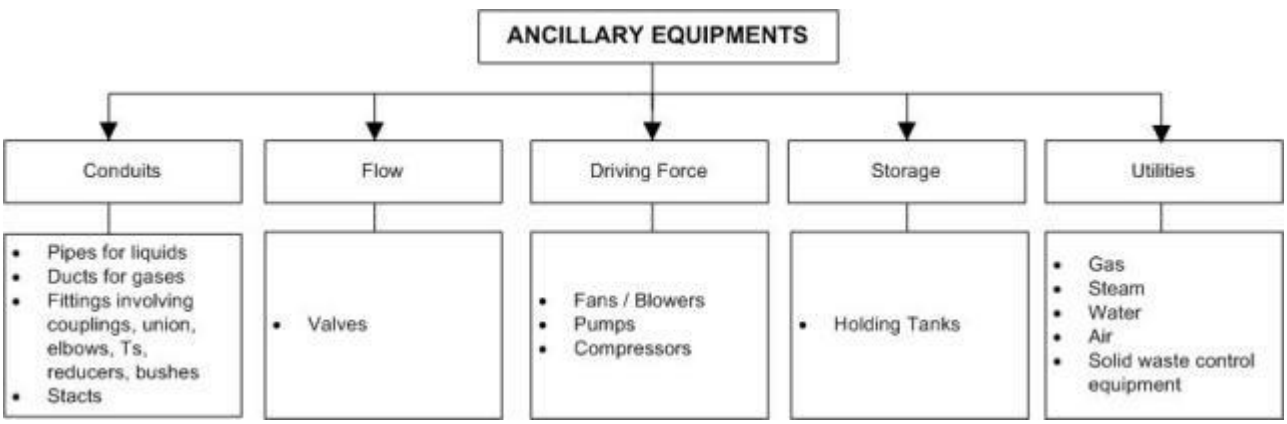
UNIT OPERATION

The basic physical operations of chemical engineering in a chemical process plant, that is distillation, fluid transportation, heat and mass transfer, evaporation, extraction, drying, crystallization, filtration, mixing, size separation, crushing and grinding, and conveying. In simple terms, the operation which involves **physical changes** are known as Unit Operation.

1. Distillation is a unit operation is used to purify or separate alcohol in the brewery industry.
2. The same distillation separates the hydrocarbon in a petroleum industries.
3. Dry grapes and other food products or similar drying of filter precipitate like rayon industry where yarn is produced.
4. Absorption of oxygen from air in a fermentation process of a sewage treatment plant and half hydrogen gas in a process for liquid hydrogenation of oil.
5. Evaporation of salts solutions similar to evaporation of sugar solution in the industry.
6. Settling and sedimentation of suspend solids similar to minimizing and sewage treatment plant.
7. Flow of liquid hydrocarbon in a petroleum refinery and flow of milk in a daily plant for the solidification in spray dryer.

Classification of Unit Operations

1. **Fluid Flow** : Concerns the principle that determine the flow or transformation of fluids from one point to another. The fluid can be a liquid or a gas. This unit is entirely based on Bernoulli e's equation followed by continuity correlation.
2. **Heat Transfer** : Deals with principles that govern accumulation and transfer of heat and energy from one place to another. The three concepts followed here are conduction, convection and radiation.
3. **Evaporation** : A special case of heat transfer which deals with the evaporation of volatile solvent such as waste from a non-volatile solute such as salt or any other material in the solution. The evaporation of trichloro-ethylene a cleaning agent in the automobile service industry and acetone in the case of glassware in a chemical process industries follow this unit operations.
4. **Drying** : An operation in which volatile liquids (usually water) are removed from solid material.
5. **Distillation** : An operation where a components of the liquid mixture are separated by boiling because of their difference in vapor pressure.
6. **Absorption** : A process whereby a component is removed from gas mixture by treatment with liquid.
7. **Liq-Liq Extraction** : A process in which a solute in a liquid solution is removed by contact with another liquid solvent that is relatively irreversible with solution.
8. **Liq-Solid Leaching**: It involves treating a finely divided solid with a liquid that dissolves and removes a solute contain in the solid.
9. **Crystallization** : The removal of a solute such as a salt from solution by precipitation in the industries for large scale operations, electrostatic precipitation is operated for this concept.
10. **Mechanical physical separation**: This involves separation of solids, liquids or gases by mechanical means such as filtration, settling, size reduction which are classified as separate unit operations.
    - The outline of unit operation defines the settling tanks for sedimentation, filter press for separations, pressurized spheres for ammonia storage, pellatising for fertilizer compounds, pneumatic conveyors for cement industry, bucket wheel elevators for thermal power stations and belt conveyors for core industries and many more in operation.



Stacks

Gases are discharged into the ambient atmosphere by stacks (referred to as chimneys in industry) of several types. The chemical process steps involved the following;

1. Preparing the Reactors
2. React them
3. Separate the Products
4. Purify the Products

The purpose of chemical industry is to start from one and other chemical raw material arrive at a consumer product through a group of physical and chemical products. Therefore it is called as a creative industry rather than assembly industry.

This mainly fall into inorganic, natural products, organic chemicals and metallurgical industry.

UnitProcesses

Processes that involve making chemical changes to materials, as a result of chemical reaction taking place. For instance, in the combustion of coal, the entering and leaving materials are differ from each other chemically. Coal and Air enters, and flue gases and residues leave the combustion chamber. Combustion is therefore a unit process. Unit processes are also referred to as chemical conversions. In simple terms, the process which involves **chemical changes** are known as Unit Processes.

Together with unit operations (physical conversions), unit processes (chemical conversions) form the basic building blocks of a chemical manufacturing process. Most chemical processes consist of a combination of various unit operations and unit processes.

1. **Alkylation**:

Addition of alkyl radical (CH3) with side chain final product. This alkylation process is widely used in organic chemicals and petroleum industries. The reaction is given as,

C=C-C-C + C-C-C

2. **Amination by Ammonolysis**:

$Cl\text{-}CH_2CH_2Cl + 4NH_3 \text{ -------} > NH_2CH_2CH_2NH_2$
EDC Ethylene Diamine

This reaction is used in manufacture of dye stuffs, organic chemicals and synthetic fibres.

3. **Amination by Reduction**:

$CH_3CHNO_2CH_3 + 3H_2 \text{ ------} > CH_3CHNH_2CH_3$
2 Nitro Paraffin Iso Propylamine

This unit process is also used in the manufacture of dye stuffs and organic chemicals.

4. **Amino Oxidation**:

$CH_3CH_2CH_3 + NH_3 + 1.5\ O_2 \text{ -----} > CH_2{:}CHCN + H_20$
Propylene Acrylonitrile

This reaction is used in the manufacture of plastics and synthetic fibres.

5. **Calcination**:

$CaCO_3 \text{ ---}^{Heat}\text{---} > CaO + CO_2$
Limestone Lime

This reaction is used in the cement industry.

6. **Carbonylation**:

CH_3OH + CO -----> CH_3COOH
Methanol Acetic Acid

This is used in the manufacture of organic chemicals.

7. **Carboxylation**:
This reaction is used in the organic chemical industry.

8. **Combustion**:

$CH_4 + O_2$ ------> $CO_2 + 2H_2O$ (Process Heating)

9. **Condensation**:

$C_6H_5CHO + CH_3CHO$ ------> $C_6H_5CH:CHCHO + H_2O$
Benzaldehyde+Acetaldehyde Cinnamaldehyde

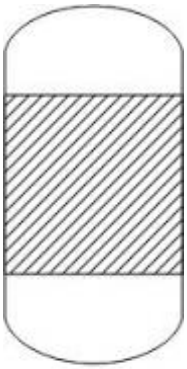
10. **Cracking or Pyrolysis**:

C-C-C-C-C-C-C --------> C-C-C + C=C-C-C

This reaction is used in petroleum destruction and distillation of coal.

1. **Fluid - Solid Contact**:

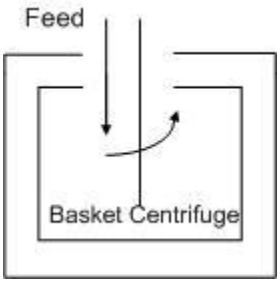
Represented by fixed bed reaction. It is most widely used in catalytic reactor used with precious metal catalyst to minimize attrition losses. The catalyst used in the form of pellets. It can represented by the following figure.


Fixed Bed

This is used in the packed column. The design of the column is determined by the breakthrough curve, equilibrium line for the given system of adsorbent and adsorbate's. The volume of the reactant coming from the top and the volume of which the product leaves the column, residence time, distribution decides the dimensions of the column. It is contrary to the fluid bed reactor where the bed is fluidized. Once the minimum fluidized velocity is reached the porosity of the bed is faster in a fixed bed reactor but varies from the fluidized bed where the porosity changes according to the height of the bed.

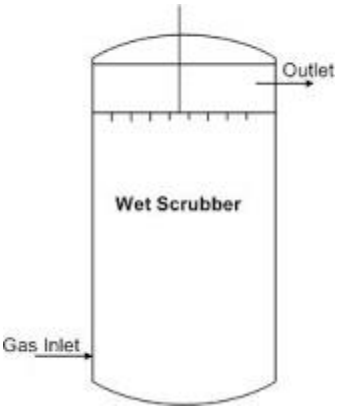
2. **Fluid - Solid Separation**: **(Centrifugation)**

This operation separates very finely divided solids from liquid or mixture of liquid and liquid emulsion.



3. **Wet Scrubber**:

It is an effective means of removing suspended particles from gas string by contact with liquid shower.



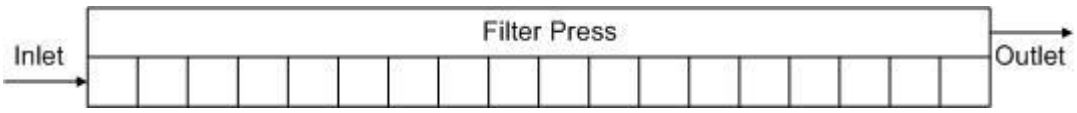
When solids are used in the place of liquid the operation is called Dry Scrubber. In the manufacture of MEK, wet scrubber is used and in other selected process industries Dry Scrubbers are used,

Scrubber just washes away the impurities and separate the product for further purification.

4. **Filter Press**:

It is the simplest type of pressure filtration. the two important parts of the filter press are plates & frames and fabric used in between the two are made of variety of corrosion resistant materials. In the laboratory scales asbestos cloth are used for filtration at different pressures.

The operation decides the value of specific cake resistance, filter medium resistance and compressibility of the chemical namely Kieselghur a specific compound in the nature of diatomacceous earth which are used in the application of bio-physics and cyrstallography.



5. **Fluid Storage**:

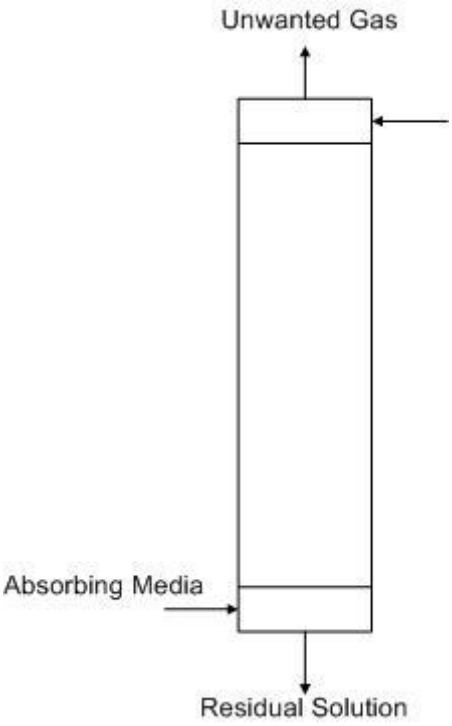
Tanks are widely used for storage of liquids of all types and atmospheric pressure when the liquid is highly volatile there is a floating roof which acts as lid for chemicals as and when the vapour pressure at which signifying the boiling point of liquid the roof changes its position and deserves the liquid from going out to the atmosphere.

6. **Pressurized Spheres**:

Pressurized spheres are used for pressurized storage of liquefied gases or high vapors. The pressure permits safe storage with no vapor losses. This is seen in the fertilizer plant where ammonia is stored in spheres.

7. **Gas-Liquid Contact**: **(Absorption)**

The best example is Absorption. It is used for taking a soluble gas in a solvent liquid and producing a solution plus an exit gas. Hydrogen Sulphide is removed from hydrocarbon by the absorption process.



8. **Adsorption**:

It is classified into physiorption and chemisorption according to the process applied. The former one is almost a physical change or physical transformation while a later represents a chemical reaction which is a irreversible one. the common effluent treatment plants of varies nature lied textile effluents, sewage treatment, ETP plants in chemical industry, removal of hazardous solid wastes, etc are dealt with adsorption method and the adsorbent is regenerated over a period of time and used again and again.

9. **Heat Exchangers**:

The various cooling towers of natural draft and forced draft are example of industrially applied H.Es. These are common facilities in the thermal power stations and in chemical industries the application of shell & tube heat exchangers are widely used. this is an excellent application of heat transfer from one medium to the other.

10.**Membrane Separation**:

Dialysis is used to separate metals in solution having widely different molecular weight. for example caustic from sugar solution or cellulose.

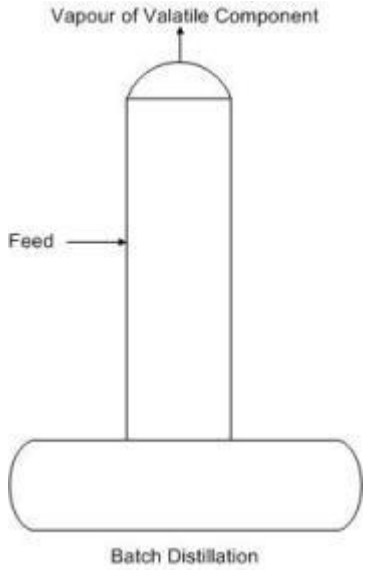
11.**Size Reduction**:

This involves crushing, grinding, pelletizing and prilling. Pelletizing is used in pharmaceutical industries and prilling used the manufacture of Urea.

Distillation:

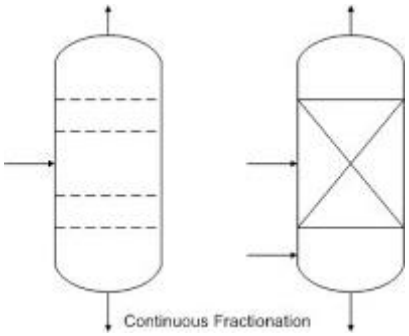
It is classified into Batch and Continuous Fractionation.

a. Batch Fractionation:



Used for intermittent operation and handling of small volume of feed and products.

b. Continuous Fractionation:



These are used for high volume continous seperation of complex mistures such as petroleum fractions connected to appropriate pumps, re-boilers, condensers, scrubbers, strippers and finally automatic controls.

2. **Drying of Solids**:

Spray Dryer , Rotary Dryer & Tunnel Dryer are some example of these types.

3. **Evaporation**:

Open pan evaporators and multiple effect evaporators as used in sugar and salt industries for example. Among these halogen family we have technology to separate chlorine and fluride but production of bromine from the 'sea

brine'is almost not put into practice as the bromine chemicals is highly corrosive and necessary precaution has to be laid out for practical purpose.

4. **Extraction**:

- Liquid - Liquid Extraction
- Solid - Liquid Leaching are examples for this process

5. **Fluid Handling Equipments**:

- Centrifugal pumps
- Reciprocating pumps
- Jet ejectors

6. **Fluid - Solid Contacting**:

- Fixed Bed
- Fluidized Bed
- Moving Bed, etc.

7. **Fluid - Solid Separation**:

- Centrifugation
- Settling Tank / Sedimentation
- Wet Scrubber / Dry Scrubber
- Crystallization
- Rotary Filter
- Filter Press
- Cyclone Separator
- Electro-static Preciptator
- Bag Filter
- Thickeners based on Kynch Theory

8. **Fluid Storage**:

- Gas Holders
- Tanks
- Pressurized Spheres
- Underground Caverns which are used for the purpose of Natural Gas Storage.

9. **Gas - Liquid Contact**:

- Absorption
- Stripping

10.**Heat Exchangers**:

- Fired Heaters
- Re-boilers
- Condensers
- Shell & Tube Heat Exchangers
- Jacketed Kettle
- Quenching applied in conventional Heat Transfer and Metallurgical Operations.

11.**Membrane Separation**:

- Dialysis
- Gaseous Diffusion

12.**Mixing**:

- Agitation
- Solids Blending

13.**Size Reduction & Enlargement**:

- Crushing
- Grinding
- Pelletizing

14.**Solids Handling**:

- Pneumatic Conveying - Juices transfered to 200 km in Brazil
- Bucket Elevators - Coal Industries
- Screw Conveyors - Tooth Paste, Turbine Liquids
- Belt Conveyors

15.**Solid - Solid Separation**:

- Screening
- Elutriation
- Froth Rotation
- Jigging
- Magnetic Separation

CHEMICAL REACTORS

The Reactor is the heart of the chemical process. The design of an industrial chemical reactor must satisfy the requirements in four main areas.

1. Chemical Factors
2. Mass Transfer Factors
3. Heat Transfer Factors
4. Safety Factors

1. Chemical Factors:

This involve the kinetics of the reaction weather it's first order or second order and based on this chemical reaction engineering is built on the design must provide sufficient residence time to proceed the reaction for the required degree of reaction and conversion to product.

2. Mass Transfer Factors:

The reaction rate of homogeneous reaction may be controlled by the rate of diffusion of reactants rather than the chemical kinetics of Langmuir isotherm and Frendlich isotherm.

3. Heat Transfer Factors:

These describes weather the reaction is exothermic or endothermic. In Exothermic, heat is released outside and In Endothermic, heat is absorbed by reactants. The value of heat of reaction is necessary to operate the chemical reactor.

4. Safety Factors:

This involve the confinement of any hazardous reactant and products as well as the control of reaction and process conditions.

Based on these factors the Reactor Types as follows;

a. Mode of Operation - Batch or Continuous
b. Phases Types - Homogeneous or Heterogeneous
c. Reactor Geometry - Flow Pattern & Process of contacting the phases.

The five major classes of Reactor;

i. Batch
ii. Stirred
iii. Tubular
iv. Packed Bed (Fixed)
v. Fludised Bed

Compounds like pigments, dye stuffs, pharmaceuticals and polymers are manufactured by Batch Processes.
The Latest Heat Exchangers are Direct or Contact Exchangers In addition to Double Pipe Exchanger, Shell & Tube Exchanger and Plated Frame Exchanger.

PROCESS CLASSIFICATION

The food industry relied on large-scale continuous processes for a long period. Initially, due to reduced investment costs, the production facility for a new product used to be either a batch process or a laboratory process produced on a larger scale.

As the economy of scale became a key factor, process engineering in general and food process industries focused on designing and developing continuous processes, at least for mass production goods

Sauces, pasta, extrusion cooking products are some examples of this type of processing.However, market and product diversification and specialty products, with an increased emphasis on and customer requirements for high quality and food security and traceability requirements, means that equal focus has switched to batch processing, and today, almost half of the processes in the food industry are batch processes

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

- Continuous processes.
- Discrete processes.
- Batch processes

CONTINUOUS PROCESSES

- In a continuous process, as suggested by the name, the flow of material or product is continuous.
- Processing the materials in different equipment produces the products.
- Each machine operates in a single steady state and performs a specific processing function.
- Some examples of continuous processes are pasta production, tomato sauce and juice production, ice cream production, mayonnaise production, etc
- Continuous transformation of mass, energy and momentum.
- The target is a product which is uniform in time.
- The process is stopped only for maintenance (scheduled or not), cleaning, irregular working.

Continuous processes have the following advantages over a batch process:

- **Production of a narrow specification product, i.e., higher and consistent product quality.**
- **Reduced manufacturing cost.**
- **Improved asset utilization.**
- **Reduced waste**

DISCRETE PROCESSES

- In a discrete process, the output of the process appears one-by-one or in discrete quantities.
- The products are produced in lots based on common raw materials and production history.
- In a discrete process, a specified quantity of products moves as a unit or group of parts between workstations.
- Some examples of discrete processes are assembly processes

BATCH PROCESS

Economic and technical factors could suggest that batch processes in some cases are more favorable than continuous processes:

- Simple processing units like mixers and stirrers versus complex production systems.
- Multipurpose units which may be used for several processing phases of the batch and could support multi-product manufacturing within the facility.
- Batch manufacturing plants are comparatively more robust than a continuous plant.
- Batch process manufacturing facility is easier to scale up depending on market demand and requirements.
- Better control of process of a confined step

Definition of Batch Processes

A batch is defined as:

- The material that is produced by a single execution of a batch process, or
- an entity that represents the production of a single material at any point of time in the process.
- The term 'batch' means both the material produced by and during the process, and also an entity that represents the production of that material.
- The term 'batch' can be considered a shortcut for "the production of a batch".
- A process is considered to be a batch process if the process consists of a sequence of one or more steps that must be performed in a defined order.
- At the end of the sequence of steps, a finite quantity of the finished product is produced. The sequence is repeated to produce another batch of the product.
- 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 pices of equipment.
- Discrete quantities of raw materials or products are processed, and easier tracking of these discrete quantities of materials or products is allowed.
- More than one type of product can be processed simultaneously, as long as the products are separated by the equipment layout.Movement of discrete products from different processing areas.
- In a batch process, the output of the process appears in quantities of materials or lots.
- Batch processes are neither continuous nor discrete, but have the characteristics of both.
- Batch processes are usually performed in a sequential way.
- Batch processes define a sub-class of sequential processes.
- Batch processes generate a product but the sequential processes need not necessarily generate a product.
- Some examples of batch processes are beverage processing, biotech products manufacturing, dairy processing, food processing, pharmaceutical formulations
- The nature of each step can be simple or complex, consisting of one or more unit operations, and generally a step is started when the previous one is completed.
- There is frequent provision for non-normal exits to be taken because of operator intervention, equipment failure or the detection of hazardous conditions.
- Depending on the recipe for the product being processed, a step may be bypassed for some products.
- Quality control is sometimes required by automatic or operator approval before leaving one step and starting the next.
- The processing operations for each step are generally under recipe control, but may be modified by operator override action.

PROCESS STRUCTURE

- *Single-path batch process.*
- *Multi-path batch process.*
- *Network batch process*

Processcomplexity

The matrix indicates the degree of complexity involved in automation of various combinations. The more complex a process, the more it requires allocation, arbitration and batch management solutions.

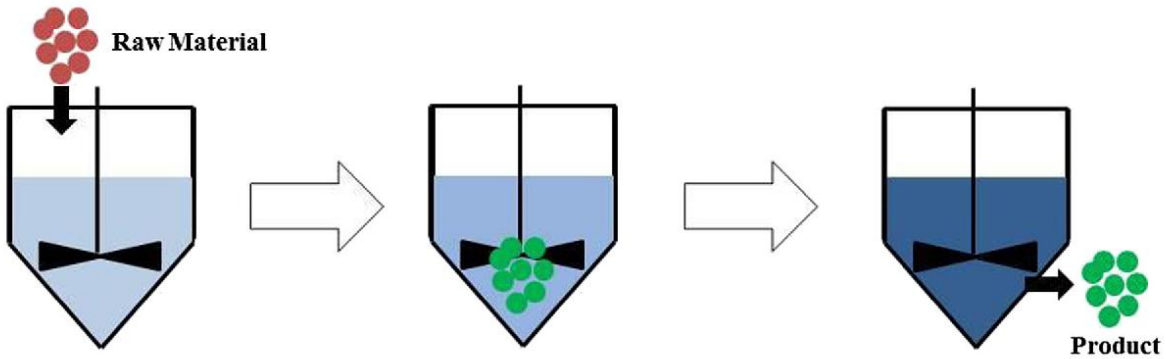
- The higher the number of products manufactured by a process, the greater is the need for recipe management and batch management solutions.
- A single-product, single-path batch plant is simple, while a multiproduct, network structured is the most complex combination.

DIFFERENCE BETWEEN BATCH PROCESS & CONTINUOUS PROCESS

Factor	Batch Processes	Continuous Processes
Size	Smaller throughput favours batch operators. As throughput increases, the required size of the process equipment increases, and the technical difficulties of moving large amounts of product from equipment rapidly increase.	Economies of scale favours continuous processes for large throughput
Batch accountability/Product Quality	If the product quality of each batch of material must be verified and certified, batch operations are preferred, and this is especially true for food products. If reworking(reprocessing or waste recovering)of off-specification product is usually not permitted, small batches are favoured	Continuous or periodic testing of product quality is carried out, but some potentially large quantities of off-specification product can be produced. If off specification material may be blended or stored in dump/slop tanks and reworked through the process when the schedule permits, continuous processes are favoured.
Safety	Generally, worker exposure to chemicals and operator error will be higher(per pound of product)than for continuous processes. Operator training in chemical exposure and equipment operation is critical	Large chemical plants operating continuously have excellent safety records and safety procedures are well established. Operator training is still of great importance, but many of the risks associated with opening equipment containing chemicals are eliminated.
Controllability	This problem arises because batch processes often use the same equipment for different unit operations and sometimes to produce different products. The efficient scheduling of equipment becomes very important. The control used for this scheduling is complicated.	Generally, continuous processes are easier to control. Also, more work and research have been done for these processes. For complicated and highly integrated plants, the control becomes complex, and operational facility is greatly induced.
Operational Flexibility	Often the same equipment can be used for multiple operations-for ex, a stirred tank can be used as a mixer, then a reactor, and then as a stage of a mixer for liquid-liquid extraction.	Operational flexibility can be built in to continuous processes but often leads to inefficient use of capital. Equipment not required for one process but needed for another may sit idle for months.
Product demand	Seasonal demand for products such as fertilizers, gas-line antifreeze, deicing chips for roads and pavements and so on can be easily accommodated. Because batch plants are flexible, other products can be made during the off-season.	Difficult to make other products during the off-season. However, similar but different products can be produced using the same processes through a series of campaigns at different times during the year. Each campaign may last several months.

Particulars	Batch Process	Continuous Process
Definition	Batch process refers to a process that consists of a sequence of one or more steps that should be performed in a defined order. A finite quantity of the product is produced at the end of the sequence, which is repeated in order to produce another product batch.	A continuous process refers to a processing that involves moving a single work unit at a time between every step of the process without any breaks in time, substance, sequence or extend. As the name suggests, the flow of product or material is continuous.
Co-ordination between the equipments	The equipments may or may not be coordinated. The time between to equipments is maintained by scheduling.	Every machine operates in a steady state and performs a certain processing function.
Quantities Produced	Small quantities of products are obtained. Production rate is usually less than $5x10^5$ kg/year.	Large quantities of products are obtained.
Fouling	If fouling expectations is large than Batch Processes are preferred.	If fouling can be eliminated than continuous process is chosen.
Product Life Span	Short, 1 – 2 years.	Larger Product Life expectancy.
Cost of factory equipment	Low cost equipments. (Even if special equipments are constructed.)	High Cost of equipments
Controlling	Easier to control and maintain Process	Difficult to control, requires sophisticated control system.
Shut Down Times	Often	Rare
Workforce	Small Work force needed	Large Work force is needed. (If not fully automated).
Examples	Pharmaceuticals, Specialty Chemicals.	Petroleum Industry, Fertilizer Industry.

(a) Batch Manufacturing



(b) Continuous Manufacturing