## Lecture Thirteen

## (MATERIAL BALANCES FOR PROCESSES INVOLVING RECYCLE WITH OUT CHEMICAL REACTION)

In this Lecture we discuss material balances involving recycle (الراجع) -instances in which material from downstream of the process, returns and reenters the process again. Cases with and without reaction will be discussed. Typical material balance calculations a process involving such streams are given in this lecture.

### 13.1 Introduction

### 13.2 Recycle without Chemical Reaction

## Your Objectives in Studying this Lecture are :

- Draw a flow diagram or sketch for problems involving recycle.
- Apply the 10 -step strategy to solve steady-state problems (with and without chemical reaction) involving recycle stream.
- Solve problems involving a modest number of interconnected units by making appropriate balances.
- Use the concepts of extent of reaction, overall conversion, and single-pass (once-through) conversion in solving recycle problems involving reactors.
- Explain the purpose of a recycle stream


### 13.1 Introduction

In Lecture 8-10 we restricted the discussion and examples to a single unit with stream inputs and outputs as illustrated in Figure 1-a. In this Lecture we take up processes in which material is recycled, that is fed back from a downstream unit to an upstream unit, as shown in Figure 1-b.


Figure 13.1-a: shows a single unit with serial flows. Figure 13.1-b shows the addition of recycle.

## Terminology

a. Recycle stream - The stream containing the recycled material.
b. Recycle system - Is a system that includes one or more recycle streams.

## Examples

a. Recycle systems can be found in everyday life. Used newspaper is collected from households, processed to remove the ink, and used to print new newspapers. Clearly, the more newspapers recycled, the fewer trees that have to be consumed to produce newspapers. Recycling of glass, aluminum cans (علب), plastics, copper, and iron are also common.
b. Recycle systems also occur in nature. For example, consider the "water cycle" shown in Figure 13.2. If a section of the earth is the system, the recycle stream consists of evaporated water that falls to earth as precipitation, and the flow of water in creeks and rivers brings the water back into the system.


Figure 13.2: water cycle.

## An important consideration to use recycle

a. Because of the relatively high cost of industrial feedstock's, when chemical reactions are involved in a process, recycle of unused reactants to the reactor can offer significant economic savings for high-volume processing systems.
b. Heat recovery within a processing unit (energy recycle) reduces the overall energy consumption of the process.
c. Process integration is terminology applied to using material and energy recycle in process design.

## Some Examples of the application of material recycling in the process industries

a. Increased reactant conversion: Recycling the reactants back to the feed to a reactor can significantly increase the overall conversion of the reactants. For certain systems recycle allows the reactor to be operated at low conversion levels, yielding improved selectivity.
b. Continuous catalyst regeneration: Catalysts are used to increase the rate of chemical reactions, but their effectiveness can diminish with use (catalyst deactivation). For example, in a fluidized catalytic cracking (FCC) process (Figure 13.3), the cracking catalyst deactivates almost immediately upon contact with the gas oil feed at the reaction temperature because of the formation of coke on the surface of the catalyst. Therefore, the deactivated (spent مستزهل ) catalyst is transported to the catalyst regenerator where most of the coke is burned off the surface of the catalyst to restore the activity of the catalyst.
c. Circulation of a working fluid: A number of processes use the closed circulation of a working fluid for heating or refrigeration. Refrigeration systems (Figure 13.4), including home air conditioning systems, circulate a refrigerant gas by a compressor so that the gas absorbs heat from the room air and discharges heat to the outside atmosphere.


Figure 13.3: Diagram of an FCC process.


Figure 13.4: Schematic for a closed refrigeration cycle.

EXAMPLE -13.1 How many recycle streams occur in the flowing flow sheet.


## Solution: 2

### 13.2 Recycle without Chemical Reaction

Recycle of material occurs in a variety of processes that do not involve chemical reaction, including distillation, crystallization, and heating and refrigeration systems. As an example of a recycle system, look at the process of drying lumber shown in Figure 13.5. If dry air is used to dry the wood, the lumber will warp (اعوجاج) and crack. By recycling the moist air that exits from the drier and mixing it with dry air, the inlet air can be maintained at a safe water content to prevent warping and cracking of the lumber.


Figure 13.5: Lumber drying process.
The first step in problem solving is to pick a good system(s) for analysis. Examine Figure 6. You can write material balances for several different systems, four of which are shown by dashed lines in Figure 13.6, namely:

1. About the entire process including the recycle stream, as indicated by the dashed lines identified by 1. These balances contain no information about the recycle stream. Note that the fresh feed enters the overall system and the overall or net product is removed.
2. About the junction point (mixing point) at which the fresh feed is combined with the recycle stream (identified by 2) to produce the total, or gross, feed. These balances do contain information about the recycle stream.
3. About the basic process itself (identified by 3). These balances do not contain any information about the recycle stream. Note that the total (gross) feed enters the process and the gross product is removed.
4. About the junction point at which the gross product is separated into recycle and overall (net) product (identified by 4 in Figure 12.8). These balances do contain information about the recycle stream.

The recycle ratio, sometimes called reflux ratio, is widely used in recycle calculations. It is the ratio between the amount of recycle to that of the net product, i.e. (R / P).


Figure 13.6: Process with recycle (the numbers designate possible system boundaries for the material balances; see the text).

## EXAMPLE -13.2 A Continuous Crystallizer Involving a Recycle Stream

Figure E1 is a schematic of a process for the production of flake NaOH , which is used in households to clear plugged drains in the plumbing (e.g., Drano).


Figure E13.2 (a)

The fresh feed to the process is $10,000 \mathrm{Ib} / \mathrm{hr}$ of a $40 \%$ aqueous NaOH solution. The fresh feed is combined with the recycled filtrate from the Crystallizer, and fed to the evaporator where water is removed to produce a $50 \% \mathrm{NaOH}$ solution, which in turn is fed to the Crystallizer. The Crystallizer produces a filter cake that is $95 \% \mathrm{NaOH}$ crystals and $5 \%$ solution that itself consists of $45 \% \mathrm{NaOH}$. The filtrate contains $45 \% \mathrm{NaOH}$.
a. You are asked to determine the flow rate of water removed by the evaporator, and the recycle rate for this process.
b. Assume that the same production rate of NaOH flakes occurs, but the filtrate isnot recycled. What would be the total feed rate of $40 \% \mathrm{NaOH}$ have to be then? Assume that the product solution from the evaporator still contains $50 \% \mathrm{NaOH}$.

## Solution:

Open, steady-state process

## a. Steps 1, 2, 3, and 4

Figure E12.1a contains the information needed to solve the problem.

## Step 5

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

## Steps 6 and 7

The unknowns are $W, G, P$, and $R$. You can make two component balances about three systems: the mixing point A , the evaporator, and the crystallizer as well as two overall component balances. You can also make total balances for the same selection of systems. What balances should you choose to solve the problem? If you plan to put four equations in an equation solver, it does not make any difference as long as the equations are independent. But if you solve the problem by hand, you should count the number of unknown variables involved for each of the three subsystems and the overall system as follows:

## Component balances <br> Mixing point

Evaporator
Crystallizer
Overall

Unknowns
$R$ plus feed (and compositions) to evaporator (not labeled)
$W, G$, and feed to evaporator
$G, P$, and $R$
$W$ and $P$

You can see that by using just two overall component balances (you can substitute the overall total balance for one component balance) you can determine the values of $W$ and $P$. Consequently, you should start with overall balances.

## Steps 8 and 9

Overall NaOH balance

$$
\begin{aligned}
(0.4)(10,000) & =[0.95+(0.45)(0.05)] P \\
P & =4113 \mathrm{lb}
\end{aligned}
$$

Overall $\mathrm{H}_{2} \mathrm{O}$ balance

$$
\begin{aligned}
(0.6)(10.000) & =W+[(0.55)(0.05)](4113) \\
W & =5887 \mathrm{lb}
\end{aligned}
$$

(or use the overall total balance $10,000=4113+W$ )
The total amount of NaOH exiting with $P$ is

$$
[(0.95)+(0.45)(0.05)](4113)=4000 \mathrm{lb}
$$

Are you surprised at this result? You shouldn't be. If you put 4000 lb of NaOH into the process, 4000 lb should come out. The amount of water in $P$ is 113 lb . As a check, $113+5887=6000 \mathrm{lb}$ as expected.

## Steps 6 and 7 (repeated)

Now that you know $W$ and $P$, the next step is to make balances on a system that involves the stream $R$. Choose either the mixing point A or the crystallizer. Which one should you pick? The crystallizer involves three unknowns, and you now know the value of $P$, so that only two unknowns are involved versus introducing a considerable number of new unknowns if you chose mixing point A as the system.

## Steps 8 and 9 (repeated)

NaOH balance on the crystallizer

$$
0.5 G=4000+0.45 R
$$

$\mathrm{H}_{2} \mathrm{O}$ balance on the crystallizer

$$
0.5 G=113+0.55 R
$$

(or use the total balance $G=R+4113$ )

$$
R=38,870 \mathrm{lb}
$$

b. Now, suppose recycle from the crystallizer does not occur, but the production and composition of $P$ remains the same. Then the output of the crystallizer is just $P$, as indicated in Figure E12.1b. How should you proceed? Do you recognize that the problem is analogous to the ones that you read about in Chapter 11 ?


Figure E13.2 (b)

## Step 5

The basis is now $P=4113 \mathrm{lb}$ (the same as 1 hour)

## Steps 6 and 7

The unknowns are now $F, W, G$, and $H$. You can make two component balances on the evaporator and two on the crystallizer plus two overall balances. Only four are independent. The evaporator balances would involve $F, W$, and $G$. The crystallizer balances would involve $G$ and $R$ while the overall balances would involve $F, W$, and $H$. Which balances are best to start with? If you put the equations in an equation solver, it makes no difference which four equations you use as long as they are independent. The crystallizer balances are best to start with by hand because then you have to solve just two pertinent equations for $G$ and $H$.

## Steps 8 and 9

NaOH balance on the crystallizer

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

$\mathrm{H}_{2} \mathrm{O}$ balance on the crystallizer

$$
\begin{gathered}
0.5 G=[(0.05)(0.55)(4113)+0.55 H \\
H=38,870 \mathrm{lb}
\end{gathered}
$$

An overall NaOH balance gives the new $F$ Overall NaOH balance

$$
\begin{gathered}
0.40 F=0.45(38,870)+4000 \\
F=53,730 \mathrm{lb}
\end{gathered}
$$

Note that without recycle, the feed rate must be 5.37 times larger than with recycle to produce the same amount of product, not to mention the fact that you would have to dispose of a large volume of filtrate.

## Lecture Thirteen / Tutorials

## (MATERIAL BALANCES FOR PROCESSES INVOLVING RECYCLE WITH OUT CHEMICAL REACTION)

P.13.1 Explain the purpose of using recycle in a process.
P.13.2 Will a recycle stream always have the same composition as a product stream?
P.13.3 The Hooker Chemical Corporation operates a process in Michigan for the purification of HCI. Figure 2 shows the flow sheet for the Hooker process. The streams from the bottoms of the five towers are liquid. The streams from the tops of the towers are gases. HCI is insoluble in the HCB (hexachlorobutadiens). The various stream compositions are shown in Figure 2.

How many recycle streams are there in the Hooker process? (5)


Figure P.13.3
P.13.4 Why have we not considered the buildup of material in recycle streams in this lecture?
P.13.5 Under what circumstances might material be accumulated or depleted in a recycle stream?
P.13.6 Can you make material balances in both steady-state and unsteady-state flow processes that involve recycle?
P.13.7 Can you formulate sets of equations that are not independent if recycling occurs in a system?

## P.13.8 Binary mixture

A binary mixture consists of $45 w t \%$ benzene and $55 w t \%$ toluene are continuoush Feed to the distillation column at a rate of 2500 167tir The top product contains $97.5 \mathrm{wt} \%$-benzene, whereas the bottom -product contains $90 \mathrm{wt} \%$ toluene The column operates with refiux-ratio of 2.5 .
Calculate:-(a) the top \& bottom products produced per hour.
(b) the recyete-stream and the vapour input to the condenser perthour.

P.13.9 Extraction oils from soybean by hexane

Soybean flakes (S) containing $19 \mathrm{wt} \%$ oil \& $81 \mathrm{wt} \%$ solids are continuously ted at . $=\alpha$-rate of $=5000$-g/thr to the vegetable of -production process in which soybeanizit are-extracted by hexane as shown in the following block -diagram:


The filter cake (C) contains $90 \mathrm{wt} \%$ solids $410 \mathrm{wt} \%$ liquid of hexane + ort of the same-composition of the filtrate (F). Calculate (a) the flow rates in $(k g / 4$. of att streams of the process ard the cemperition of $(N 1) f(E)$, (b) yield af thepree

