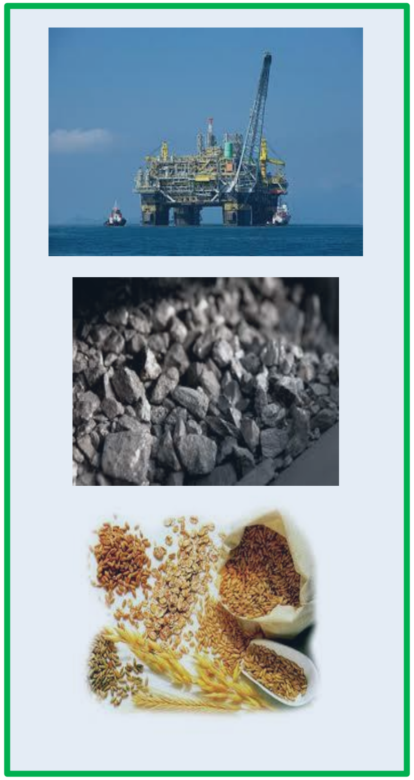
Fondamenti dell’ingegneria di processo

anno accademico 2021-2022

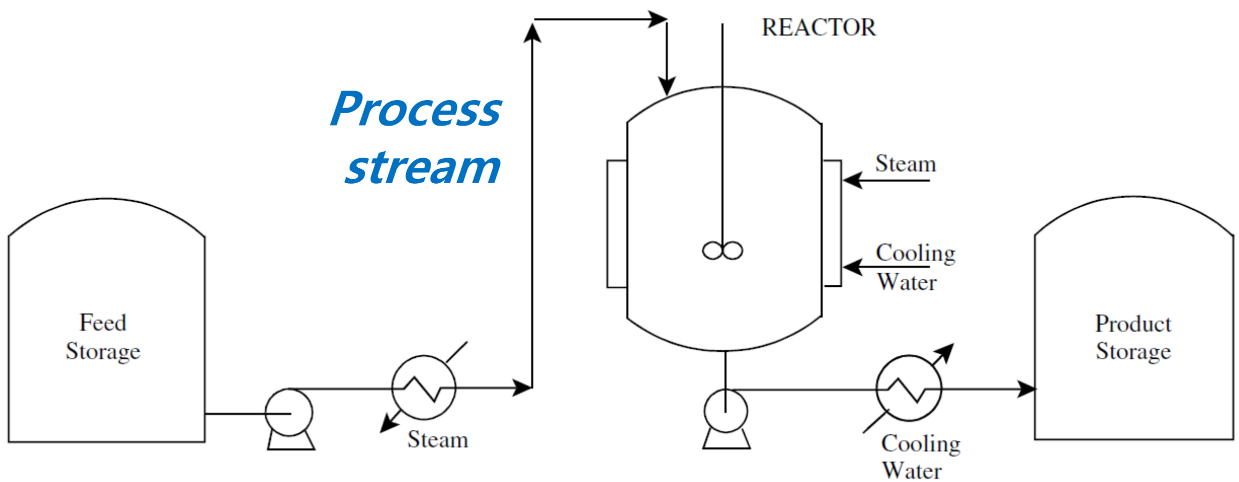
Process Design

Materie prime → *Processi e Impianti* → *Prodotti*

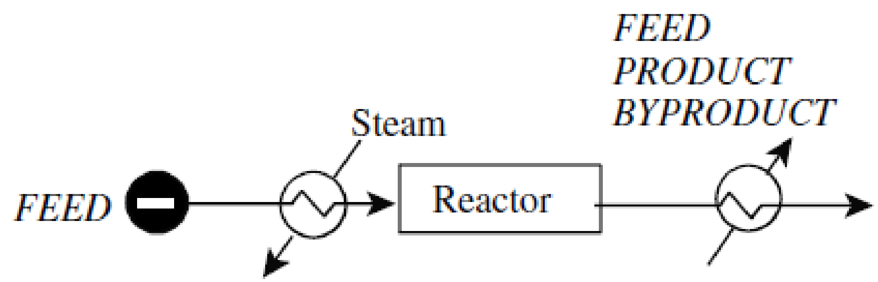


Process Design

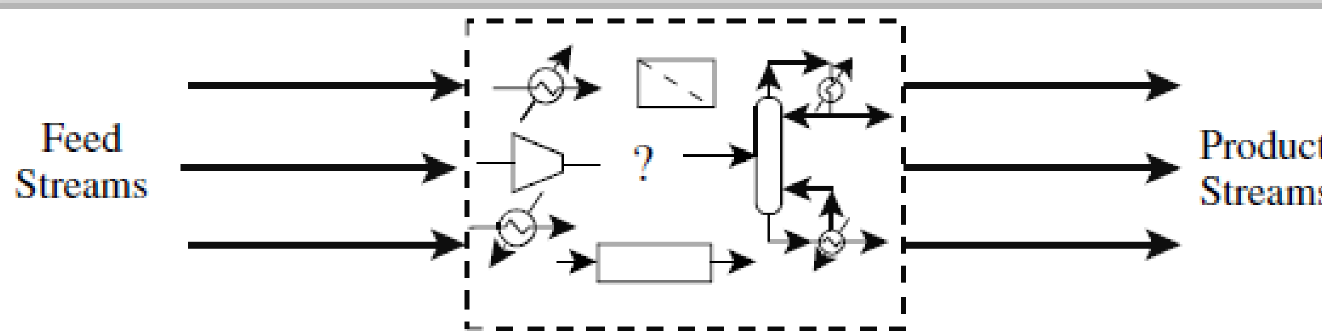
Unit process & Chemical process



Hierarchy of Process Design

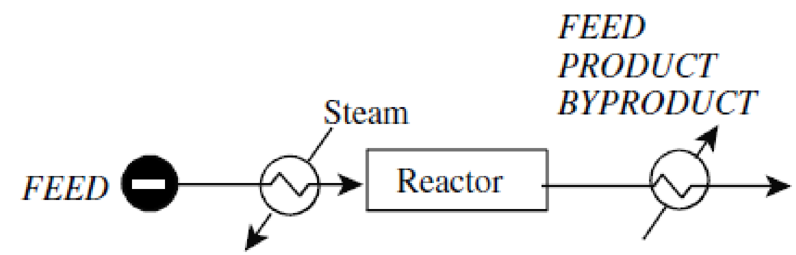


(a) A reactor transforms *FEED* into *PRODUCT* and *BYPRODUCT*.

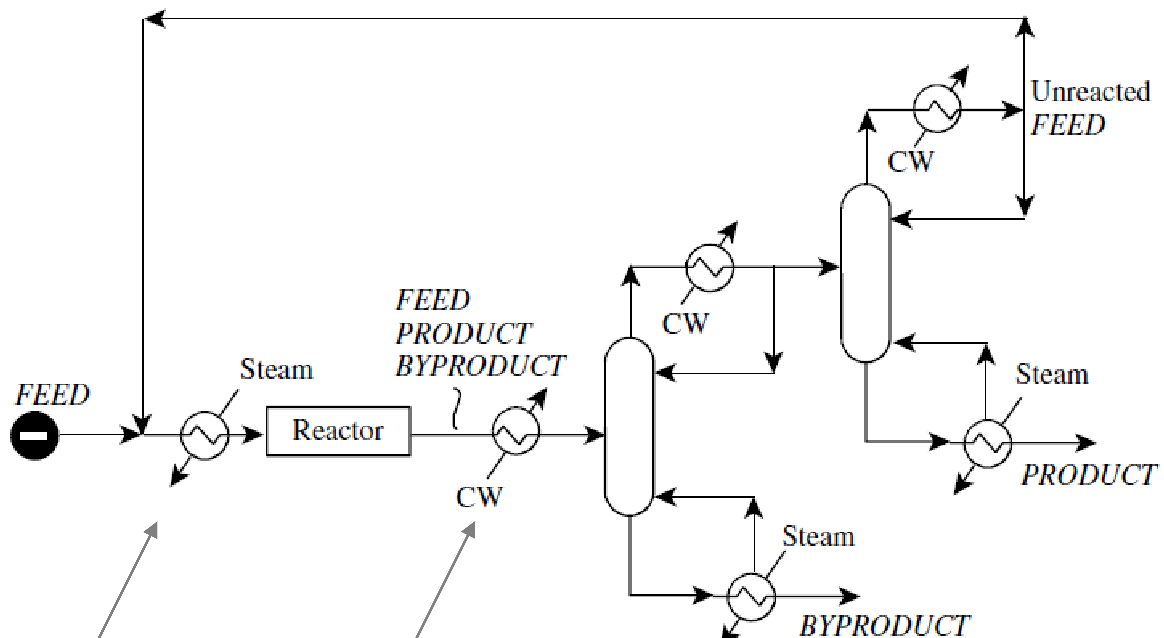


(a) Process design starts with the synthesis of a process to convert raw materials into desired products.

Hierarchy of Process Design

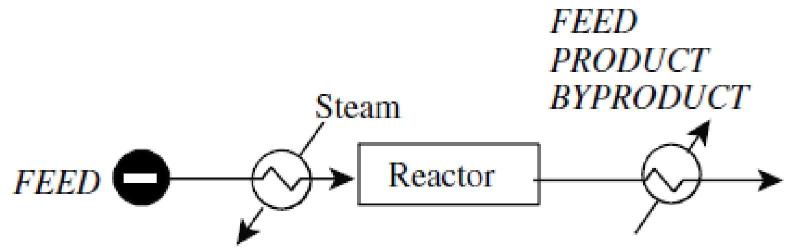


(a) A reactor transforms *FEED* into *PRODUCT* and *BYPRODUCT*.

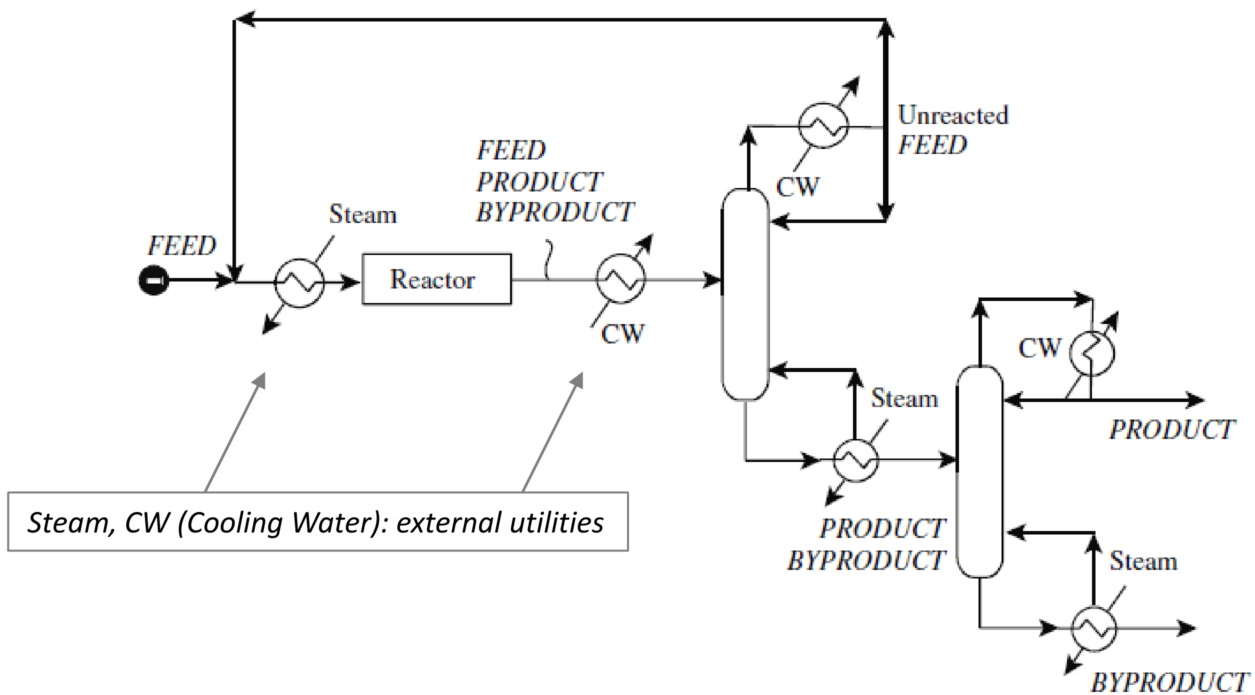


Steam, CW (Cooling Water): external utilities

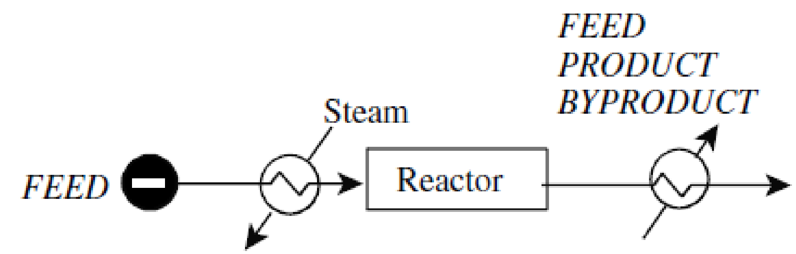
Hierarchy of Process Design



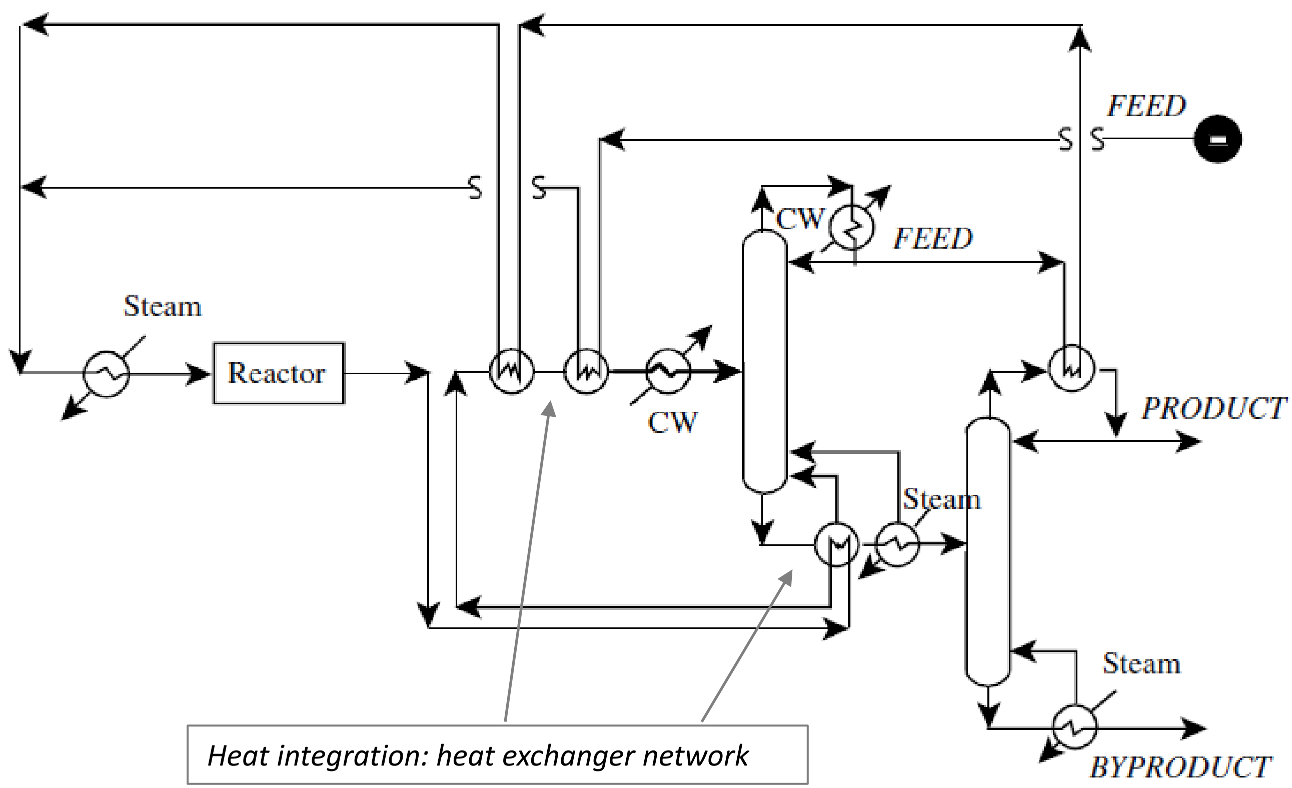
(a) A reactor transforms *FEED* into *PRODUCT* and *BYPRODUCT*.



Hierarchy of Process Design

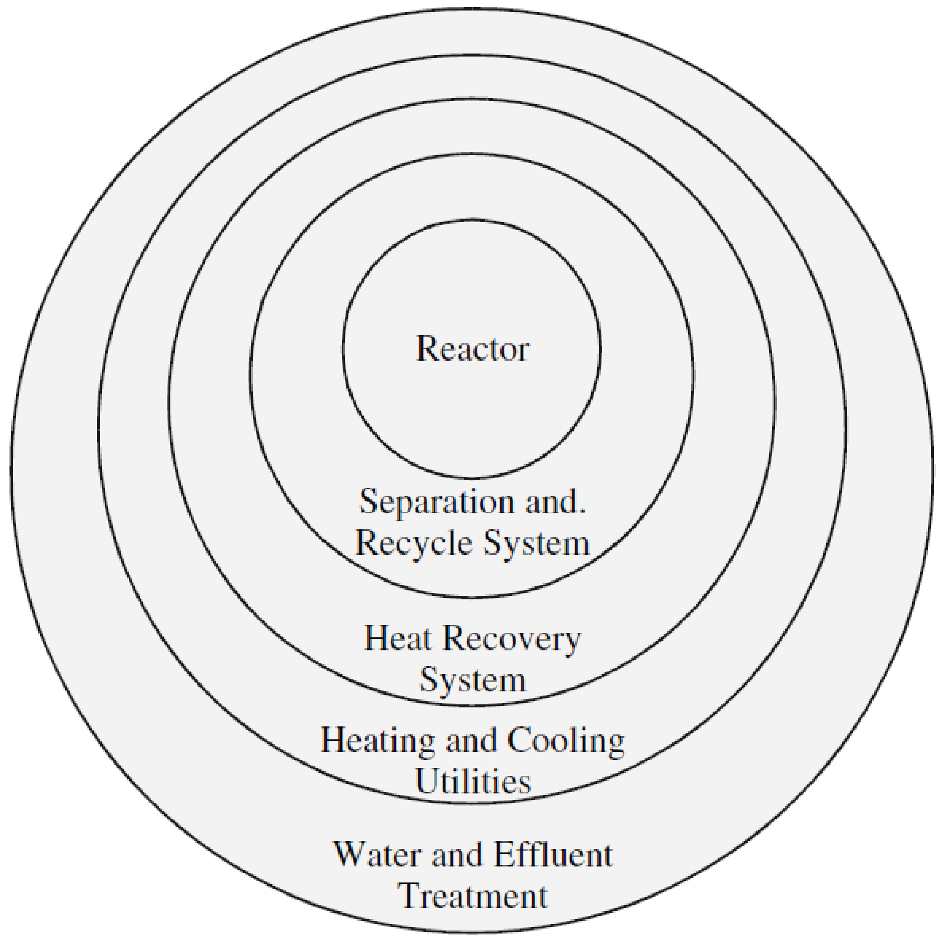


(a) A reactor transforms *FEED* into *PRODUCT* and *BYPRODUCT*.



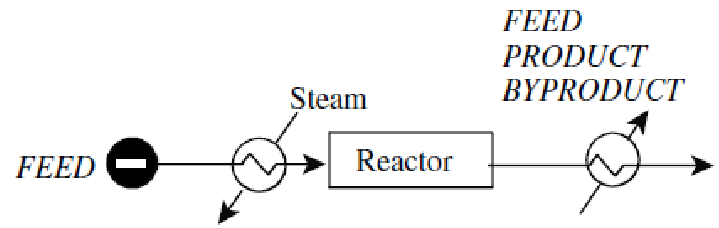
Hierarchy of Process Design

The onion model of process design



**Smith, R., Chemical Process Design and Integration(John Wiley & Sons, 2005)*

Hierarchy of Process Design



(a) A reactor transforms *FEED* into *PRODUCT* and *BYPRODUCT*.

*Douglas**, among others, has proposed a hierarchical approach to conceptual process design. In this approach, the design process follows a series of decisions and steps.

The order in which these decisions are made forms the **hierarchy of the design process**.

These decisions are listed as follows.

I. Decide whether the process will be batch or continuous.

II. Identify the input/output structure of the process.

III. Identify and define the recycle structure of the process.

IV. Identify and design the general structure of the separation system.

V. Identify and design the heat-exchanger network or process energy recovery system.

In designing a new process, we follow steps 1 through 5 in that order. Alternatively, by looking at an existing process, we can work backward from step 5 and eliminate or greatly simplify the PFD and, hence, reveal much about the structure of the underlying process

**Douglas, J.M., Conceptual Design of Chemical Process (New York, McGraw-Hill, 1989)*

1. Continuous and batch processes

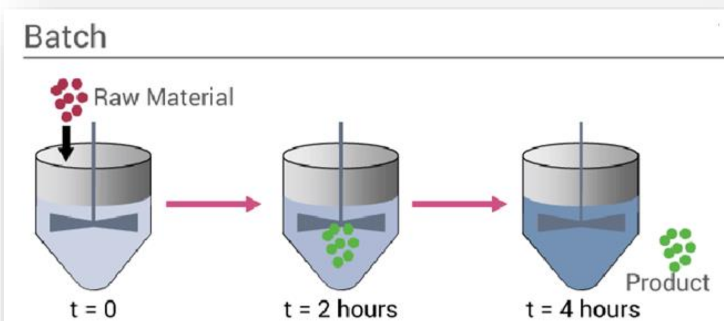
Industrial processes can be classified depending on the output of the process as:

- ✓ Continuous processes
- ✓ Batch processes

Batch process

A **batch process** is one in which a finite quantity (batch) of product is made during a period of a few hours or days.

As a general definition, a batch process is a process that leads to the production of finite quantities of material by subjecting quantities of input raw materials to an ordered set of processing activities over a finite period of time using one or more pieces of equipment.



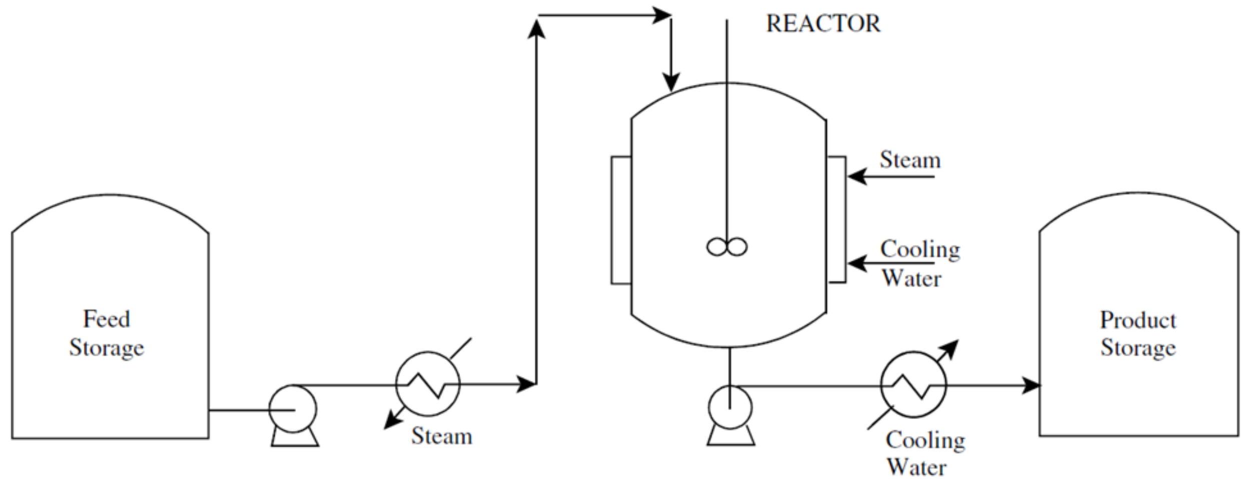
Batch manufacturing: the material(s) is charged before the start of processing and the product is discharged at the end of processing.

The feed is charged (fed) into a vessel at the beginning of the process and the vessel contents are removed sometime later. No mass crosses the system boundaries between the time the feed is charged and the time the product is removed.

Example: Rapidly add reactants to a tank and remove the products and unconsumed reactants sometime later when the system has come to equilibrium

1. Continuous and batch processes

Batch process



…heat, mass, temperature, concentration and other properties vary with *time*.

Semicontinous process

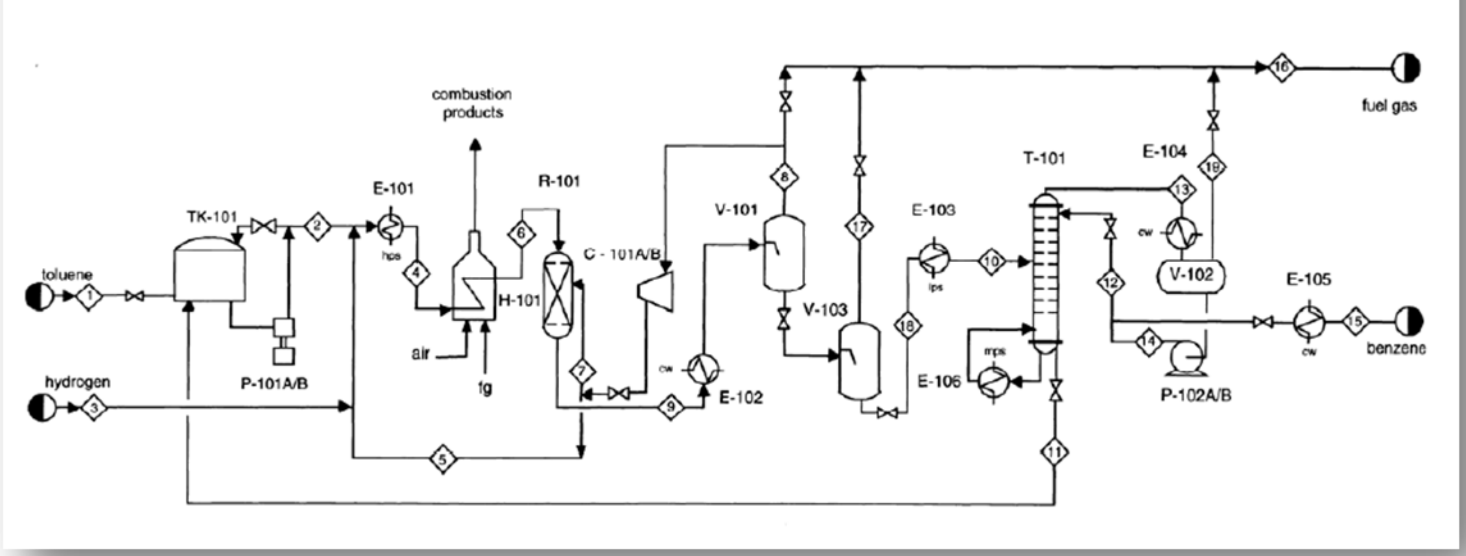
A semicontnuous step run continouously with periodic strat-ups and shutdowns.

1. Continuous and batch processes

Continuous process

A **continuous process** is one in which feed is sent *continuously* to a series of equipment, with each piece usually performing a single unit operation

In a continuous process, as suggested by the name, the flow of material or product is continuous.
The inputs and outputs flow continuously throughout the duration of the process.
Processing the materials in different equipment produces the products.
Each machine operates in a single steady state and performs a specific processing function.



1. Continuous and batch processes

If the values of all the variables in a process (i.e., all temperatures, pressures, volumes, flow rates) do not change with time, except possibly for minor fluctuations about constant mean values, the process is said to be operating at **steady state**

If any of the process variables change with time, **transient** or **unsteady-state** operation is said to exist.

By their nature, batch and semibatch processes are unsteady-state operations, whereas continuous processes may be either steady-state or transient. Continuous processes are usually run as close to steady state as possible; unsteady-state (transient) conditions exist during the start-up of a process and following changes - intentional or otherwise - in process operation conditions.

Examples:

Classify the following processes as batch, continuous, or semibatch, and transient or steady state.

1. A balloon is filled with air at a steady rate of 2 g/min.

2. A bottle of milk is taken from the refrigerator and left on the kitchen table.

3. Water is boiled in an open flask.

1. Continuous and batch processes

Some Factors to Consider When Deciding between Batch and Continuous Processes

Batch processes

• capital investment are lower for producing relatively small quantities (less than 500 t/y)

• are flexible in accommodating changes in product formulation

• are flexible in changing production rate by changing the number of batches made in an y period of time

• allow the use of standardized multipurpose equipment for the production of a variety of products from the same plant;

• are amenable to direct scale-up from the laboratory

• allow product identification. Each batch of product can be clearly identified in terms of when it was manufactured, the feeds involved and conditions of processing

This is particularly important in industries such as pharmaceuticals and foodstuffs

Continuous processes

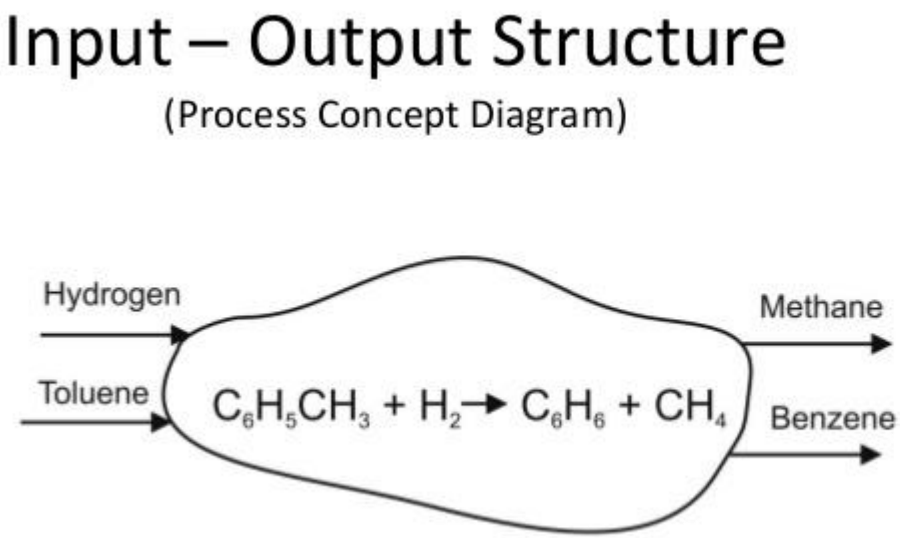
• operating labor costs and utility costs are lower for producing large quantities (greater than 5000 t/y)

• equipment tends to be designed and optimized for a single or small number of products

• generally, as throughput increases, become more efficient

2. The Input/Output Structure of the Process

Input/Output Structure of the Process Concept Diagram for the Toluene Hydrodealkylation Process



Inputs: feed streams
Outputs: product streams, by-products or waste streams

2. The Input/Output Structure of the Process

Process Concept Diagram:
The Input/Output Structure of the Process Flow Diagram

i. A single “cloud” is drawn to represent the concept of the process. Within this cloud the stoichiometry for all reactions that take place in the process is written. The normal convention of the reactants on the left and products on the right is used.

ii. The reactant chemicals are drawn as streams entering from the left. The number of streams corresponds to the number of reactants (two). Each stream is **labeled** with the name of the reactant (toluene and hydrogen).

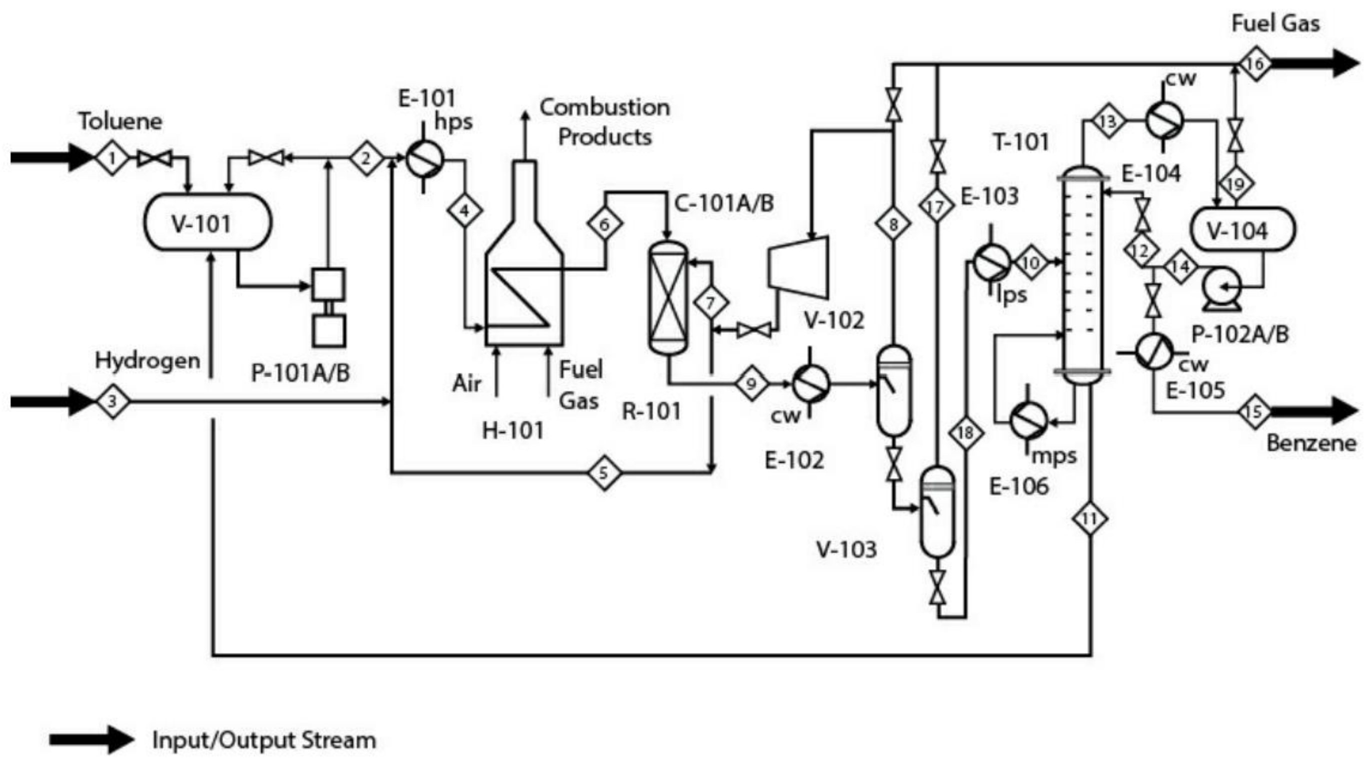
iii. Product chemicals are drawn as streams leaving to the right. The number of streams corresponds to the number of products (two). Each stream is **labeled** with the name of the product (benzene and methane).

iv. Seldom does a single reaction occur, and unwanted side reactions must be considered. All reactions that take place and the reaction stoichiometry must be included. The unwanted products are treated as by-products and must leave along with the product streams shown on the right of the diagram.

2. The Input/Output Structure of the Process

Process Concept Diagram:

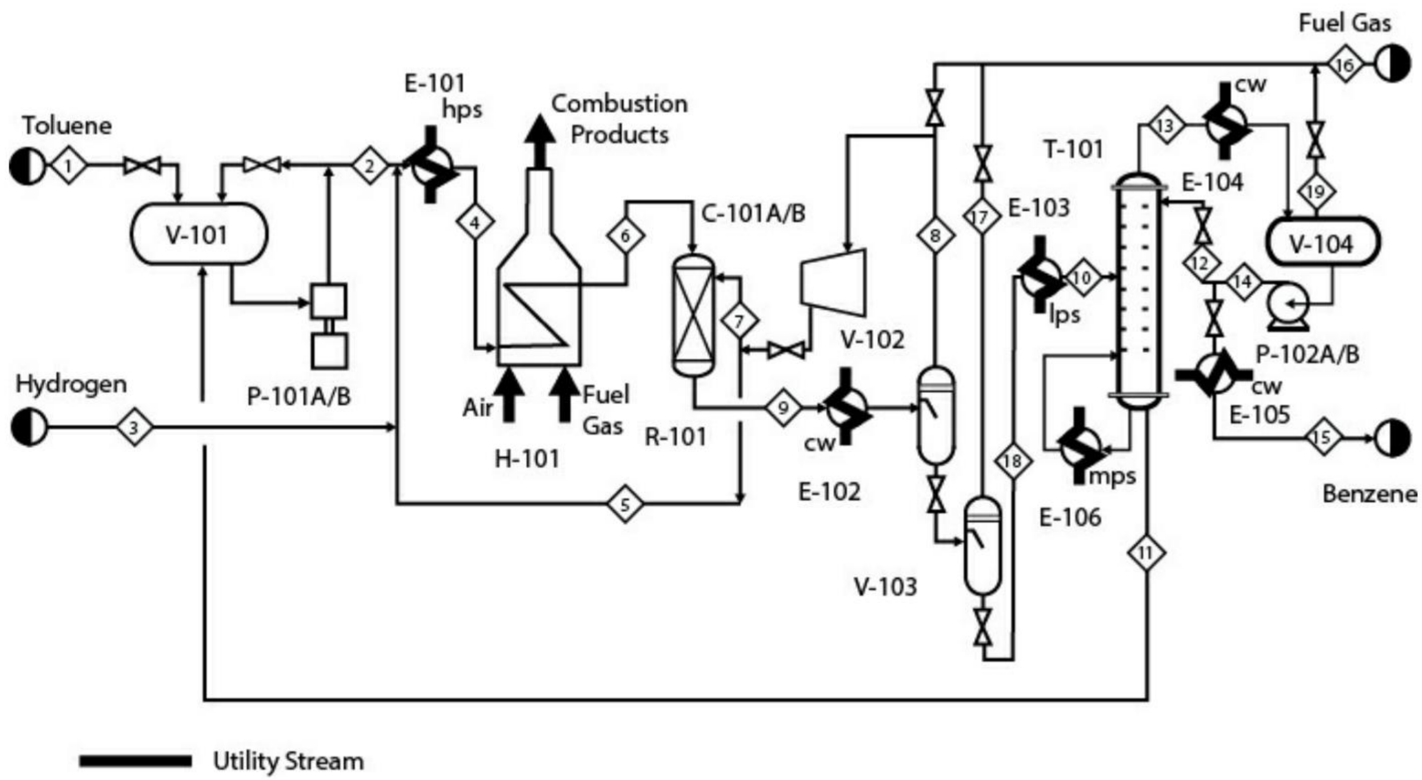
The Input/Output Structure of the Process Flow Diagram



2. The Input/Output Structure of the Process

Process Concept Diagram:

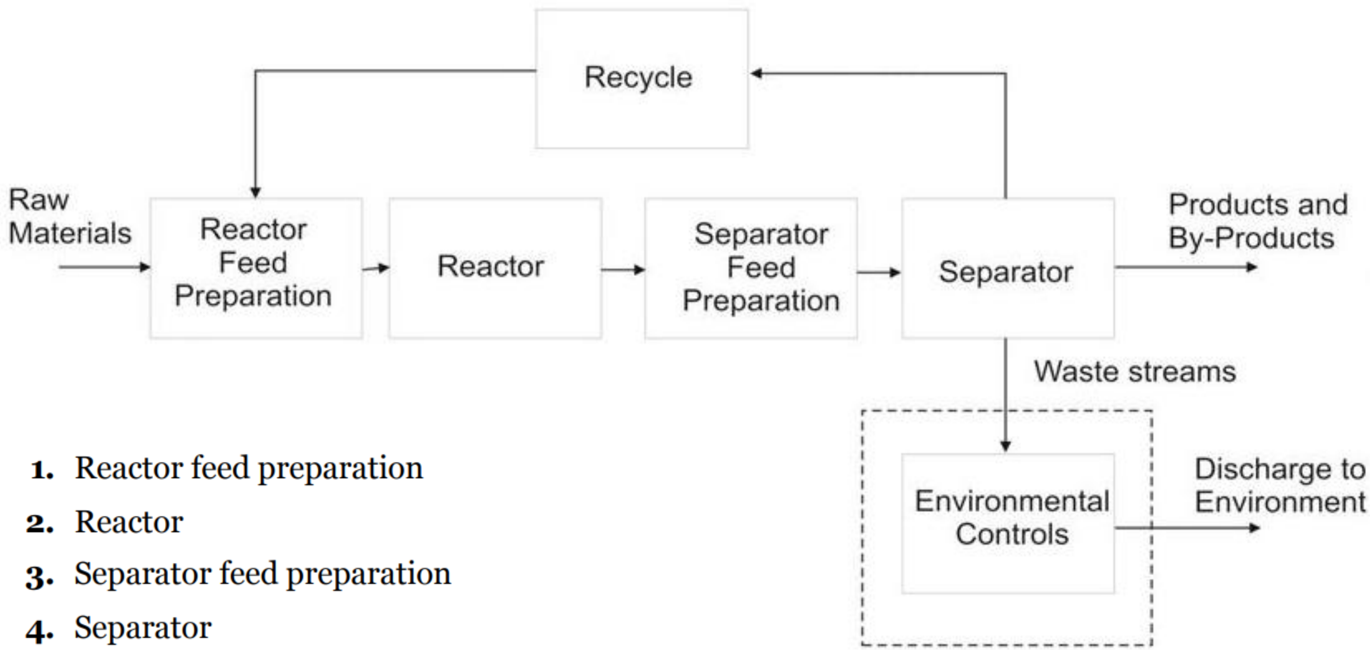
The Input/Output Structure of the Process Flow Diagram



2. The Input/Output Structure of the Process

Process Concept Diagram:

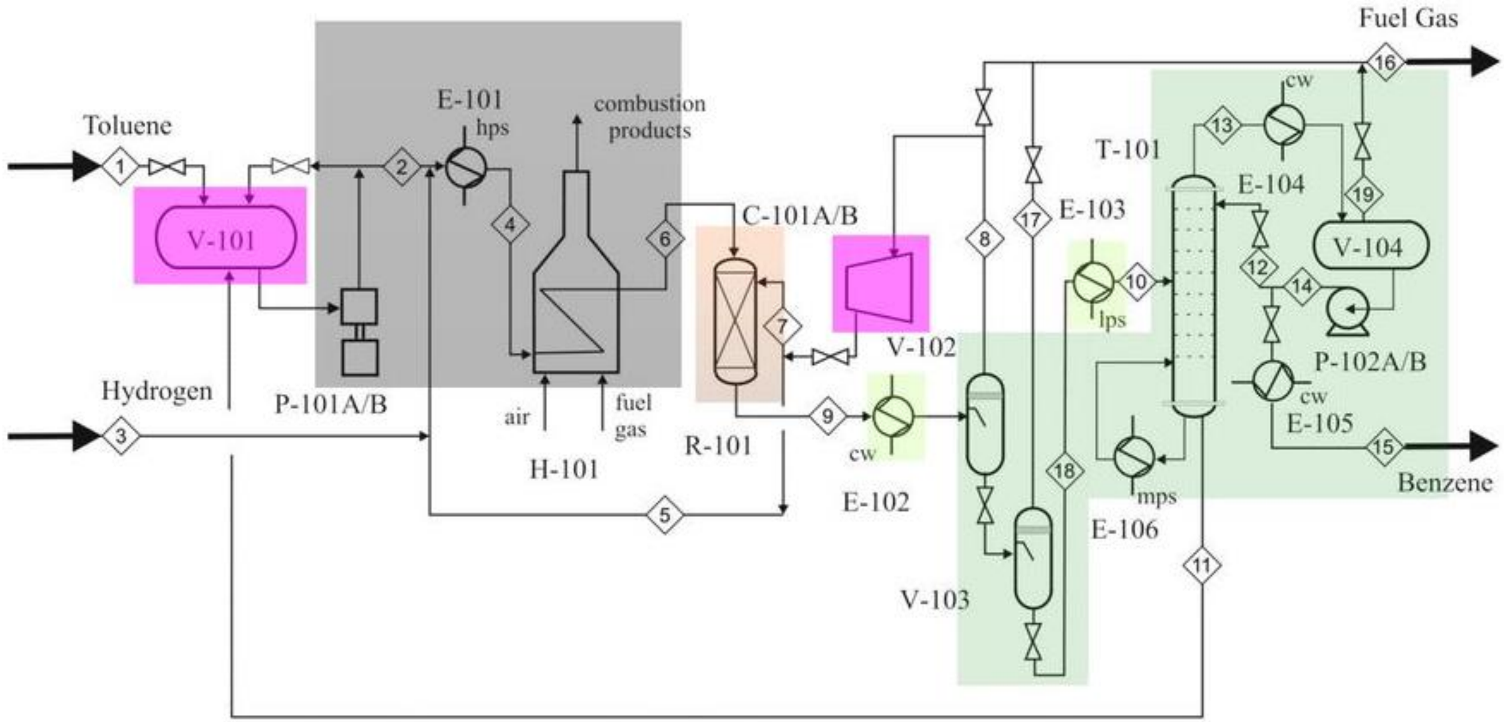
Input/Output Structure of the Generic Block Flow Diagram



1. Reactor feed preparation
2. Reactor
3. Separator feed preparation
4. Separator
5. Recycle
6. Environmental control

2. The Input/Output Structure of the Process

Input/Output Structure of the Process Flow Diagram



2. The Input/Output Structure of the Process

Input/Output Structure of the Process Flow Diagram

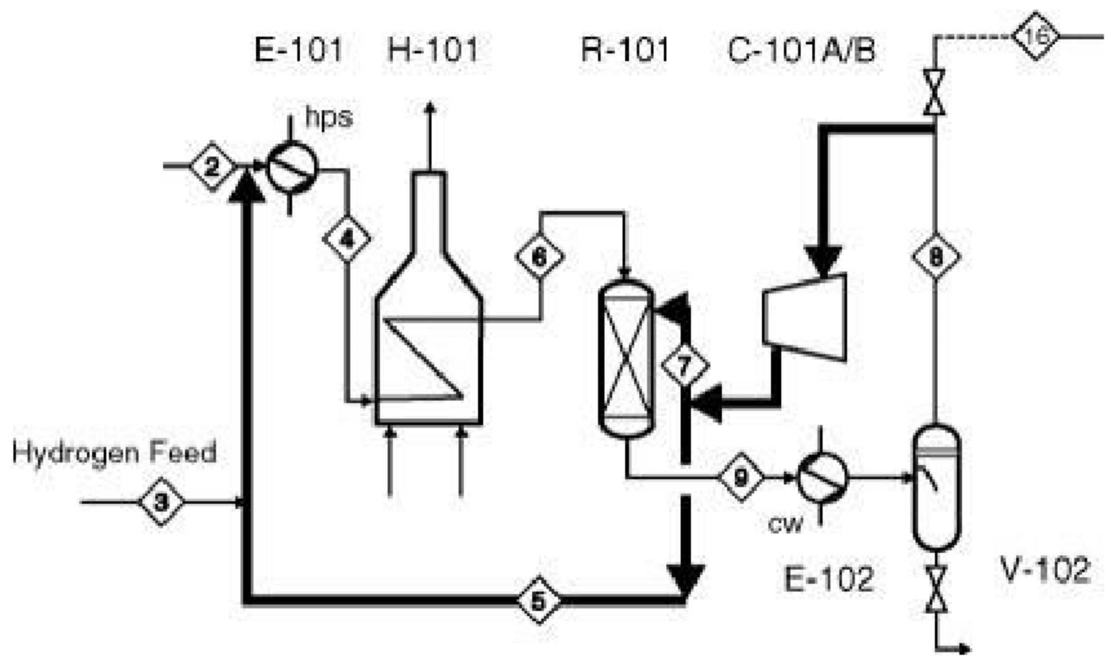
What Information can be determined using the Input/Output Diagram for a Process?

The following basic information, obtained from the input/output diagram, is limited but nevertheless very important.

- ✓ Basic economic analysis on profit margin
- ✓ What chemical components must enter with the feed and leave as products
- ✓ All the reactions, both desired and undesired, that take place

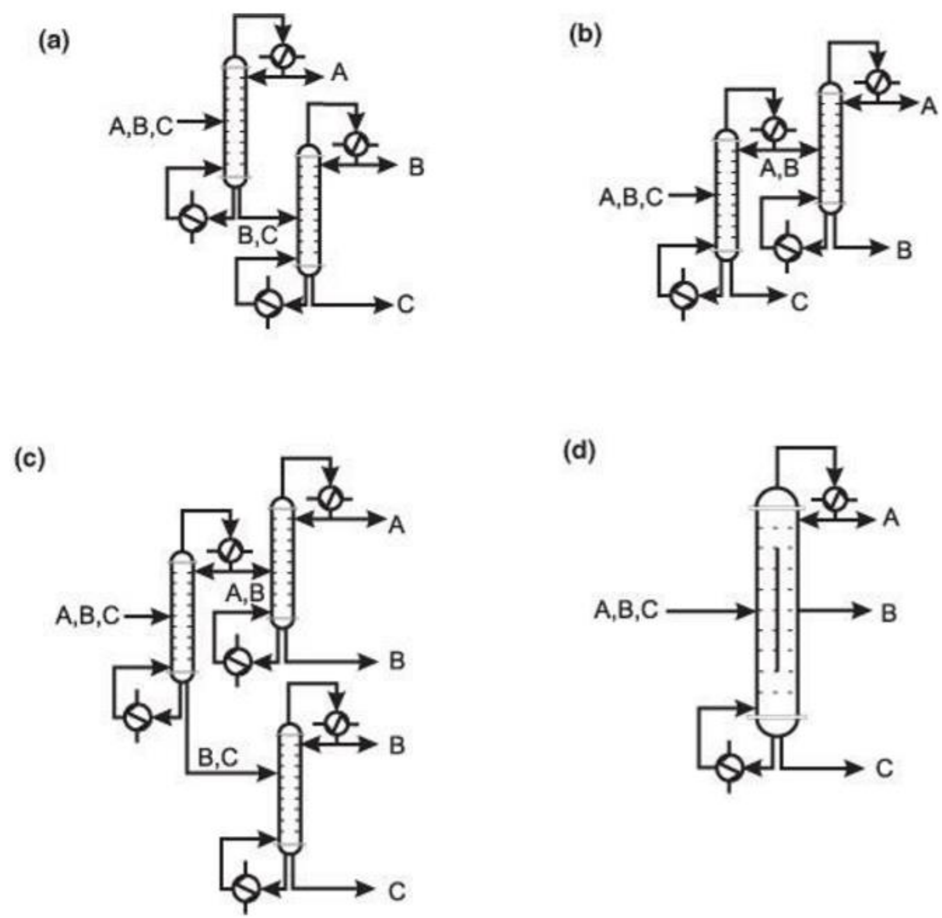
3. The Recycle structure of the Process

….the recovery of materials from the process



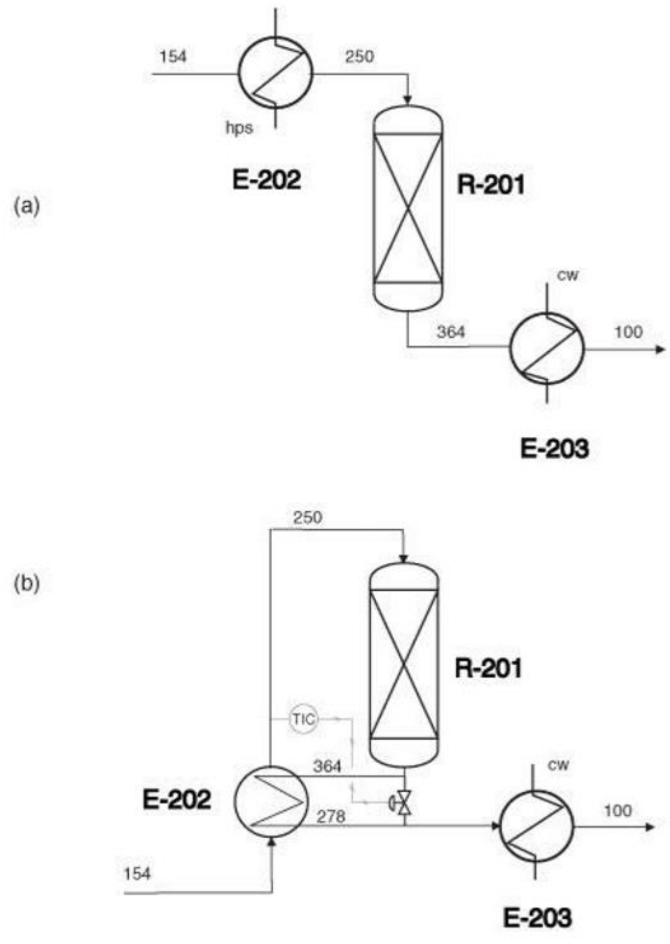
4. General structure of the separation system

….the structure of the separation sequence



5. Heat-exchanger network or process energy recovery system

….the main objective of process energy recovery is to optimize the e nergy that a process exchanges with the utilities



Reactor Feed and Effluent Heat Exchange System

(a) Without Heat Integration

(b) With Heat Integration