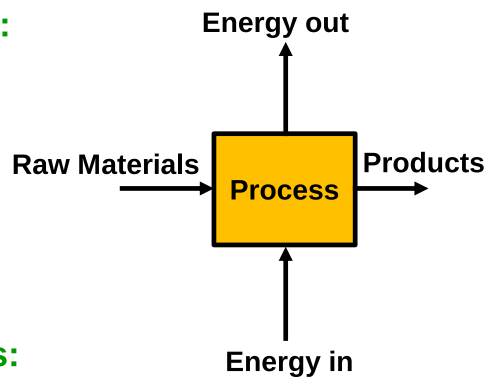
Topic I: Introduction to Process Control

➢ 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

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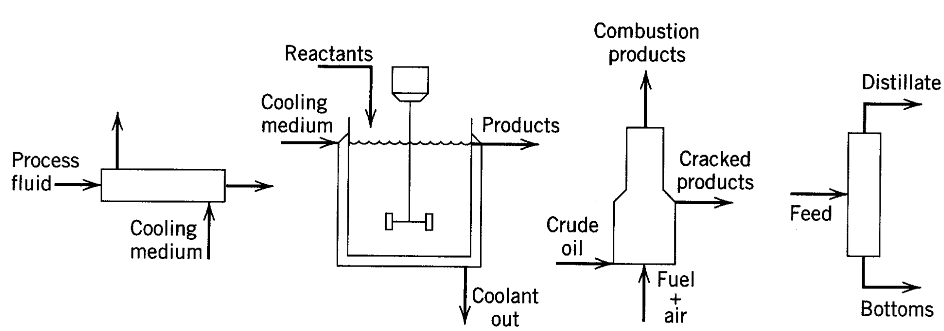
➢ Classification of processes:

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



(*a*) Heat exchanger (*b*) Chemical reactor (*c*) Cracking furnace (*d*) Distillation column

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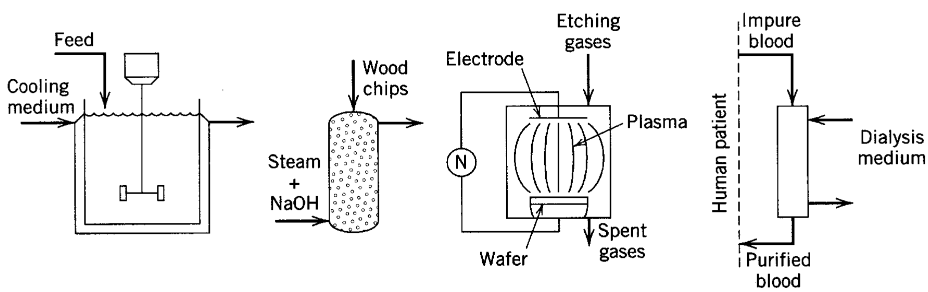
- **Examples:**



(*e*) Semi-batch reactor (*f*) Wood chip digester (*g*) Plasma etcher (*h*) Kidney dialysis unit

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- **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
  - **Ex)** flow rate by control valve, motor speed by inverter

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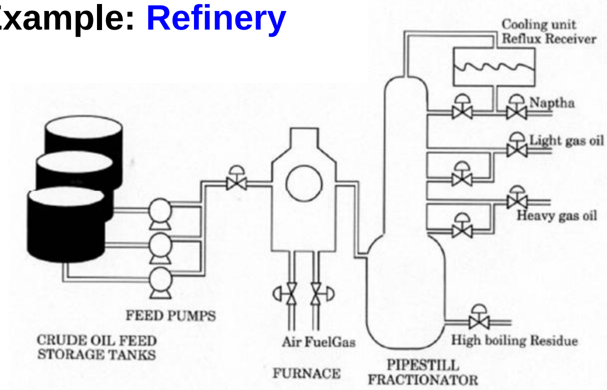
Example: Refinery



➢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

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➢ Specific objectives of control:

- Increased product throughput
- Increased yield of higher valued products
- Decreased energy consumption
- Decreased pollution
- Decreased off-spec product
- Increased safety
- Extended life of equipment
- Improved operability
- Decreased production labor

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➢ Justifications of process control

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

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➢ Through control, we can achieve

- Safe operation
- Satisfying environmental constraints
- Economic benefit
- Increased production level
- Reduced raw material cost
- Enhanced product quality
- Extended equipment life
- Potential benefits of improved process control

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➢ 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 variable(s) 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. (CV's 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)

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➢ 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.

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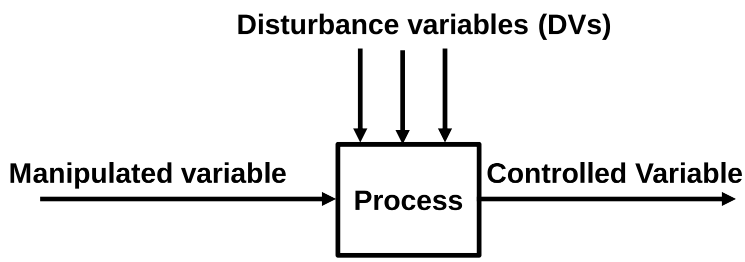
➢ How to control a process?



Control Objective: Maintain controlled variable at its set point, despite disturbances.

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➢ 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.

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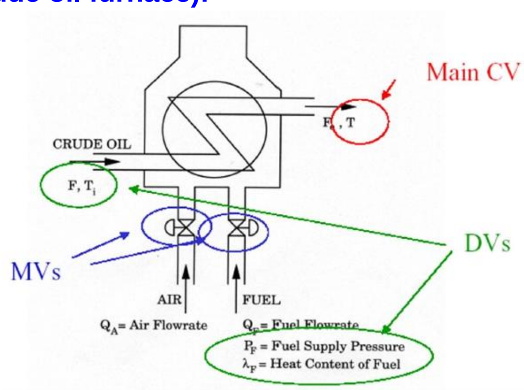
– Manual control:

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

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– Automatic control: different control strategies

A. **FEEDBACK (FB) CONTROL**

B. **FEEDFORWARD (FF) CONTROL**

C. **COMBINED FF/FB CONTROL**

D. **ADVANCE CONTROL….**

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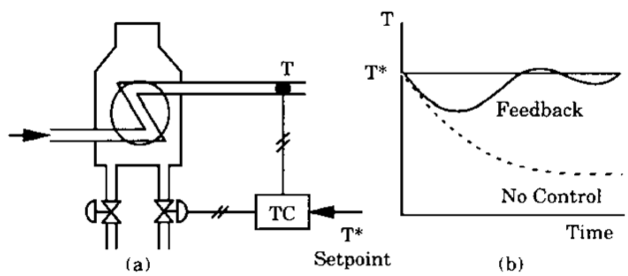
A. FEEDBACK (FB) CONTROL



- 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.

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A. FEEDBACK (FB) CONTROL:

- **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.

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A. FEEDBACK (FB) CONTROL:

- **Disadvantages:**
  - FB control takes no corrective action until a deviation in the controlled variable.
  - FB control is incapable of correcting 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.

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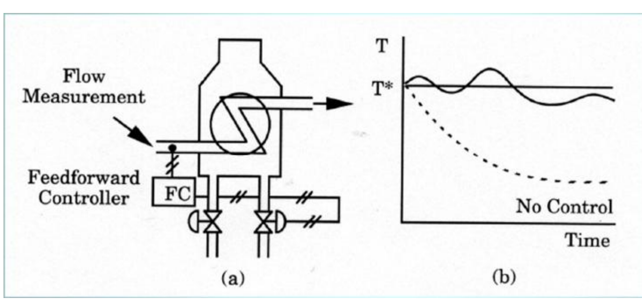
B. FEEDFORWARD (FF) CONTROL



- 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

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B. FEEDFORWARD (FF) CONTROL

- **Distinguishing feature**: measure a disturbance variable and transmit its value to the controller.
- **Advantage:**
  - Correct for disturbance before it upsets the process.
  - Theoretically capable of "perfect control".
  - Does not affect system stability.
- **Disadvantage:**
  - Must be able to measure the disturbance.
  - No corrective action for unmeasured disturbances.
  - Requires more knowledge of the process to be controlled (process model)

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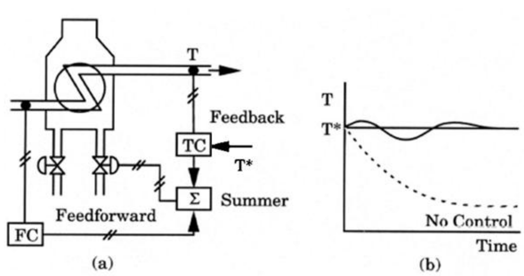
C. COMBINED FF/FB CONTROL

- 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 effect appears at exit temperature

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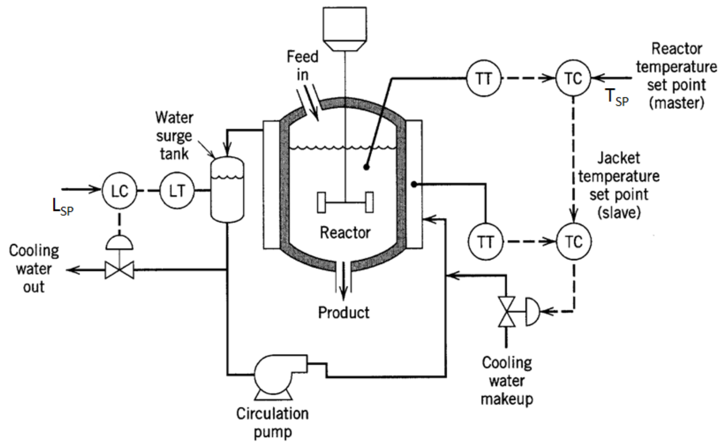
D. ADVANCED CONTROL

Example. Cascade Control:



"Cascade Control of an exothermic chemical reactor"

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➢ 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

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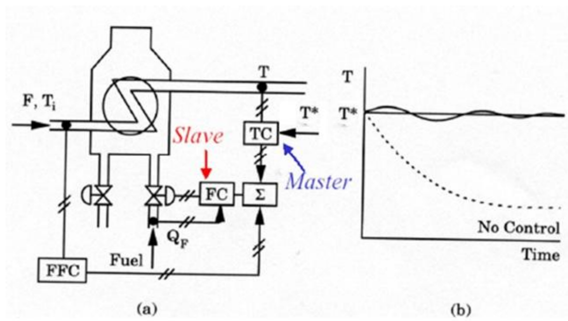
➢ FF/FB + CASCADE Control



- 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

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– Identification letters in instrumentation and process control:

	First letter		Succeeding letters		
	Measured or initiating var.	**Modifier**	**Readout or passive func.**	**Output function**	**Modifier**
A	Analysis		Alarm		
B	Burner, combustion		User's choice	User's choice	User's choice
C	User's choice			Control	
D	User's choice	Differential			
E	Voltage		Sensor (primary element)		
F	Flow rate	Ratio (fraction)			
G	User's choice		Glass, viewing device		
H	Hand				High
I	Current (electrical)		Indication		
J	Power	Scan			
K	Time, time schedule	Time rate of change		Control station	
L	Level		Light		Low
M	User's choice	Momentary			Middle, interm.
N	User's choice		User's choice	User's choice	User's choice
O	User's choice		Orifice, restriction		
P	Pressure, vacuum		Point (test connection)		
Q	Quantity	Integrate, totalizer			
R	Radiation		Record		
S	Speed, frequency	Safety		Switch	
T	Temperature			Transmit	
U	Multivariable		Multifunction	Multifunction	Multifunction
V	Vibration, mechanical analysis			Valve, damper, louver	
W	Weight, force		Well		
X	Unclassified	X axis	Unclassified	Unclassified	Unclassified
Y	Event, state, or presence	Y axis		Relay,compute,convert	
Z	Position, dimension	Z axis		Driver, actuator	

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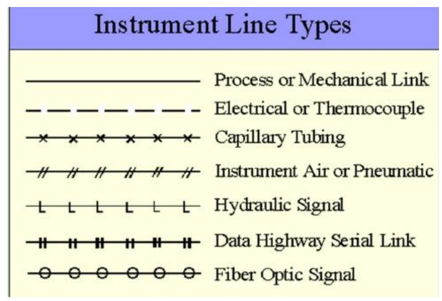
Example: **P D I C**

First letter (pressure) — P

Supplementary letter (differential) — D

1st succeeding letter (indication) — I

2nd succeeding letter (control) — C



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Instrument description examples

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

etc…..

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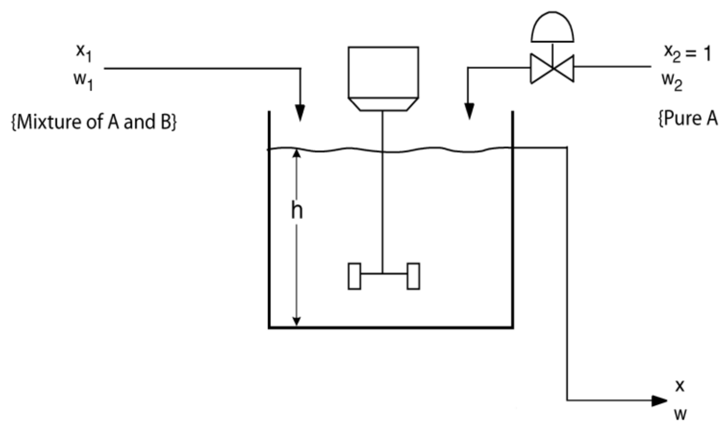
Illustrative example: Stirred-Tank Blending System



Notation:

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

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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

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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:

$$0 = \bar{w}_1 + \bar{w}_2 - \bar{w} \quad \textbf{(1)}$$

Component A mass balance:

$$\bar{w}_1\bar{x}_1 + \bar{w}_2\bar{x}_2 - \bar{w}\bar{x} = 0 \quad \textbf{(2)}$$

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

$$\bar{w}_2 = \bar{w}_1 \frac{x_{SP} - \bar{x}_1}{1 - x_{SP}} \quad \textbf{(3)}$$

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- 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;

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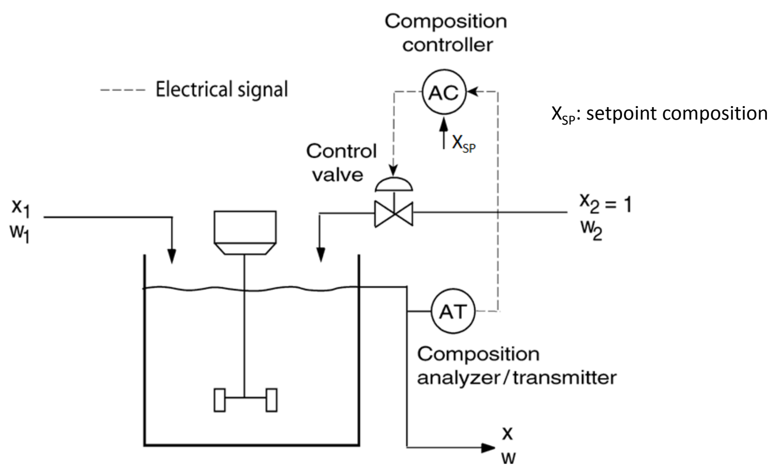
Method 2. *Measure x and adjust w_2 automatically:*



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

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Method 3. *Measure x_1 and adjust w_2 automatically.*

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

$$w_2(t) = \overline{w}_1 \frac{x_{SP} - x_1(t)}{1 - x_{SP}} \qquad \textbf{(4)}$$

- **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.

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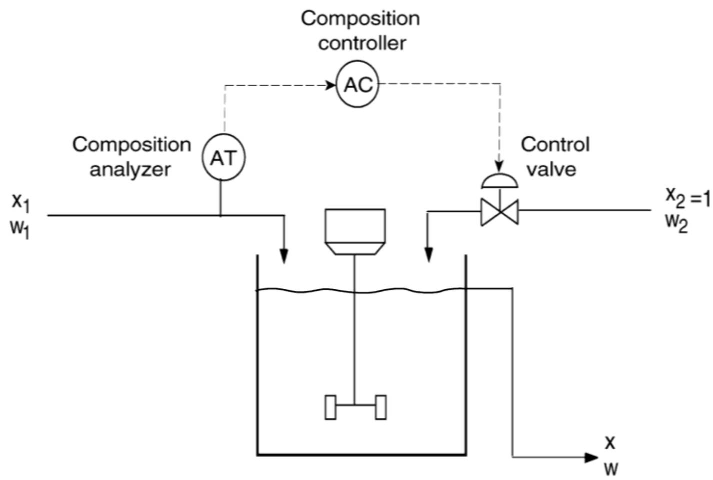
Method 3. *Measure x_1 and adjust w_2 automatically.*



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

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Method 4. *Measure x_1 and x, 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.

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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

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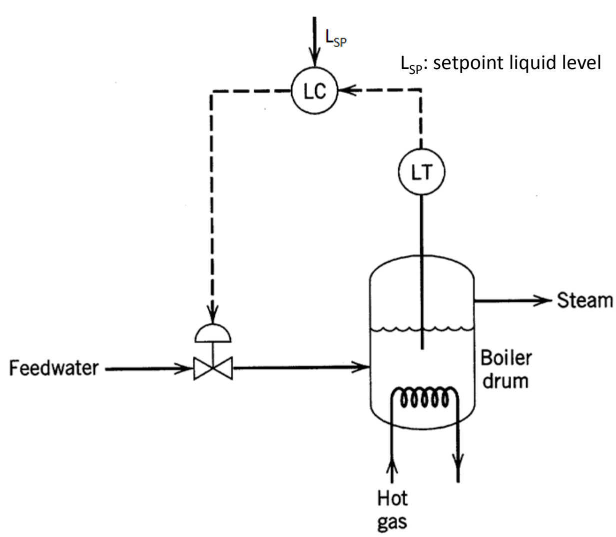
More illustrative examples:



"Feedback control of liquid level in a boiler drum"

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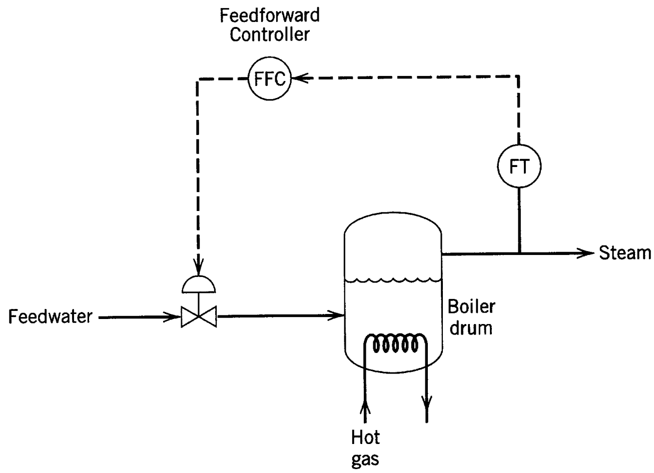
More illustrative examples:



"Feedforward control of liquid level in a boiler drum"

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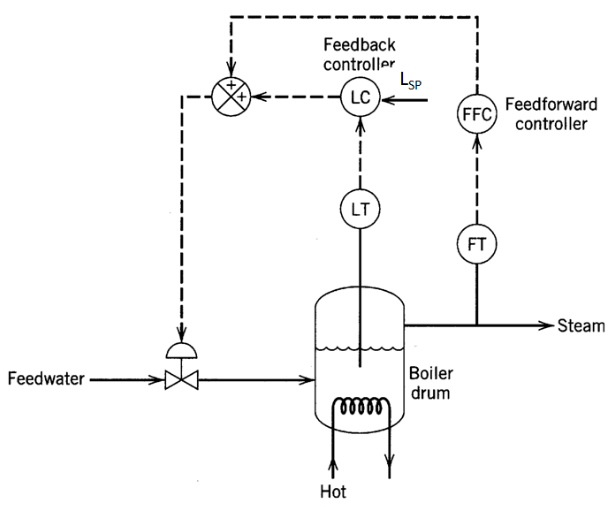
More illustrative examples:



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

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➢ 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

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➢ 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

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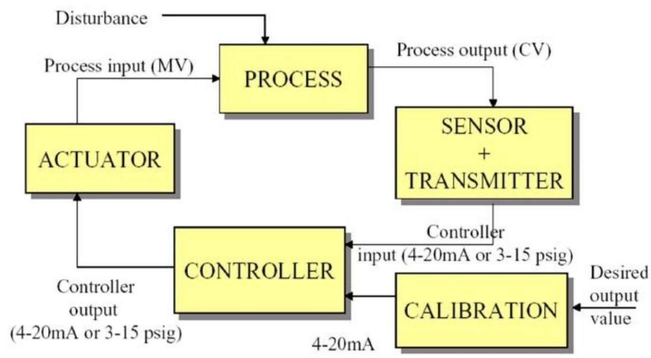
➢ **In this course we will focus on the feedback control**

➢ **Elements of process control loop:**

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



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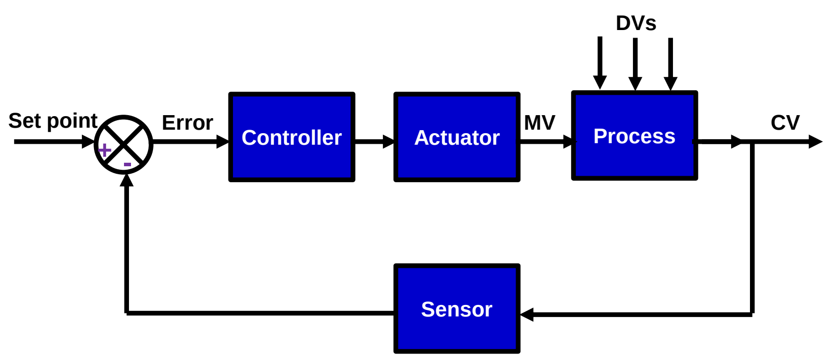
➢ **The block diagram of feedback control system is:**



- 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.

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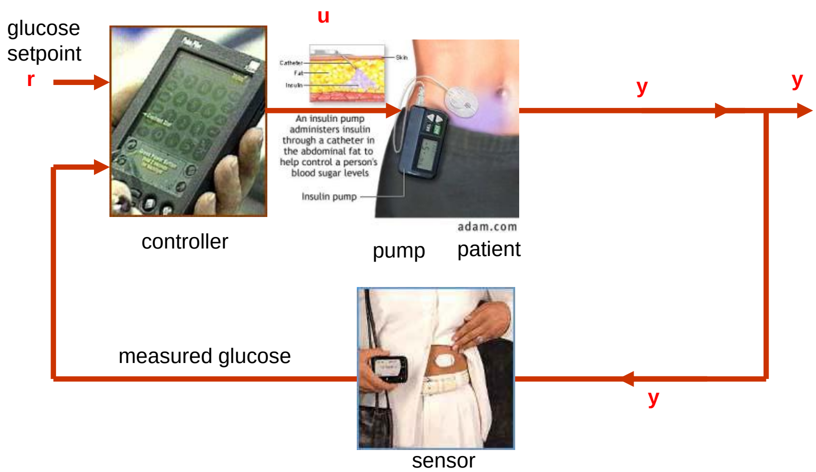
➢Illustrative examples:

- Closed-loop Artificial Pancreas:



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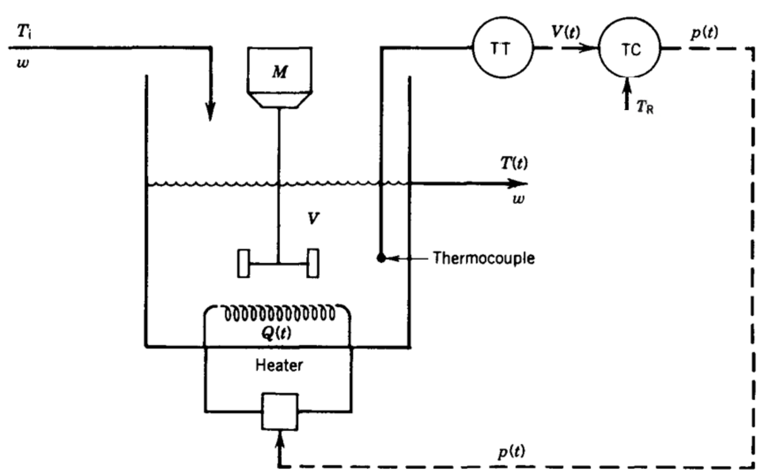
➢Illustrative examples:

- schematic diagram of a temperature feedback control system for stirred-tank heater:



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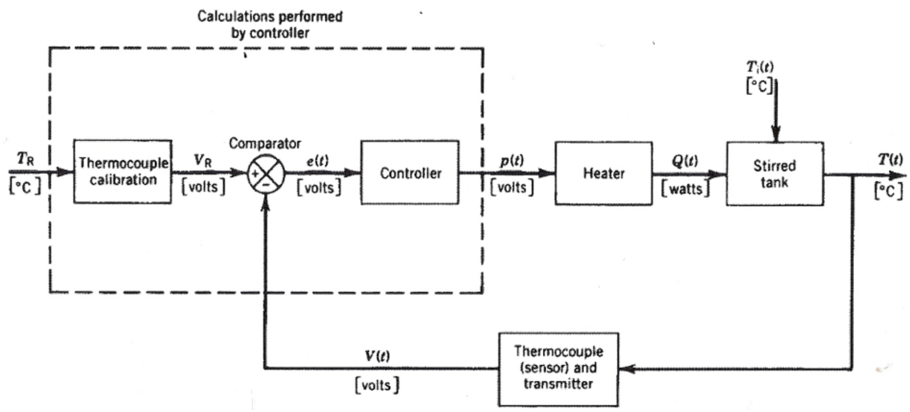
➢Illustrative examples:



“ Block diagram for temperature feedback control system”

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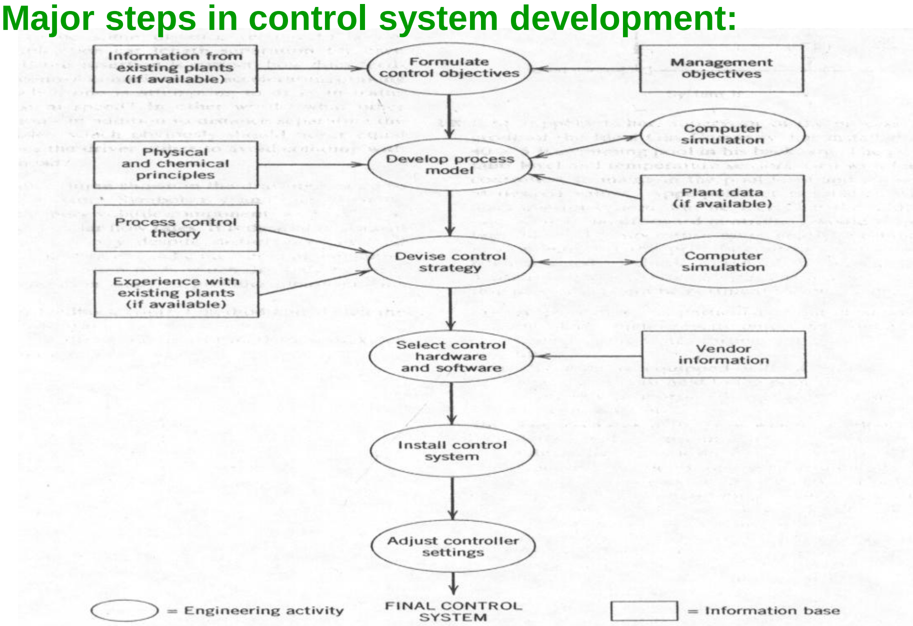
➢ Major steps in control system development:



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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