Topic 1

Introduction To Process Control

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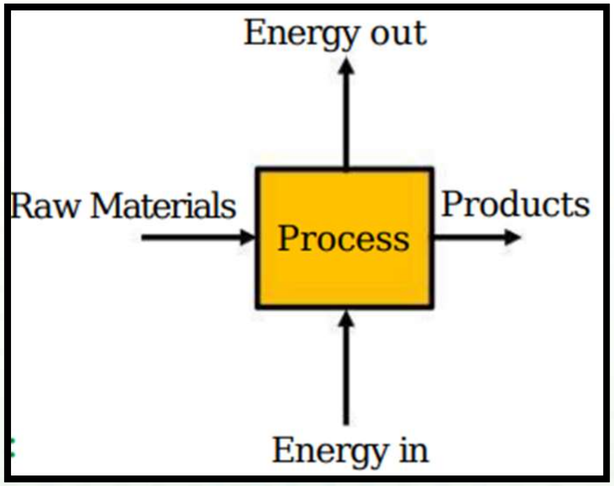
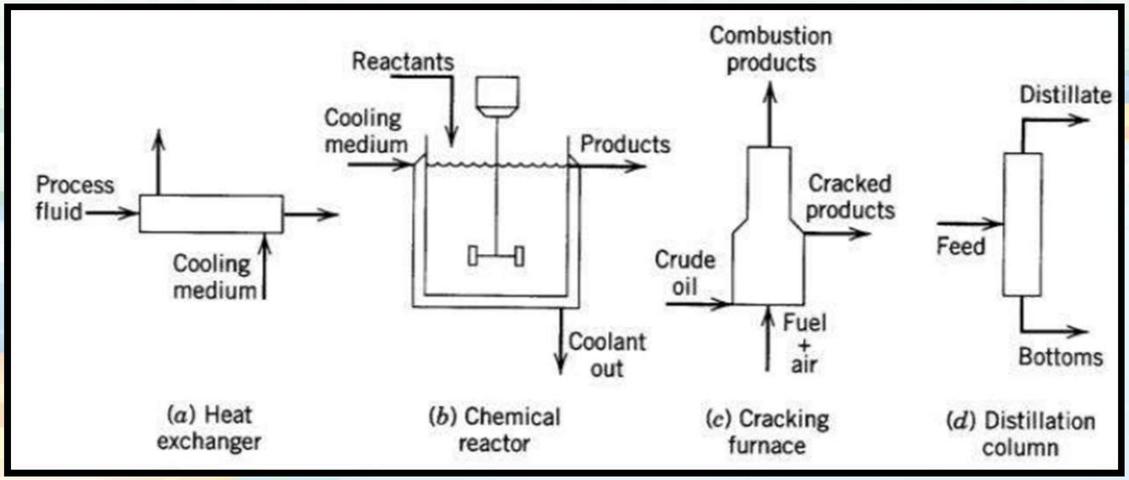
- **Goal of Plant Operation**
  - *Safety*
  - *Production schedule*
  - *Product quality*
  - *Maximum profit*



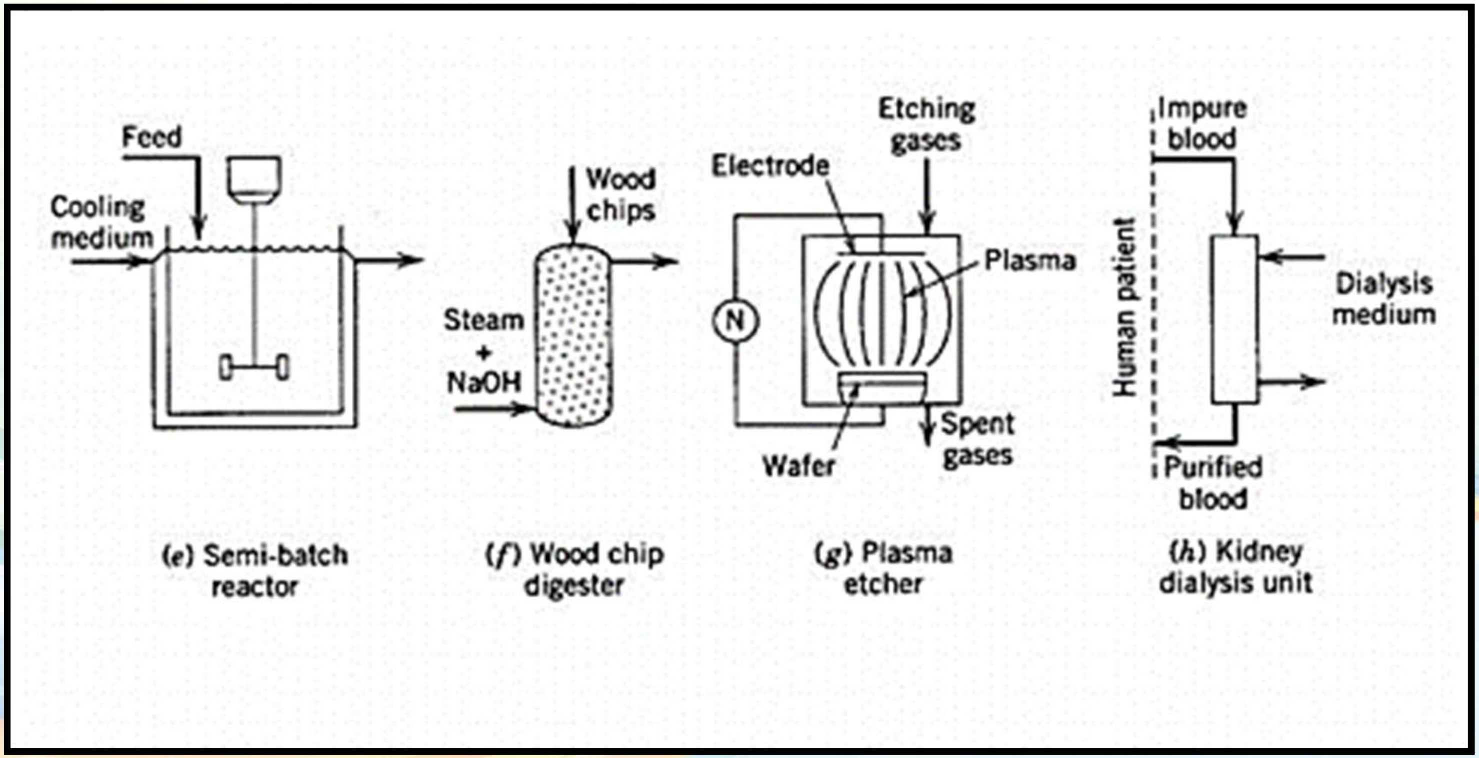
- **Industrial Perspectives**
  - *Accidents should be avoided (human, properties)*
  - *Exploit the opportunities*
  - *Enterprise image, loyal customers, competitiveness*
  - *Game of survival*

Classification of Processes

- *Based on time: Steady-state (no variations with time) and unsteady state (variations with time).*
- *Based on flowing streams: continuous, non-continuous, batch, and semi-batch.*
- *Examples:*



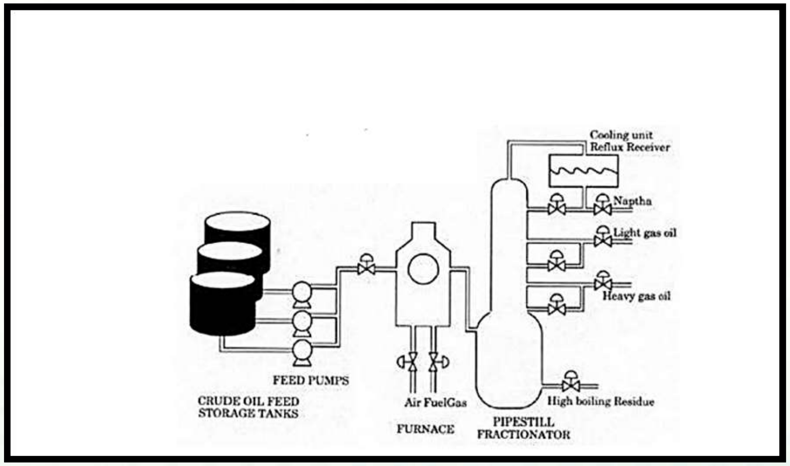
- *Examples:*



Feed
Cooling medium
(e) Semi-batch reactor
Wood chips
Steam + NaOH
(f) Wood chip digester
Etching gases
Electrode
Plasma
N
Spent gases
Wafer
(g) Plasma etcher
Impure blood
Human patient
Dialysis medium
Purified blood
(h) Kidney dialysis unit

- *What is Process Control?*
  - *Monitor the process status*
  - *To drive the process to desired condition*
    - *By manipulating adjustable handles*
- *How to Monitor Process Status?*
  - *Measure important process variables by sensors*
  - *Estimate the important variable through indirect measurements*
- *What are Adjustable Handles?*
  - *Process variables manipulated by actuators*
  - *Example: flow rate by control valve, motor speed by inverter*

Example: refinery



➢ Some Important Issues:

- Measure product quality
- Adjust energy input and product distribution
- Make more valuable products with least energy
- Not to violate any process constraints

- *Specific Objectives of Control:*
  - *Increase product throughput*
  - *Increase yield of higher valued products*
  - *Decrease energy consumption*
  - *Decrease pollution*
  - *Decrease off-spec product*
  - *Increase safety*
  - *Extend life of equipment*
  - *Improve operability*
  - *Decrease production labor*

- *Justifications of Process Control*
  - *Stronger competition*
  - *Tougher environment regulation*
  - *Tougher safety regulation*
  - *Rapidly changing economic conditions*
  - *Highly integrated plants*
  - *Strict quality control*
  - *Due to the uncertainties:*
    - *Imperfect process design*
    - *Disturbances and changes in operating conditions*
    - *Difficulties in startup and shutdown*

- *Through Control, We Can Achieve*
  - *Safe operation*
  - *Satisfying environmental constraints*
  - *Economic benefits*
  - *Increased production level*
  - *Reduced raw material cost*
  - *Enhanced product quality*
  - *Extended equipment life*
  - *Potential benefits of improved process control*

Process Control Terminology

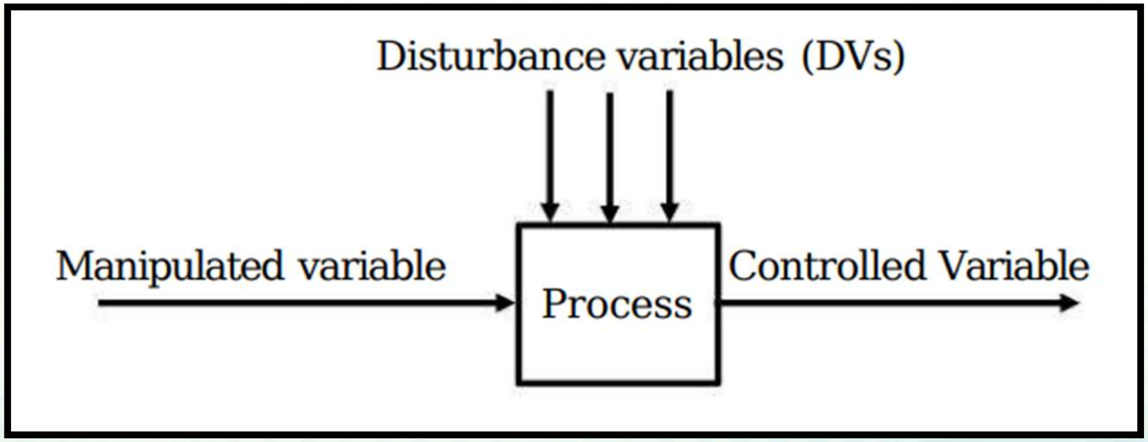
- Controlled variables (CV's): important process variables to be controlled at some desired values (set points).
- Manipulated variables (MV's): adjustable variables to keep the controlled variables at their set-points.
- Disturbance variables (DV's): also called "load" variables and represent input variables that can cause the controlled variables to deviate from their respective set points.

Remarks:

- All important variables to be controlled (CV) must be identified and measurable. (CVs are usually direct or indirect quality variables).
- Manipulated variables (MV) to be adjusted must have significant impacts on controlled variable. (MV's are usually affect the CV's)

- *Process Control Terminology*
  - *Set-point change: implementing a change in the desired operating conditions. The set-point signal is changed, and the manipulated variable is adjusted appropriately to achieve the new operating conditions. Also called servomechanism (or "servo") control.*
  - *Disturbance change: when a disturbance enters, also called regulatory control or load change. A control system should be able to return each controlled variable back to its set-point.*

- *How to Control a Process?*



Control Objective:

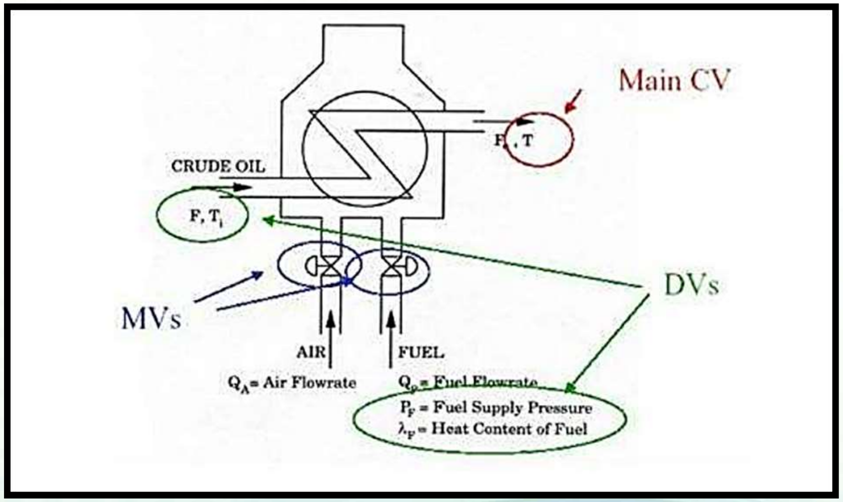
Maintain controlled variable at its set point, despite disturbances.

➢ How to Control a Process?

- Manual control:

  - Read the sensors, then decide the amount of change in adjustable variable, then adjust the variable by changing the knob, or dialing and so on.
  - See if the controlled variable is moving toward the desired set point (SP) fast enough.
  - Repeat this procedure perpetually unless you are 100% sure that the process will not deviate from set points.

Example (crude oil furnace):

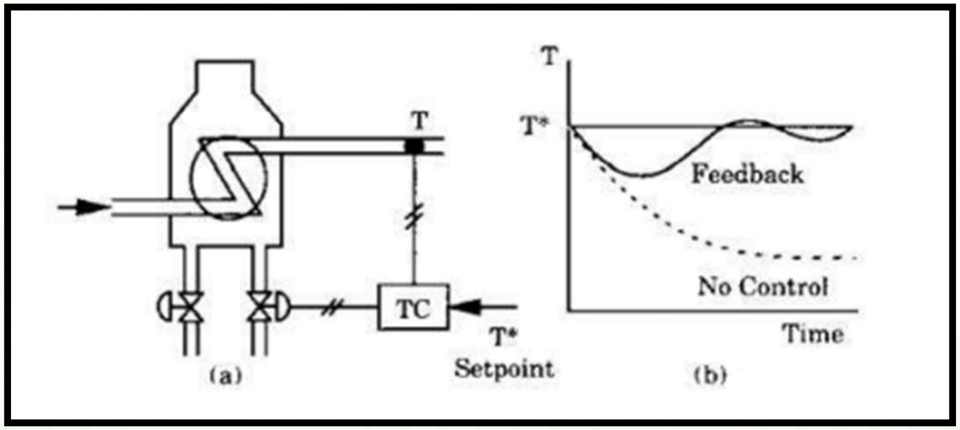


- *Operator has to change two MV's for one CV*
- *Operator relies on the observations and prior experiences*
- *Corrected by trial-and-error, inconsistent, unreliable*

- Automatic Control: Different Control Strategies

A. Feedback (FB) control
B. Feedforward (FF) control
C. Combined FF/FB control
D. Advance control…

A. Feedback (FB) Control

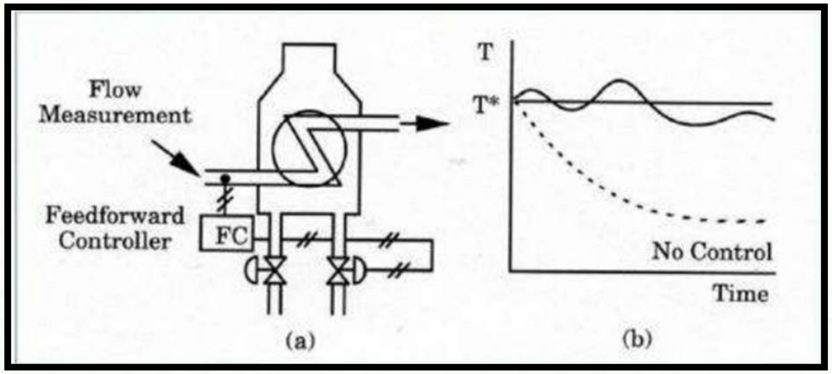


- Widely used (e.g., PID controllers)
- Controller will adjust the fuel valve somehow until T is settled at set point
- The fuel valve will be adjusted only after some change happen at the measurement.

- *Distinguishing feature: measure the controlled variable and transmit its value to the controller*
- *Advantages:*
  - *Corrective action is taken regardless of the source and type of the disturbance.*
  - *Reduces sensitivity of the controlled variable to disturbances and changes in the process (shown later).*
  - *Requires little knowledge about the process.*

- Disadvantages:
  - FB control takes no corrective action until a deviation in the controlled variable.
  - FB control is incapable of correction a deviation from set point at the time of its detection.
  - Theoretically not capable of achieving "perfect control".
  - Very oscillatory responses, or even instability (process may not settle out) for frequent and severe disturbances.

B. Feedforward (FF) Control



- *If there is a change in feed flow, controller will change fuel flow and exit temperature will not deviate too much*
- *But the correction is based on the estimated effect of feed flow rate on T and if it is not accurate, the exit T will not be at set point.*
- *Distinguishing feature: measure a disturbance variable and transmit its value to the controller.*

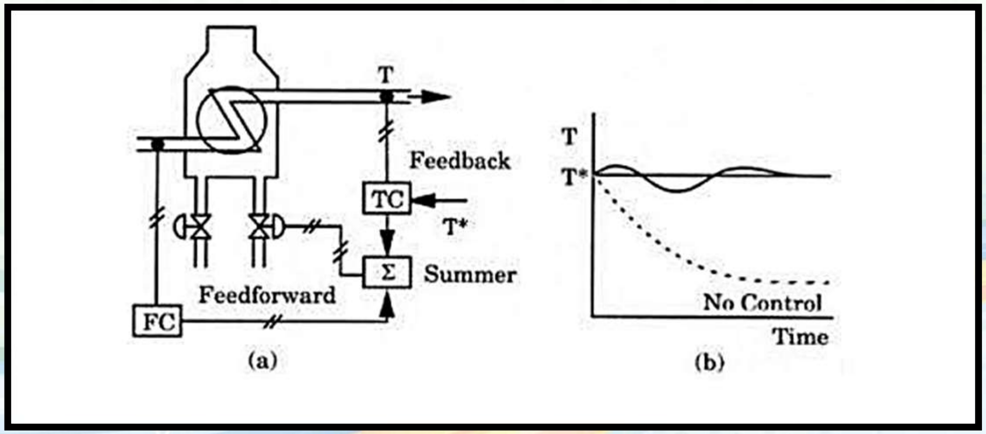
- *Advantages:*
  - *Correct for disturbance before it upsets the process.*
  - *Theoretically capable of "perfect control".*
  - *Does not affect system stability.*
- *Disadvantages:*
  - *Must be able to measure the disturbance.*
  - *No corrective action for unmeasured disturbances.*
  - *Requires more knowledge of the process to be controlled (process model).*

C. Combined FF/FB Control

- Obtain combined advantages of FF and FB control:

FF control: attempts to eliminate the effects of measurable disturbances.

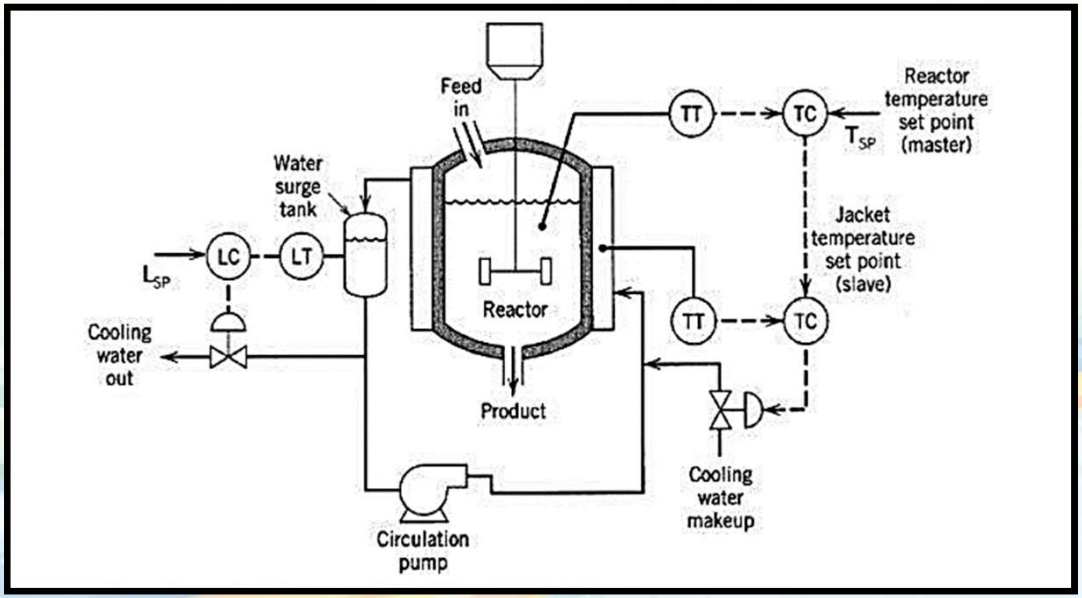
FB control: Corrects for unmeasurable disturbances, modeling errors, etc.



- But if there is a change in fuel pressure, this strategy will act only after the effects appears at exit temperature.

D. Advanced Control

Example: Cascade control



"Cascade Control of an exothermic chemical reactor"

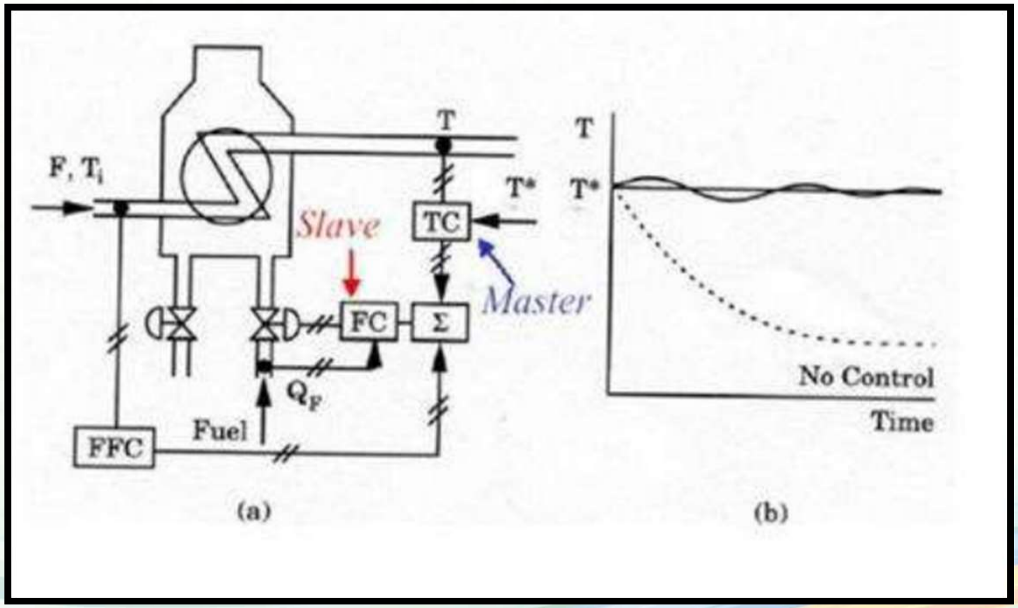
- *Cascade Control (multi-loop)*
  - *Distinguishing features:*

1. *Two FB controllers but only a single control valve (or other-final control element).*
2. *Output signal from the "master" controller is the set-point for "slave" controller.*
3. *Two FB control loops are "nested" with the "slave"(or "secondary") control loop inside the "master" (or "primary") control loop.*

- *Terminology:*

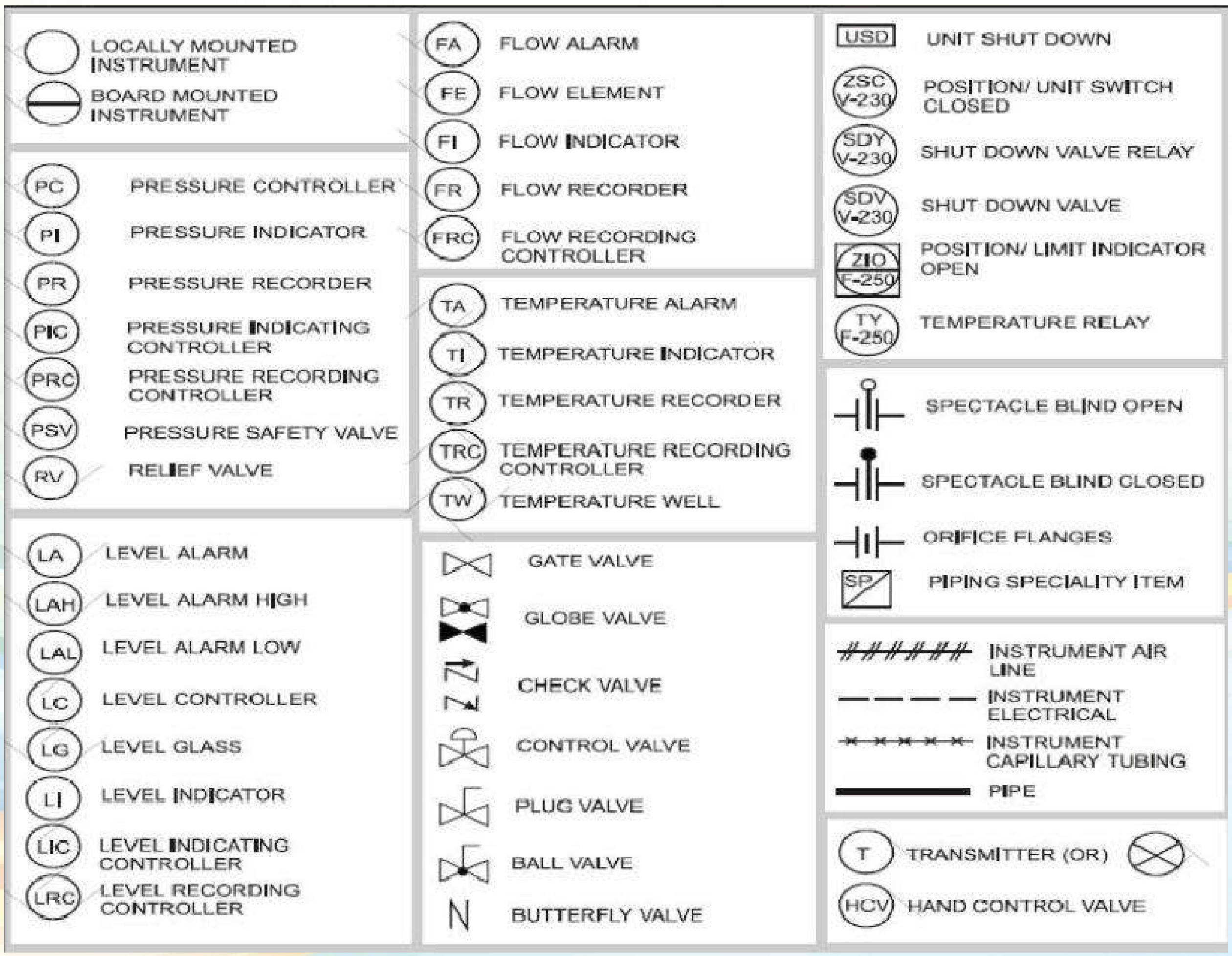
Slave vs Master *Secondary vs Primary* *Inner vs Outer*

➢ *FF/FB + Cascade Control*



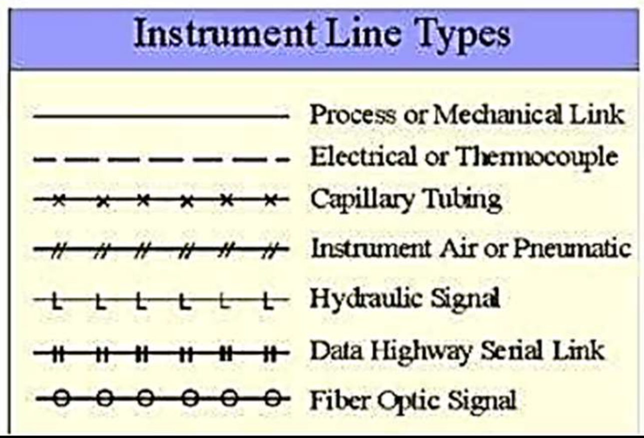
- *Better than the others (Best so far).*
- *There can be other requirements to enhance the control performance.*
- *Need to design controllers based on the objectives given.*

- *Identification letters in instrumentation and process control:*



Example: P D I C

- First letter (pressure) — P
- Supplementary letter (differential) — D
- 1st succeeding letter (indication) — I
- 2nd succeeding letter (control) — C

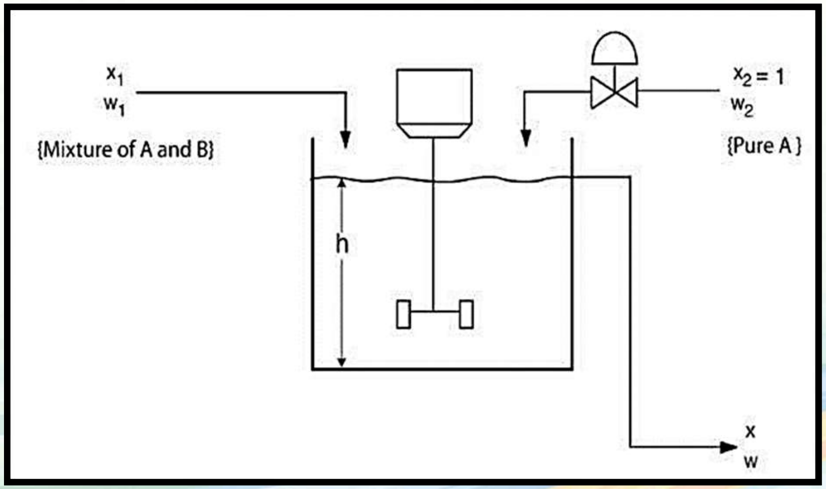


Instrument description examples

- *TT : Temperature Transmitter*
- *LT: Level Transmitter*
- *LC: Level Controller*
- *FC: Flow Controller*
- *PI: Pressure Indicator*
- *TAH/L: Temperature Alarm High/Low, (Normal)*
- *TI: Temperature Indicator*
- *TR: Temperature Recorder*
- *TIRC: Temperature Indicator, Recorder, and Controller.*

Etc….

Illustrative example : Stirred-Tank blending system



Notation:

- *w_1, w_2 and w are mass flow rates*
- *x_1, x_2 and x are mass fractions of component A*

Assumptions:

1. w_1 is constant
2. x_2 = constant = 1 (stream 2 is pure A)
3. Perfect mixing in the tank

Control Objective: keep x at a desired value (or "set point") x_{sp}, despite variations in $x_1(t)$. Flow rate w_2 can be adjusted for this purpose.

Terminology:

- Controlled variable (or "output variable"): x
- Manipulated variable (or "input variable"): w_2
- Disturbance variable (or "load variable"): x_1

Design Question. What value of $\bar{w}_2$ is required to have $\bar{x} = x_{SP}$?

(the overbar denotes nominal steady-state design values.)

Overall balance:

$$0 = w_1 + w_2 - w \qquad (1)$$

Component A mass balance:

$$w_1 x_1 + w_2 \bar{x}_2 - w\bar{x} = 0 \qquad (2)$$

- At the design conditions: $\bar{x} = x_{SP}$ but $\bar{x}_2 = 1$
- Solve Eqns.(1) and (2) for $\bar{w}_2$ to have:

$$\bar{w}_2 = \bar{w}_1 \left[\frac{x_{SP} - \bar{x}_1}{1 - x_{SP}}\right] \qquad (3)$$

- Eq. (3) is the design equation for the blending system.
- If our assumptions are correct, then this value of $\bar{w}_2$ will keep $\bar{x}$ at x_{SP}. But what if conditions change?

Control question. Suppose that the inlet concentration x_1 changes with time. How can we ensure that x remains at or near the set point x_{SP}?

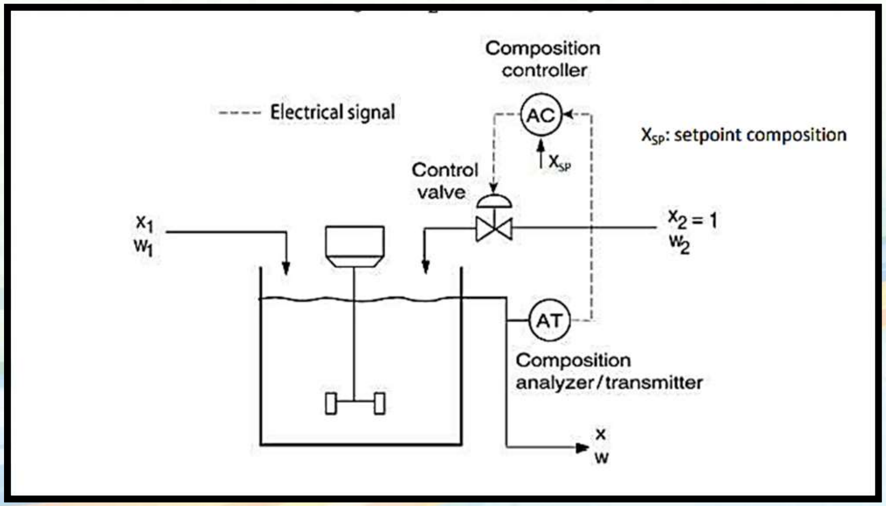
As a specific example, if $x_1 > \bar{x}_1$ and $w_2 = \bar{w}_2$, then $x > x_{SP}$

Some possible control strategies:

Method 1. Measure x and adjust w_2 manually.

- *Intuitively, if x is too high, we should reduce w_2;*

Method 2. Measure x and adjust w_2 automatically:



"Feedback control of composition (x) in Stirred-Tank blending system"

Method 3. Measure x_1 and adjust w_2 automatically

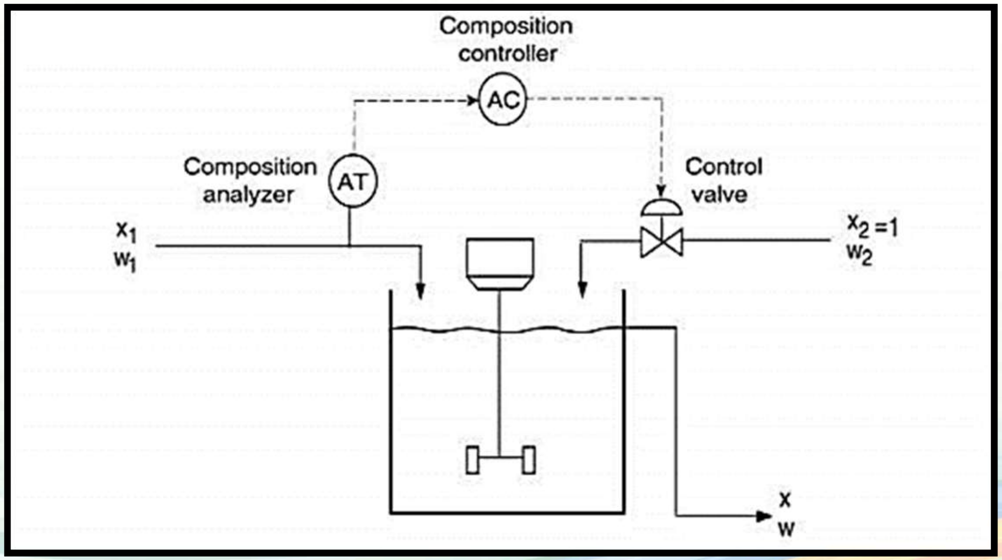
- Thus, if x_1 is greater than $\bar{x}_1$, we would decrease w_2 so that $w_2 < \bar{w}_2$
- One approach: Consider Eq. (1-3) and replace $\bar{x}_1$ and $\bar{w}_2$ with $x_1(t)$ and w2(t) to get a control law:

$$\bar{w}_2(t) = \bar{w}_1 \frac{x_{SP} - \bar{x}_1(t)}{1 - x_{SP}} \qquad (4)$$

- Remark:

Because Eq.(3) applies only at steady state, it is not clear how effective the control law (Eq.4) will be for transient conditions.

Measure x_1 and adjust w_2 automatically



"Feedforward control of composition (x) in Stirred-Tank Blending System"

Method 4: Measure x_1 and x, and adjust w_2.

- This approach is a combination of methods 1 and 2.

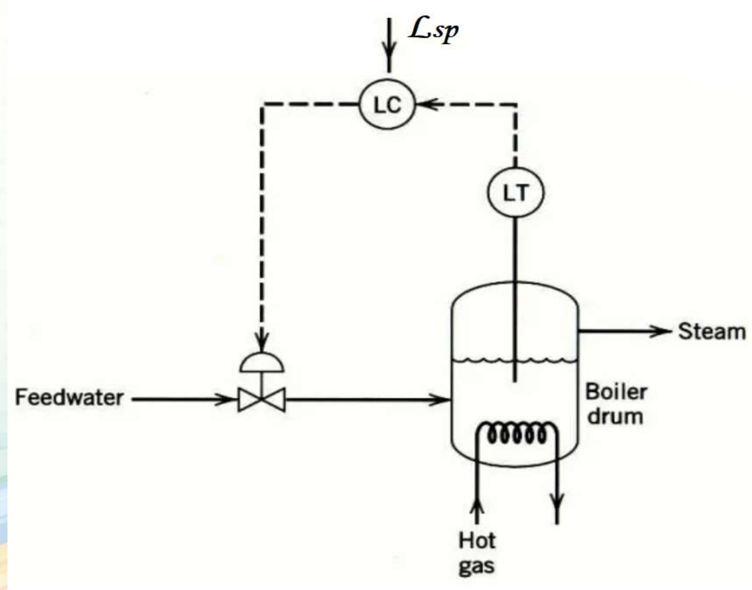
Method 5. Use a larger tank

- If a larger tank is used, fluctuations in x_1 will tend to be damped out due to the larger capacitance of the tank contents.
- However, a larger tank means an increased capital cost.

Table 1: Control strategies for the blending system

Method	Measured Variable	Manipulated Variable	Category
1	x	w_2	Manual
2	x	w_2	FB
3	x_1	w_2	FF
4	x_1 and x	w_2	FF/FB
5	-	-	Design change

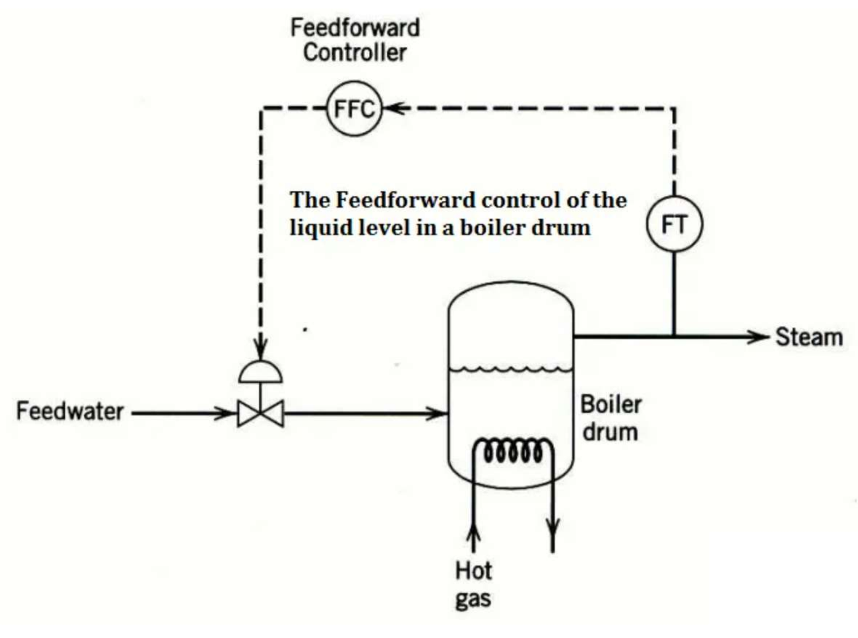
- More illustrative examples:
- The level of the boiling liquid is measured and used to adjust the feedwater flow rate.
- This control system tends to be quite sensitive to rapid changes in the disturbance variable, steam flow rate, as a result of the small liquid capacity of the boiler drum.
- Rapid disturbance changes can occur as a result of steam demands made by downstream processing units



"Feedback control of liquid level in a boiler drum"

More illustrative examples:

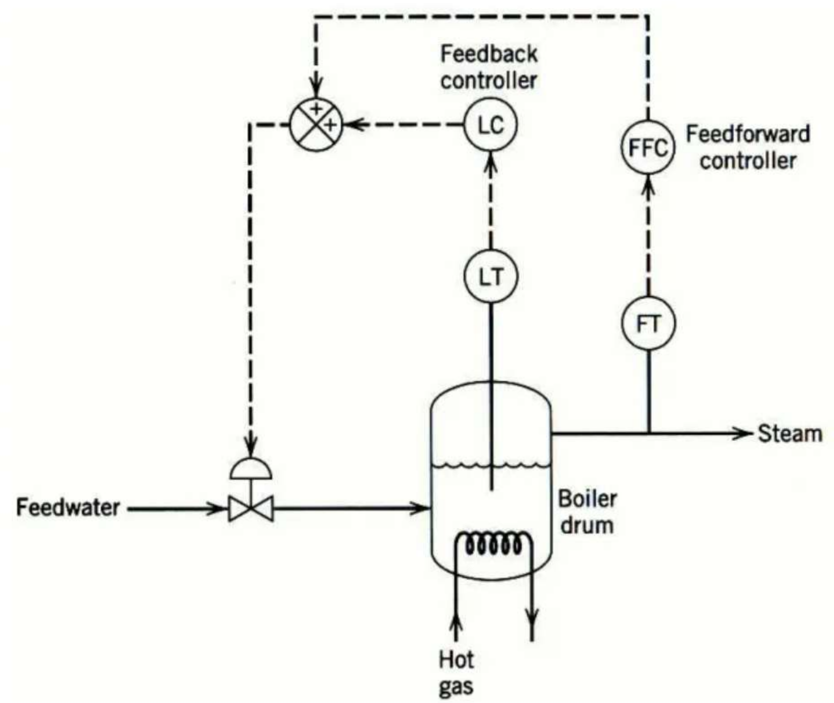
- The feedforward control scheme in the Figure can provide better control of the liquid level.
- Here the steam flow rate is measured, and the feedforward controller adjusts the feedwater flow rate



"Feedforward control of liquid level in a boiler drum"

More illustrative examples:

- *In practical applications, feedforward control is normally used in combination with feedback control.*
- *Feedforward control is used to reduce the effects of measurable disturbances, while feedback trim compensates for inaccuracies in the process model, measurement error, and unmeasured disturbances.*



"Feedforward-feedback control of liquid level in a boiler drum"

Classification of control strategies

- Based on the decision:
  - Feedback control: based on measurement of CV
  - Feedforward control: based on measurement of DV
  - Open-loop control (manual): based on predetermined scenario

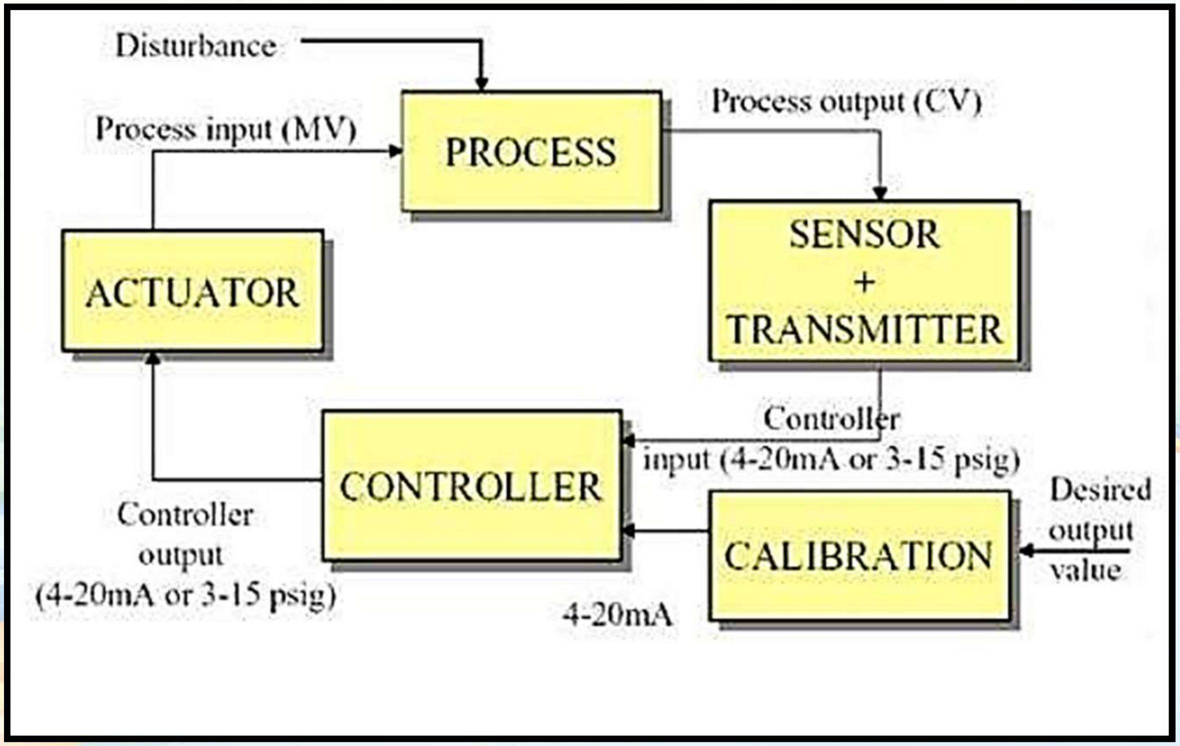
- Based on set point type:
  - Regulatory control: follow constant set point overcoming the disturbance
  - Servo control: follow the changing set point

Classification of variables

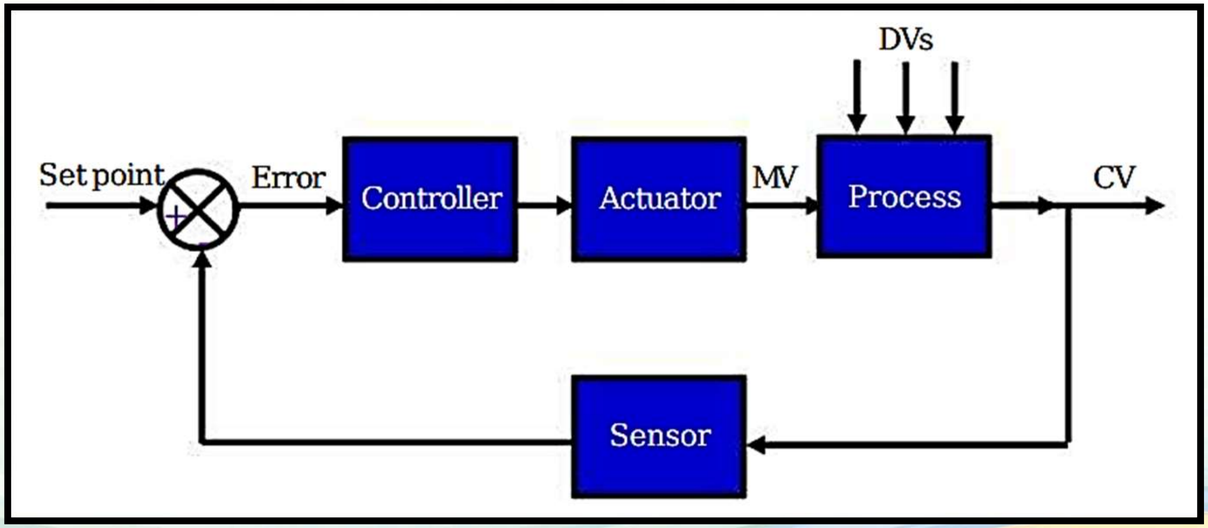
- Input
  - MV (manipulated Var.): Operator can adjust it.
  - DV (disturbance Var.): Decided by external reasons (feed flow, fuel press.) (measured DV and unmeasured DV)
  - Fixed inputs.
- Output
  - CV (Controlled Var.): Decided by the changes in input variables (assumed to be measured)
  - Measured and unmeasured outputs.

- *In this course we will focus on the feedback control*
- *Elements of process control loop;*

- *Process*
- *Sensors*
- *Transmitters*
- *Controller*
- *Actuator*



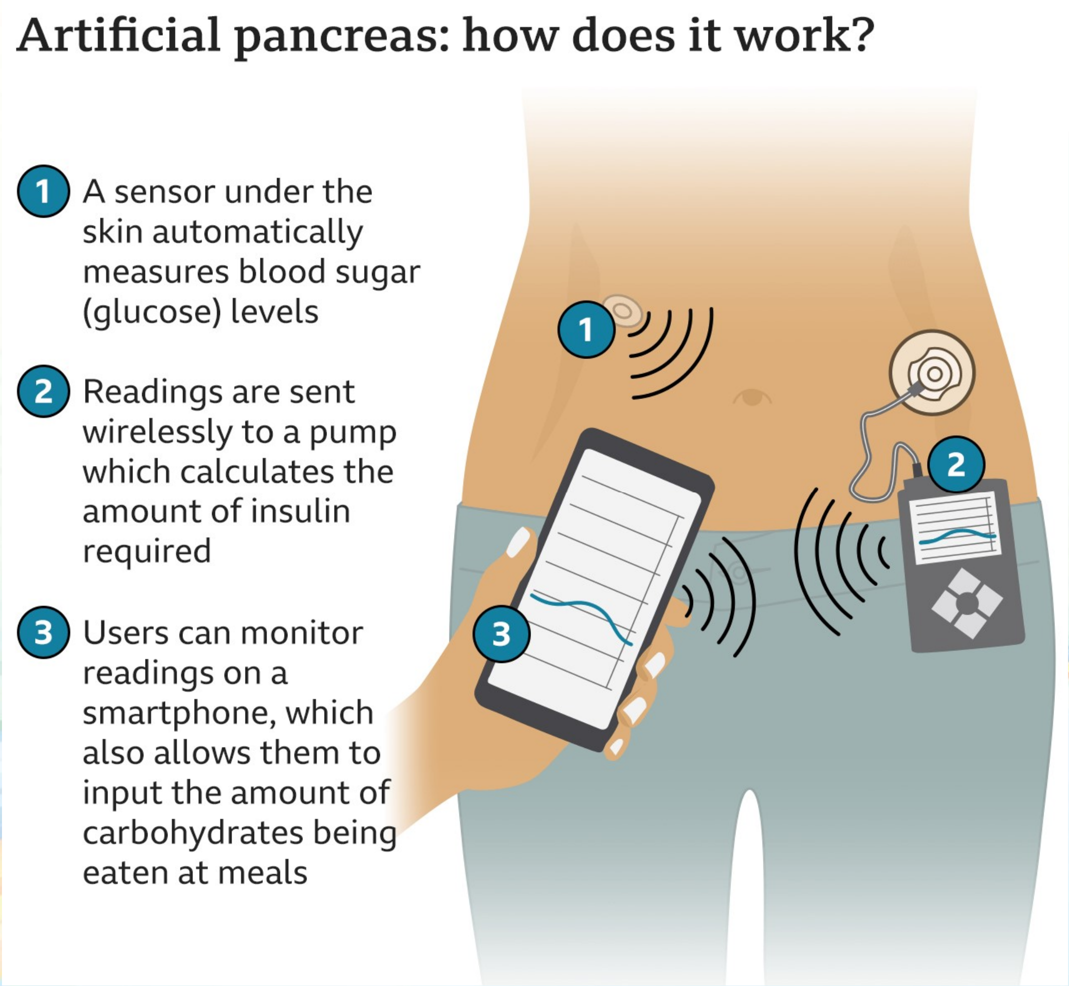
➢ *The block diagram of feedback control system is:*



- *In this course we will visit all the block elements of the control system, first.*
- *Then, analyze the whole system all together.*
- *Then, consider the variations of the elements.*

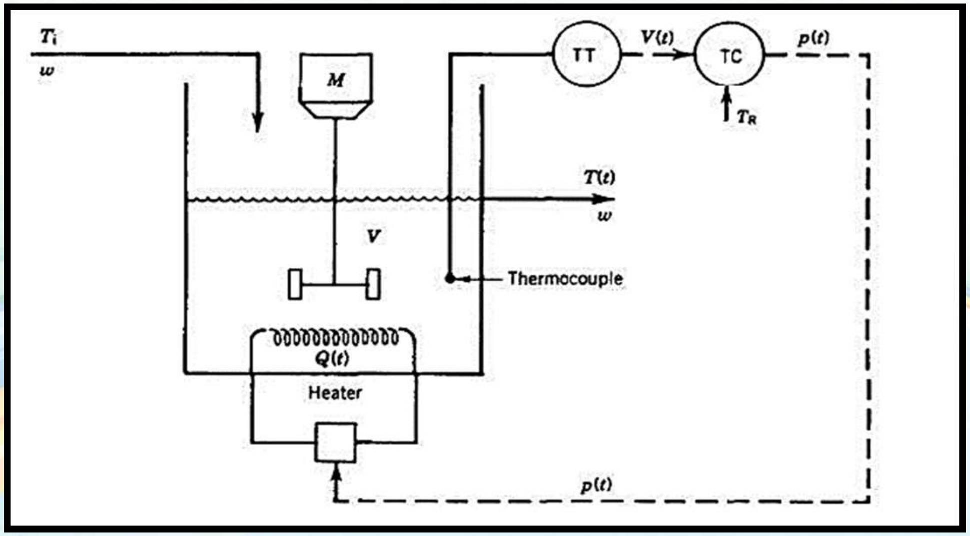
Illustrative examples:

- *Closed-loop artificial Pancreas:*

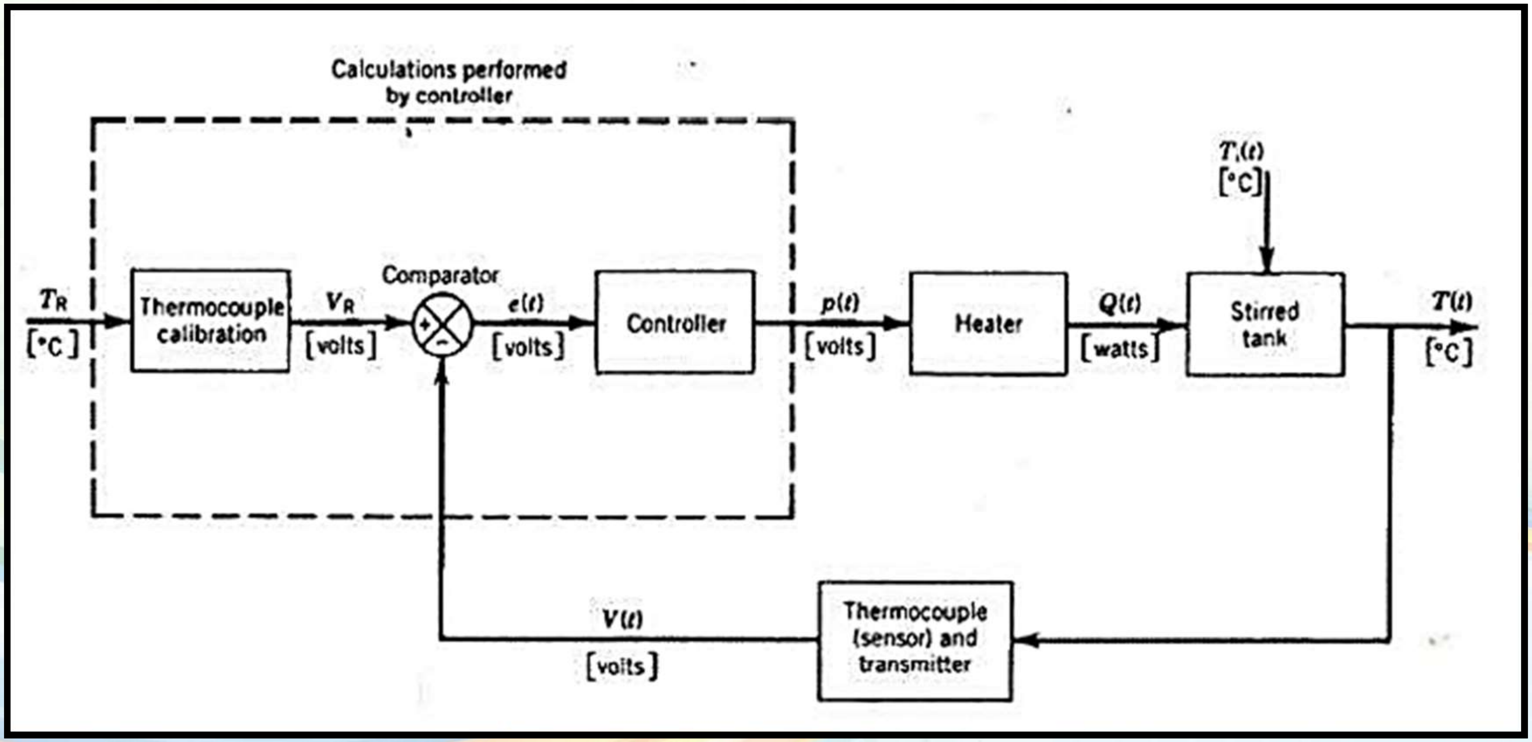


➢ *Illustrative examples:*

- *To keep the tank temperature T at the desired value T_R by adjusting the rate of heat input Q from the heater.*
- *Basic components in the feedback control loop*·
  - ✓ *Process being controlled (stirred tank).*
  - ✓ *Sensor and transmitter.*
  - ✓ *Controller.*
  - ✓ *Silicon controlled rectifier (SCR) and final control element (electrical heater) ⟸ Actuator.*
  - ✓ *Transmission lines (electrical cables) between the various instruments.*

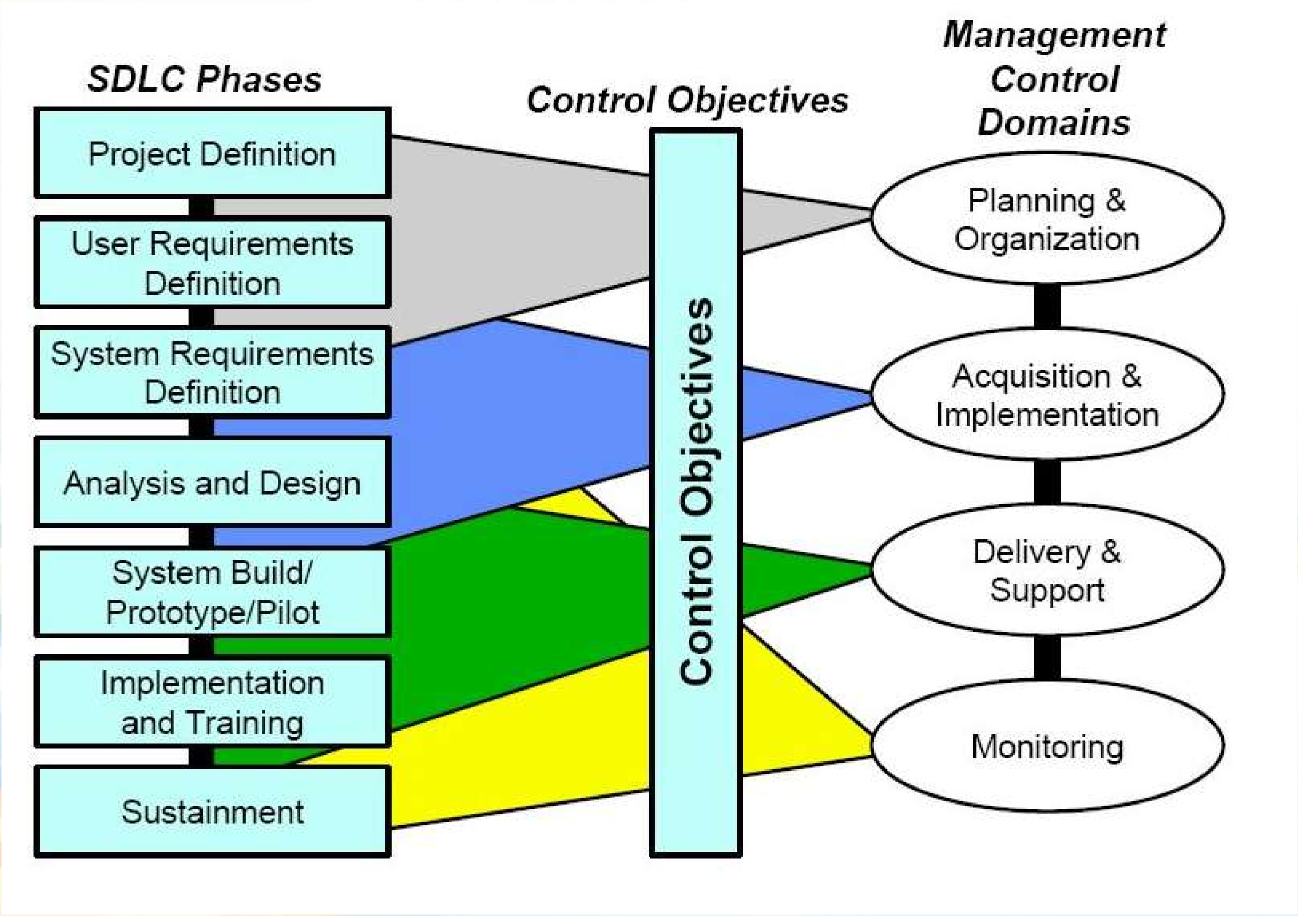


➢ *Illustrative examples:*



"Block diagram for temperature feedback control system"

- *Major steps in control system development:*



- *Performance assessment of process control:*
  - *Closeness to set points*
  - *Short transient from one set point to other set points*
  - *Smaller overshoot and less oscillation (stable control system)*
  - *Smooth and minimum changes of variable manipulation*
  - *Minimum usage of materials and energy*