring of the equipment as per planned schedule.
- Corrective maintenance of the equipment based on condition monitoring. Examples of such jobs are replacement of bearings, seals, alignment correction, dynamic balancing and machining jobs of minor nature.
- Repair of valves, control valves, steam traps etc.
- *Investment in purchase of maintenance tools and facilities* should be found very useful for safe and smooth working of the plants. Hence the following should be considered.

- A dynamic balancing machine may be installed in-house when the numbers of rotating equipment in the plant are large. This will depend on the quantum of balancing jobs, size of the rotary machines, criticality of the job etc. Technicians should be trained in working on the balancing machine. Plant management should carry out detailed cost–benefit analysis to decide purchasing the balancing machine for carrying out corrective actions to minimise sudden breakdowns.
- Sufficient sets of oxyacetylene gas cutting sets and brazing sets.
- Welding transformers (AC- and DC-based) and special warm, dry storage facilities for welding rods.
- *Welding sets should be with sufficiently long insulated cables (including earth cables). Existing process piping or vessels should not be used for earth connection.*
- Movable tripod stands along with chain pulley blocks of various capacities.
- Separate sets of chain pulley blocks (1–2-5–10 MT), link chains.
- A stock of sealing compounds to arrest leakages from various piping, flanges etc. should always be available.
- Tools such as bearing heaters, bearing and coupling pullers, torque-tightening machines, feeler gauges for checking clearances in pumps/blowers etc should be available at site.
- Calibration/testing of thermocouples by comparing and checking output by mV/mA measurement.
- Calibration/testing of pressure gauges.
- Manual hydraulic test unit (water tank, HP pump, standardised pressure gauge) should be very useful for in-house testing of pressure vessels, pipelines.
- Tong testers (clip-on meters), handheld testers, portable dryers for electrical work.
- Transformer oil filtration and drying unit where a number of electrical transformers are installed and it rains frequently at site.
- Sets of spanners (fixed-/ring-/box- type), Allen key sets, and other common tools of trade for fitters, welders, electricians, refractory work masons
- Crimping tool, cable lug filling and soldering torches, handheld dust blowers (for cleaning electrical mains), fuse extractors
- Portable folding type scaffolding set
- Light folding type aluminium ladder
- Exhaust fans and air circulating fans (pedestal/wall mounted type)
- 24-V lighting system (flame-proof type, if necessary)
- Quick setting cements mixture and quick setting chemical resistant pastes

The list can be made more exhaustive and will depend on individual type of industry.

Equipment for Major Maintenance or Fabrication Optional additional purchases: If more funds are available, one may procure drilling machine, lathes, grinders, shapers, band saws if more repair jobs are to be taken up in house. These can be used for minor fabrication work in-house and hence can be useful for future expansion work also. *However, pressure vessels may not be fabricated in-house as this would require special expertise and statutory licence.*