



Principles of Chemical Industries

Chemical industry:

The chemical industry exists to increase wealth, or add value (primarily of the shareholders in the companies which make up the industry), by taking raw materials such as salt, limestone and oil, and turning them into a whole range of chemicals which are then either directly, or indirectly, converted into consumer products.



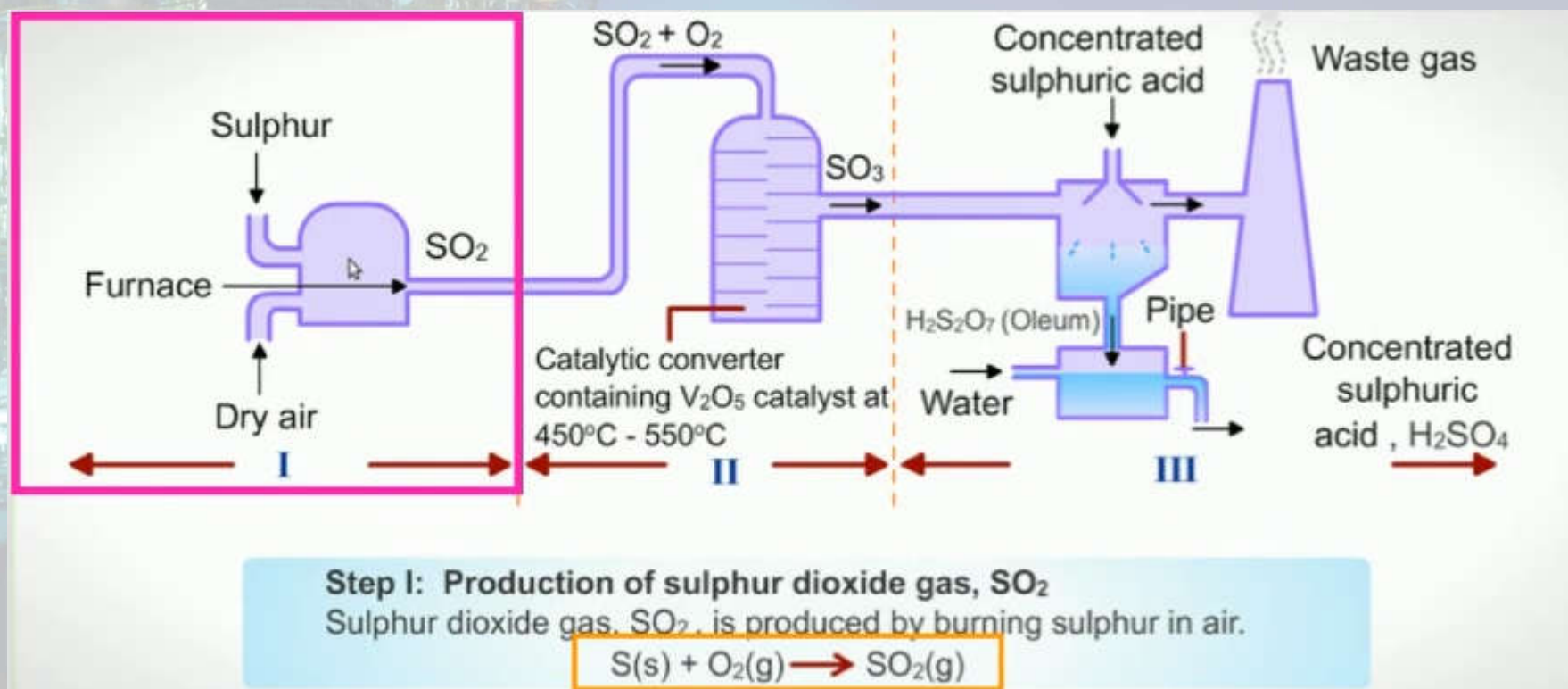
Chemical industry is a vast industry that incorporates all different types of product producing industries whose generation is based on heavy use of chemicals. Usually, industries that are involved with industrial chemical generation are broadly known as chemical industry.



What are the 5 most common industrial chemicals?

- ✓ Sulfuric Acid (H_2SO_4) Sulfuric acid is the most commonly-produced industrial chemical in the world.
- ✓ Ethylene (C_2H_4) Over 150 million tons of ethylene is produced every year, more than any other organic compound.
- ✓ Sodium Hydroxide (NaOH)
- ✓ Propylene (C_3H_6)
- ✓ Nitrogen (N_2)

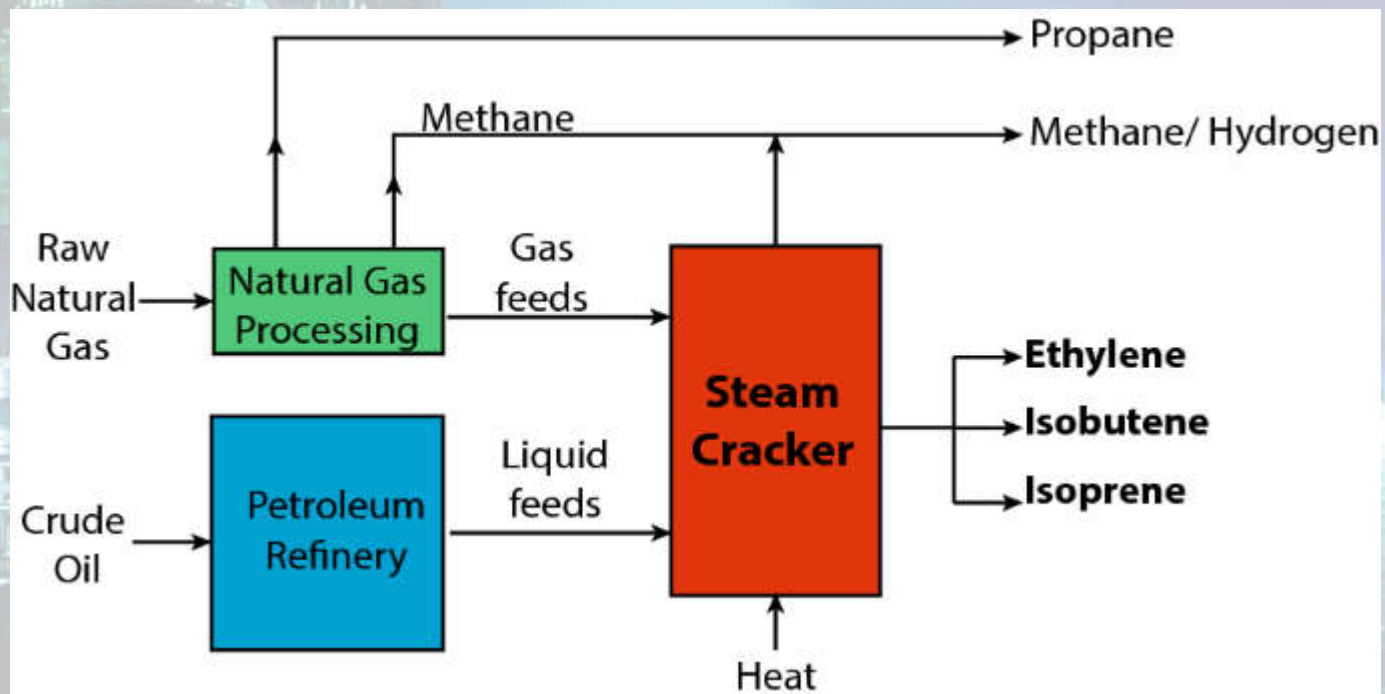
Sulfuric acid is prepared industrially by the reaction of water with sulfur trioxide, which in turn is made by chemical combination of sulfur dioxide and oxygen either by the contact process or the chamber process..



How is ethylene produced?

Usually via steam cracking of crude oil.

Over 95% of the worldwide annual commercial production of ethylene is currently based on steam cracking of petroleum hydrocarbons.





Sodium Hydroxide:

Sodium hydroxide is an inorganic compound vital to many industries. It's used for industrial applications ranging from paper production to textile development to cleaning agent manufacturing; over 70,000,000 tons are produced each year. It is typically derived as a co-product during the manufacture of chlorine. Its popularity rests largely on its inexpensiveness and its ability to “scrub” gases to effectively remove acids during burning.



Sodium Hydroxide, or Caustic Soda, is made via the electrolysis of brine in a process known as the chlor-alkali process. During electrolysis, an electrical current is used to cause an otherwise non-spontaneous chemical reaction; in this case, the decomposition of salt.

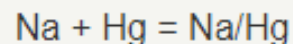
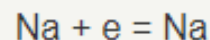
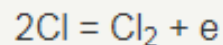
Reaction at the anode:



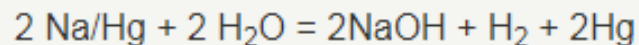
Reaction at the cathode:



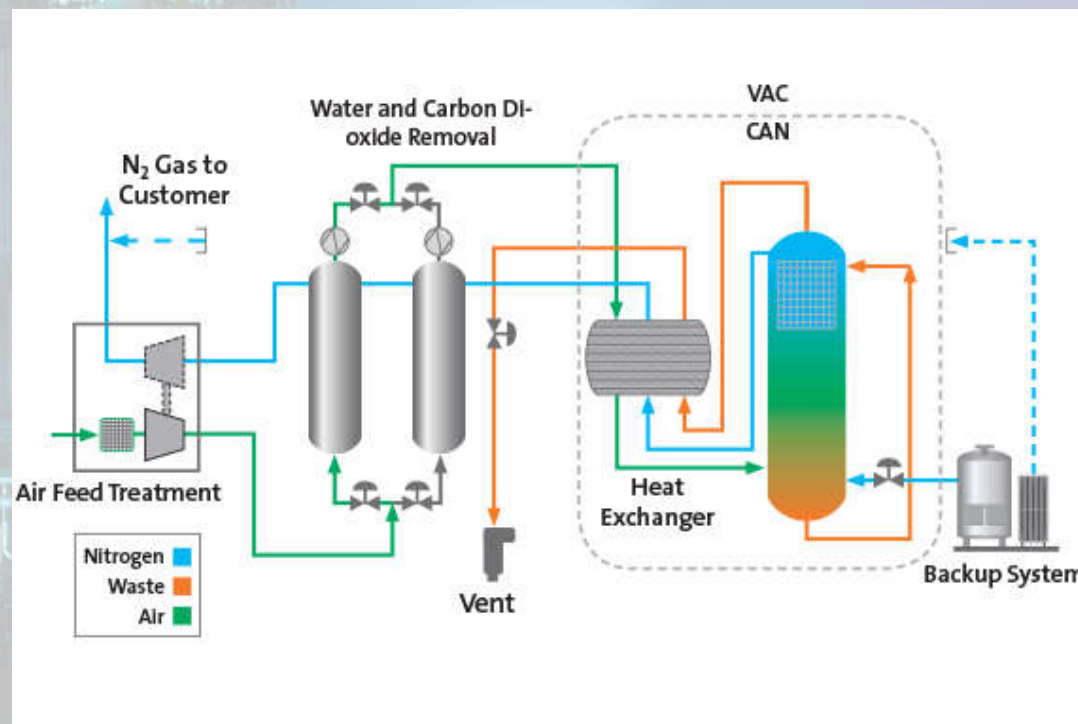
Brine Cell

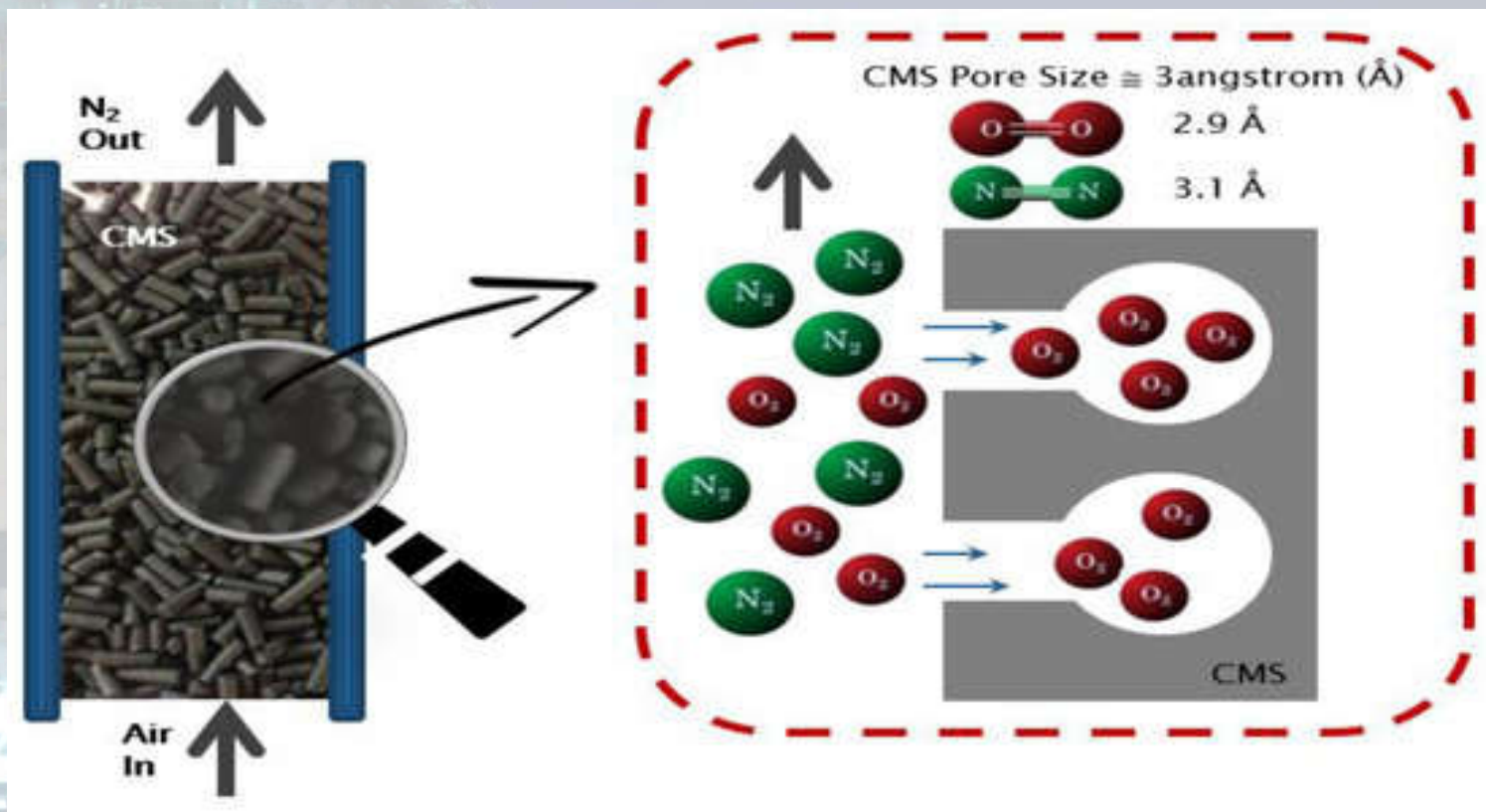


Soda Cell



Industrial nitrogen gas is produced by cryogenic fractional distillation of liquefied air, separation of gaseous air by adsorption, or permeation through membranes. Cryogenic distillation of air is the oldest method of nitrogen production and was developed in 1895.

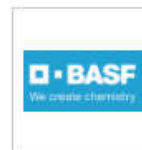




Top 10 Chemical Companies in the World in 2021:

BASF SE

Headquarters	Germany
Sector	Chemicals
Parent/Subsidiary/IndependentParent	
Annual Revenue (\$M)	92,938



Premium Data

Dow Inc

Headquarters	United States of America
Sector	Chemicals
Parent/Subsidiary/IndependentParent	
Annual Revenue (\$M)	54,968



Premium Data

BASF in 1866:



Saudi Basic Industries Corp

Premium Data

Headquarters Saudi Arabia

Sector Chemicals

Parent/Subsidiary/Independent Subsidiary (of Saudi Arabian Oil Co)

Annual Revenue (\$M) 46,682



LyondellBasell Industries NV

Premium Data

Headquarters United Kingdom

Sector Chemicals

Parent/Subsidiary/Independent Parent

Annual Revenue (\$M) 46,173



Mitsubishi Chemical Group Corp

Premium Data

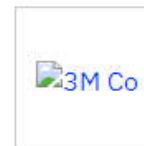
Headquarters	Japan
Sector	Chemicals
Parent/Subsidiary/Independent	Parent
Annual Revenue (\$M)	35,405



3M Co

Premium Data

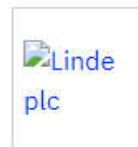
Headquarters	United States of America
Sector	Industrial Goods and Machinery
Parent/Subsidiary/Independent	Parent
Annual Revenue (\$M)	35,355



Linde plc

Premium Data

Headquarters	United Kingdom
Sector	Chemicals
Parent/Subsidiary/Independent	Parent
Annual Revenue (\$M)	30,793



Air Liquide SA

Premium Data

Headquarters	France
Sector	Chemicals
Parent/Subsidiary/Independent	Parent
Annual Revenue (\$M)	27,592



Sumitomo Chemical Co Ltd

Premium Data

Headquarters	Japan
Sector	Chemicals
Parent/Subsidiary/Independent	Parent
Annual Revenue (\$M)	24,619



Henkel AG & Co KGaA

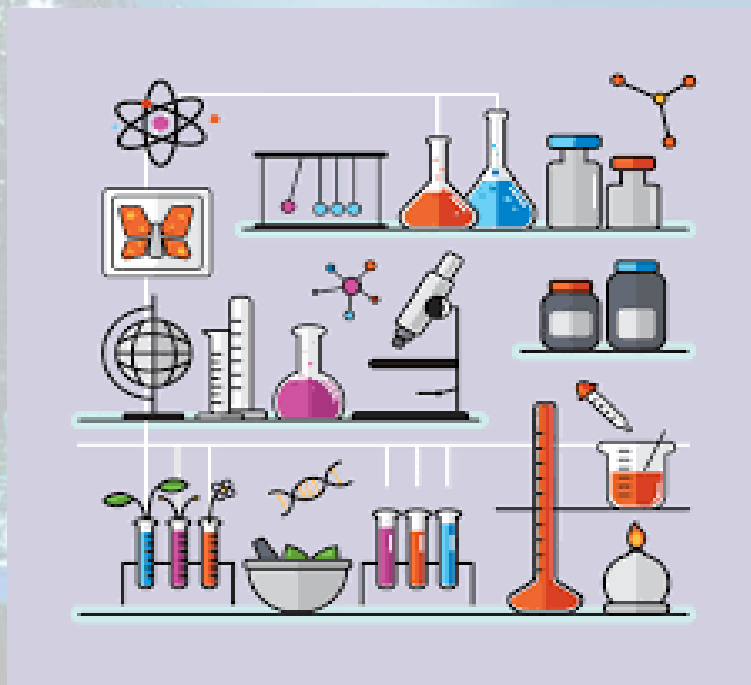
Premium Data

Headquarters	Germany
Sector	Consumer Packaged Goods
Parent/Subsidiary/Independent	Parent
Annual Revenue (\$M)	23,727



Chemical Processes:

Every industrial process is designed to produce a desired product from a variety of starting raw materials using energy through a succession of treatment steps integrated in a rational fashion. The treatments steps are either physical or chemical in nature.



Unit processes:

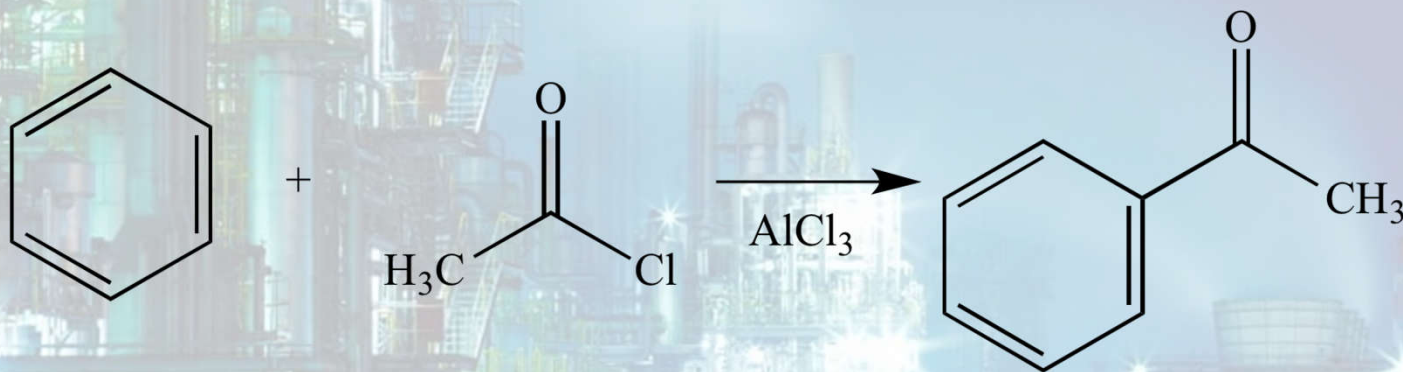
Unit processes are the chemical transformations or conversions that are performed in a process.

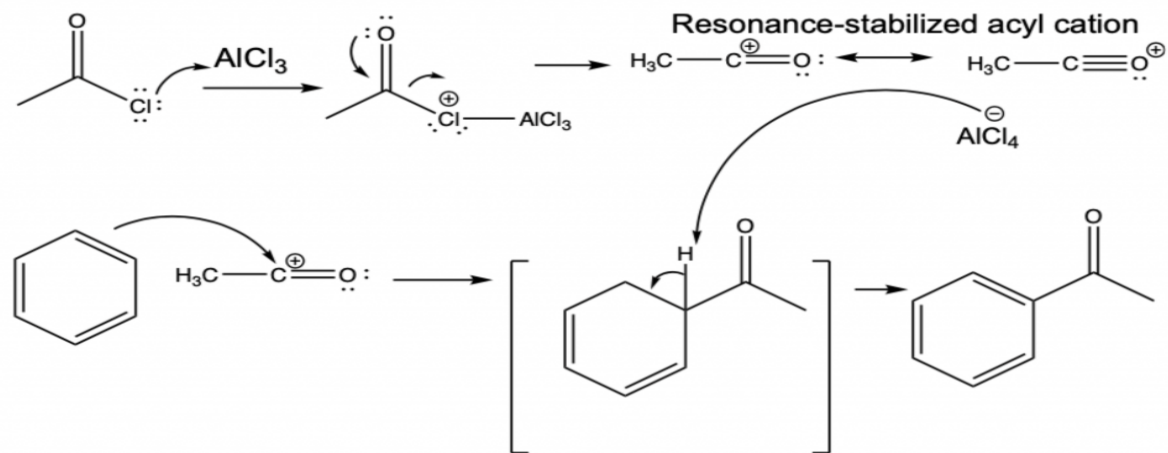
Table 1.1 Examples of unit processes

Acylation	Calcinations	Dehydrogenation	Hydrolysis
Alcoholysis	Carboxylation	Decomposition	Ion Exchange
Alkylation	Causitization	Electrolysis	Isomerization
Amination	Combustion	Esterification	Neutralization
Ammonolysis	Condensation	Fermentation	Oxidation
Aromatization	Dehydration	Hydrogenation	Pyrolysis

Acylation:

Acylation is an organic reaction that involves adding an acyl group to an organic substrate.

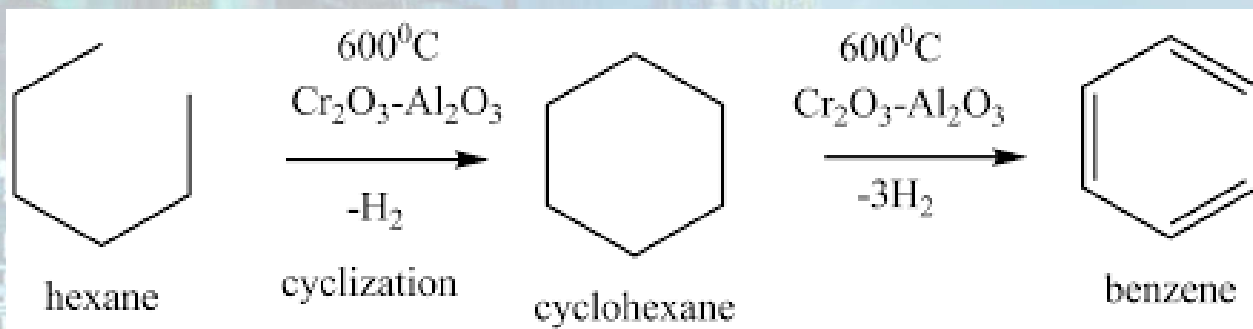




ChemTalk

Aromatization:

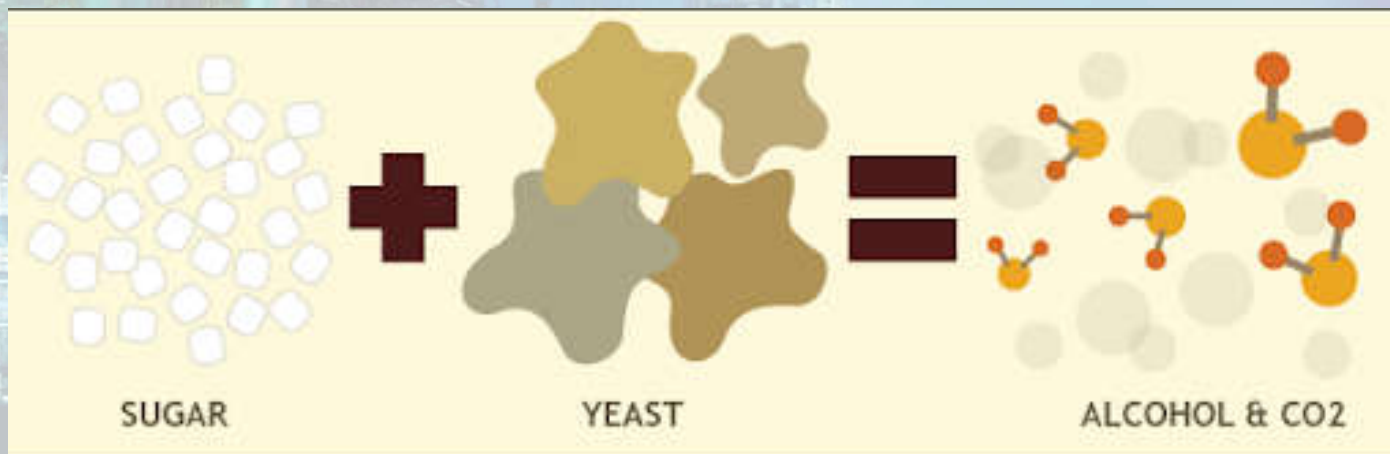
Aromatization is a chemical reaction in which an aromatic system is formed from a single nonaromatic precursor. Typically aromatization is achieved by dehydrogenation of existing cyclic compounds, illustrated by the conversion of cyclohexane into benzene.



Fermentation:

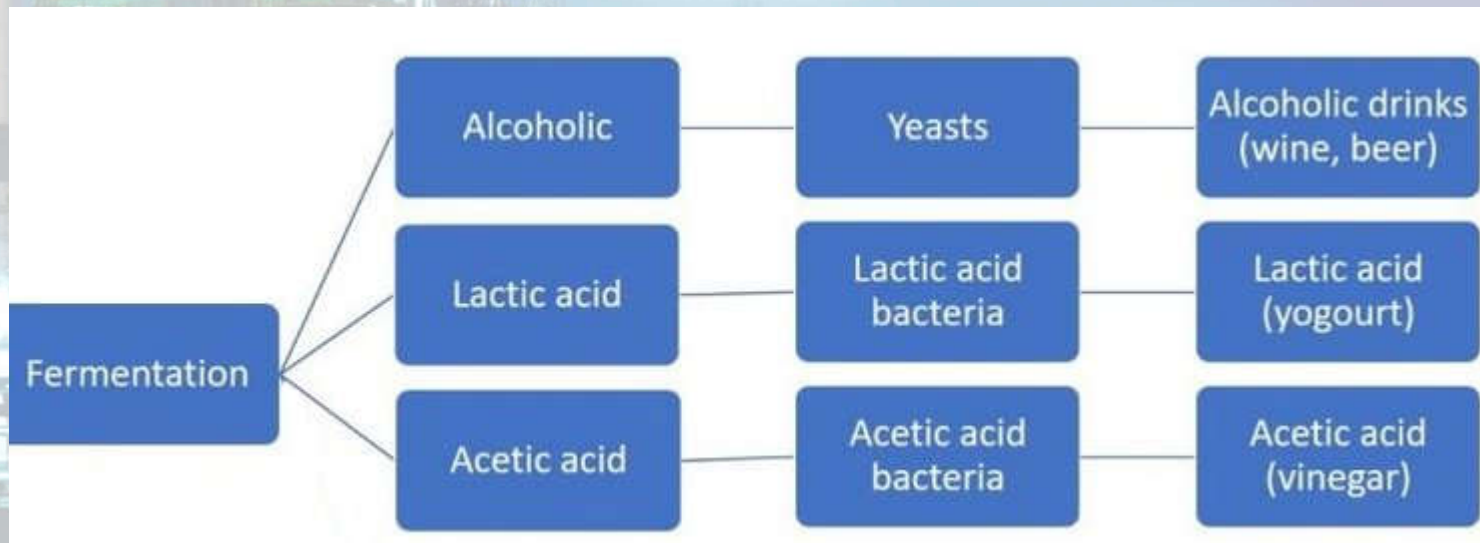
Fermentation is a reaction wherein a raw material is converted into a product by the action of micro-organisms or by means of enzymes.

When micro-organisms are used, they produce enzymes in-situ which then catalyze fermentation reactions.



1- Microbial fermentations promoted by micro-organisms:

Micro-organisms include bacteria, viruses, fungi and protozoa. During microbial fermentation, a raw organic feed is converted into a product by the action of micro-organisms.

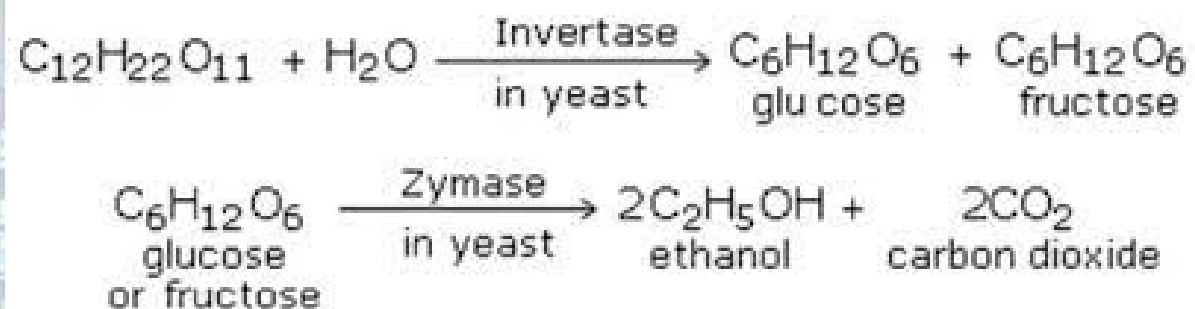


What Is Molasses?

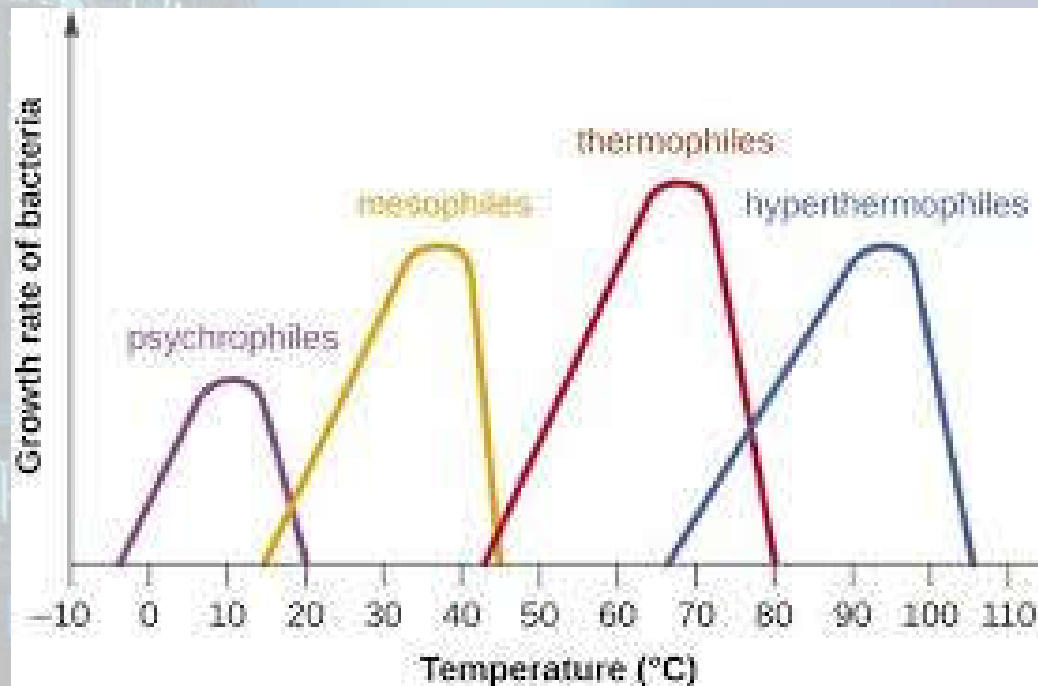
Molasses is a thick, dark syrup made during the sugar-making process. First, the sugar cane is crushed and the juice is extracted. The juice is then boiled to form sugar crystals and removed from the liquid. The thick, brown syrup left after removing the sugar from the juice is molasses.



Saccharomyces cerevisiae contains two main enzymes **Invertase** and **Zymase**. Invertase converts sucrose present in the sample to glucose and fructose, while zymase converts it finally to ethanol and CO₂. A fixed volume of fruit extracts were fermented anaerobically by *Saccharomyces cerevisiae*.

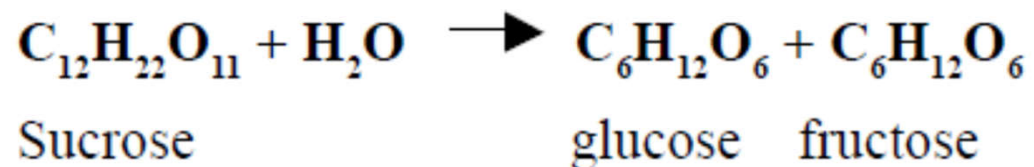


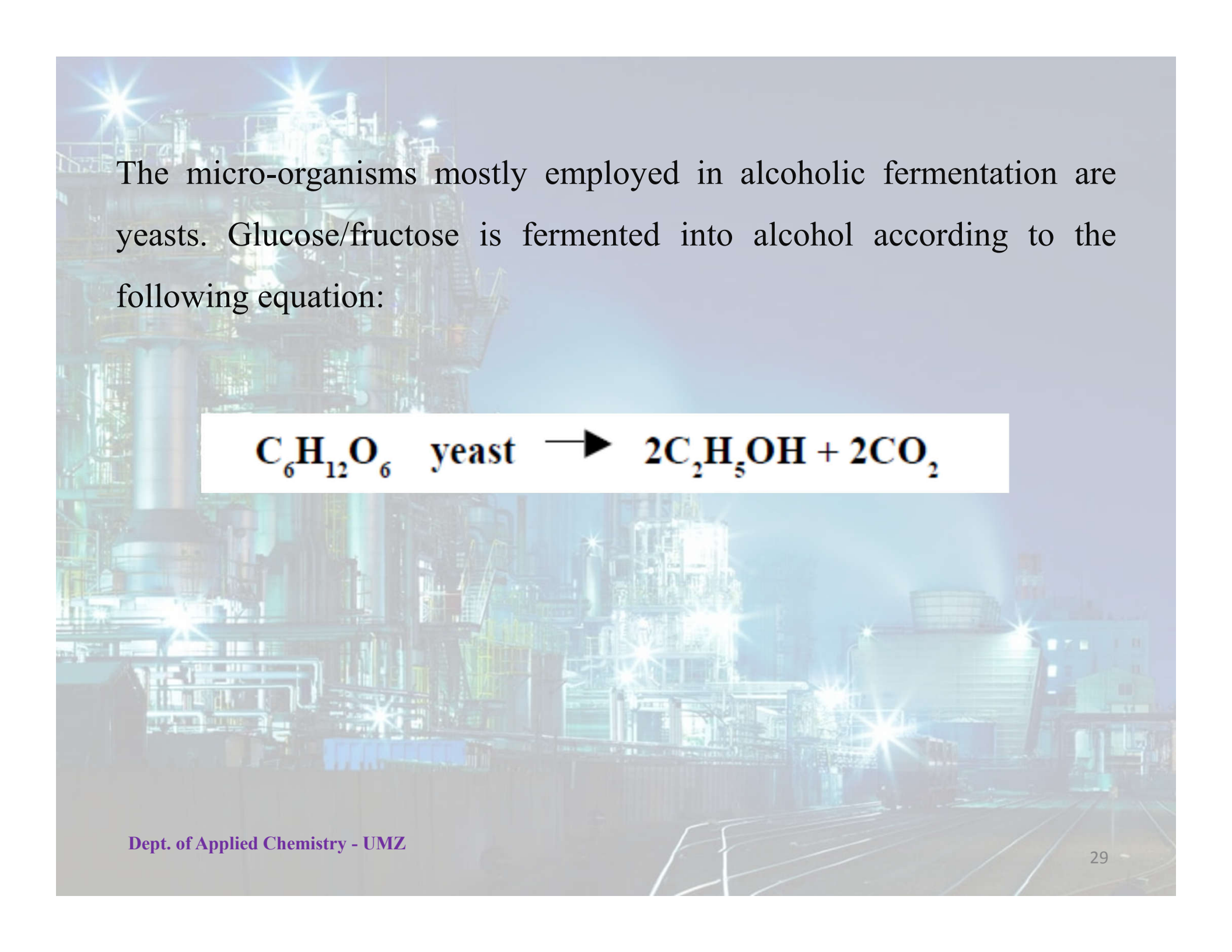
Micro-organisms whose growth is favored by low temperatures are referred to as psychrophilic. Those that grow better at higher temperatures (thermophilic) offer a technical advantage in that the growth of contaminants is inhibited.



Manufacture of Fermentation Ethanol:

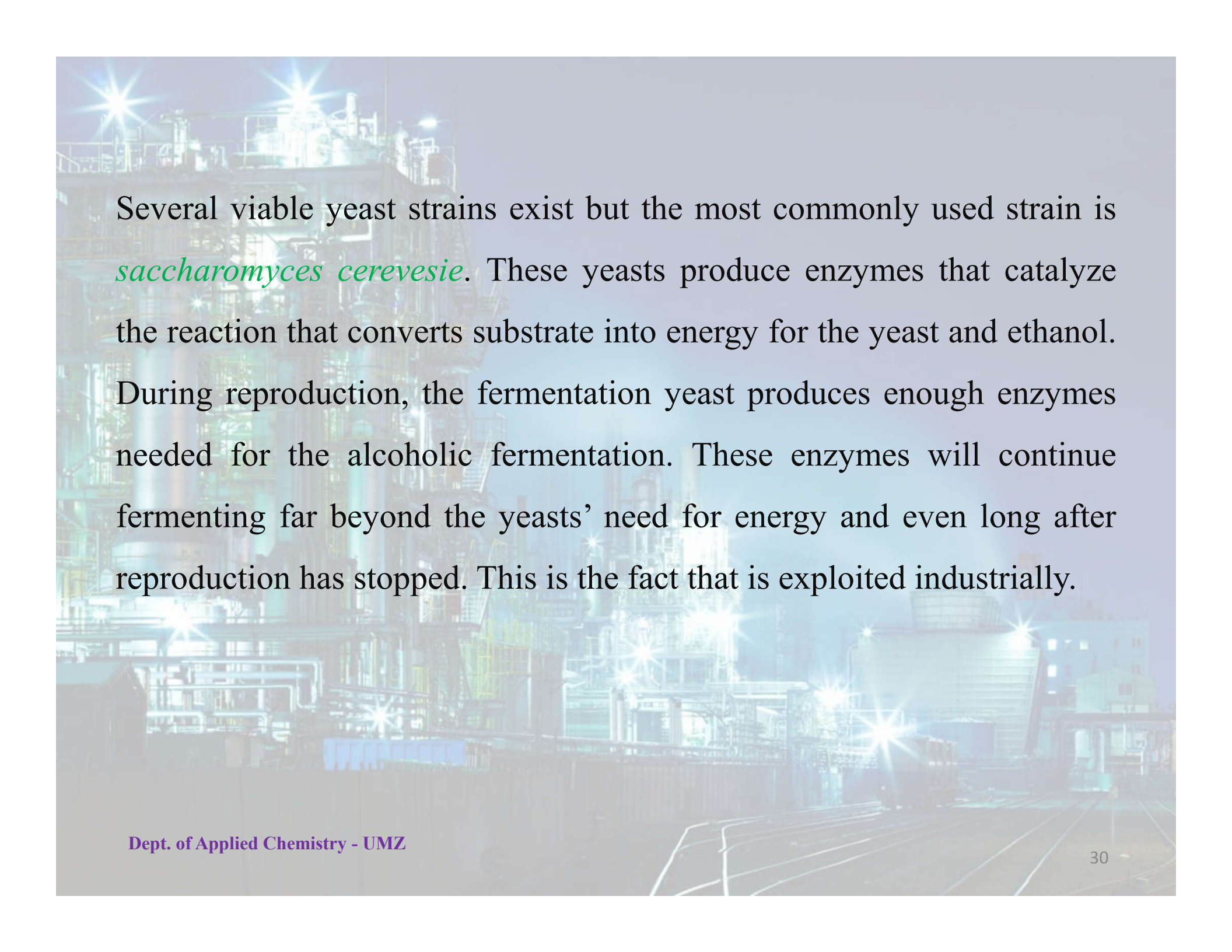
Biomass raw materials include those containing sugar, starch and cellulose. The sugar-containing raw materials include sugar cane, sweet sorghum, sweet potatoes, sugar beet and molasses. These materials contain disaccharides which are easily hydrolyzed by water to reducing sugar (glucose and fructose) in equations similar to the following:



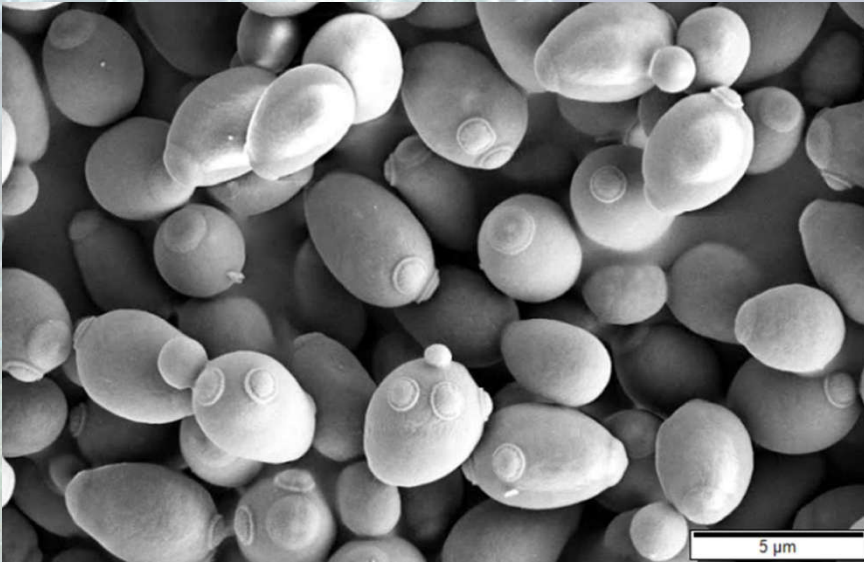


The micro-organisms mostly employed in alcoholic fermentation are yeasts. Glucose/fructose is fermented into alcohol according to the following equation:





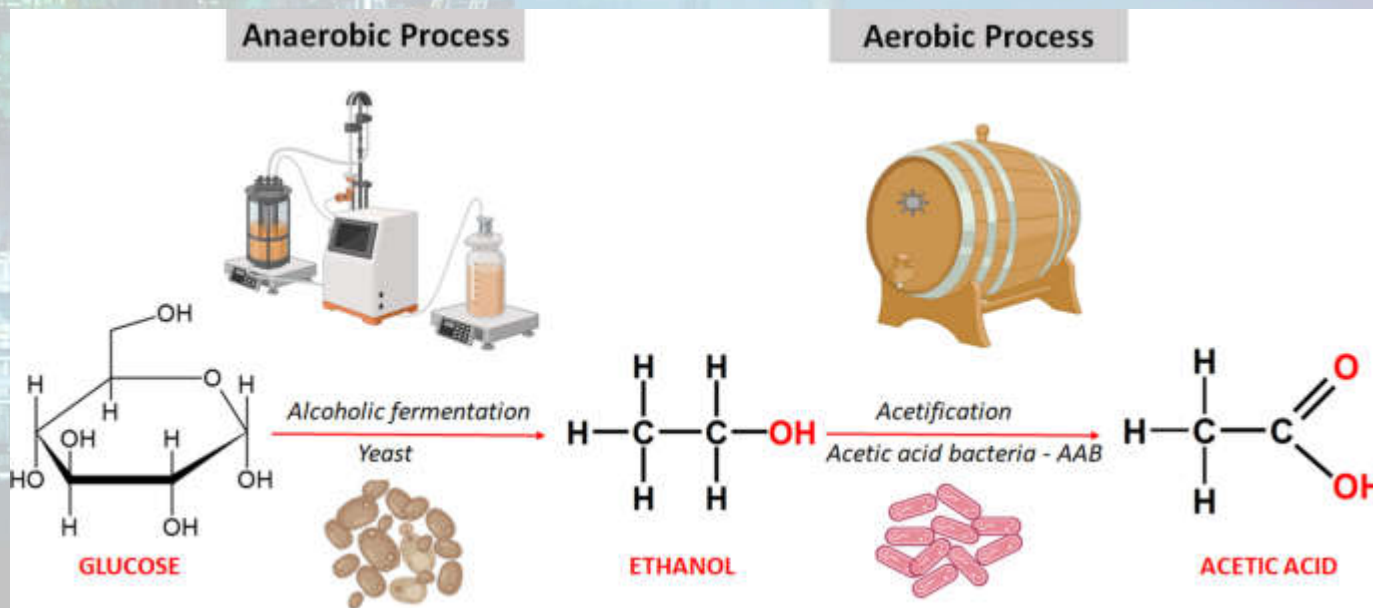
Several viable yeast strains exist but the most commonly used strain is *saccharomyces cerevesie*. These yeasts produce enzymes that catalyze the reaction that converts substrate into energy for the yeast and ethanol. During reproduction, the fermentation yeast produces enough enzymes needed for the alcoholic fermentation. These enzymes will continue fermenting far beyond the yeasts' need for energy and even long after reproduction has stopped. This is the fact that is exploited industrially.



saccharomyces cerevesie



The main species responsible for the production of vinegar belong to the genera *Acetobacter*, *Gluconacetobacter*, *Gluconobacter* and *Komagataeibacter* because of their high capacity to oxidize ethanol to acetic acid and high resistance to acetic acid released into the fermentative medium.





Yogurt:

Contains bacteria that are “thermophilic” = heat loving.

Two main types of Lactic Acid Bacteria:

Lactobacillus:

- meaning “milk” and “rod”
- over 50 different species
- found on plants and in the digestive system of animals such as cows and humans.

Lactococcus:

- meaning “milk” and “sphere” because of its shape
- found primarily on plants
- less common than lactobacillus

Lactic acid Bacteria

Lactose
(Milk sugar)

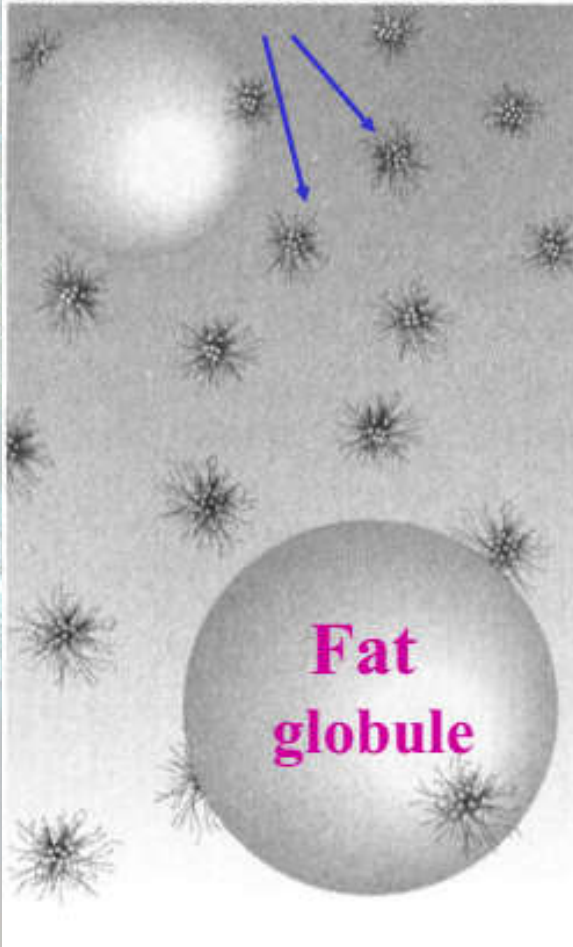
-----> Lactic Acid



Acid causes casein (milk protein) to *denature* and hold water into a semi-solid gel = yogurt

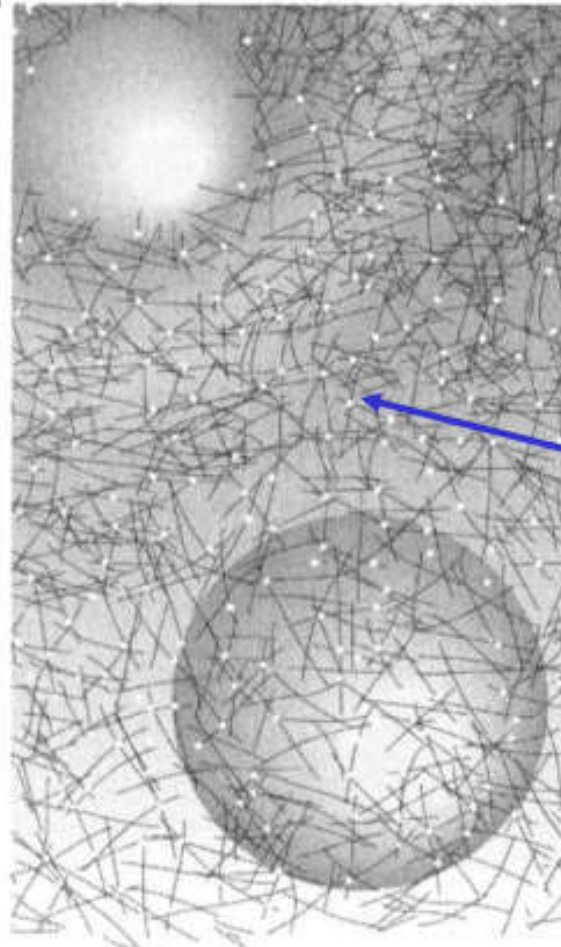
Milk

Casein protein micelles
(bundles)
 10^{-7} meters in diameter



Yogurt

Bacteria produce acid

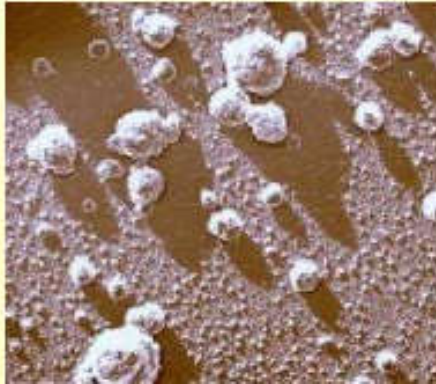


Acid causes
Casein bundles to
fall apart into
separate casein
molecules.

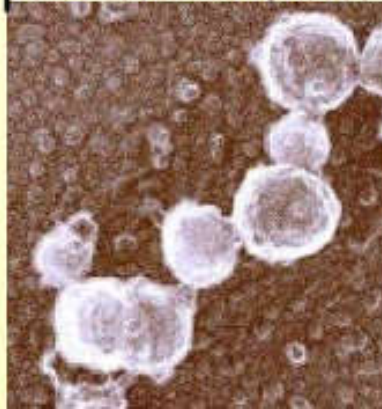
These rebind to
each other in a
network that traps
water.

=> makes a gel

Casein before heat pre-treatment:



Casein after heat pre-treatment:



Casein after acid:





Unit Operations:

*There are many types of chemical processes that make up the global chemical industry. However, each may be broken down into a series of steps called **unit operations**.*

These are the physical treatment steps, which are required to:

- put the raw materials in a form in which they can be reacted chemically
- put the product in a form which is suitable for the market

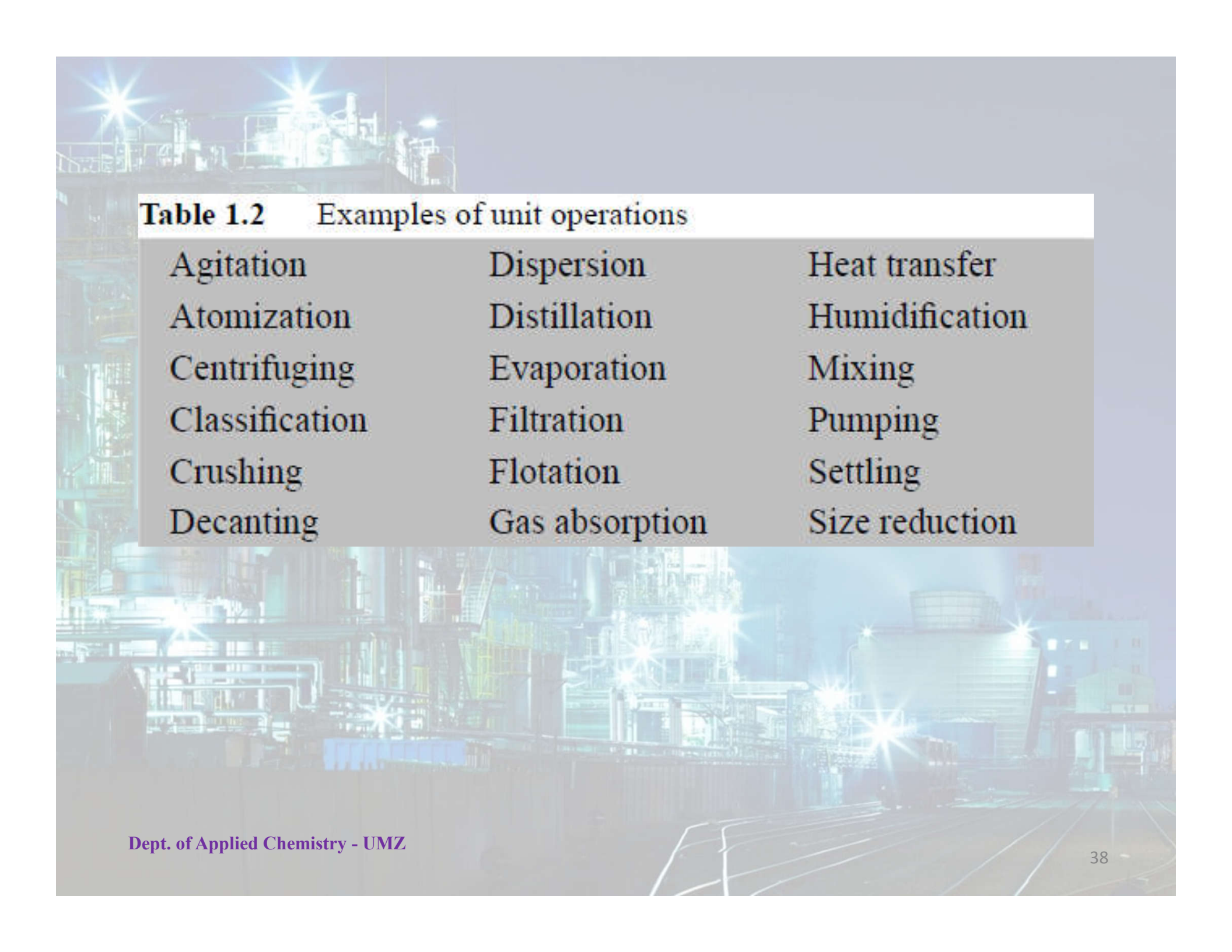
A background image of an industrial plant at night, illuminated by bright lights, with various pipes, tanks, and structures visible.

Table 1.2 Examples of unit operations

Agitation	Dispersion	Heat transfer
Atomization	Distillation	Humidification
Centrifuging	Evaporation	Mixing
Classification	Filtration	Pumping
Crushing	Flotation	Settling
Decanting	Gas absorption	Size reduction

Atomization:

Atomization refers to the disintegration of a liquid into droplets in a surrounding gas. The characteristics of the spray are highly dependent on the spray nozzle type.



Flow Diagrams:

A picture says more than a thousand words.



Some chemical processes are quite simple; others such as oil refineries and petrochemical plants can be very complex. The process description of some processes could take a lot of text and time to read and still not yield 100% comprehension. Errors resulting from misunderstanding processes can be extremely costly.





Block Diagrams:

This is a schematic diagram, which shows:

- **what is to be done rather than how it is to be done. Details of unit operations/processes are not given**
- **flow by means of lines and arrows**
- **unit operations and processes by figures such as rectangles and circles**
- **raw materials, intermediate and final products**

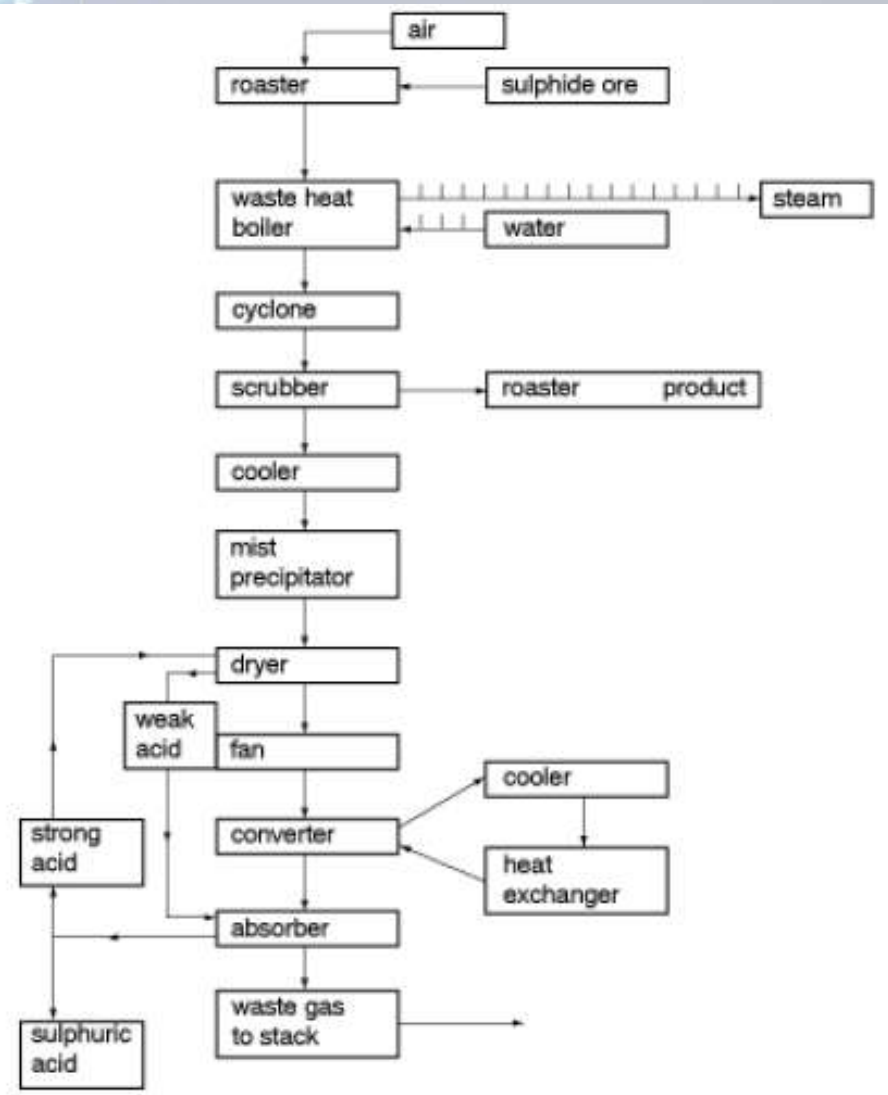


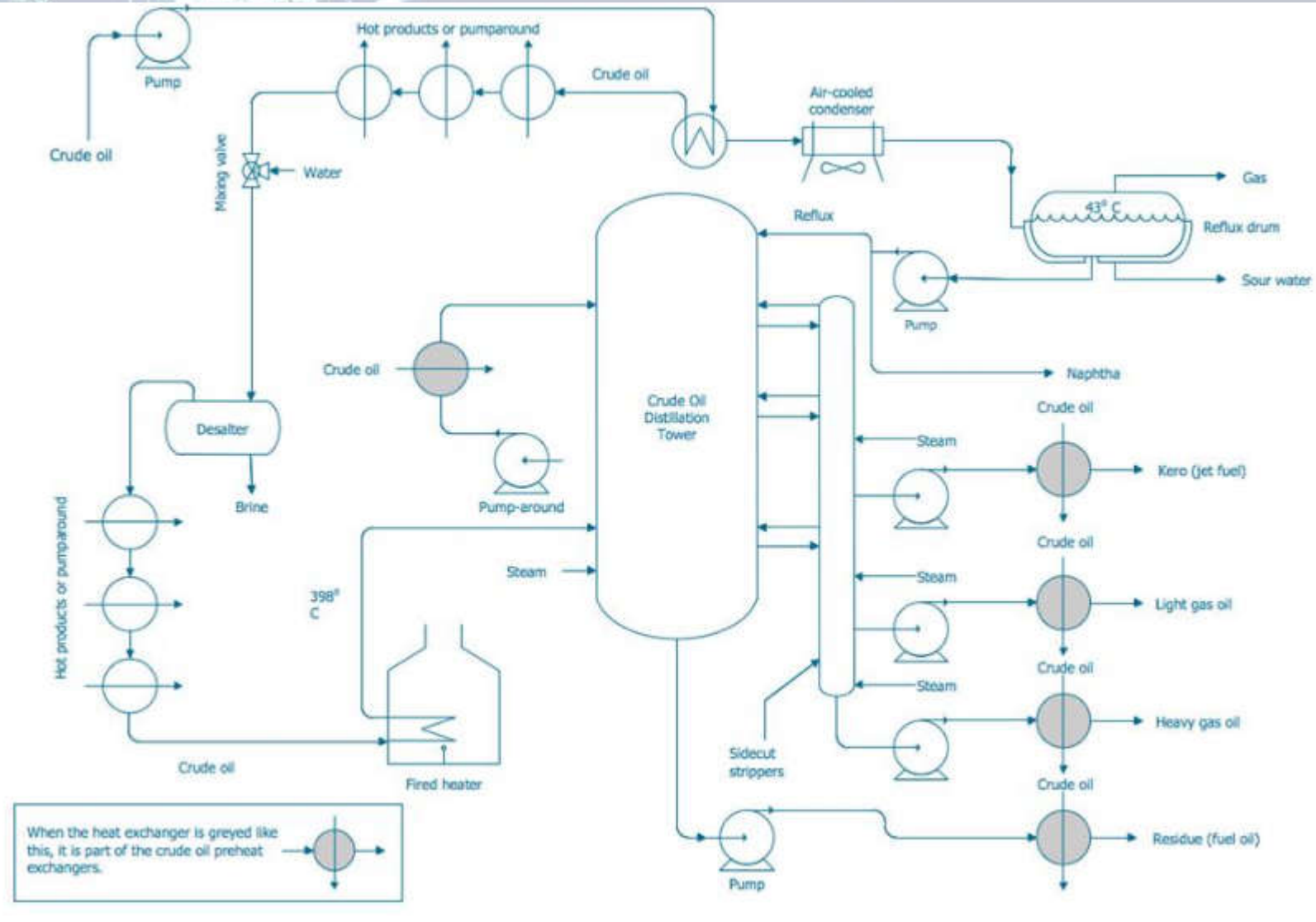
Fig 1.1 A block diagram for a sulphuric acid plant

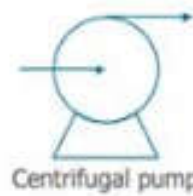
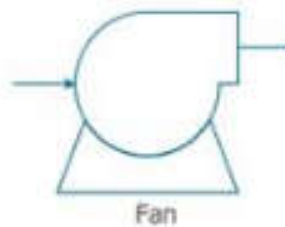
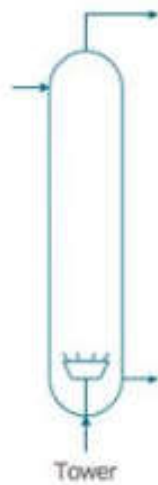
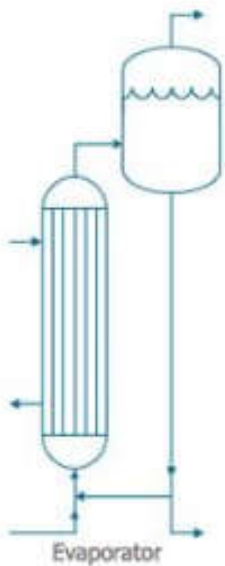
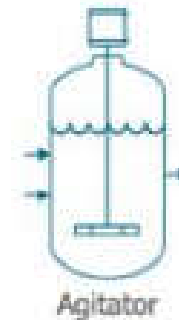
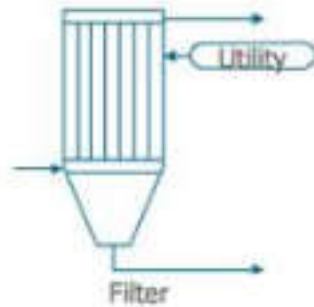
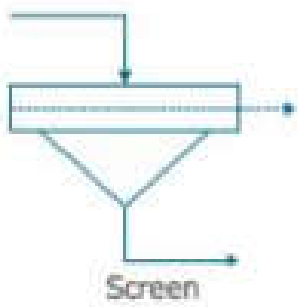
Process flow diagram (PFD):

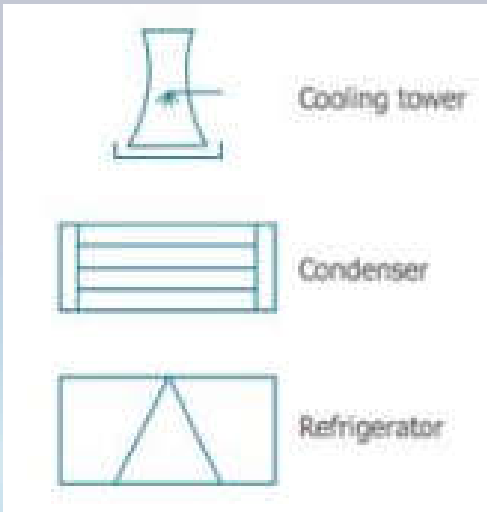
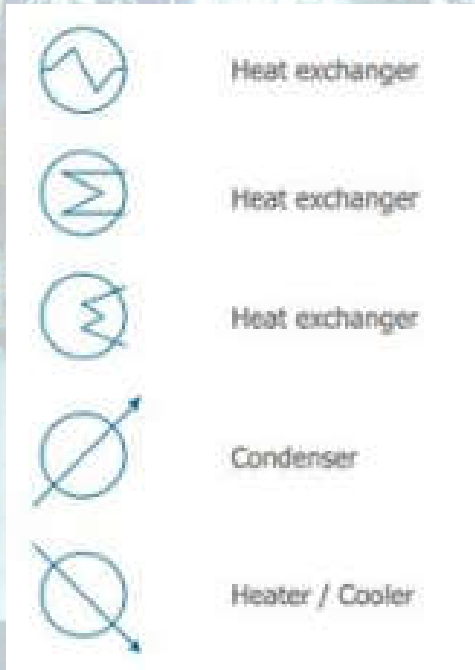
Communication is improved if accepted symbols are used. The advantages of correct use of symbols include:

- the function being performed is emphasized by eliminating distractions caused by detail
- possibility of error that is likely to occur when detail is repeated many times is virtually done away with

Flow sheet symbols are pictorial quick-to-draw, easy-to-understand symbols that transcend language barriers.









Mass balance:

Mass balance calculations serve the following purposes:

1. They help us know the amount and composition of each stream in the process.
2. The calculations obtained in 1 form the basis for energy balances through the application of *the law of conservation of energy*.
3. We are able to make technical and economic evaluation of the process and process units from the knowledge of material and energy consumption and product yield obtained.
4. We can quantitatively know the environmental emissions of the process.

Process Classification:

Three type of process:

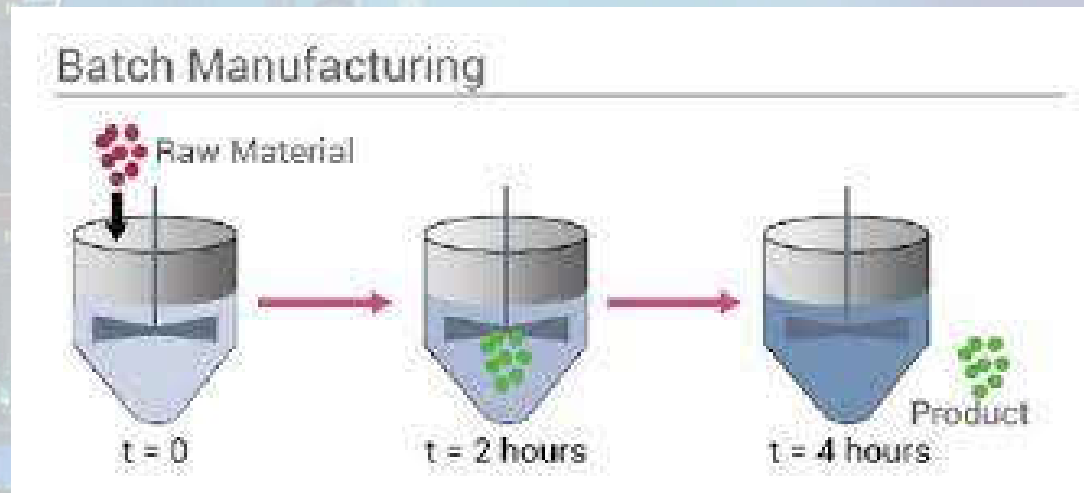
1- Batch process

Feed is charged to the process and product is removed when the process is completed

No mass is fed or removed from the process during the operation

Used for small scale production

Operate in unsteady state



Process Classification:

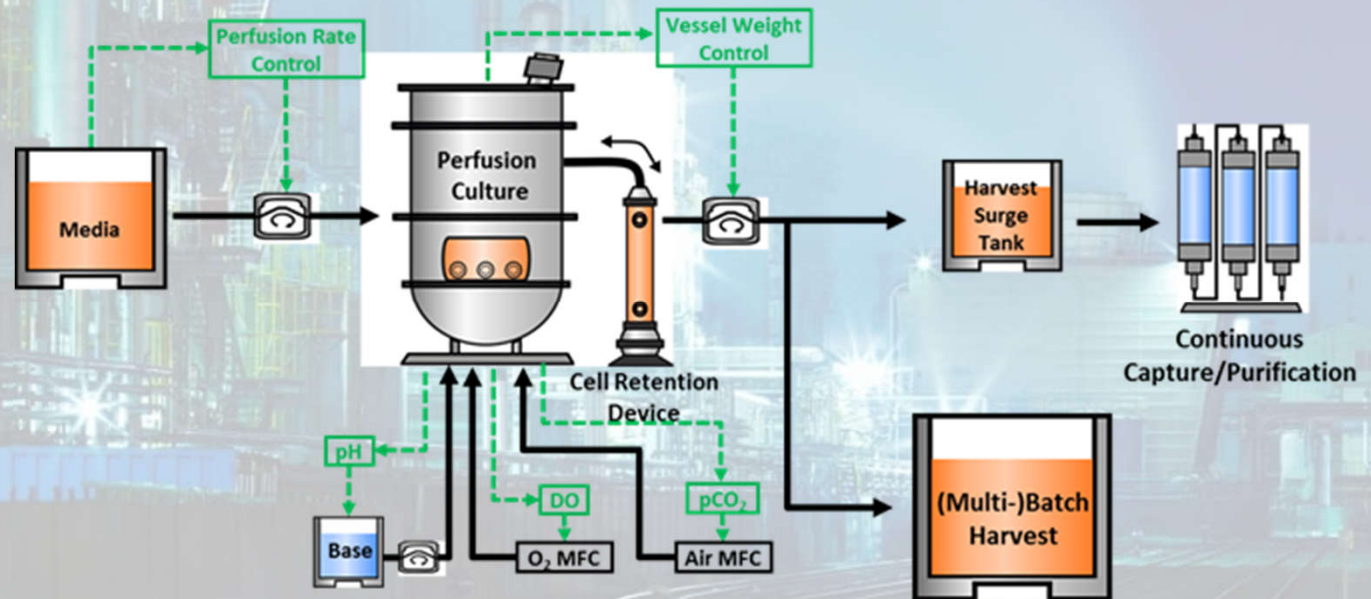
Three type of process:

2- Continuous process

Input and output is continuously fed and remove from the process

Operate in steady state

Used for large scale production



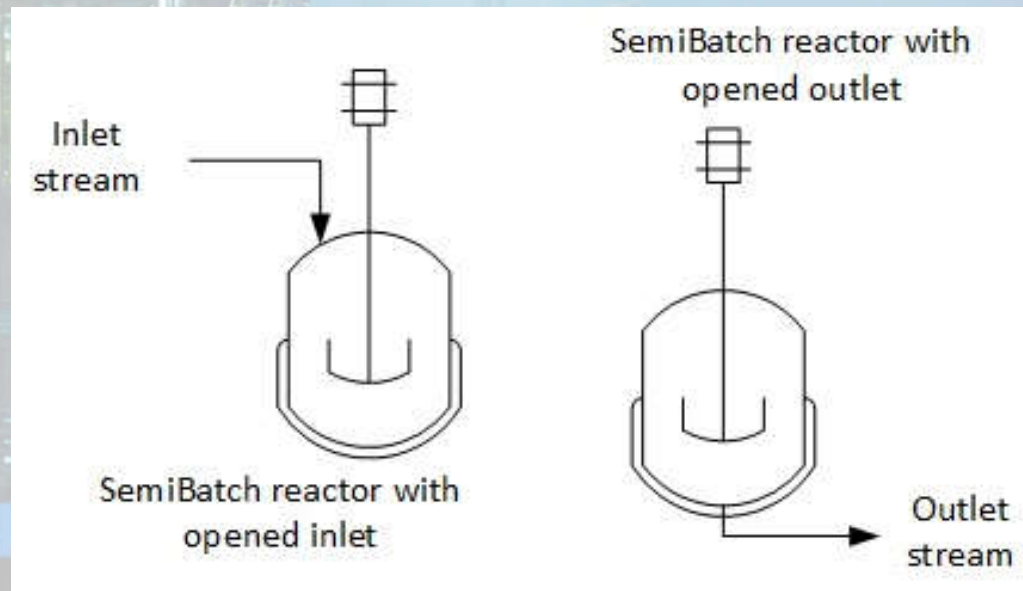
Process Classification:

Three type of process:

3- Semibatch process

Neither batch nor continuous

During the process a part of reactant can be fed or a part of product can be removed.



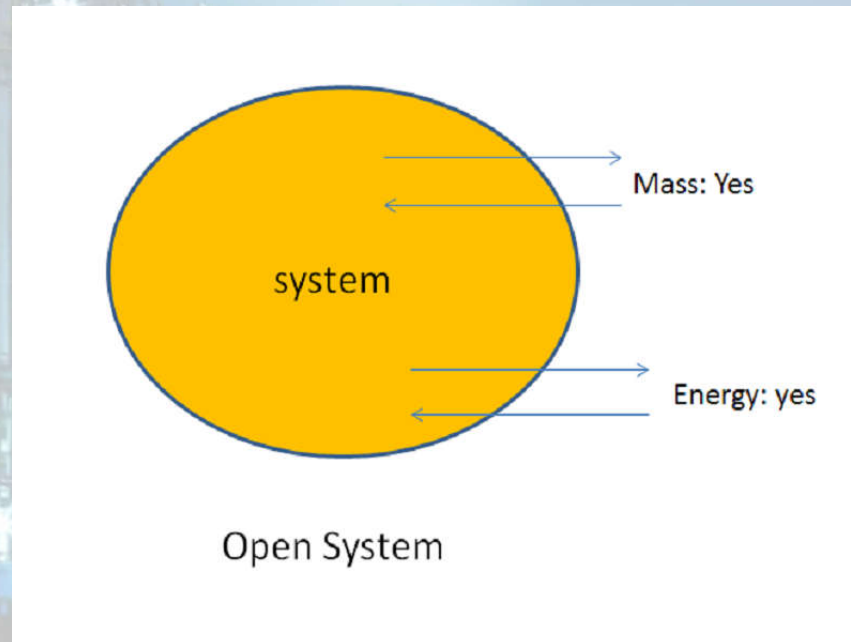
Balances:

General Balance:

A balance on a conserved quantity (total mass, mass of a particular species, energy, momentum) in a system (a single process unit, a collection of units, or an entire process) may be written in the following way:

$$\text{INPUT} + \text{GENERATION} - \text{OUTPUT} - \text{CONSUMPTION} = \text{ACCUMULATION}$$

The system is any process or portion of a process chosen for analysis. A system is said to be “open” if material flows across the system boundary during the interval of time being studied; “closed” if there are no flows in or out.





Simplified Rule for Mass Balance:

If the balanced quantity is TOTAL MASS, set generation = 0 and consumption = 0. Mass can neither be created nor destroyed.

If the balanced substances is a NONREACTIVE SPECIES (neither a reactant nor a product), set generation = 0 and consumption = 0.

If a system is at STEADY STATE, set accumulation = 0, regardless of what is being balanced.



Balances on Continuous Steady State Process:

Steady state: accumulation = 0

$$\text{INPUT} + \text{GENERATION} - \text{OUTPUT} - \text{CONSUMPTION} = 0$$

If balance on nonreactive species or total mass; balance equation become

$$\text{INPUT} = \text{OUTPUT}$$



Balances on Batch Process:

From GMBE: (input=0; output=0):

Generation – Consumption = Accumulation

For batch reactor:

Accumulation = Final output – Initial Input

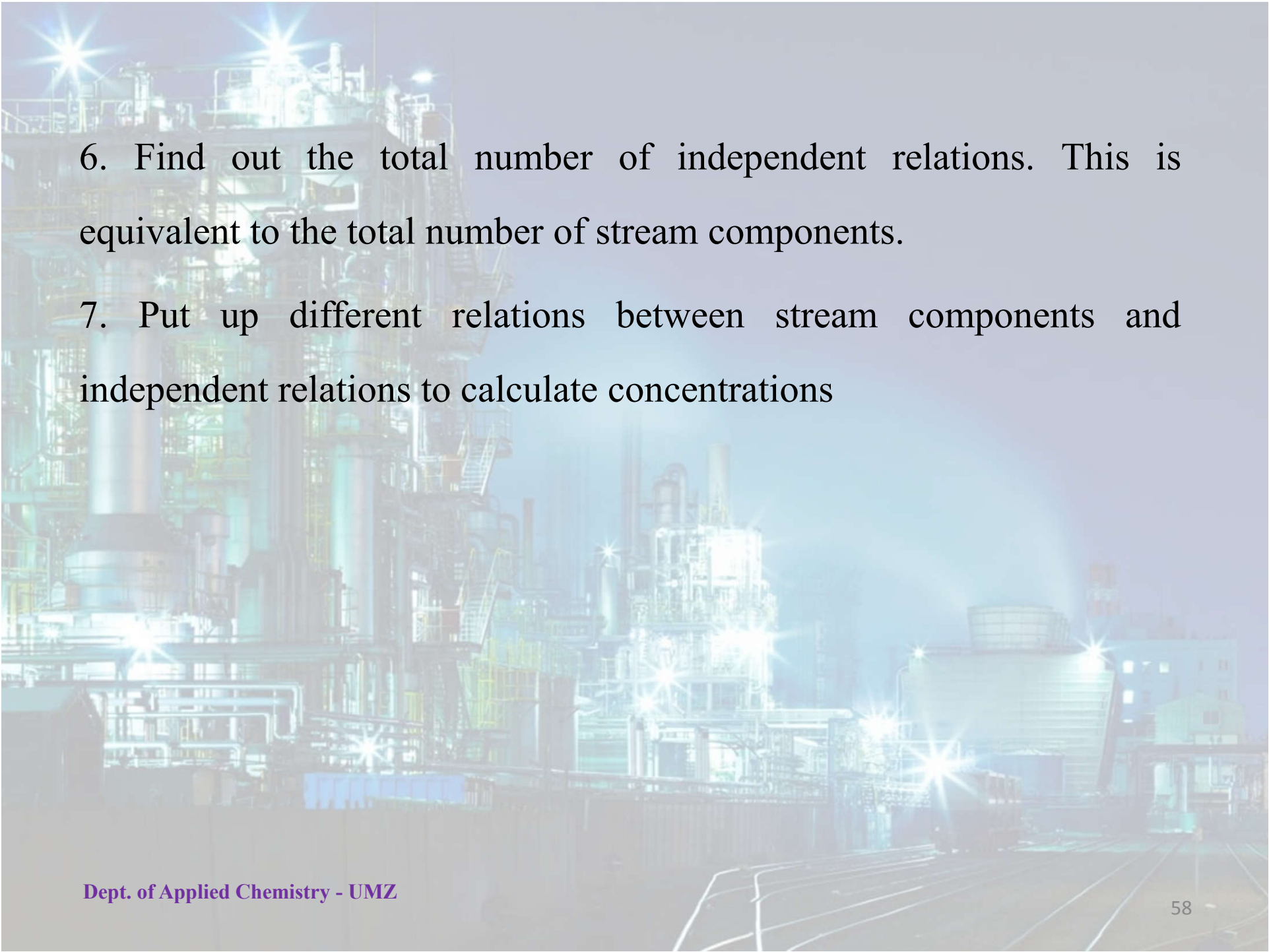
Final GMBE for batch process:

Initial input + Generation = Final output + Consumption

Mass balance calculation procedure:

The general procedure for carrying out mass balance calculations is as follows:

1. Make a block diagram (flow sheet) over the process
2. Put numbers on all the streams
3. List down all the components that participate in the process.
4. Find the components that are in each stream and list them adjacent to the stream in the block diagram
5. Decide on an appropriate basis for the calculations e.g. 100kg raw material A, 100kg/hr A, 1 ton of product, 100 moles reactant B etc.

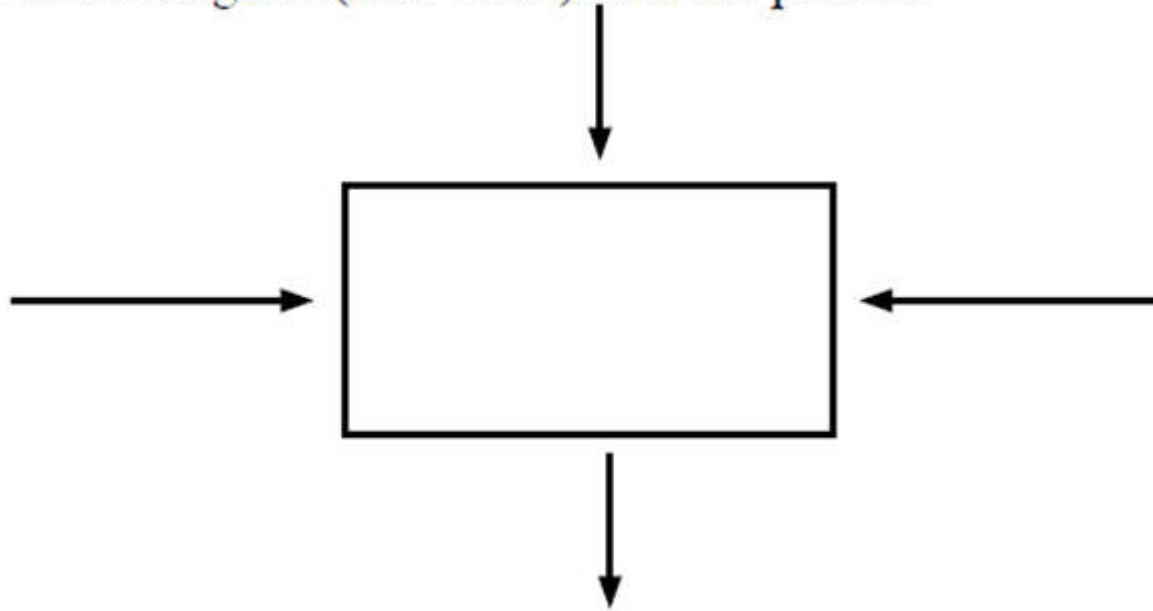
- 
6. Find out the total number of independent relations. This is equivalent to the total number of stream components.
 7. Put up different relations between stream components and independent relations to calculate concentrations



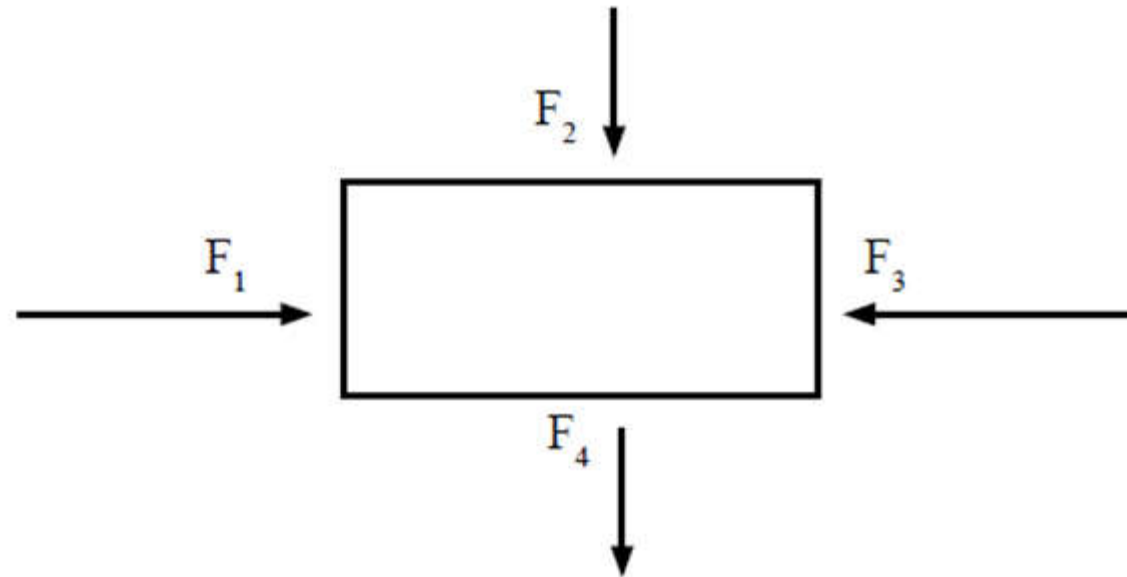
Example:

Three raw materials are mixed in a tank to make a final product in the ratio of 1:0.4:1.5 respectively. The first raw material contain A and B with 50% A. The second raw material contain C while the third raw material contain A and C with 75% A. Assuming a continuous process at steady state, find the flow and composition of the product.

1. Make a block diagram (flow sheet) over the process



2. Put numbers on all the streams

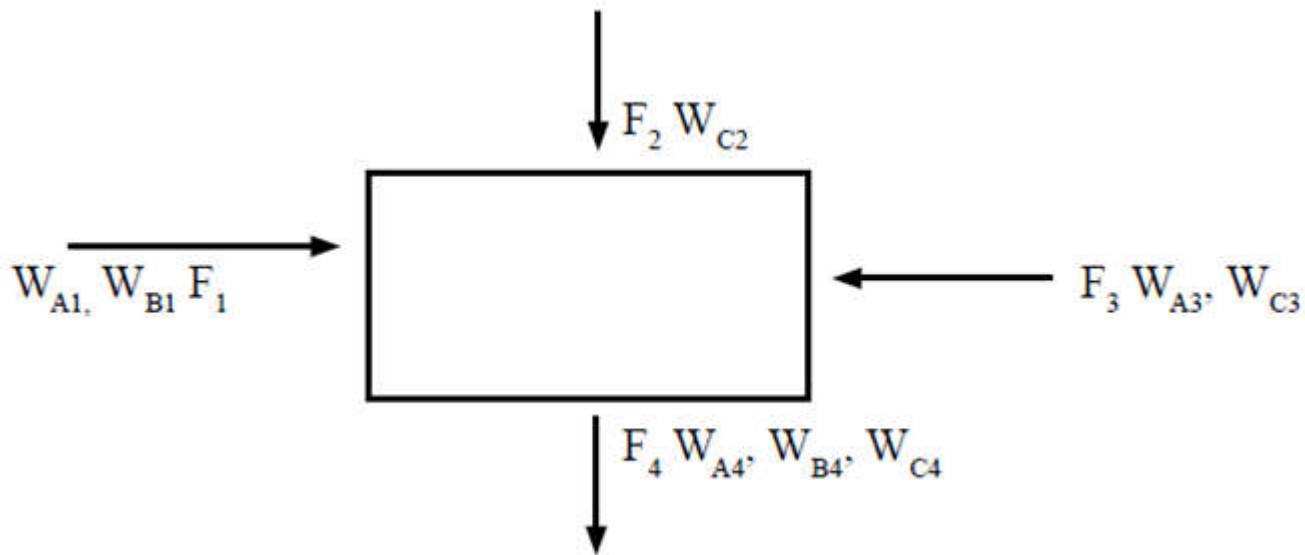


3. List down all the components that participate in the process.

The components are A, B and C.

4. Find the components that are in each stream and list them adjacent to the stream in the block diagram.

Let W represent composition by weight.



5. Decide on an appropriate basis for the calculations.

Let us use as basis 100 kg/hr of the first raw material

6. Find out the total number of independent relations. This is equivalent to the total number of stream components.

The total number of independent relations = the total number of stream components

Stream components are $W_{A1}, W_{B1}, W_{C2}, W_{A3}, W_{C3}, W_{A4}, W_{B4}, W_{C4} = 8$

Therefore total number of independent relations = 8

7. Put up different relations between stream components and independent relations to calculate concentrations

We need at least 8 independent mathematical relations to enable us solve the problem.

These are:

- Basis: Stream F_1 is 100kg
- The ratio of the three raw materials
- W_{A1} is 50%
- W_{C2} is 100%
- W_{C3} is 25%
- Material balance for A
- Material balance for B
- Material balance for C

We have the required number of independent relations and we can proceed to do the calculations.

We start with the general balance equation:

$$\mathbf{Accumulation = Flow\ in - Flow\ out + Production - Consumption}$$

For a mixing reaction, production and consumption are zero. Therefore:

$$\mathbf{Accumulation = (F_1 + F_2 + F_3) - F_4}$$

where the flow rates are in kg per hour.

Because the system is at steady state, accumulation is zero, and:

$$\mathbf{F_4 = F_1 + F_2 + F_3}$$

From the ratio of input flows, $F_2 = 0.4X(100/1) = 40\text{kg}$

$$F_3 = 1.5X(100/1) = 150\text{kg}$$

$$\begin{aligned}\text{Therefore } F_4 &= 100 + 40 + 150 \\ &= 290\text{kg}\end{aligned}$$

The next step is to find the quantities of A, B and C in F_4 . To do this, we shall write the mass balance equation for each of these three components assuming no accumulation. For A:

$$\text{Accumulation}_A = \text{Flow in}_A - \text{Flow out}_A + \text{Production}_A - \text{Consumption}_A$$

$$\text{Accumulation}_A = 0 = (F_1 W_{A1} + F_2 W_{A2} + F_3 W_{A3}) - F_4 W_{A4}$$

$$0 = 100(0.5) + 40(0) + 150(0.75) - 290W_{A4}$$

$$= 162.5 - 290W_{A4}$$

$$W_{A4} = 162.5/290$$

$$= 0.56$$

Similar balances are done for B and C:

$$\begin{aligned}\text{Accumulation}_B = 0 &= (F_1 W_{B1} + F_2 W_{B2} + F_3 W_{B3}) - F_4 W_{B4} \\ 0 &= 100(0.5) + 40(0) + 150(0) - 290W_{B4} \\ &= 50 - 290W_{B4}\end{aligned}$$

$$\begin{aligned}W_{B4} &= 50/290 \\ &= 0.17\end{aligned}$$

$$\begin{aligned}\text{Accumulation}_C = 0 &= (F_1 W_{C1} + F_2 W_{C2} + F_3 W_{C3}) - F_4 W_{C4} \\ 0 &= 100(0) + 40(1) + 150(0.25) - 290W_{C4} \\ &= 77.5 - 290W_{C4}\end{aligned}$$

$$\begin{aligned}W_{C4} &= 77.5/290 \\ &= 0.27\end{aligned}$$

It is always good to check answers for consistency. We do this by summing the weight fractions:

$$W_{A4} + W_{B4} + W_{C4} = 0.56 + 0.17 + 0.27 = 1.0$$

This proves that the solution is right.

8. Tabulate results.

Stream	Components	Kg/hr	Σ Kg	%	Σ %
1	A	50		50	
	B	50	100	50	100
2	C	40	100	100	100
3	A	112.5		75	
	C	37.5	150	25	100
4	A	162.5		56	
	B	50		17	
	C	77.5	290	27	100