Process Dynamics & Control
CHE 442

Text and References

- **Text**
  - Stephanopoulos G., "Chemical Process Control-An Introduction to Theory and Practice,"Prentice -Hall, New Jersey, 1984
- **References**
  - Seborg D. E., T. F. Edgar, and D. A. Mellichamp, "Process Dynamics and Control,"John Wiley & Sons, New York, 1989
  - Su whan Sung and In-Beum Lee, "PID Controllers and Automatic Tuning" Ajin Press, 1998
  - Luyben W. L., "Process Modeling, Simulation and Control for Chemical Engineers," McGraw-Hill, New York, 2nd Ed., 1990

What is Chemical Engineering

Raw materials $\longrightarrow$ Useful Products

In Large scale (Commercial)

By certain arrangement of equipments (reactors, heat exchangers, condensers, distillation Columns, mixers , ……etc)

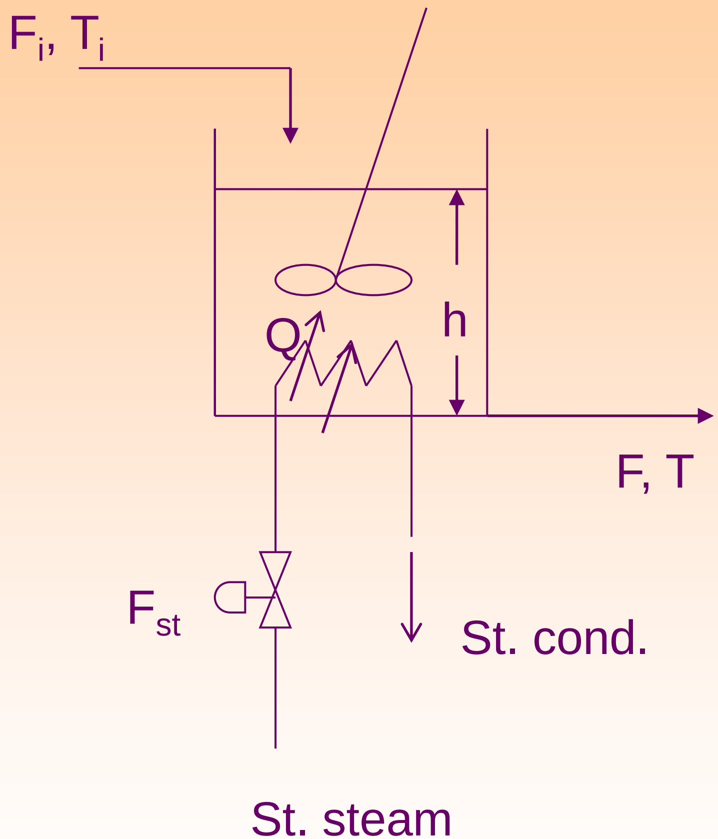
1. Introduction to Process Control

- '***Process Control***' makes processes satisfy following requirements:
  - Safety
  - Production specifications
  - Environmental regulations
  - Operational constraints
  - Economics

Can be summarized as follows:

- Suppress the influence of external disturbances
- Ensuring the stability
- Optimization of the performance

Suppress the influence of external disturbances (most common)



Consider the tank heating system shown in the figure.

A liquid enters the tank with a flow rate F_i (ft^3/min) and a temperature of T_i (^{0}F) where it is heated with steam having a flow rate of Fst (l/min). Let F and T be the flow rate and temperature of the stream leaving the tank.

The tank is considered to be well stirred, which implies that the temperature of the effluent is equal to the temperature of the liquid in the tank.

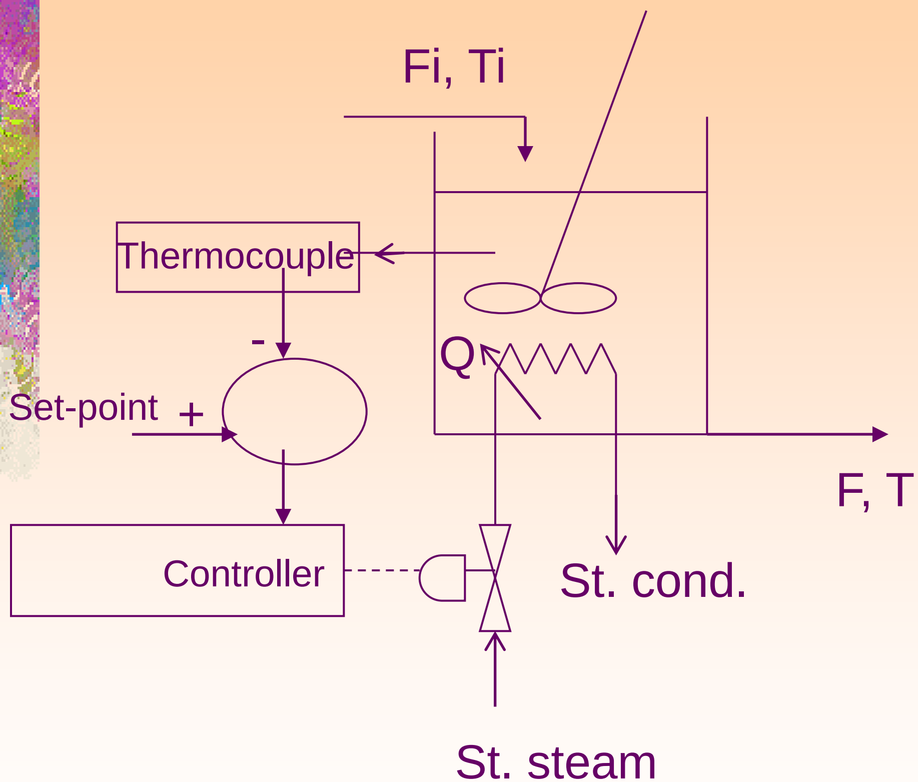
The control objectives of this process are:

1. To keep the effluent temperature T at the desired value T_d.
2. To keep the volume of the liquid in the tank at a desired value V_d (h_d).

The operation of the heater is disturbed by external factors such as changes in the feed flow rate F_i and temperature T_i. (If nothing changed, then after attaining $T=T_d$ and $V=V_d$ we could leave the system alone without any supervision and control.

Feedback

Temp. Control



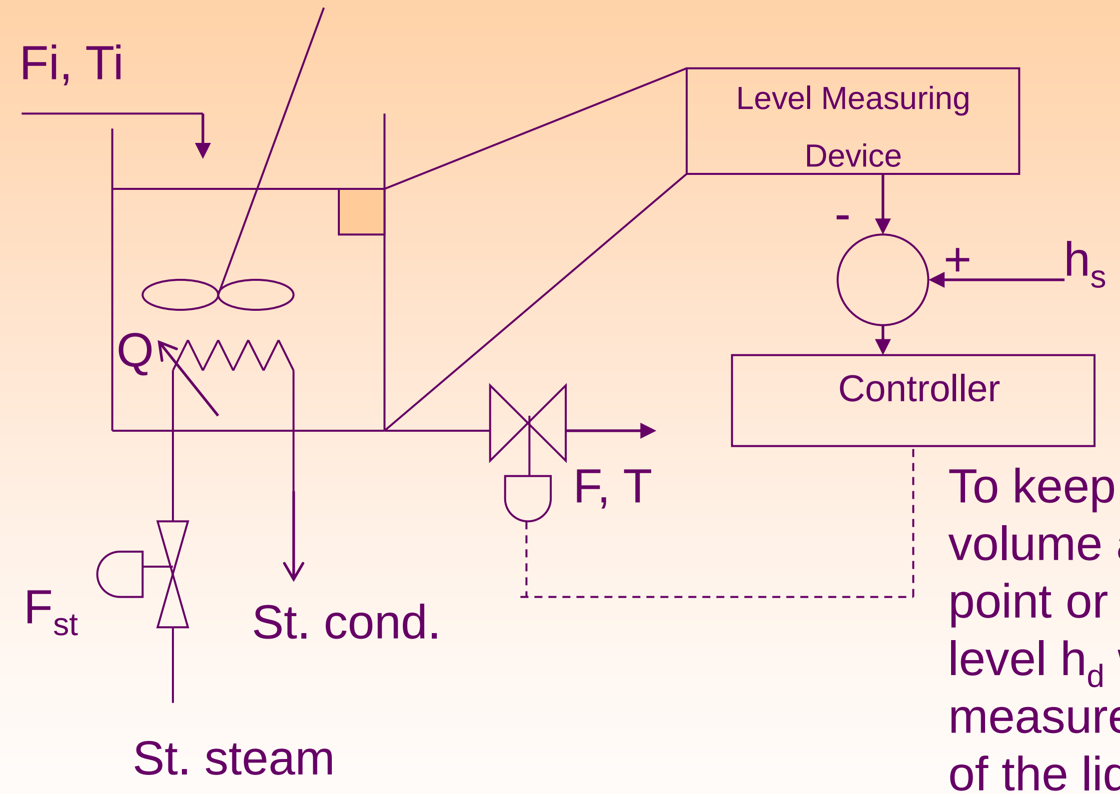
A thermocouple measures the temperature of the fluid in the tank. Then this temperature is compared with the desired value yielding a deviation

$\varepsilon = T_d - T$

The value of deviation is sent to a control mechanism which decides what must be done in order for the temperature to turn back to the desired value.

Feedback

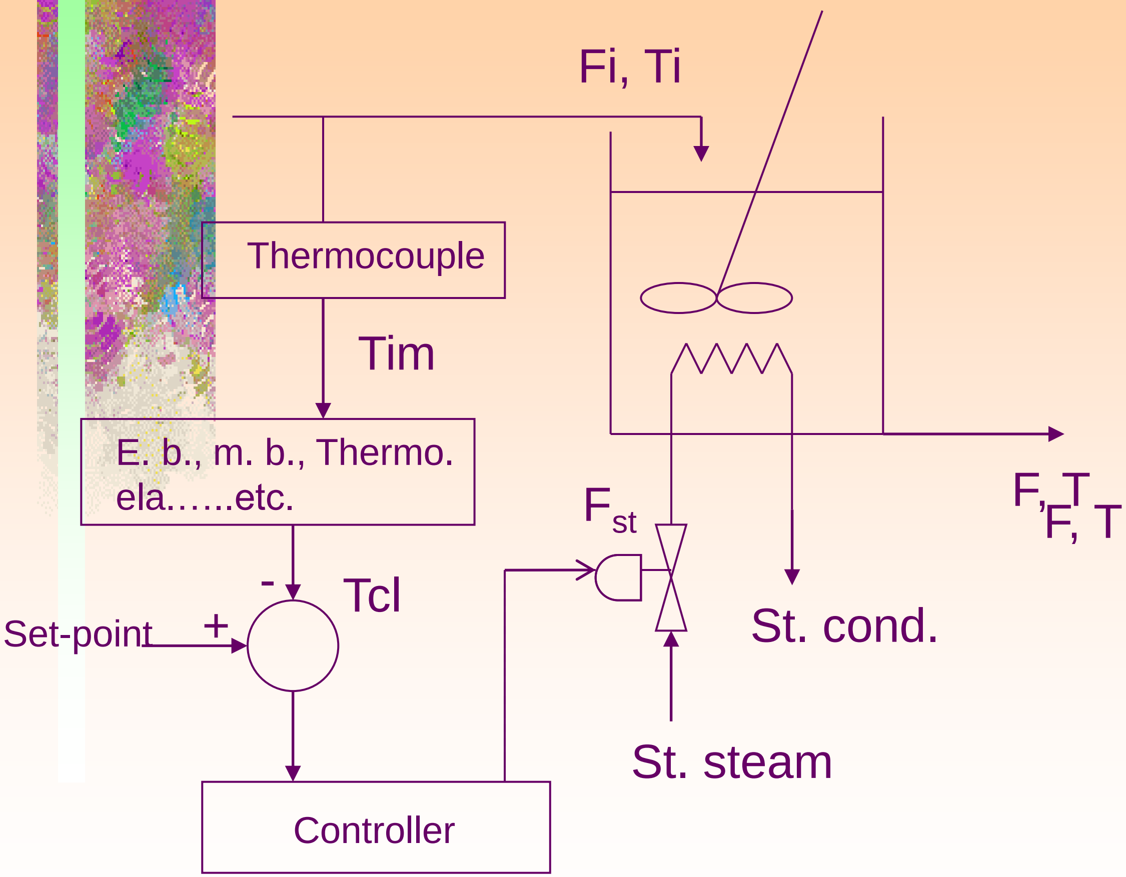
Level Control



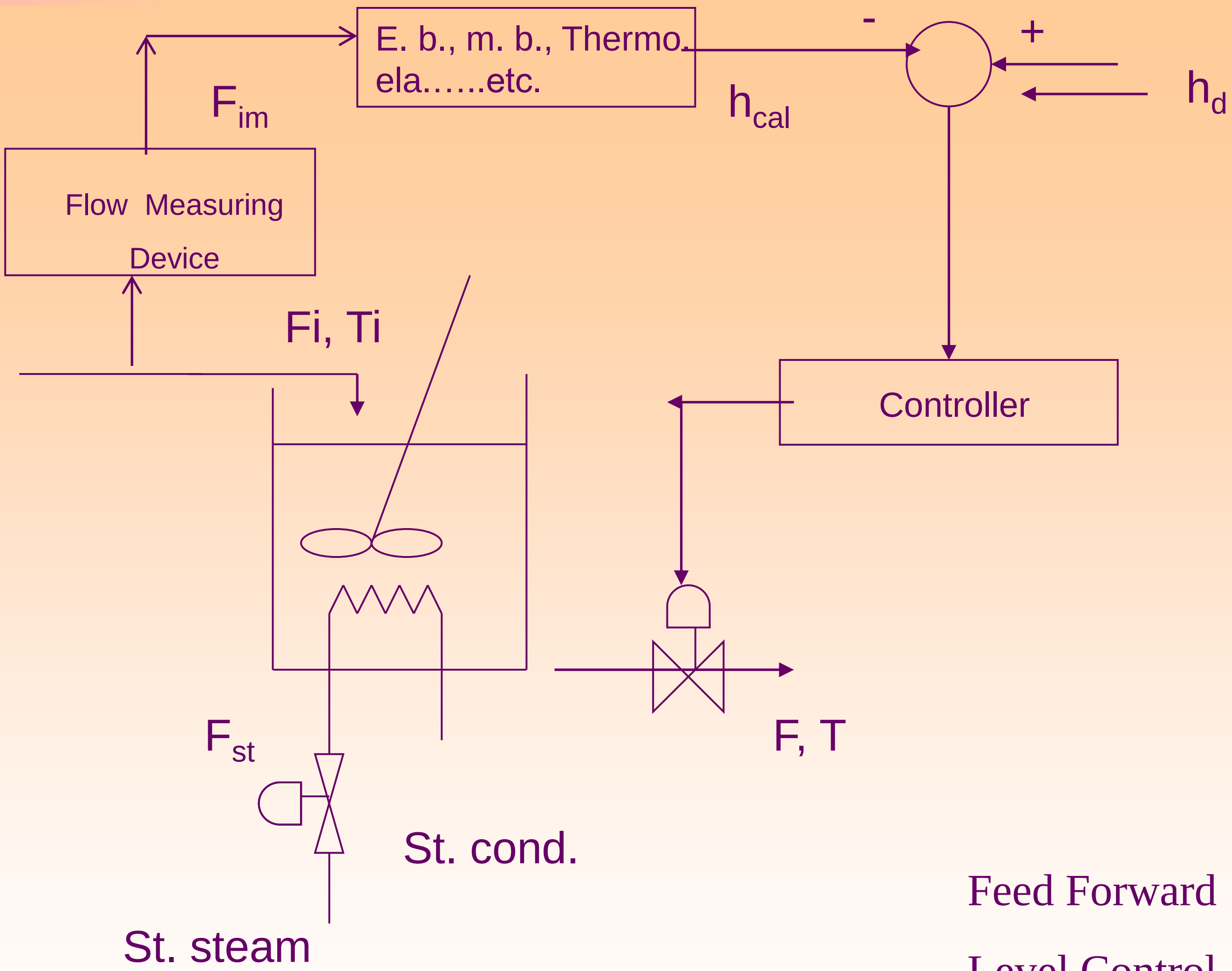
To keep the volume at its set point or the liquid level h_d we measure the level of the liquid in the tank and we open or close the effluent flow rate.

Feed Forward

Temp. Control



Notice that feed forward control does not wait until the effects of the disturbances has been felt by the system, but acts appropriately before the external disturbance affects the system anticipating what its effect will be.



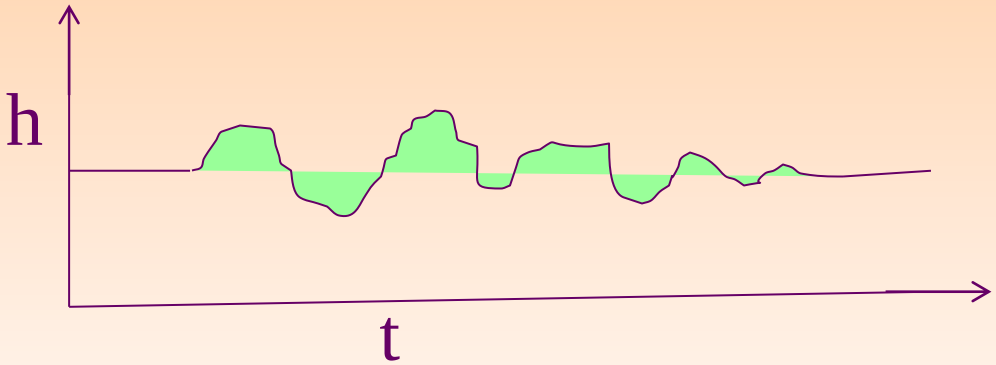
Feed Forward

Level Control

Ensure the stability of thr Process

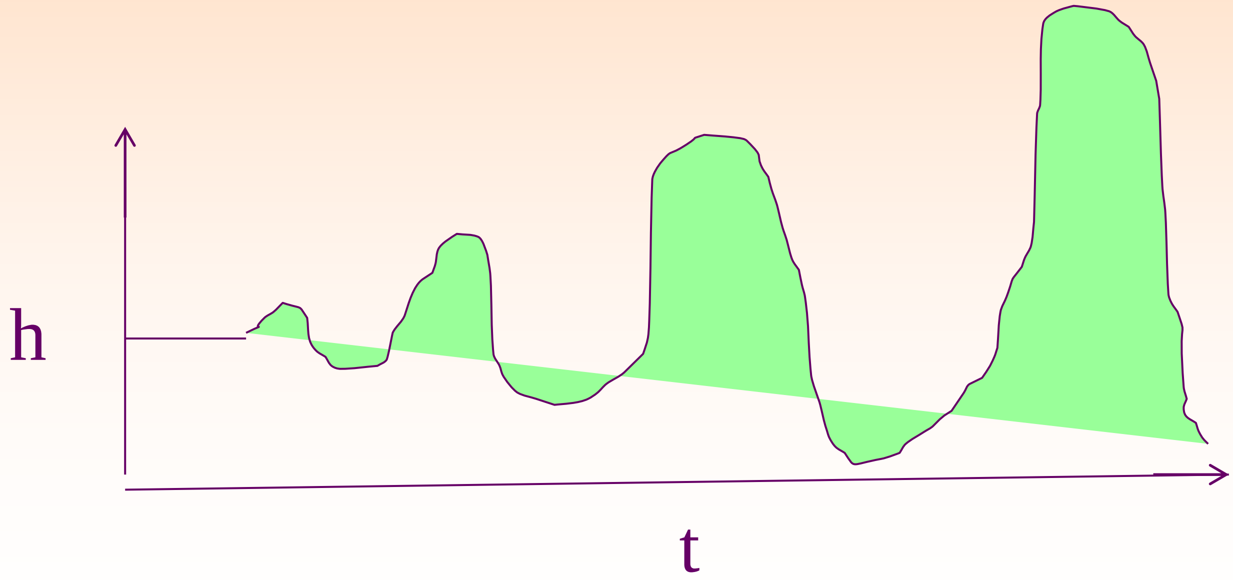
- Stable Process: returns to its initial value

  It is also called self regulatory



- Unstable Process :

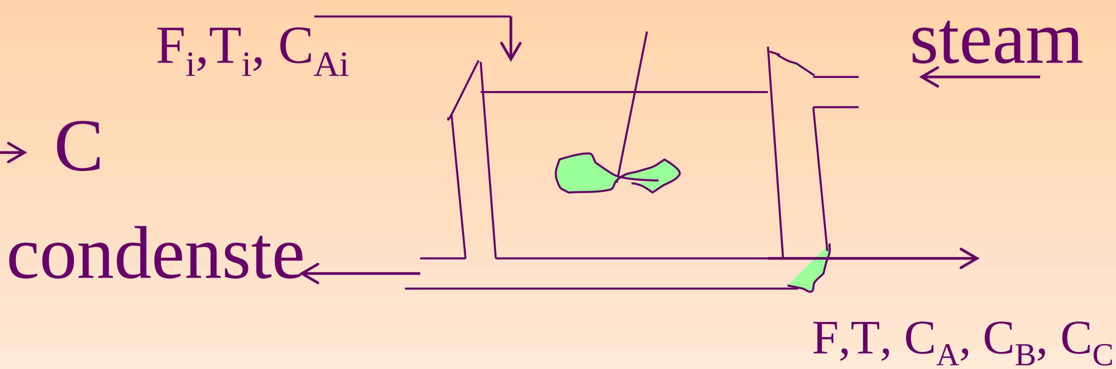
  Requires external control for stabilization



Optimize the Performance of the process

- Safety and product specifications

$$A \longrightarrow B \longrightarrow C$$



$$\text{Maximizing profit} = \int_0^t [\text{revenue of B} - \text{Cost of A} - \text{Cost of steam}]$$

- Input variables are:
- Effect of surroundings on the process
- Output variables are:
- Effect of process on the surroundings

- For this STH example;
- input variables are: F_i, T_i and F_{st}
- output variables are: F, V and T

- The input variables can be further classified into the following categories:

1. Manipulated (or adjustable) variables, if their values can be adjusted freely by the human operator or a control mechanism.
2. Disturbances, if their values are not the result of adjustment by an operator or a control system.

- The output variables are also classified into the following categories:

1. Measured output variables, if their values can be measuring directly.
2. Unmeasured output variables, if their values cannot be measured directly.

- State variables: A set of fundamental dependent Quantities whose values will describe the natural state of a given system (ex. C, T, P, F….etc.).
- State equation : Relate dependent variables (state variables to independent variables.

Designe Elements of a Control System

- Define Control Objectives
- Select measurement
- Select manipulated variable
- Select Control configuration
- Controller Design

Measurements

- Primary Measurements

  Monitor the variable that directly represents the control objective.

- Secondary measurements

  The real output can't be measured directly. variable which can be related to the real variable is measured.

The relation can be made by :

Mass B., Energy B., Thermodynamics,
V-L quilibrium, Reaction Kinetics ….etc.

- Manipulated variable

  Select manipulated variable that effect objective directly.

- Control configuration:

  - Feedback control
  - Feed forward control
  - Inferential control

- Controller Design

  How should manipulated variable changes in order to keep the controlled variable at he desired level.

PROCESS CONTROL LAWS !

- First Law: The best control system is the simplest one that will do the job.
- Second Law: You must understand the process before you can control it.
- Third Law: The control is never possible if the mathematical model can not be developed.

Process Modeling

Observing the behavior of the output when the input changes.

1- Experimental approach

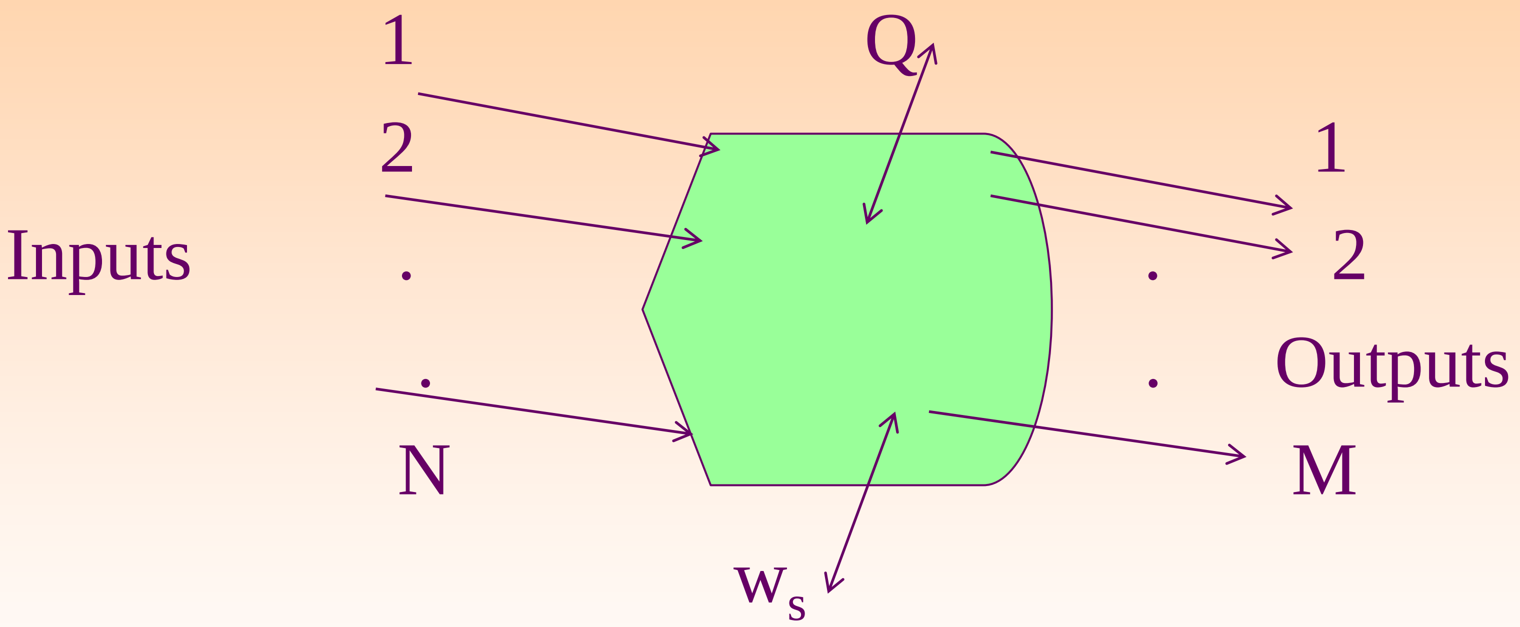
- Equipment is available
- Time and effort consuming
- Cost more

2- Theoretical approach

- Design stage (no equipment)
- Use of m. b., E. b., Thermodynamics relations to represents the process as a set of mathematical equations.

Modeling Steps

- Determine the boundary of the system
- Determine inputs, outputs, work done by or on the system, Heat added or withdrawn by the system.



– Based on conservation of mass, energy and momentum

Mass Balance

$$\begin{array}{c}\textit{Rate of Accumulation}\\ \textit{of fundamental quantity}\end{array} = \sum_{In} \textit{Flow} - \sum_{Out} \textit{Flow} + \textit{Generation} - \textit{Consumption}$$

T. M. B.

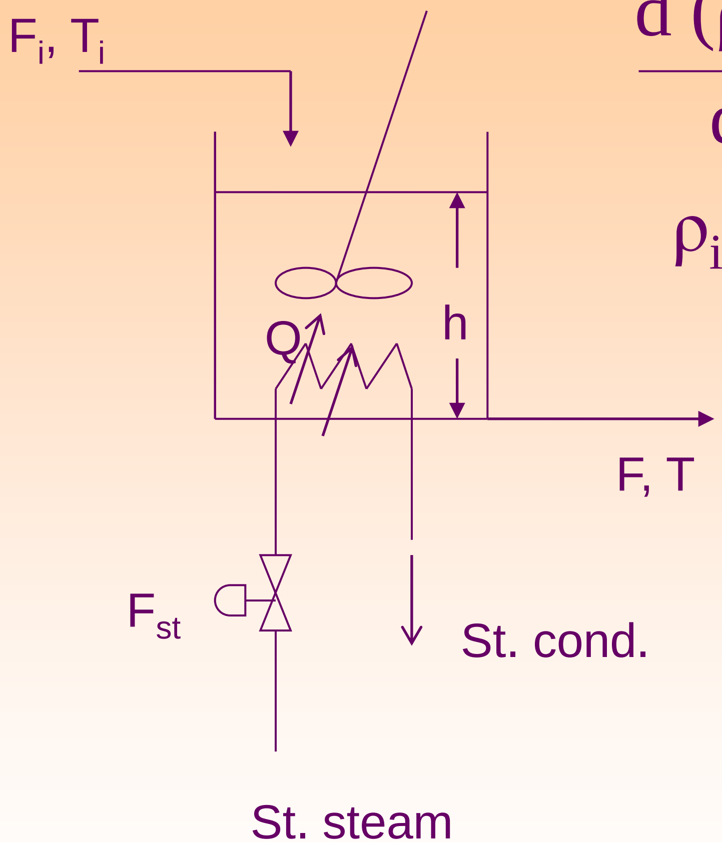
$$\frac{d(\rho v)}{dt} = \sum_{i=1}^{N} \rho_i F_i - \sum_{j=1}^{M} \rho_j F_j$$

M. B. Component A

$$\frac{d\,n_A}{d\,t} = \frac{d\,(C_A v)}{dt} = \sum_{i=1}^{N} C_{Ai}\,F_i - \sum_{j=1}^{M} C_{Aj} F_j \pm r_A v$$

Energy balance

$$\frac{d\,E}{d\,t} = \frac{d\,(U+K+P)}{dt} = \sum_{i=1}^{N} \rho_i\,F_i\,h_i - \sum_{j=1}^{M} \rho_j\,F_j\,h_i \pm Q \pm w_s$$



T. M. B.

$$\frac{d(\rho v)}{dt} = \rho_i F_i - \rho_j F_j$$

$$\rho_i = \rho_j = \rho = \text{constant}$$

$$v = A.\, h,\ A = \text{constant}$$

$$\frac{A dh}{dt} = F_i - F$$