Example : SYNTHESIZING A NETWORK OF MASS EXCHANGERS

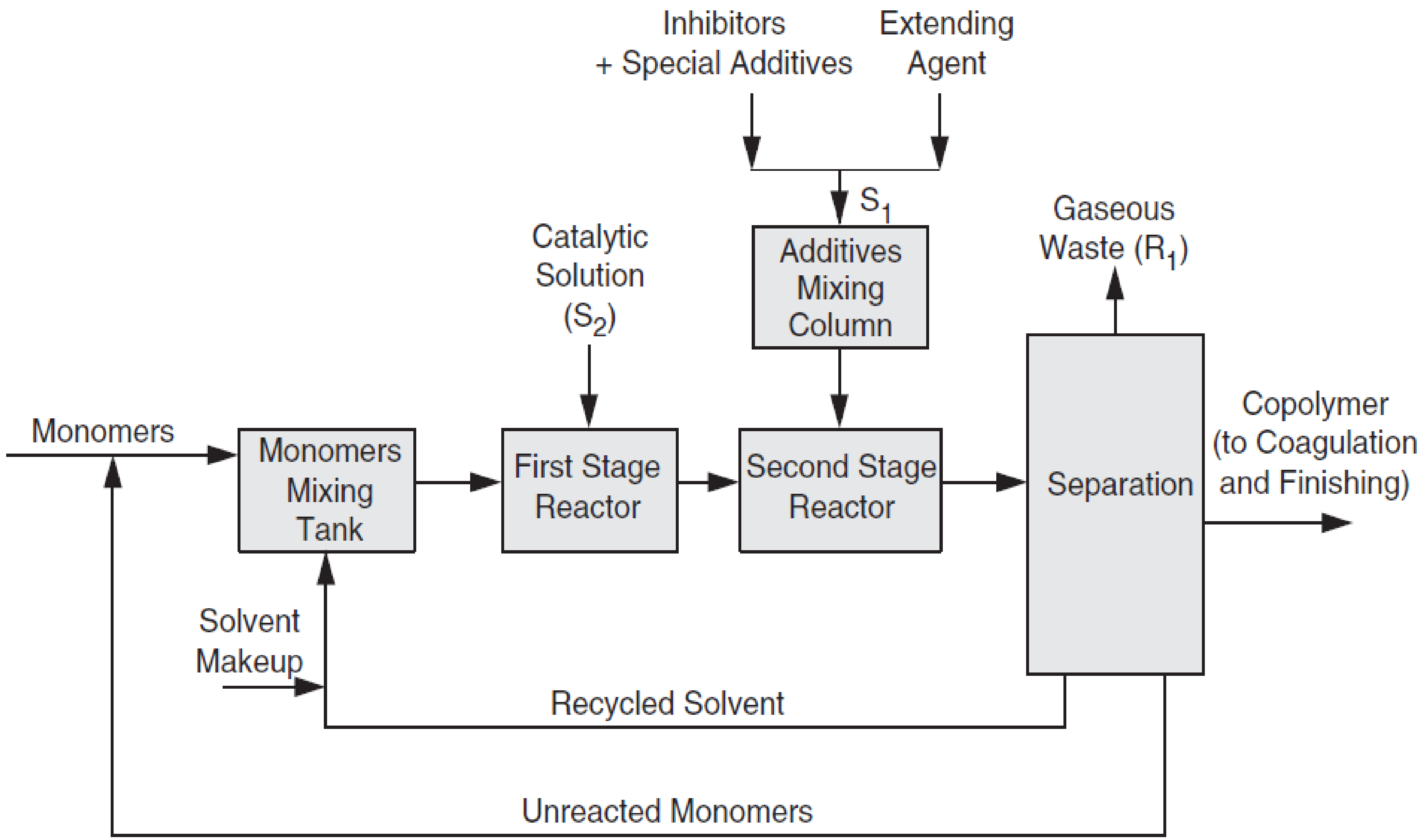
EXAMPLE : SYNTHESIZING A NETWORK OF MASS EXCHANGERS FOR BENZENE RECOVERY

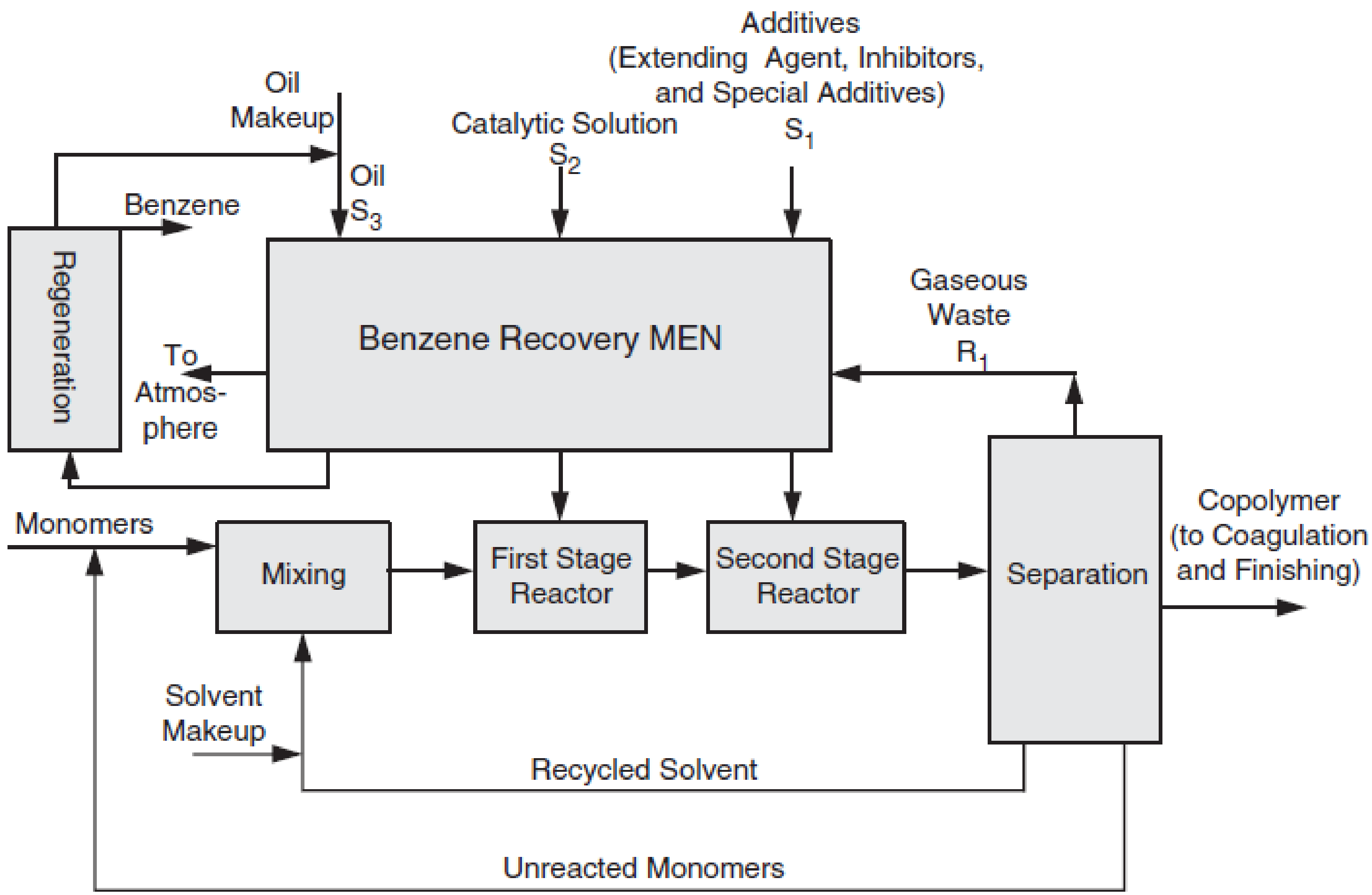
- Figure below shows a simplified flowsheet of a copolymerization plant. The copolymer is produced via a two-stage reaction. The monomers are first dissolved in a benzene-based solvent. The mixed-monomer mixture is fed to the first stage of reaction where a catalytic solution is added. Several additives (extending oil, inhibitors, and special additives) are mixed in a mechanically stirred column.

- The resulting solution is fed to the second-stage reactor, where the copolymer properties are adjusted.

- The stream leaving the second-stage reactor is passed to a separation system which produces four fractions: copolymer, unreacted monomers, benzene, and gaseous waste.

- The copolymer is fed to a coagulation and finishing section. The unreacted monomers are recycled to the first-stage reactor, and the recovered benzene is returned to the monomer-mixing tank.


Inhibitors
+ Special Additives
Extending
Agent
S1
Additives
Mixing
Column
Catalytic
Solution
(S2)
Gaseous
Waste (R1)
Monomers
Monomers
Mixing
Tank
First Stage
Reactor
Second Stage
Reactor
Separation
Copolymer
(to Coagulation
and Finishing)
Solvent
Makeup
Recycled Solvent
Unreacted Monomers



THE COPOLYMERIZATION PROCESS WITH A BENZENE RECOVERY MEN

- The gaseous waste, R_1, contains benzene as the primary pollutant that should be recovered. Two process MSAs and one external MSA are considered for recovering benzene from the gaseous waste. The two process MSAs are the additives, S_1, and the liquid catalytic solution, S_2. They can be used for benzene recovery at virtually no operating cost.

- The stream data for R_1, S_1, S_2, S_3 are given in following Table .

DATA OF WASTE STREAM FOR THE BENZENE REMOVAL EXAMPLE

Stream	Description	Flowrate G_i (kg-mol/s)	Supply composition (mole fraction) y_i^s	Target composition (mole fraction) y_i^t
R_1	Off-gas from product separation	0.2	0.0020	0.0001

DATA OF PROCESS LEAN-STREAMS FOR THE BENZENE REMOVAL EXAMPLE

Stream	Description	Upper bound on flowrate (kg-mol/s) L_j^C	Supply composition of benzene (mole fraction) x_j^s	Target composition of benzene (mole fraction) x_j^t
S_1	Additives	0.08	0.003	0.006
S_2	Catalytic solution	0.05	0.002	0.004

DATA FOR THE EXTERNAL MSA FOR THE BENZENE REMOVAL EXAMPLE

Stream	Description	Upper bound on flowrate (kg-mole/s) L_j^c	Supply composition of benzene (mole fraction) x_j^s	Target composition of benzene (mole fraction) x_j^t
S_3	Organic oil	?	0.0008	0.0085

- The equilibrium data for benzene in the two process MSAs are given by:

$$y_1 = 0.25x_1$$

$$y_1 = 0.50x_2$$

- where y_1, x_1, and x_2 are the mole fractions of benzene in the gaseous waste, S_1 and S_2, respectively.

- For control purposes, the minimum allowable composition difference for S_1 and S_2 should not be less than 0.001.

- The external MSA, S_3, is an organic oil that can be regenerated using flash separation. The equilibrium relation for transferring benzene from the gaseous waste to the oil is given by :

$$y_1 = 0.10x_3$$

Using the graphical pinch approach, **synthesize a cost-effective MEN that can be used to remove benzene from the gaseous waste**

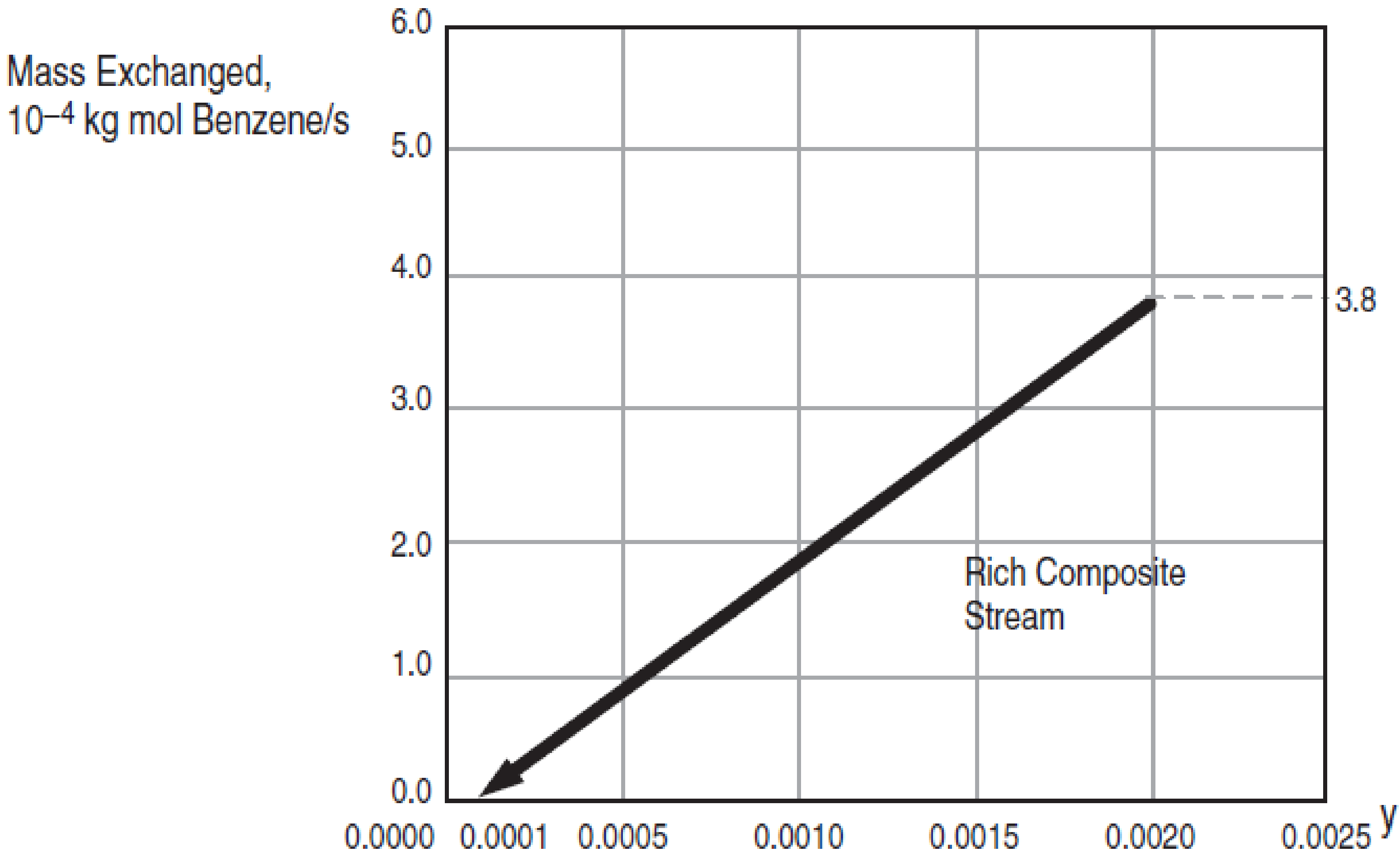
Constructing the Pinch Diagram

- As has been described earlier, the rich composite stream is first plotted as shown in next Figure. Next, the lean composite stream is constructed for the two process MSAs using the relation.

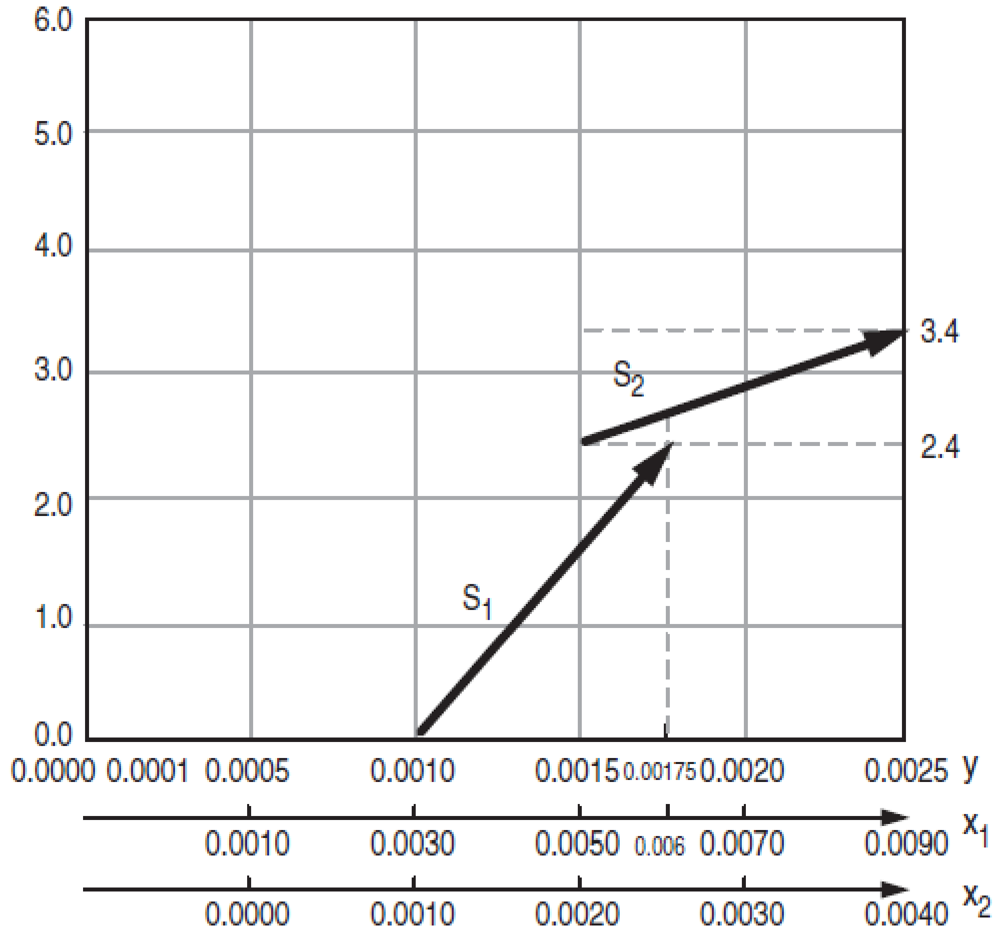
$$x_j^{\max} = \frac{y_i - b_j}{m_j} - \varepsilon_j$$

$$y_i = m_j(x_j^{\max} + \varepsilon_j) + b_j$$

- The least permissible values of the minimum allowable composition differences are used ($\varepsilon_1 = \varepsilon_2 = 0.001$).



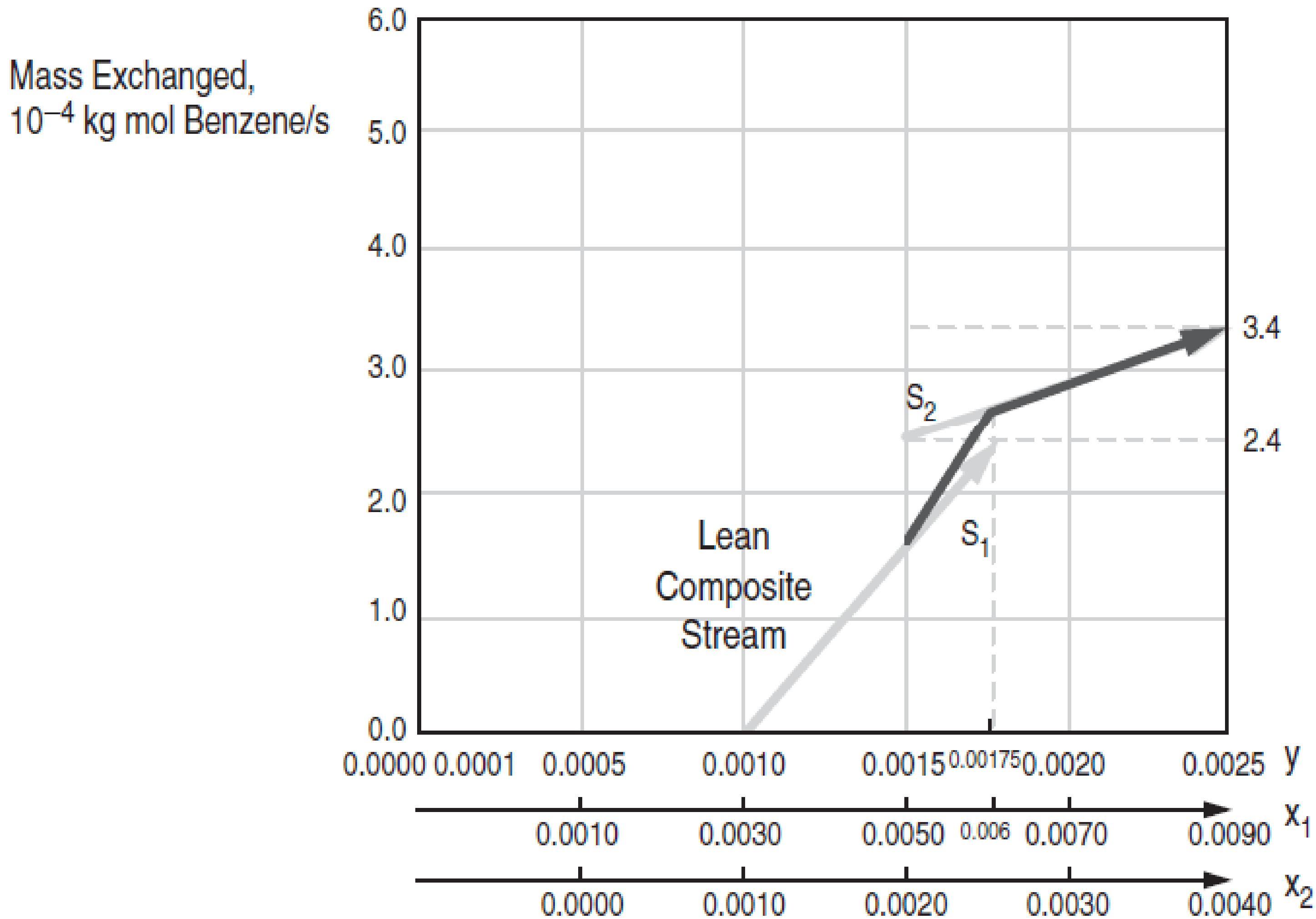
RICH COMPOSITE STREAM FOR THE BENZENE RECOVERY EXAMPLE



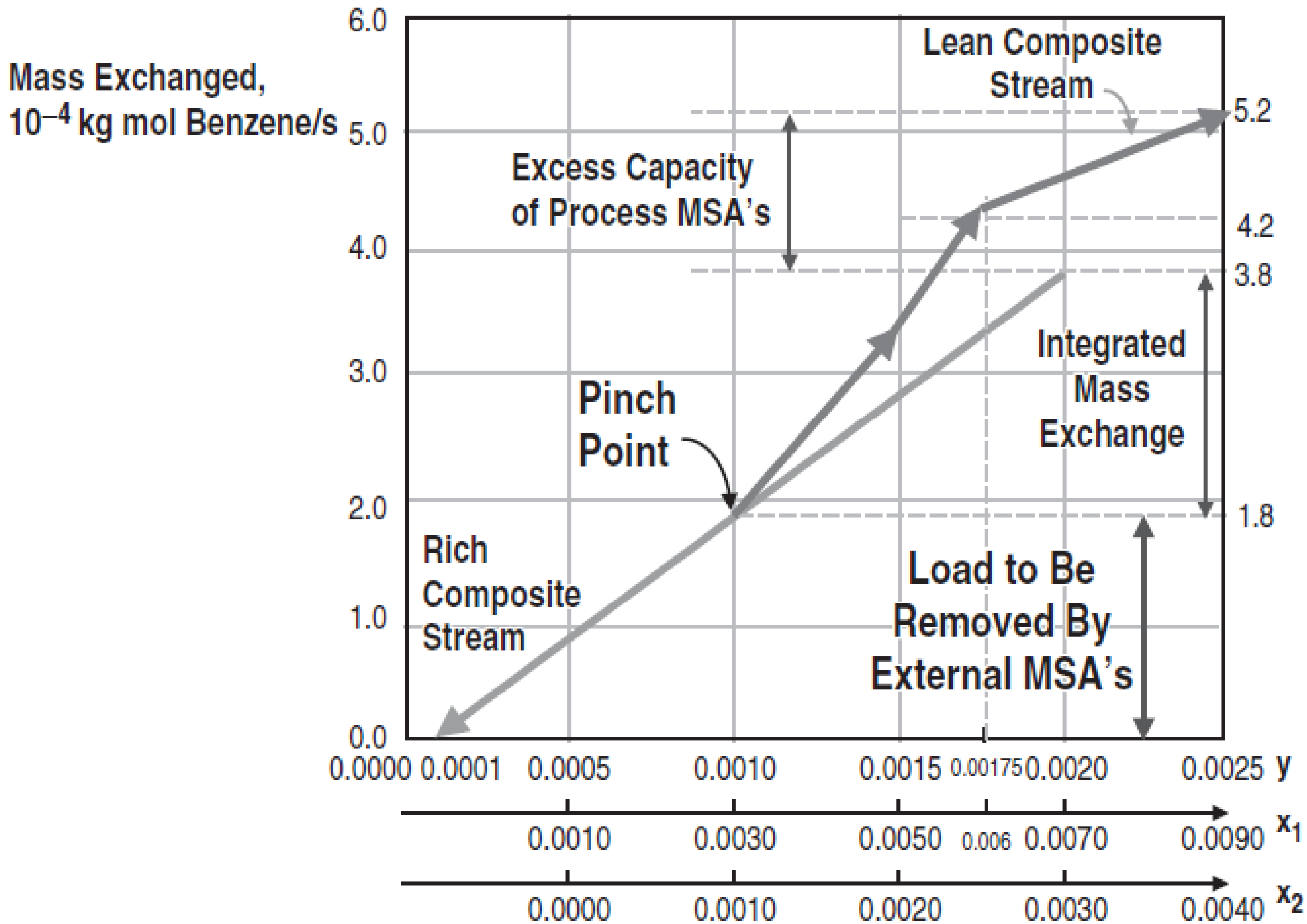
$$x_1 = \frac{y - b_1}{m_1} - \varepsilon_1$$

$$x_2 = \frac{y - b_2}{m_2} - \varepsilon_2$$

REPRESENTATION OF THE TWO PROCESS MSAs FOR THE BENZENE RECOVERY EXAMPLE



CONSTRUCTION OF THE LEAN COMPOSITE STREAM FOR THE TWO PROCESS MSAs OF THE BENZENE RECOVERY EXAMPLE



THE PINCH DIAGRAM FOR THE BENZENE RECOVERY EXAMPLE
($\varepsilon_1 = \varepsilon_2 = 0.001$)

- As can be seen from the pinch diagram, the pinch is located at the corresponding mole fractions (y_1, x_1, x_2)=(0.0010, 0.0030, 0.0010). The excess capacity of the process MSAs is 1.4×10^{-4} kg-mol benzene/s and cannot be used because of thermodynamic and practical-feasibility limitations.

- This excess can be eliminated by reducing the outlet compositions and/or flowrates of the process MSAs.

- Since the inlet composition of S_2 corresponds to a mole fraction of 0.0015 on the y scale, the waste load immediately above the pinch (from y_1 = 0.0010 to y_1= 0.0015) cannot be removed by S_2.

- S_1 alone can be used to remove all the waste load above the pinch (2×10^{-4} kg-mol benzene/s).

- To reduce the fixed cost by minimizing the number of mass exchangers, it is preferable to use a single solvent above the pinch rather than two solvents.

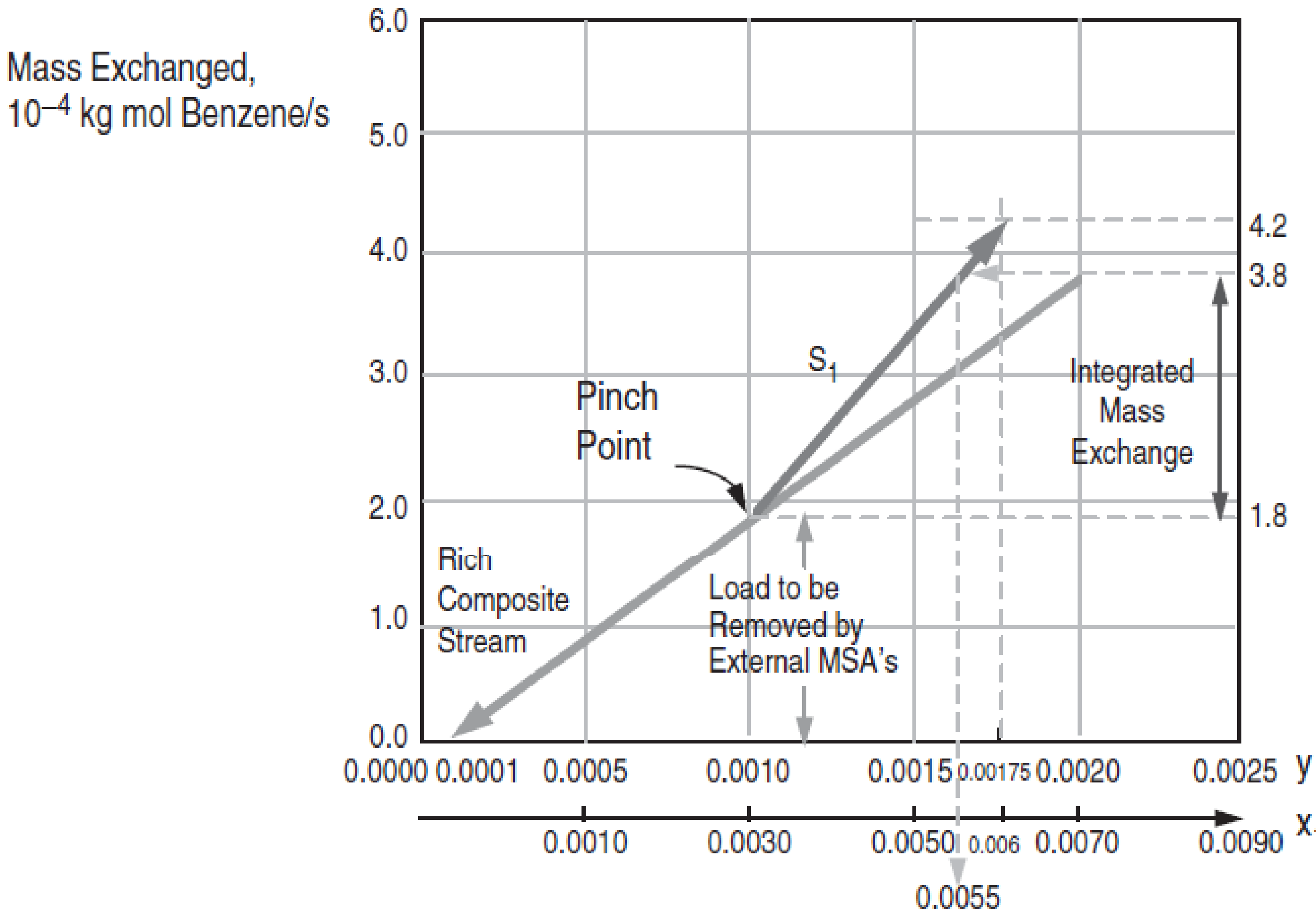
- This is particularly attractive if given the availability of the mechanically stirred additives-mixing column for absorption. Hence, the excess capacity of the process MSAs is eliminated by avoiding the use of S_2 and reducing the flowrate and/or outlet composition of S_1.

- There are infinite combinations of L_1 and x_1^{out} that can be used to remove the excess capacity of S_1 according to the following material balance:
- Benzene load above the pinch to be removed by

$$S_1 = L_1(x_1^{out} - x_1^{s})$$

$$2 \times 10^{-4} = L_1(x_1^{out} - 0.003)$$

- Nonetheless, since the additives-mixing column will be used for absorption, the whole flowrate of S_1 (0.08 kg-mol/s) should be fed to the column. Hence, according to the above equation, the outlet composition of S_1 is 0.0055.



GRAPHICAL IDENTIFICATION OF x_1^{out}

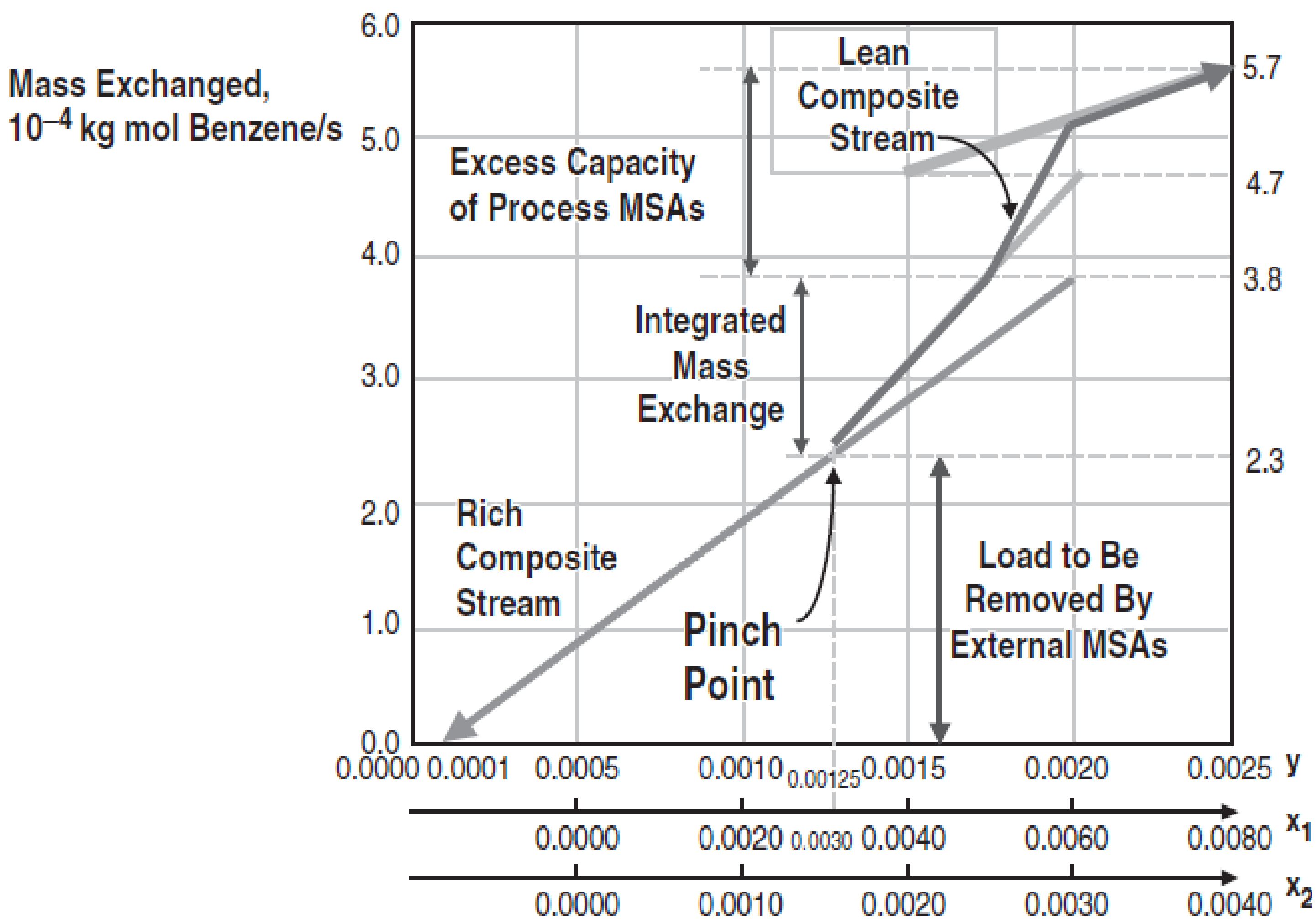
Selection of the Optimal Value of $\varepsilon 1$

- Since S_1 is a process MSA with almost no operating cost and since it is to be used in process equipment (the mechanically stirred column) that does not require additional capital investment for utilization as an absorption column, S1 should be utilized to its maximum practically feasible capacity for absorbing benzene.

- The remaining benzene load (below the pinch) is to be removed using the external MSA. The **higher the benzene load below the pinch**, the **higher the operating and fixed costs**. Therefore, in this example, it is desired to **maximize the integrated mass exchanged above the pinch**.

- As can be seen on the pinch diagram when ε increases, the x_1 axis moves to the right relative to the y axis. Consequently, the extent of integrated mass exchange decreases leading to a higher cost of external MSAs.

- Thus, the optimum $\boldsymbol{\varepsilon_1}$ in this example is the smallest permissible value given in the problem statement to be 0.001.

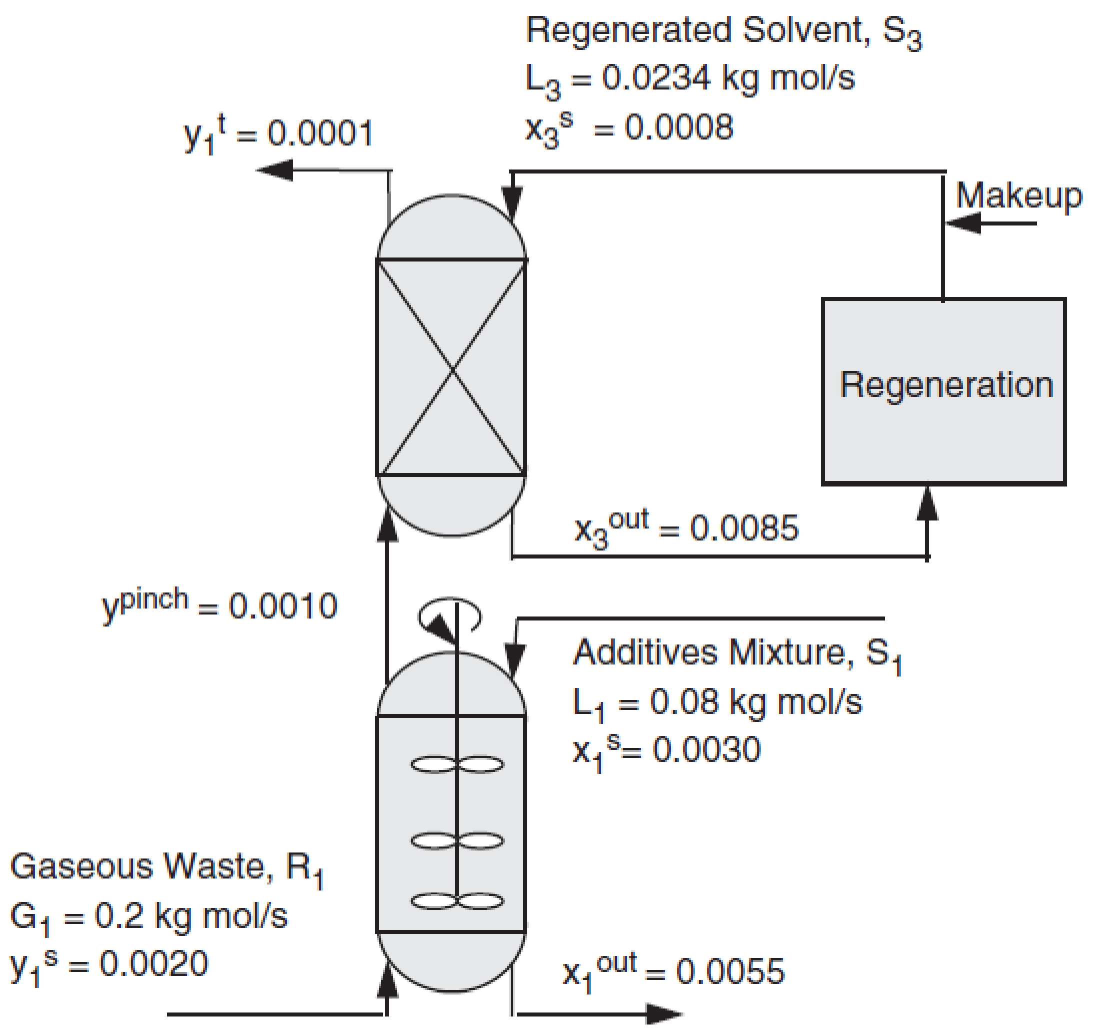


THE PINCH DIAGRAM WHEN ε_1 IS INCREASED TO 0.002

- Benzene load below the pinch to be removed by external $S_3 = L_3(X_3^{out} – X_3^{S})$

$$1.8x\ 10^{-4} = L_3(0.0085 – 0.0008)$$

Thus, flow rate of the oil: $L_3 = 0.0234$ kg-mol/s



OPTIMAL MEN FOR THE BENZENE RECOVERY EXAMPLE