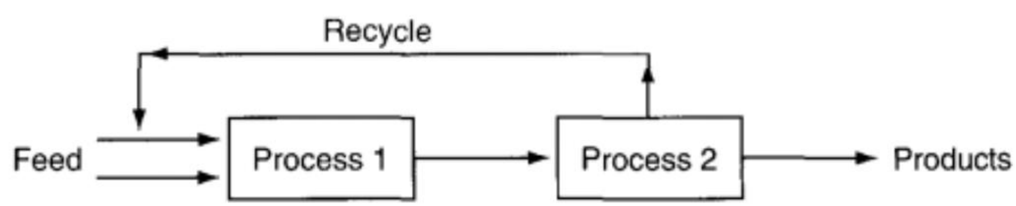
5.1 Product separation and Recycle

Recycle is fed back from a downstream unit to an upstream unit, as shown in Figure . The stream containing the recycled material is known as a recycle stream.

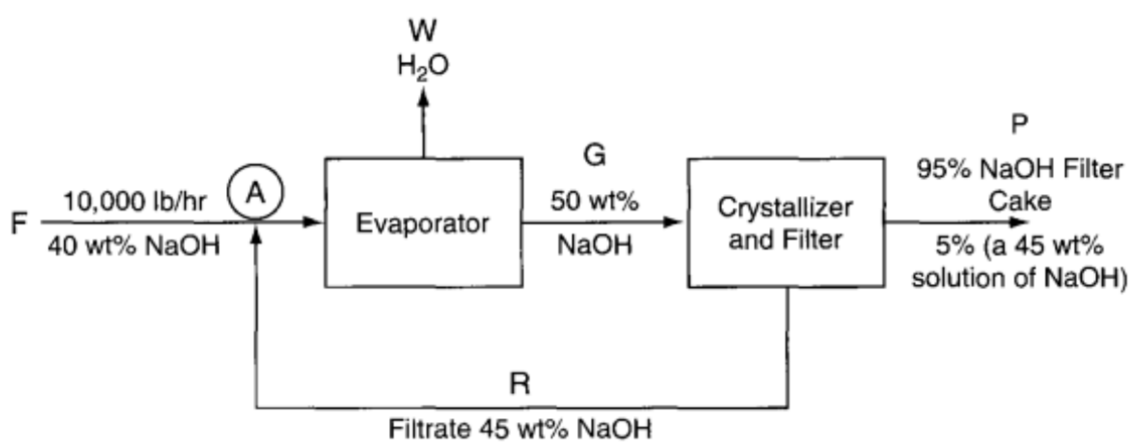
Recycle system is a system that includes one or more recycle streams.



Recycle without Chemical Reaction

Example 1:

Figure below is a schematic of a process for the production of flake NaOH. The fresh feed to the process is 10,000 lb/hr of a 40% aqueous NaOH solution.



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a. Determine the flow rate of water removed by the evaporator(W), and the recycle rate for this process (R).

b. Assume that the same production rate of NaOH flakes occurs, but the filtrate is not recycled. What would be the total feed rate of 40% NaOH have to be then? Assume that the product solution from the evaporator still contains 50% NaOH.

Solution

<u>Open, steady-state process.</u>

a. Basis: 10,000 lb fresh feed (equivalent to 1 hour)

The unknowns are W, G, P, and R.

input = output

Overall NaOH mass balance

(0.4)(10,000) = 0.95 P + (0.45) (0.05) P
P = 4113 lb

<u>Overall H_2O mass balance</u>

input = output

(0.6) (10,000) = W+ [(0.55)(0.05)](4113)
W= 5887 lb

The total amount of NaOH exiting with P is [(0.95) + (0.45)(0.05)](4113)
= 4000 lb

0.5 G = 4000 + 0.45 R (1)

NaOH mass balance on the crystallizer

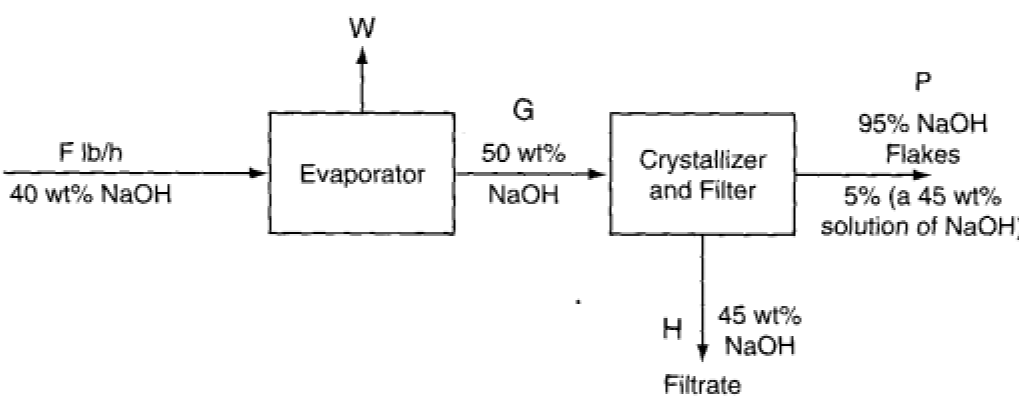
0.5 G = 4000 + 0.45 R (1)

H_2O mass balance on the crystallizer

0.5 G = 113 + 0.55 R (2)

Solving equations 1 and 2 gives:
R = 38,870 lb

b. The basis is now P = 4113 lb (the same as 1 hour)



The unknowns are now F, W, G, and H.

NaOH mass balance on the crystallizer

0.5 G = [(0.95) + (0.05) (0.45)] (4113) + 0.45 H (1)

H_2O mass balance on the crystallizer

0.5G = [(0.05) (0.55) (4113)] + 0.55 H (2)

By solving equations 1 and 2 gives:

H = 38,870 lb

Overall NaOH mass balance

0.40 F = 0.45(38,870) + 4000

F = 53,730 lb

Note that without recycle, the feed rate must be 5.37 times larger than with recycle to produce the same amount of product.

Example 2:

A distillation column sperates 10,000 kg/hr of a 50% benzene-50% toluene mixture.The product D recovered frome the condenser at the top of the column contains 95% benzene, and the bottom W from contain 96% toluene. The vapor stream V enterning the condenser from the top of the column is 8000 kg/hr. A portion of the product from the condenser is returned to the column as reflux, and the rest is withdrawn for use elsawhere. Assume that the compositions of the top the column (V), the product withdrawn (D), and the reflux (R) are identical because the V stream is condensed completely. Find the ratio of te amount refluxed to the product withdrawn (D).

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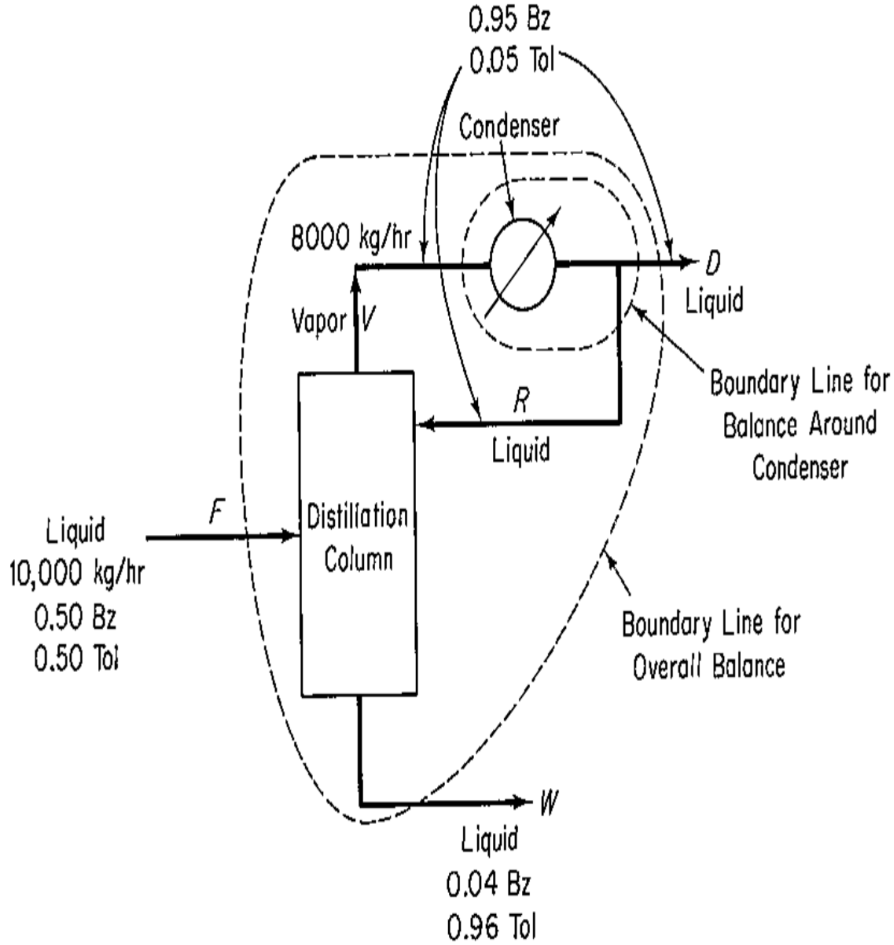
Solution

This is a steady-state problem without reaction occurring.

Steps 1, 2, and 3 See Fig. E2.24 for the known data, symbols, and other information.



Overall Material balances:

Total material:

$$F = D + W$$

$$10{,}000 = D + W \qquad \text{(a)}$$

Component (benzene):

$$F\omega_F = D\omega_D + W\omega_w$$

$$10{,}000(0.50) = D(0.95) + W(0.04) \qquad \text{(b)}$$

Solving (a) and (b) together, we obtain

$$5000 = (0.95)(10{,}000 - W) + 0.04W$$

$$W = 4950 \text{ kg/hr}$$

$$D = 5050 \text{ kg/hr}$$

Balance around the condenser:

Total material:

$$V = R + D$$

$$8000 = R + 5050$$

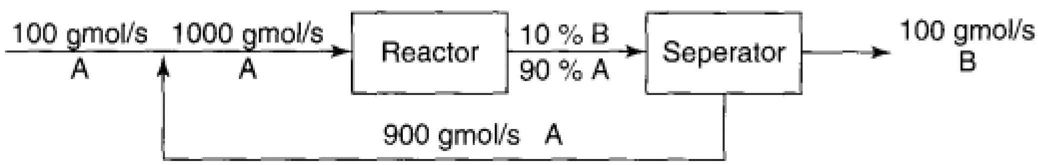
$$R = 2950 \text{ kg/hr} \qquad \text{(c)}$$

$$\frac{R}{D} = \frac{2950}{5050} = 0.58$$

Recycle with Chemical Reaction

The most common application of recycle for systems involving chemical reaction is the recycle of reactants, an application that is used to increase the overall conversion in a reactor. Figure below shows a simple example for the reaction

$A \rightarrow B$



If you calculate the extent of reaction for the overall process based on B

$$\xi_{overall} = \frac{100-0}{1} = 100 \text{ moles reacting}$$

If you use material balances to calculate the output P of the reactor(on the basis of 1 second) you get **A = 900 g mol and B = 100 g mol** and the extent of reaction based on B for the reactor by itself as the system is:

$$\xi_{reactor} = \frac{100-0}{1} = 100 \text{ moles reacting}$$

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Two types of conversion when reactions occur:

1. Overall fraction conversion:

$$\frac{\text{reactant input to process} - \text{reactant output from process}}{\text{reactant input to process}}$$

2. Single - pass fraction conversion:

$$\frac{\text{reactant input to reactor} - \text{reactant output from reactor}}{\text{reactant input to reactor}}$$

For the simple recycle reactor in Figure , the overall conversion is:

$$\frac{100-0}{100} * 100 = 100\ \%$$

And the single-pass conversion is:

$$\frac{1000-900}{1000} * 100 = 10\ \%$$

The overall conversion and the single-pass conversion can be expressed in terms of the extent of reaction, ξ.

Overall conversion of species A= $f_{OA} = \frac{-\nu_A \xi}{n_A^{\text{process feed}}}$

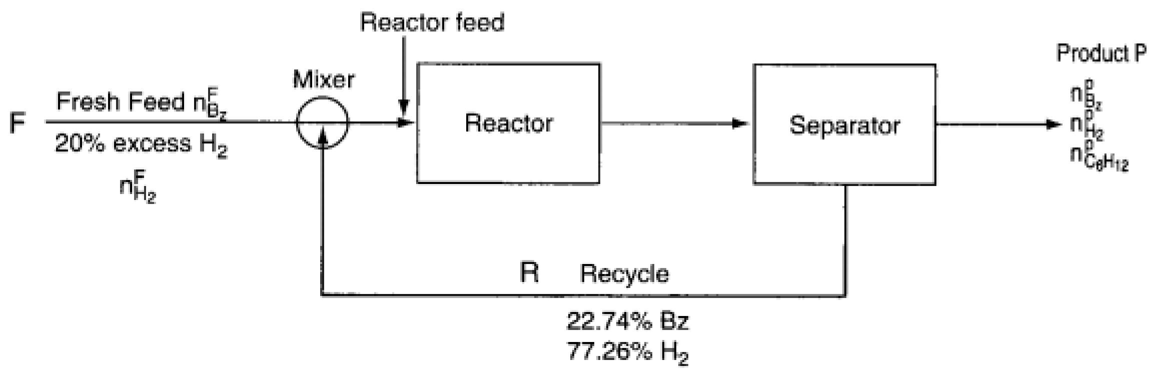
Single pass conversion of species A= $f_{SP} = \frac{-\nu_A \xi}{n_A^{\text{reactor feed}}}$

Example3:

Cyclohexane (C_6H_{12}) can be made by the reaction of benzene (Bz) (C_6H_6) with hydrogen according to the following reaction:

$$C_6H_6 + 3H_2 \rightarrow C_6H_{12}$$

For the process shown in Figure below, determine the ratio of the recycle stream to the fresh feed stream if the overall conversion of benzene is 95%, and the single-pass conversion is 20%. Assume that 20% excess hydrogen is used in the fresh feed, and that the composition of the recycle stream is 22.74 mol % benzene and 77.26 mol % hydrogen.



Solution

The process is open and steady state.

Basis = 100 mol of fresh benzene feed

$$\text{excess } H_2 = \frac{\text{in} - \text{required}}{\text{required}}$$

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In H_2(Feed):

$$0.2 = \frac{\text{in} - 3(100)}{3(100)}$$

In H_2 = 360 mol

The total process feed = 100 +360 = 460 mol

From Equation of overall conversion for benzene (ν_{Bz}= - 1):

$$0.95 = \frac{-(-1)\xi}{100}$$

ξ= 95 reacting moles.

The unknowns are R, $n_{Bz}^{P}, n_{H_2}^{P}$ *and* $n_{C_6H_{12}}^{P}$

The species overall balances are:

$$n_i^{out} = n_i^{in} + \nu_i \xi_{overall}$$

Bz overall balance

$$n_{Bz}^{P} = 100 + (-1)(95) = 5\,mol$$

H_2 overall balance

$$n_{H_2}^{P} = 360 + (-3)(95) = 75\,mol$$

C_6H_{12} overall balance

$$n^{P}_{C_6H_{12}} = 0 + (1)(95) = 95\, mol$$

P = 5 + 75 + 95 =175 mol

The amount of the Bz feed to the reactor is 100 + 0.2274 R, and ξ= 95. Thus, for benzene:

$$0.2 = \frac{-(-1)95}{100+0.227\mathrm{R}}$$

R = 1649 mol

Finally, the ratio of recycle to fresh feed is:

$$\frac{\mathrm{R}}{\mathrm{F}} = \frac{1649\ \mathrm{mol}}{460\ \mathrm{mol}} = 3.58$$

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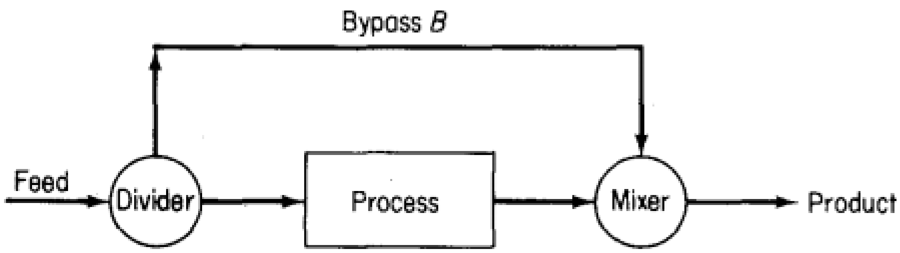
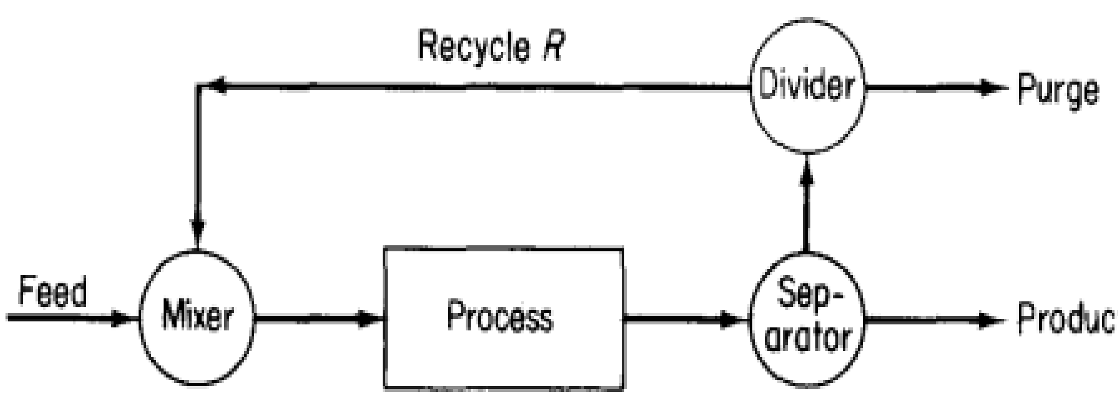
Bypass and Purge

1. A **bypass stream**—a stream that skips one or more stages of the process an goes directly to another downstream stage .



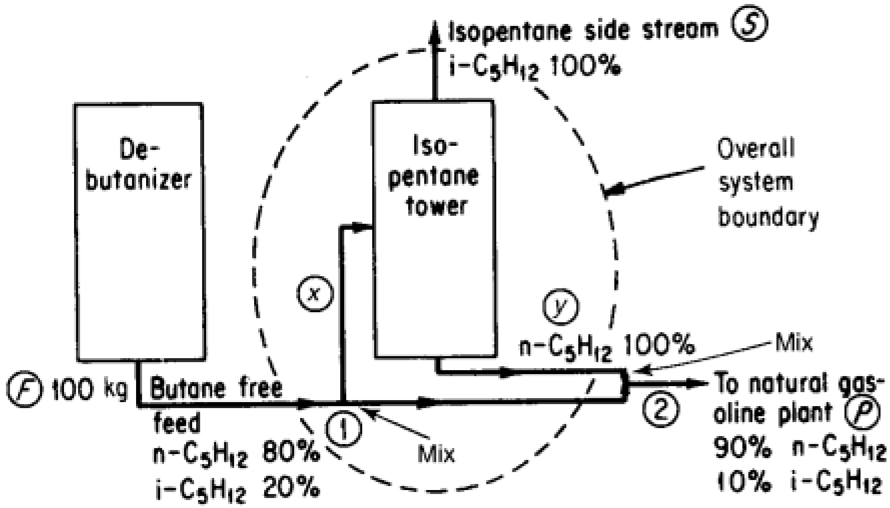
A bypass stream can be used to control the composition of a final exit stream from a unit by mixing the bypass stream and the unit exit stream in suitable proportions to obtain the desired final composition.

2. **A purge stream**—a stream bled off from the process to remove an accumulation of inert or unwanted material that might otherwise build up in the recycle stream.



Example4:

In the feedstock preparation section of a plant manufacturing natural gasoline, isopentane is removed from butane-free gasoline. What fraction of the butane-free gasoline is passed through the isopentane tower? The process is in the steady state and no reaction occurs.



Solution

Basis: 100 kg feed

Overall balances

1. Total material balance:

In = out

100 = S + P

2. Component balance for n-C_5(tie component)

In = out

100 (0.8) = S(0) + P(0.9)

Consequently,

$$P = 100\left(\frac{0.8}{0.9}\right) = 88.9\ kg$$

S = 100 – 88.9 = 11.1 kg

<u>Balance around isopentane tower:</u>

Let x be the kg of butane-free gas going to the isopentane tower, and y be the kg of the n-C_5H_{12} stream leaving the isopentane tower.

3. Total material balance:

In = Out

x = 11.1 + y

4. Component balance for n-C_5

x (0.80) = y

Consequently, combining (3) and (4) yields :

x = 55.5 kg, or the desired fraction is 0.55.

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