EQUIPMENT DESIGN

LECTURE 5
PROCESS STRUCTURE

1.3. THE ANATOMY OF A CHEMICAL MANUFACTURING PROCESS

The basic components of a typical chemical process are shown in Figure 1.3, in which each block represents a stage in the overall process for producing a product from the raw materials. Figure 1.3 represents a generalised process; not all the stages will be needed for any particular process, and the complexity of each stage will depend on the nature of the process. Chemical engineering design is concerned with the selection and arrangement of the stages, and the selection, specification and design of the equipment required to perform the stage functions.

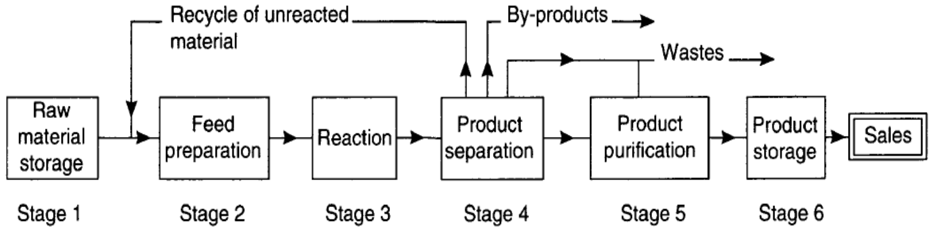
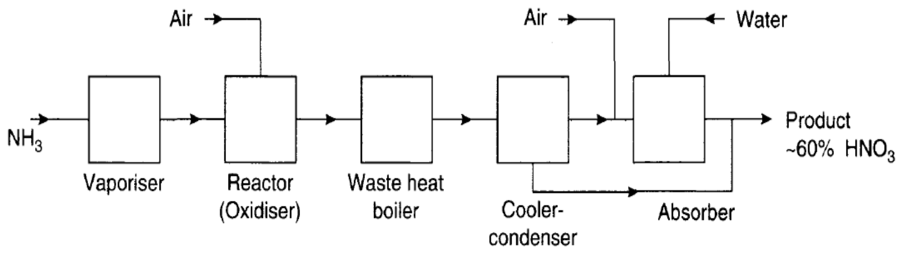


Figure 1.3. Anatomy of a chemical process

PROCESS FLOW-SHEETING



Schematic (block) diagram; production of nitric acid by oxidation of ammonia

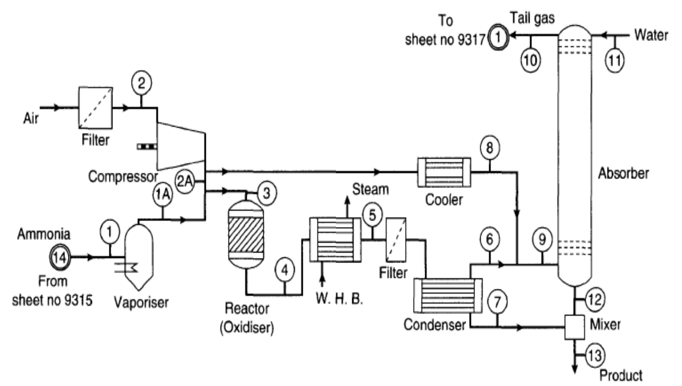
The principal reactions in the reactor (oxidiser) are:

Reaction 1. $NH_3(g) + \frac{5}{4}O_2(g) \rightarrow NO(g) + \frac{3}{2}H_2O(g) \quad \Delta H^\circ_{298} = -226{,}334$ kJ/kmol

Reaction 2. $NH_3(g) + \frac{3}{4}O_2(g) \rightarrow \frac{1}{2}N_2(g) + \frac{3}{2}H_2O(g) \quad \Delta H^\circ_{298} = -316{,}776$ kJ/kmol

The nitric oxide formed can also react with ammonia:

Reaction 3. $NH_3(g) + \frac{3}{2}NO(g) \rightarrow \frac{5}{4}N_2(g) + \frac{3}{2}H_2O(g) \quad \Delta H^\circ_{298} = -452{,}435$ kJ/kmol



Flows kg/h Pressures nominal

Line no. / Stream / Component	1 Ammonia feed	1A Ammonia vapour	2 Filtered air	2A Oxidiser air	3 Oxidiser feed	4 Oxidiser 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 per cent
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	2554.6
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 Date
Temp. °C	15	20	15	230	204	907	234	40	40	40	40	25	25	40	43	Checked 25/7/1980

Essential information

1. Stream composition, either:
   (i) the flow-rate of each individual component, kg/h, which is preferred, or
   (ii) the stream composition as a weight fraction.
2. Total stream flow-rate, kg/h.
3. Stream temperature, degrees Celsius preferred.
4. Nominal operating pressure (the required operating pressure).

Optional information

1. Molar percentages composition.
2. Physical property data, mean values for the stream, such as:
   (i) density, kg/m^3,
   (ii) viscosity, $mN\ s/m^2$.
3. Stream name, a brief, one or two-word, description of the nature of the stream, for example "ACETONE COLUMN BOTTOMS".
4. Stream enthalpy, kJ/h.

4.2.8. Batch processes

Flow-sheets drawn up for batch processes normally show the quantities required to produce one batch. If a batch process forms part of an otherwise continuous process, it can be shown on the same flow-sheet, providing a clear break is made when tabulating the data between the continuous and batch sections; the change from kg/h to kg/batch. A continuous process may include batch make-up of minor reagents, such as the catalyst for a polymerisation process.

4.2.9. Services (utilities)

To avoid cluttering up the flow-sheet, it is not normal practice to show the service headers and lines on the process flow-sheet. The service connections required on each piece of equipment should be shown and labelled. The service requirements for each piece of equipment can be tabulated on the flow-sheet.

4.2.10. Equipment identification

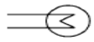
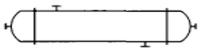
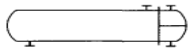
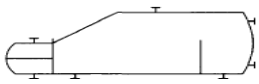
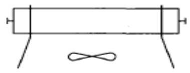
Each piece of equipment shown on the flow-sheet must be identified with a code number and name. The identification number (usually a letter and some digits) will normally be that assigned to a particular piece of equipment as part of the general project control procedures, and will be used to identify it in all the project documents.

If the flow-sheet is not part of the documentation for a project, then a simple, but consistent, identification code should be devised. The easiest code is to use an initial letter to identify the type of equipment, followed by digits to identify the particular piece. For example, H — heat exchangers, C — columns, R — reactors. The key to the code should be shown on the flow-sheet.

APPENDIX A

Basic and developed symbols for plant and equipment

Heat transfer equipment

Heat exchanger (basic symbols)	
Alternative:	
Shell and tube: fixed tube sheet	
Shell and tube: U tube or floating head	
Shell and tube: kettle reboiler	
Air - blown cooler	

PROCESS STRUCTURE

Because of the numerous process types, it is essential to be able to divide a process into a minimum number of basic logical operations to aid in the understanding of existing processes and in the development and design of new processes. The electrical engineer designs electrical circuits consisting of transistors, resistors, capacitors and other basic elements. Similarly, the chemical engineer designs process circuits consisting of reactors, separators, and other process units. Early in the development of chemical engineering the concept of unit operations and processes evolved to isolate the basic elements of a process. Unit operations consist of physical changes, such as distillation and heat transfer, and unit processes consist of chemical changes, such as nitration and oxidation. Thus, any process consists of a combination of unit operations and processes. Trescott [18] discusses the history of this concept.

A modification of the unit-operations, unit-process division is shown in Table 1.3, where a process is divided into nine basic process operations. According to this division, the unit operations are subdivided into several basic operations and conversion is substituted for all unit processes for a total of nine process

Table 1.3 Basic Process Operations

1. Conversion

Thermochemical
Biochemical
Electrochemical
Photochemical
Plasma
Sonochemical

2. Separations

Component (Examples)	*Phase(Examples)*
Distillation	Gas-Liquid
Absorption	Gas-Solid
Extraction	Liquid-Liquid
Adsorption	Liquid-Solid

3. Mixing

Component	*Phase (Examples)*
Dissolving	Gas-Liquid
	Gas-Solid
	Liquid-Liquid
	Liquid-Solid
	Solid-Solid

4. Material Transfer
Pumping Liquids
Compressing Gases
Conveying Solids

5. Energy Transfer
Expansion
Heat Exchange

6. Storage
Raw Materials
Internal
Products

7. Size reduction

8. Agglomeration

9. Size Separation

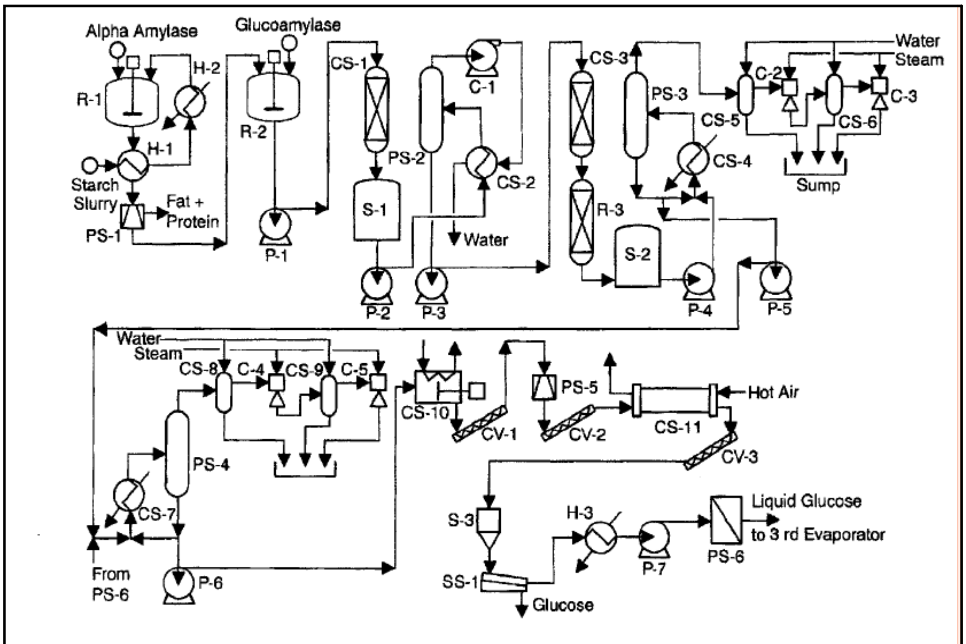


Figure 1.3 Glucose-process flow diagram.

Table 1.4 Glucose Production Process Operations

Process Unit	Process Conditions	Process Operations
Hydrolyzer, R-1	Time – 2 h Feed – 30 - 40% solids Temperature – 80 - 90 °C pH – 5.5 - 7.0 Hydrolysis – 15 - 25 %	Conversion Mixing
Interchanger, H-1		Energy Transfer
Heater, H-2		Energy Transfer
Centrifuge, PS-1	Solids Removed 0.3 - 0.4 % protein 0.5 - 0.6 % fat	Phase Separation
Hydrolyzer, R-2	Time – 48 - 72 h Temperature – 55 - 60 °C pH – 4.0 - 4.5 Dissolved Solids – 97.0 - 98.5 % glucose	Conversion Mixing
Pump, P-1		Material Transfer
Adsorber, CS-1		Component Separation
Tank, S-1		Storage
Pump, P-2		Material Transfer

Evaporators (contains three effects or stages)		
1st Effect 2nd Effect 3rd Effect	Product – 40 - 58% solids Product – 58 - 70% solids Product – 70 - 78% solids	
First Effect Evaporator, CS-2 Flash Drum, PS-2 Compressor, C-1 Pump, P-3 Adsorber, CS-3 Ion Exchanger, R-3 Tank, S-2		 Component Separation Phase Separation Material Transfer Material Transfer Component Separation Conversion Storage
Second Effect Pump, P-4 Evaporator, CS-2 Flash Drum, PS-3 Barometric Condensers 2 stages, CS-5, CS-6 Steam Jet Ejectors 2 stages, C-2, C-3		 Material Transfer Component Separation Phase Separation Component Separation & Phase Separation Material Transfer & Mixing
Third Effect		Same as Second Effect
Crystallizer, CS-10	Seed crystals – 20 - 25% of the batch Temperature – from 43 - 46 °C to 20 - 39 °C Time – 2 days Yield – 60% crystals	Component Separation
Conveyor, CV-1		Material Transfer

Conveyor, CV-1		Material Transfer
Centrifuge, PS-5	Product – 14% H_2O	Phase Separation
Conveyor, CV-2		Material Transfer
Rotary Dryer, CS-11		Component Separation
Conveyor, CV-3		Material Transfer
Bin, S-3		Storage
Melter, H-3		Energy Transfer
Pump, P-7		Material Transfer
Pressure Filter, PS-6		Phase Separation

APPENDIX A

Graphical Symbols for Piping Systems and Plant

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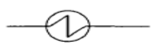
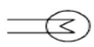
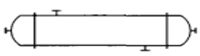
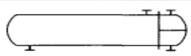
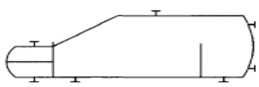
Heat exchanger (basic symbols) Alternative:	 
Shell and tube: fixed tube sheet	
Shell and tube: U tube or floating head	
Shell and tube: kettle reboiler	
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