Introduction to Chemical Engineering

Chapter 02

The Role of Chemical Processing

2.1 What is a chemical process?

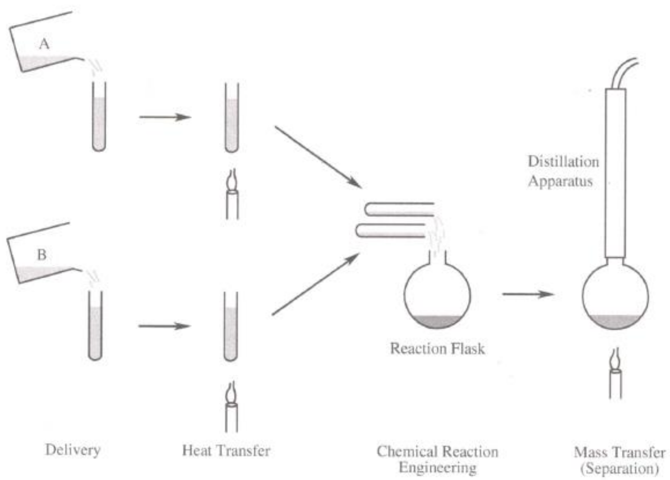
Definition of chemical process

- *A chemical process is a combination of steps in which starting materials are converted into desired products using equipment and conditions that facilitate that conversion.*

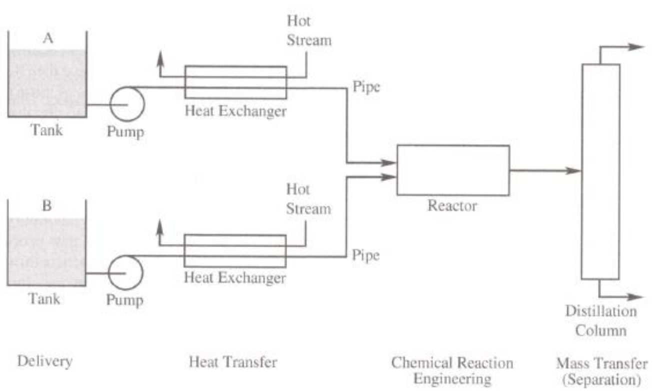
One of the things that chemical engineers do is…

- to build upon laboratory-type manual processes to create useful automated process.

A manual process (laboratory)



An automated process (industry)

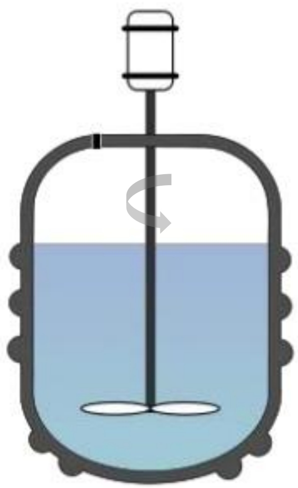


High efficiency
Environmentally friendly methods
Increase of production rate and production quality
Scaling up

2.1 What is a chemical process?

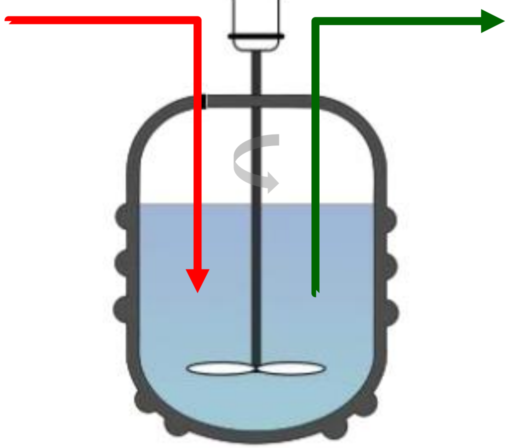
Definition of process categories

Batch process



Unsteady-state (transient) process

Continuous process



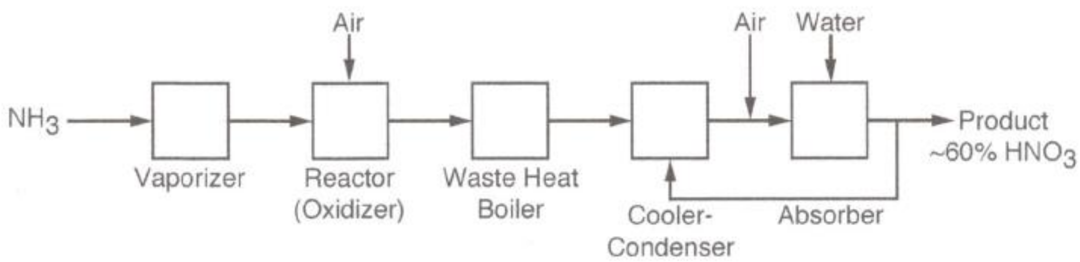
Steady-state process
or unsteady-state (transient) process

2.2 Representing chemical processes using process diagrams

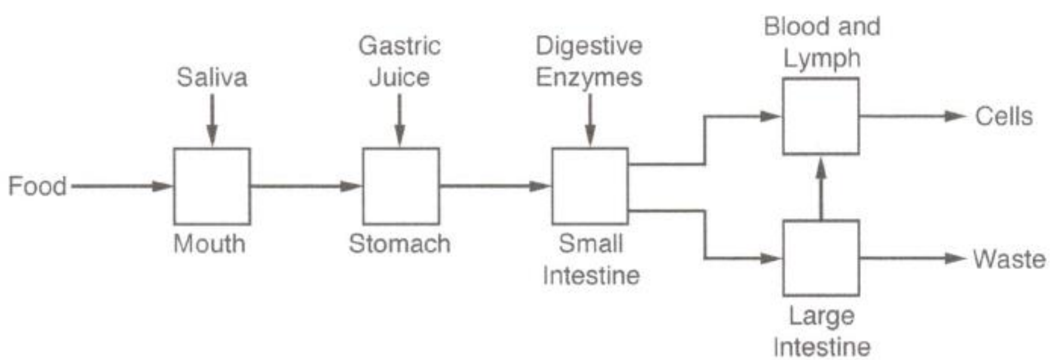
2.2.1 Block diagrams

- A simple representation of a chemical process in which a box or block is used

Block diagram for a low-pressure process to produce nitric acid



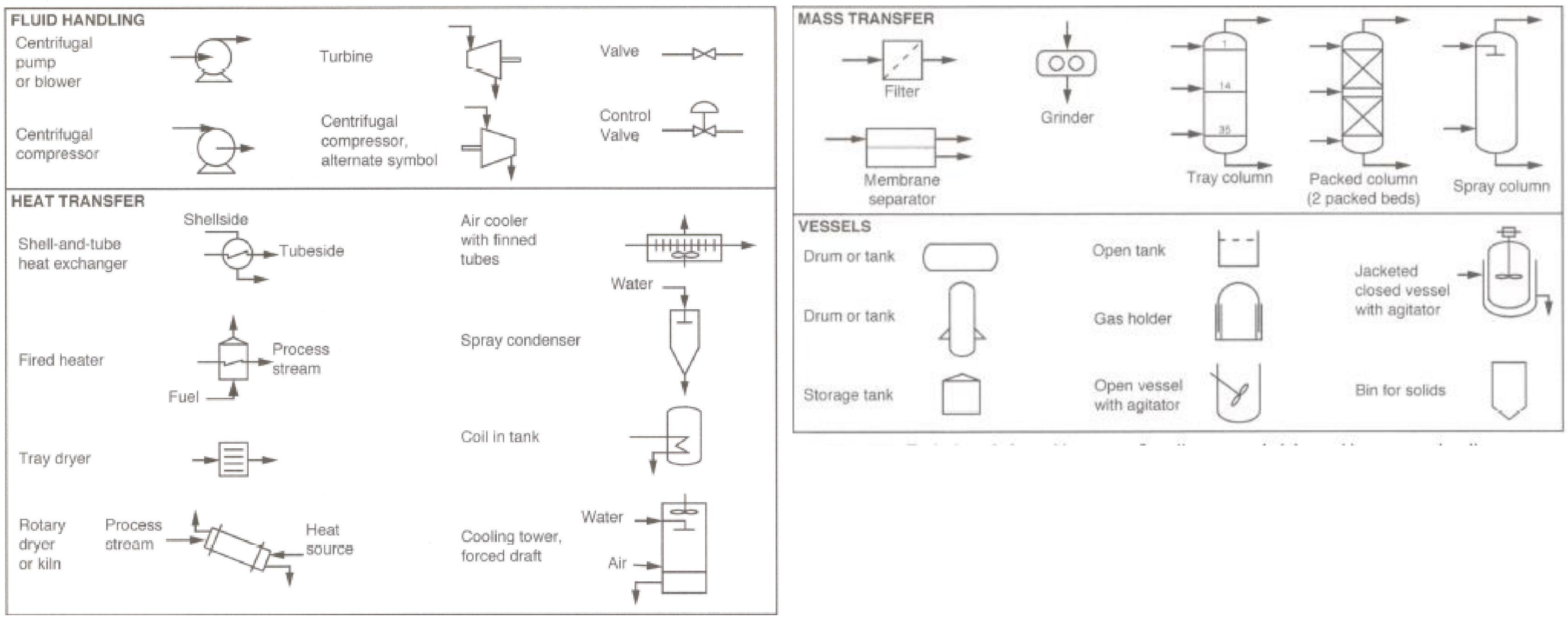
Block diagram as a simple representation of the human digestion process



2.2 Representing chemical processes using process diagrams

2.2.2 Process flow diagrams (PFD)

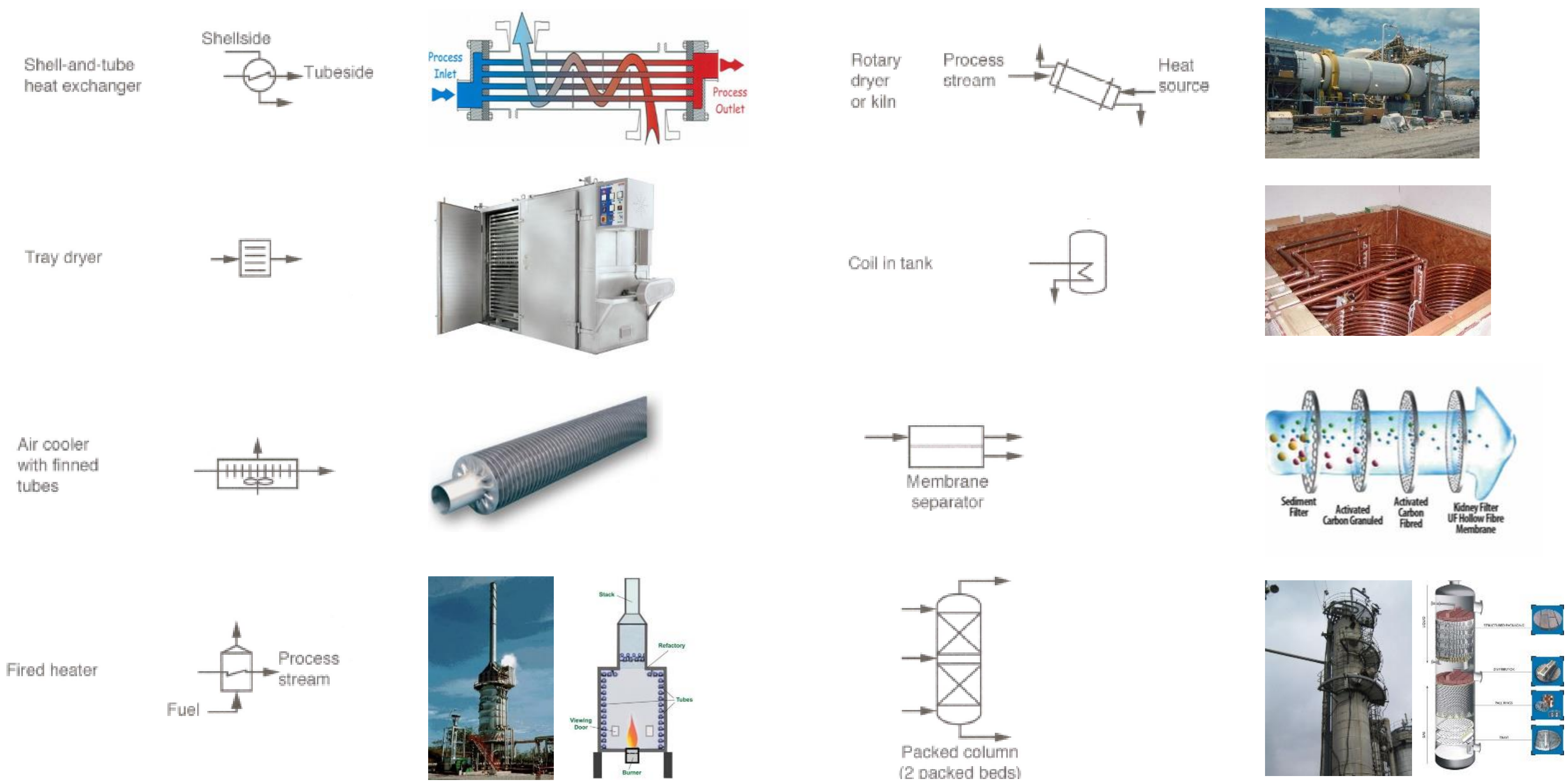
- A standard method for documenting engineering designs (more detail than a block diagram)



2.2 Representing chemical processes using process diagrams

2.2.2 Process flow diagrams (PFD)

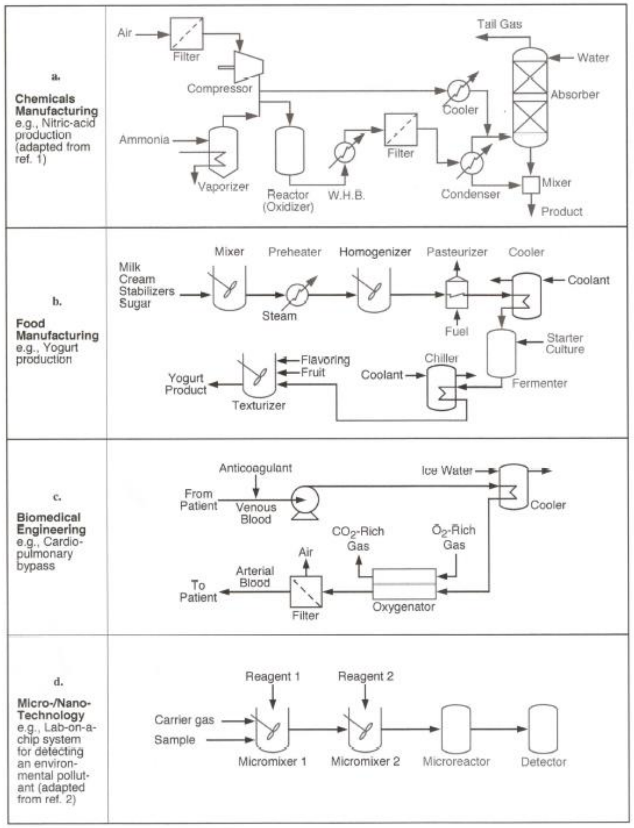
- Photo images of diagrams



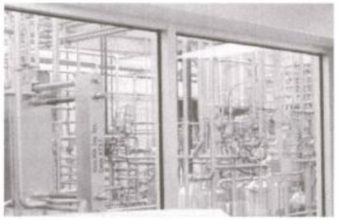
2.2 Representing chemical processes using process diagrams

2.2.2 Process flow diagrams (PFD)

- Examples of some simple PFDs and photos of chemical engineering applications

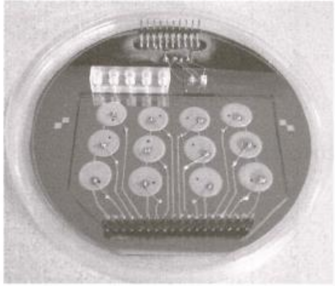


a.
A large-scale chemical processing facility similar to that represented in Figure 2.6a. Courtesy of Eastman Chemical Company, Longview, TX.



b.
Food production process similar to that represented in Figure 2.6b. The process is being viewed from a computer control room. Courtesy of Breyers Yogurt Co., North Lawrence, NY.

c.
A student operates cardiopulmonary bypass equipment in a simulated open-heart operation. The equipment utilizes chemical engineering principles and processes as represented in Figure 2.6c. Courtesy of Midwestern University, Glendale, AZ.



d.
Lab-on-a-chip assembly associated with the process represented in Figure 2.6d. Used with permission.[2]

2.2 Representing chemical processes using process diagrams

2.2.2 Process flow diagrams (PFD)

Steps for constructing a process flow diagram (PFD)

1. **Identify streams** entering the process ("feed streams") and existing the process ("product streams")
2. **Identify key process steps and major equipment items** needed for the process.
3. **Determine the symbol** to be used for each major piece of equipment.
4. **Draw the symbols on the flow diagram** and connect them with appropriate stream lines. The general flow of the diagram should be from left to right.
5. **Label major pieces of equipment,** usually using abbreviations of a few letters and numbers (e.g., P-2 for pump #2 and HX-15 for heat exchanger #15). For this introductory course, full names can also be used (as in Figure 2.6).
6. **Label streams** with a number and/or letter (e.g., 10, A, or 10A).
7. **Include a stream table,** if desired, that contains information about each stream (described below).

2.2 Representing chemical processes using process diagrams

Example 2.2

A common practice when performing open-heart surgery is to divert the patient's blood through a "cardiopulmonary bypass" system or "heart-lung machine". The following configuration is an example:

A. The blood from the main veins (called "venous blood") is caused to leave the body through plastic tubing.
B. An intravenous (IV) line adds anticoagulant drugs to the tubing.
C. The blood passes through a centrifugal pump, which provides the flow of the blood through the system.
D. The blood passes through the coil side of a coil-in-tank-type cooler to cool the patient's blood (to reduce oxygen requirements). Ice water enters and leaves the tank to supply the cooling.
E. The cooled blood passes through a membrane separator (called an oxygenator) where it flows along one side of the membrane. An oxygen-rich gas stream also passes through the oxygenator, where it passes along the other side of the membrane. Thus in the oxygenator, oxygen passes through the membrane and enters the blood, where the following reactions occur:

   $$Hb + 4O_2 \rightarrow Hb(O_2)_4$$

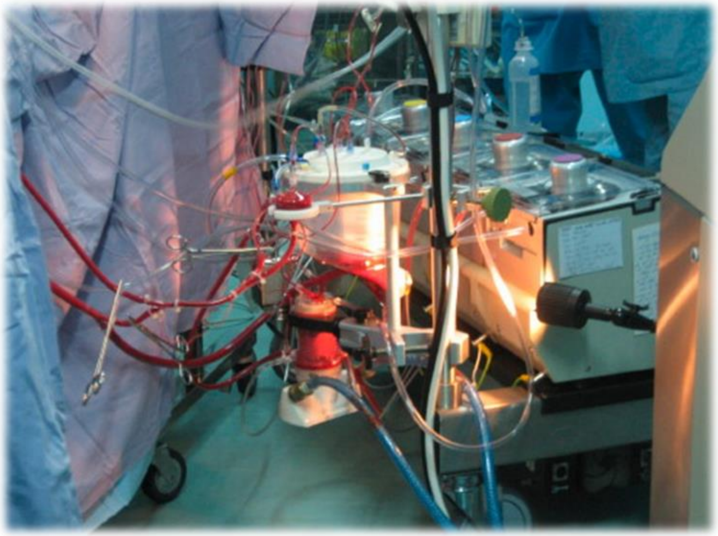
   $$H_2CO_3 \rightarrow H_2O + CO_2$$

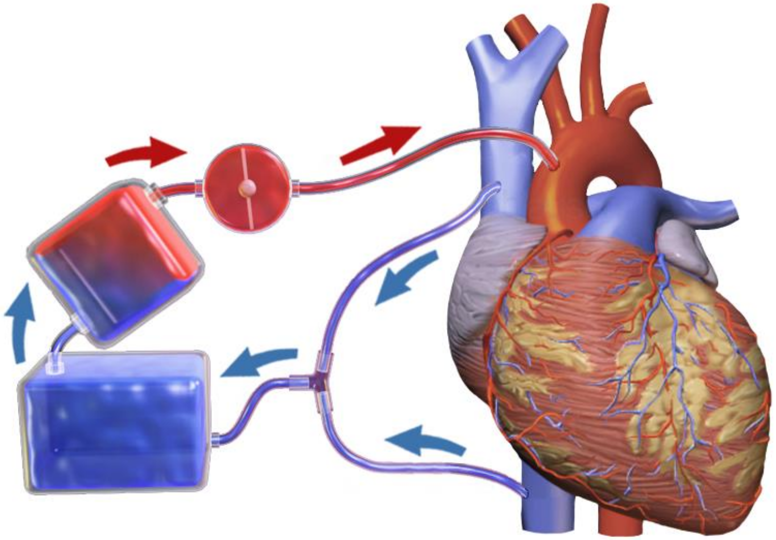
   Hb represents "hemoglobin", the protein inside red blood cells that carries the oxygen. The carbon dioxide passes from the blood through the walls of the tubes and into the gas stream. Thus, when the gas stream enters the oxygenator, it consists mainly of oxygen, and when it leaves, it contains much more carbon dioxide than when it entered.
F. The blood leaving the oxygenator passes through a filter, which traps air bubbles and removes them from the blood to form an air stream output from the filter.
G. The blood (now called "arterial blood") returns to the patient and enters the main artery.

Construct a pictorial process flow diagram using the symbols in Figure 2.5 (without a stream table).

2.2 Representing chemical processes using process diagrams

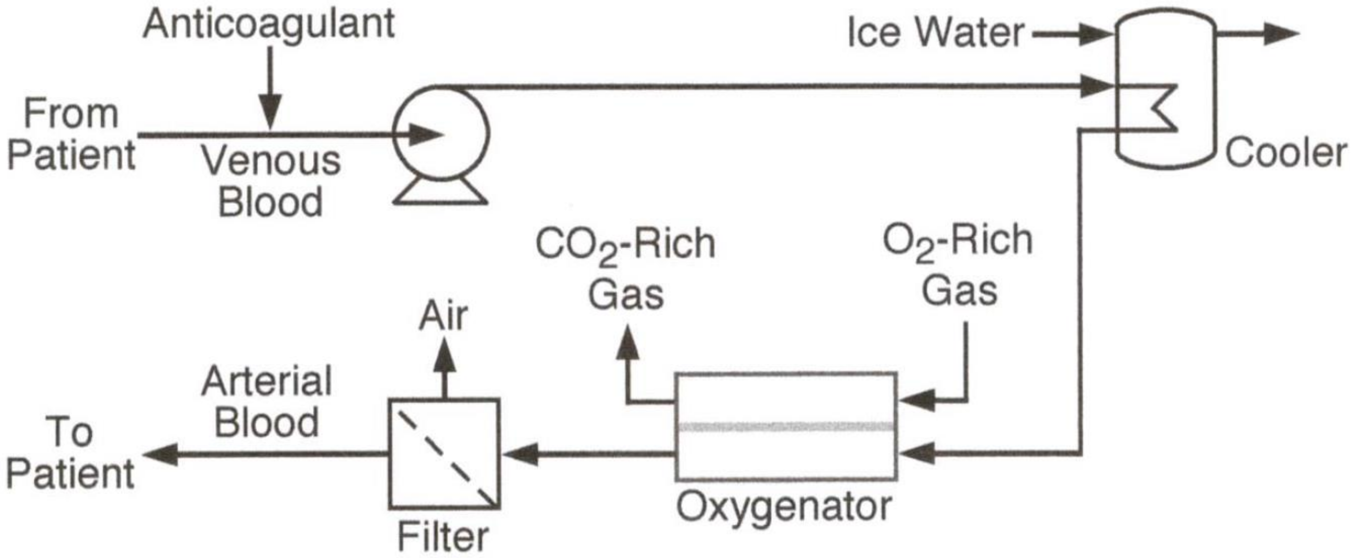
Photo and schematic diagram for cardiopulmonary bypass





2.2 Representing chemical processes using process diagrams

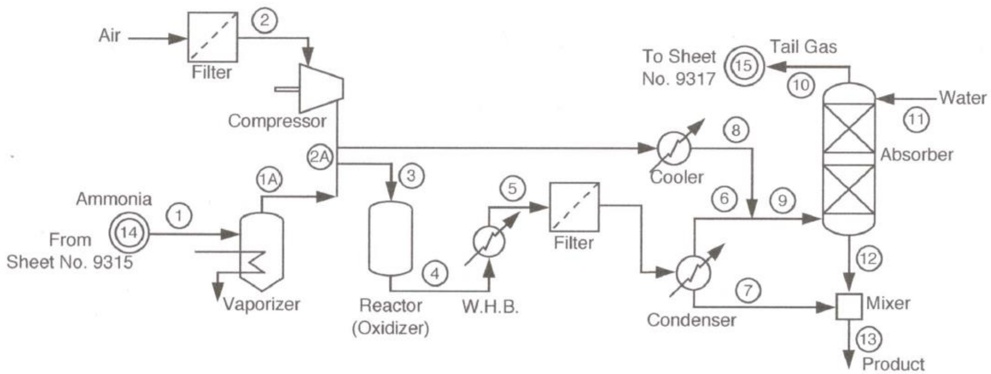
PFD for cardiopulmonary bypass (solution of example 2.2)



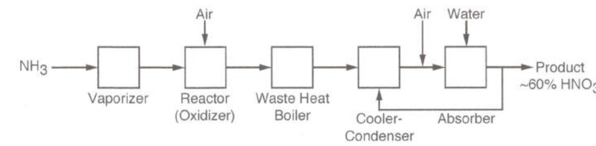
2.2 Representing chemical processes using process diagrams

2.2.2 Process flow diagrams (PFD)

with stream table



cf) Block diagram



Flows kg/h Pressures nominal

Line no. / Stream / Component	1 Ammonia feed	1A Ammonia vapour	2 Filtered air	2A Oxidizer air	3 Oxidizer feed	4 Oxidizer outlet	5 W.H.B. outlet	6 Condenser gas	7 Condenser acid	8 Secondary air	9 Absorber feed	10 Tail (2) gas	11 Water feed	12 Absorber acid	13 Product acid	C & R Construction Inc.
NH_3	731.0	731.0	—	—	731.0	Nil	—	—	—	—	—	—	—	—	—	Nitric acid 60 percent
O_2	—	—	3036.9	2628.2	2628.2	935.7	(935.7)(1)	275.2	Trace	408.7	683.9	371.5	—	Trace	Trace	100,000 t/y
N_2	—	—	9990.8	8644.7	8644.7	8668.8	8668.8	8668.8	Trace	1346.1	10,014.7	10,014.7	—	Trace	Trace	Client BOP Chemicals
NO	—	—	—	—	—	1238.4	(1238.4)(1)	202.5	—	—	202.5	21.9	—	Trace	Trace	SLIGO
NO_2	—	—	—	—	—	Trace	(?)(1)	967.2	—	—	967.2	(Trace)(1)	—	Trace	Trace	Sheet no. 9316
HNO_3	—	—	—	—	—	Nil	Nil	—	850.6	—	—	—	—	1704.0	2544.6	
H_2O	—	—	Trace	—	—	1161.0	1161.0	29.4	1010.1	—	29.4	26.3	1376.9	1136.0	2146.0	
Total	731.0	731.0	13,027.7	11,272.9	12,003.9	12,003.9	12,003.9	10,143.1	1860.7	1754.8	11,897.7	10,434.4	1376.9	2840.0	4700.6	
Press bar	8	8	1	8	8	8	8	8	1	8	8	1	8	1	1	Dwg by Checked
Temp. °C	15	20	15	230	217	907	234	40	40	40	40	25	25	40	43	Date 25/7/1980

Information in the stream table

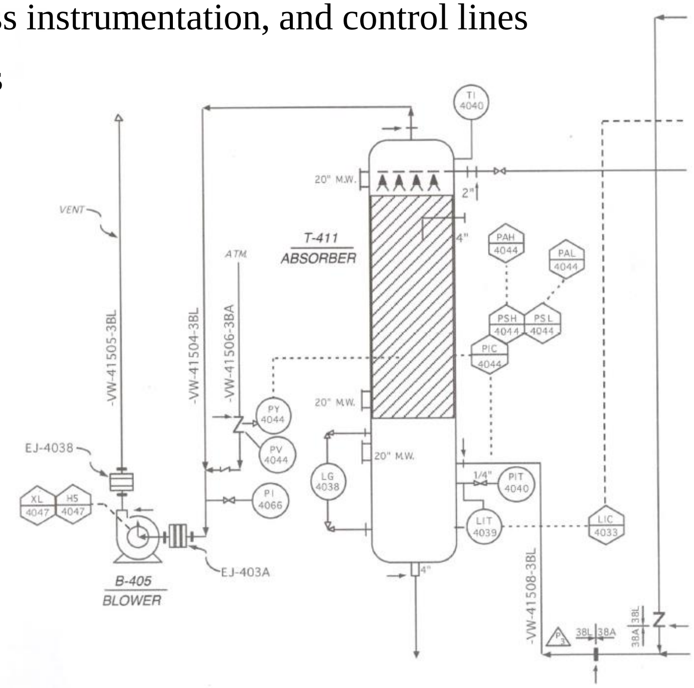
1. Stream composition (flow rate or fraction)
2. Total stream flow
3. Stream temperature
4. Normal operating pressure of the stream
5. The basis for the information in the table

Other information may also be added.

2.2 Representing chemical processes using process diagrams

2.2.3 Piping and instrumentation diagrams (P&ID)

- Even greater detail than PFDs
- Be consistent with PFDs using same number or letters
- Engineering details of equipment, instrumentation, piping, valves, and fittings.
- Piping size, material specification, process instrumentation, and control lines
- Utility (steam and high-pressure air) lines



Homework problems

Homework problem 1.

Classify the followings as either *batch* or *continuous* processes, and indicate whether each is a *steady-state* or an *unsteady-state* process:

a. A "surge tank" is used when a liquid is coming from one part of a process at a variable rate and we want to provide a reservoir of that liquid to feed another part of the process. Thus, a surge tank continuously (but at varying flow rates) receives liquid from an incoming stream and also loses that same liquid continuously (also possibly at changing flow rates) in an outgoing stream. The volume in the tank also changes with time.

b. We bake a cake by mixing together the ingredients in a cake pan, placing the pan and mixture in an oven for a prescribed amount of time, and then removing the cake to cool down.

c. A company produces latex paint base by mixing together the ingredients for the paint. All flow rates are held constant to maintain the proper ratio of ingredients. Working around the clock, the company makes approximately 800 gallons of paint every 24 hours.

Homework problems

Homework problem 4.

Hydrogen gas is a valuable product, because it is used as a feedstock (starting material) for many chemical processes. A common way to produce high-purity hydrogen gas is by reaction of propane gas with steam using the following scheme:

A. The propane gas is first sent to a Desulfurizer to remove any sulfur present in the propane gas, because the sulfur would poison catalysts in later process steps.

B. Steam is added to the desulfurized propane, and the combined gas is sent to a Reforming Furnace (a fired heater) (1500 $^\circ F$) to produce the *reforming* reaction: $C_3H_8 + 3H_2O \rightarrow 3CO + 7H_2$

C. More steam is added to the gas mixture leaving the Reforming Furnace, and the combined gas goes to a CO Converter, where the carbon monoxide in the mixture is converted: $CO + H_2O \rightarrow CO_2 + H_2$

D. The gas mixture from the CO Converter enters the CO_2 Absorber, where most of the CO_2 in the mixture is absorbed into an amine solution.

E. The gas mixture from the CO_2 Absorber now contains H_2 with traces of CO and CO_2. The last traces of CO and CO_2 are converted to methane in a Methanator: $CO + 3H_2 \rightarrow CH_4 + H_2O$, $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$

a. Construct a block diagram for the process described above.
b. Construct a pictorial process flow diagram (without the stream table) using the symbols given in Figure 2.5. The following additional information will be helpful (see page 26 in text book).