Instrumentation & Measurement

Winter 2024

Amir Jafari

Introduction

Course Outline & Plan

- Course outline PDF file in blackboard
- Course Plan PDF file in blackboard

Course Plan for MEng 2510 - Winter 2024

				Lab Sessions	Lecture Sessions
Jan 8	-	Jan 12	Week 1	Lab 1	Introduction to course, Introduction to (Process) Control
Jan 15	-	Jan 19	Week 2	Lab 2	Sensor Outputs + Calibration
Jan 22	-	Jan 26	Week 3	Lab 3	Sensor Characteristic-Static
Jan 29	-	Feb 2	Week 4	Lab 4	Sensor Characteristic-Dynamic
Feb 5	-	Feb 9	Week 5	Group Bus Project primary presentation & Discussion	Position + Displacement
Feb 12	-	Feb 16	Week 6	Bus - Narrative review and feednback discussion	Motion
Feb 19	-	Feb 23	Week 7	No Lab	Midterm
Feb 26	-	Mar 1	Week 8	**Reading Week**	
Mar 4	-	Mar 8	Week 9	Bus - BOM	Force & Mass Measurement
Mar 11	-	Mar 15	Week 10	Bus Presentation	Pressure Measurement
Mar 18	-	Mar 22	Week 11	Lab 5	Temperature measurement
Mar 25	-	Mar 29	Week 12	Lab 6	Flow Measurement
Apr 1	-	Apr 5	Week 13	Lab 7	Signal Conditioning+ Noise
Apr 8	-	Apr 12	Week 14	Bus delivery (assessment and evaluation)	Digital Processing
Apr 15	-	Apr 19	Week 15	**Final Exam**	

Assessment Weighting

- Course outline PDF file in blackboard

Assessment	Weight
Quiz and Attendances	5%
Midterm Exam	20%
Final Exam	30%
Labs	25%
Bus Project	20%
Total	100%

Source Books

1) 1. Process Control Instrumentation Technology, Curtis D. Johnson, Eighth Edition, Pearson Education Limited (2014)

ISBN 10: 1-292-02601-4 ISBN 13: 978-1-292-02601-5

2) Measurement and Instrumentation: Theory and Application, Alan S. Morris, Reza Langari, Third edition Academic Press (Oct 2020)

ISBN-13: 978-0128171417 ISBN-10: 0128171413

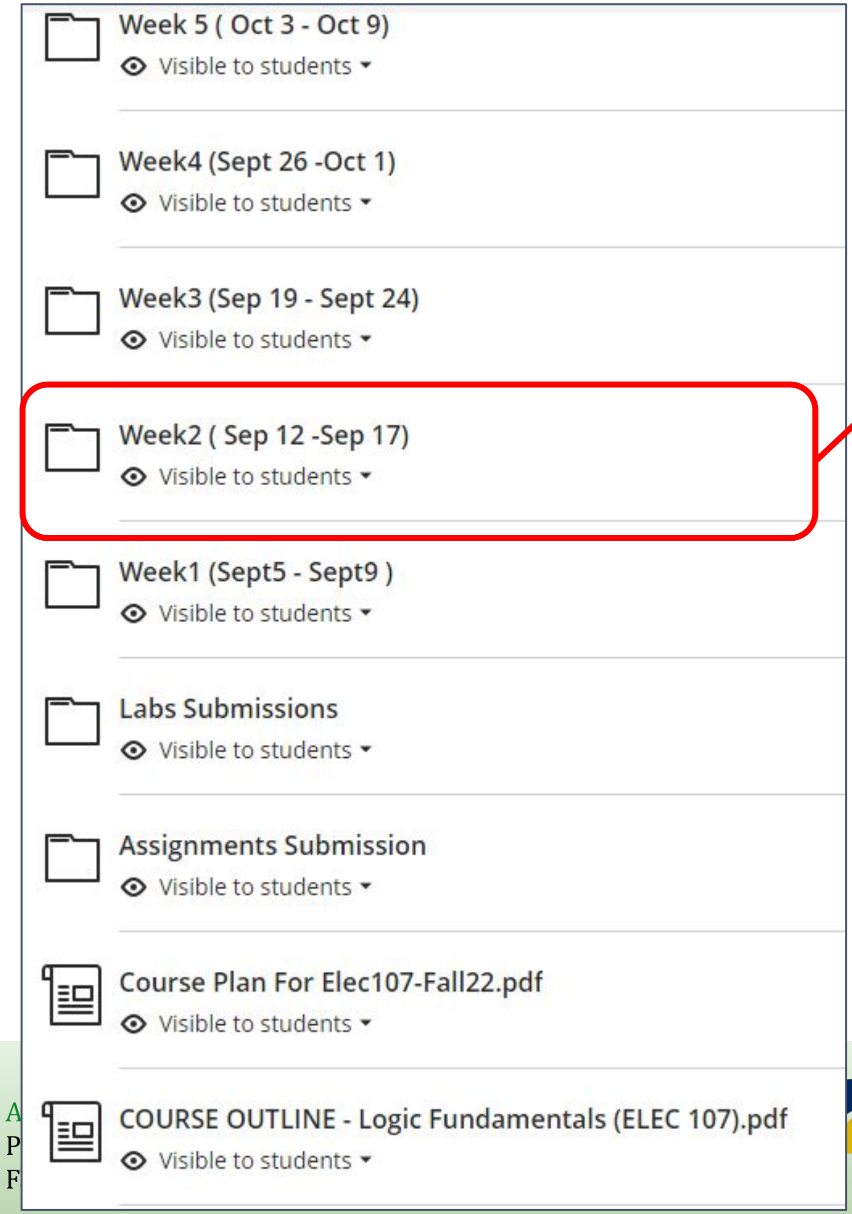
3) Instrumentation and Process Control, Franklyn Kirk, Thomas Weedon, Philip Kirk American Tech Publishers 7th Edition (May 2019)

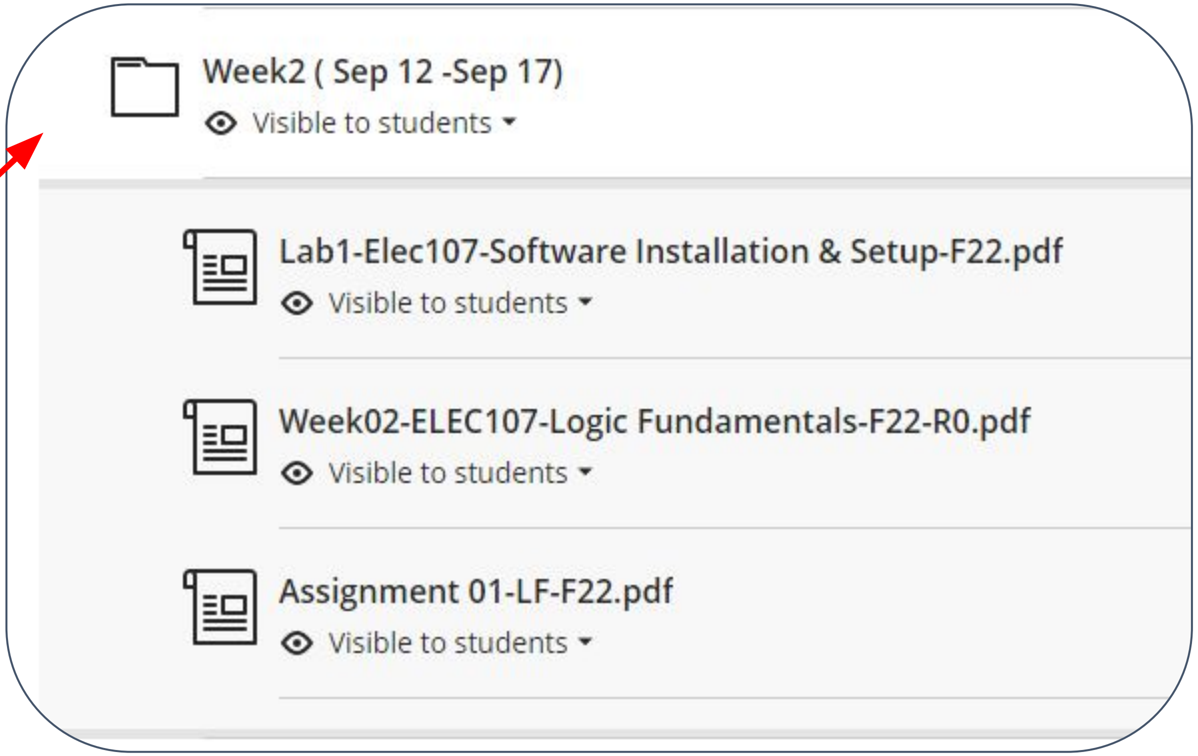
ISBN-10: 0826934463 ISBN-13: 978-0826934468

4) Principles of Measurement Systems, John P. Bentley, Pearson Canada 4th Edition (Nov 2004)

ISBN-10: 0130430285 ISBN-13: 978-0130430281

Course Materials-Blackboard





Communication
Course message & Announcement

- Via Blackboard
  - You can contact me by course messages in Blackboard.
  - Please put your Class ID (section ID) in your message.
  - Announcement is my way for contacting the whole class.
  - Your messages will be replied within 2 business days.
  - personal email not preferred

Introduction to

Process Control & Instrumentation

Introduction to Process Control

- Source Book:

  Process Control Instrumentation Technology

  Curtis D. Johnson

  Eighth Edition

  Pearson Education Limited 2014

  Chapter 1 & Appendix P&ID Symbol

- Source Book:

  Instrumentation and Process Control

  Franklyn Kirk, Thomas Weedon, Philip Kirk

  American Tech Publishers 7th Edition (May 2019)

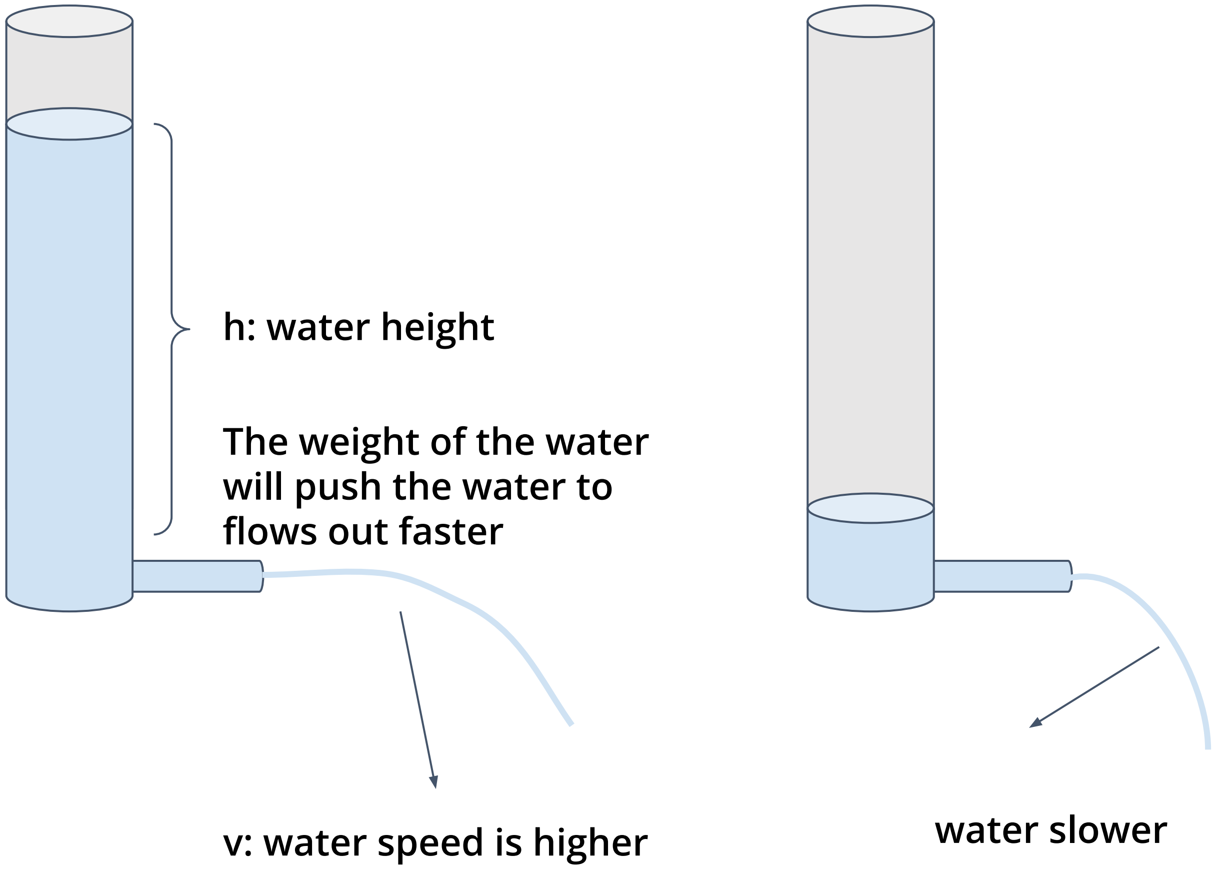
  ISBN-10: 0826934463

  ISBN-13: 978-0826934468

Objectives

- ❑ Understanding Manual and Automatic Control
- ❑ Draw a control system block diagram of a simple process-control loop and identify each element.
- ❑ Define and name control system variables and identify them on the control system block diagram
- ❑ Recognize the common P&ID symbols and tags.

Observation



V present the water speed.

$$v \, \alpha \, \sqrt{h}$$

Higher water column results in faster and more water volume flows out

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Process Example

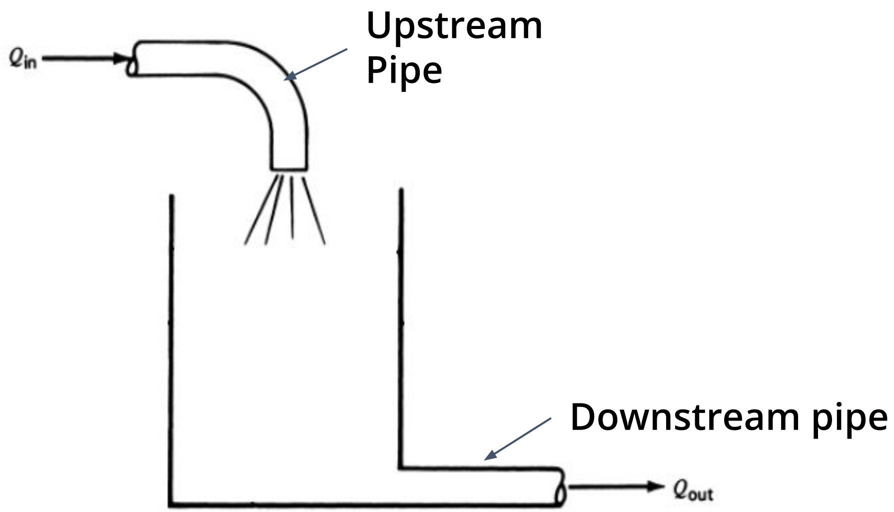
Q_{in} represents the incoming water flow rate, measured in liters per min (L/min). Let's assume the Q_{in} is constant.

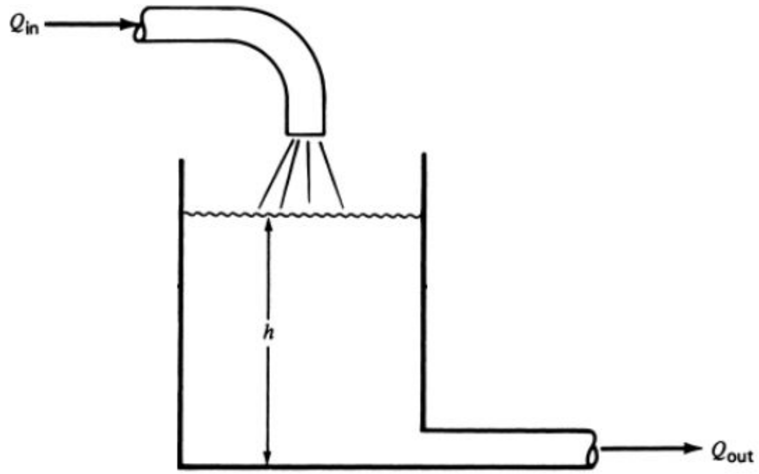
Q_{out} denotes the outgoing water flow rate (L/min). The diameter of the upstream and downstream pipes are the same.

Initially, the incoming water speed exceeds the outgoing water speed, resulting in the accumulation of water in the tank and a subsequent increase in water level.

As the water column height increases, the outgoing water speed will increases. At one specific height, the outgoing water speed will become equal to incoming water speed. This means the volume of incoming water and outgoing water will be equal (Q_{in} $=Q_{out}$) .

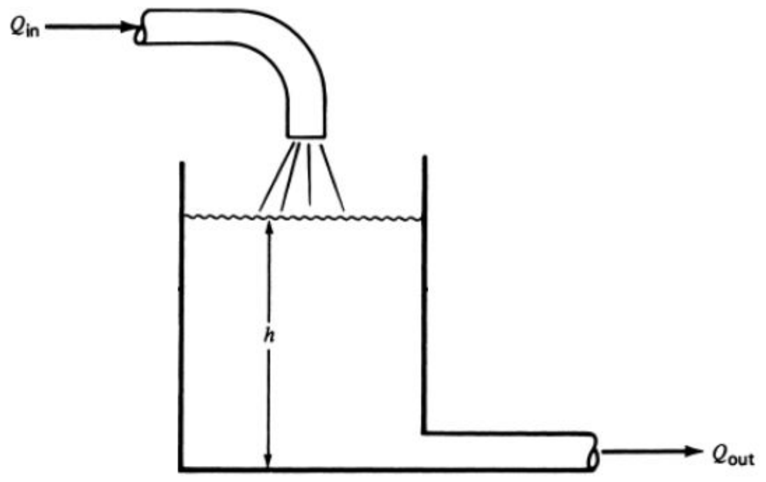
Consequently the height of the water column remains constant.





Process Example

- The front system including the tank, pipe and water of the tank is referred to as process.
- The way a system or process behaves is referred to as system dynamic or process dynamic. The previous slide presented an illustration of process dynamics by demonstrating how an incoming water resulted in the reaction of the water level height.
- If we aim to force the water level to stay at specific height for example in middle of the tank, this is referred to as controlling the process level.
- The collection of all components utilized to control a process are referred to as control system.
- The parameter which is going to be controlled is named process variable. (here h)



Control Definition

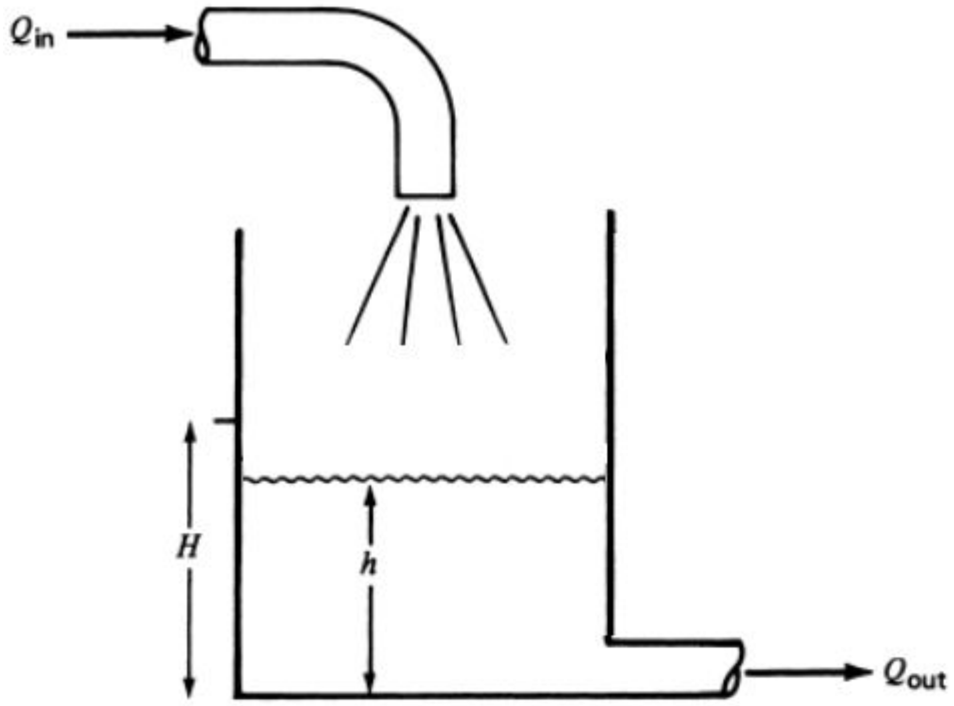
- Simply stated, the term *control* means methods to force parameters in the environment to have specific values.

- This can be as simple as making the temperature in a room stay at 21 ℃ or as complex as self driving car or navigating airplane in the sky.

- In general, all the elements necessary to accomplish the control objective are described by the term *control system*.

Setpoint

- The primary objective of the process control is to regulate the value of some quantity. ”Regulate” in this context implies maintaining quantity at a desired value independent of external influences. The desired value is commonly referred to as the *reference value* or *setpoint*.
- Let's assume we want to bring and maintain the level of the tank to the height H (Capital).
  - H is known as setpoint.



Question: What can we do to bring the water level to *H*?

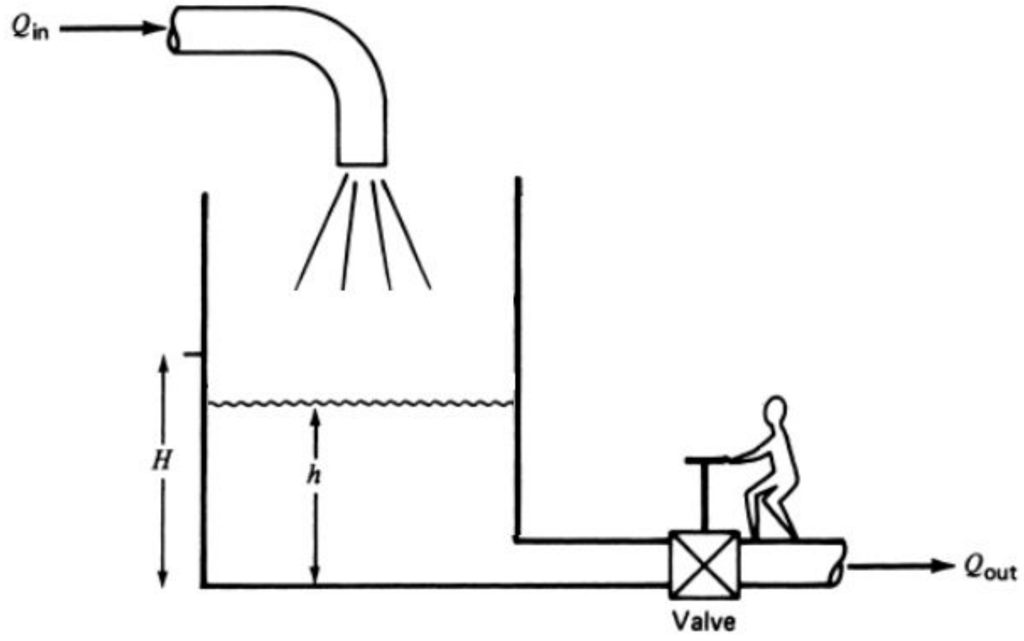
Introduction to Open Loop Control System Concept

Solution: A valve can be added to change the outlet volume and the level of the tank.

An operator can open and close the valve to adjust the level at H. The tank is made of steel and he does not see the actual water level. However, based on the trial and error experiences, he knows how much he should open or close the valve to maintain the level around H.

The operator does not see the level unless he goes up the ladder and check the level, which he does not do it always. Then he is working under the assumption that the level will be ok with the current valve position. In other words, the operator doesn't have access to factual information about the actual level and therefore they lacks feedback on the outcome of their actions.

This type of control which lacks feedback from process variable, is referred to as Open Loop Control system.



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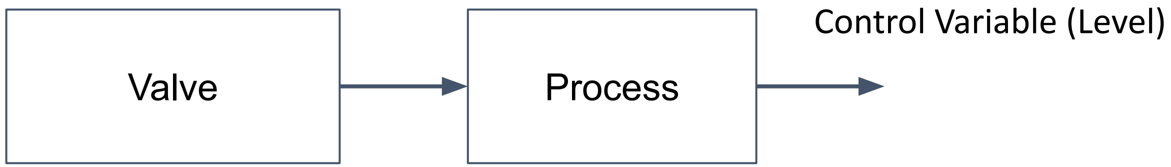
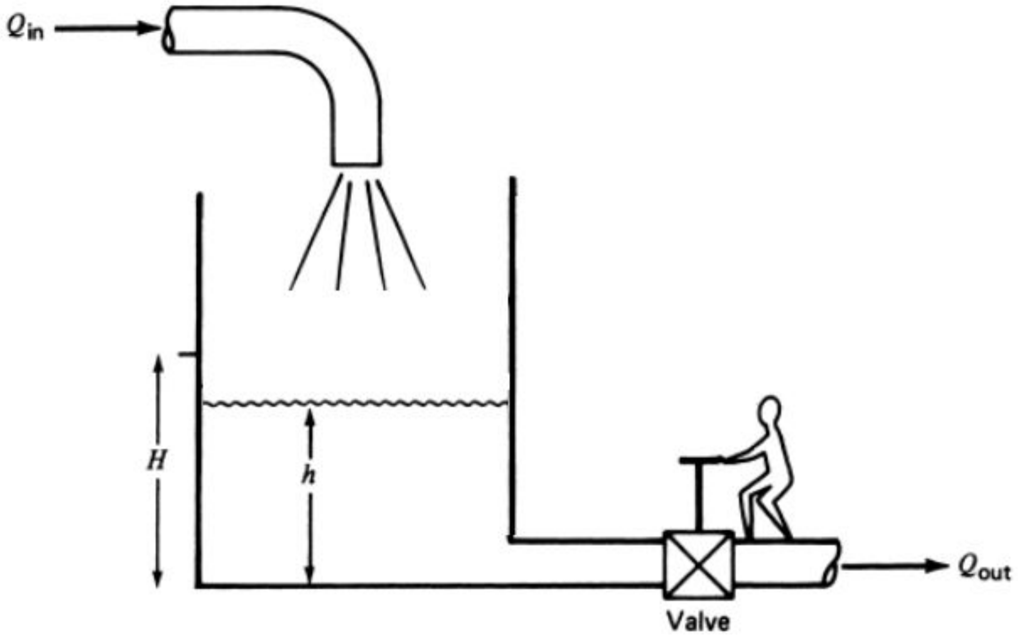
Block Diagram Drawing

To illustrate the relationship between a control system and a process in a simplified manner, a block diagram such as the one shown below is utilized.





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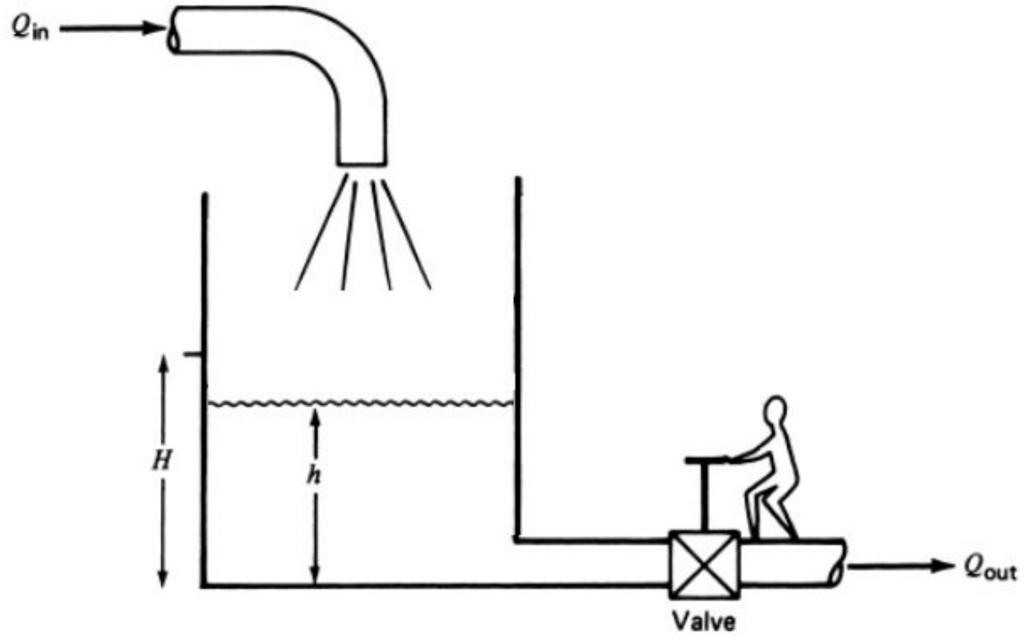
Feedback Introduction

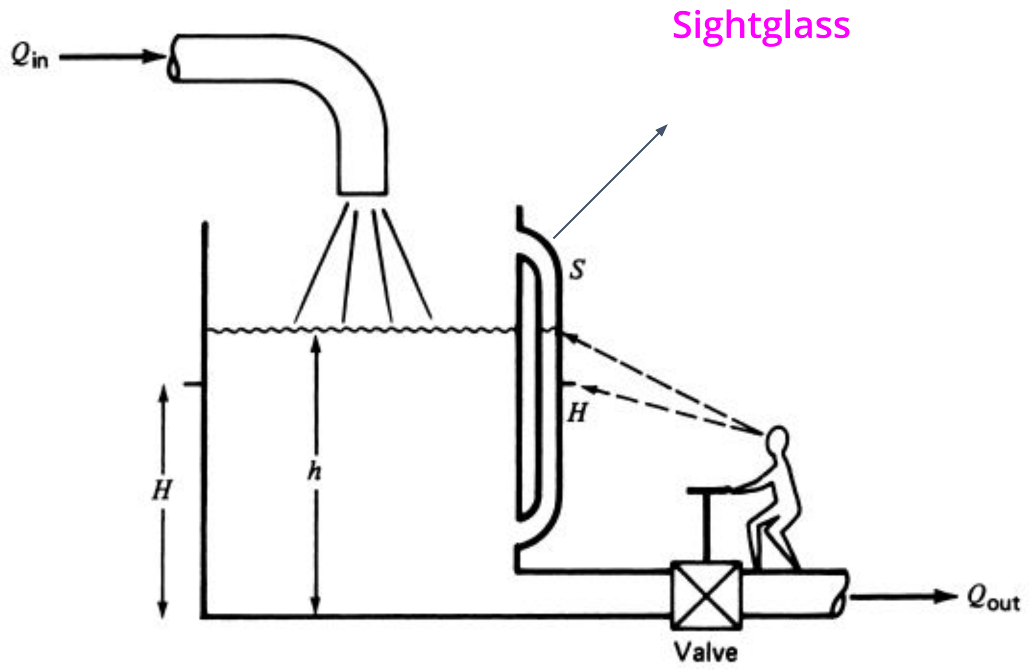
The absence of feedback can lead to problems. For instance, if the valve becomes blocked over time, the water could overflow, then it is better to provide them with information regarding the actual water level.

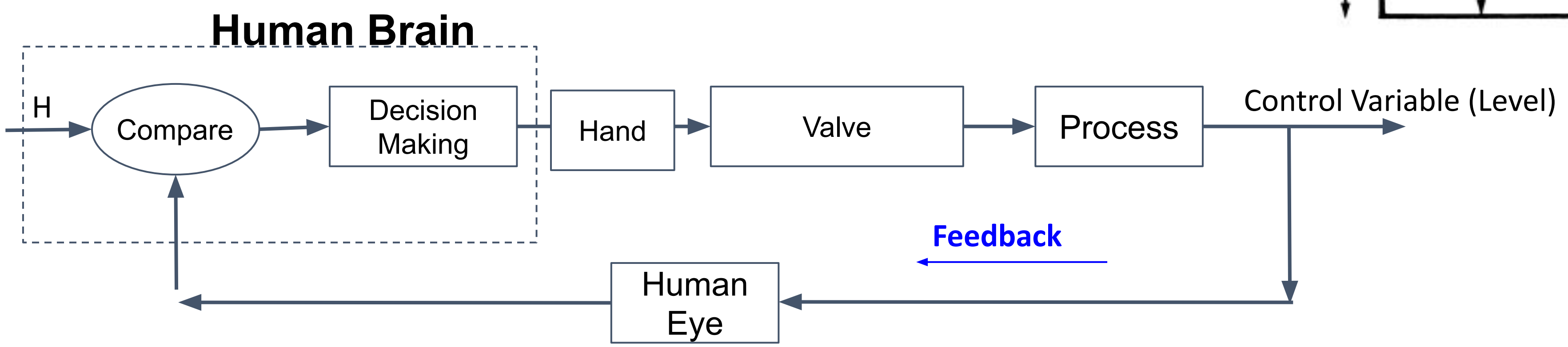
Question: What can we do to provide the operator with feedback about actual water level?



Providing Feedback

As a solution we can add a sight glass. By doing so, the operator will be able to visually observe the changes in the water level every time they open or close the valve. This enables the operator to have direct feedback regarding the impact of their actions. They will have factual information about the actual level rather than relying solely on assumptions or wishful thinking that everything is in order.

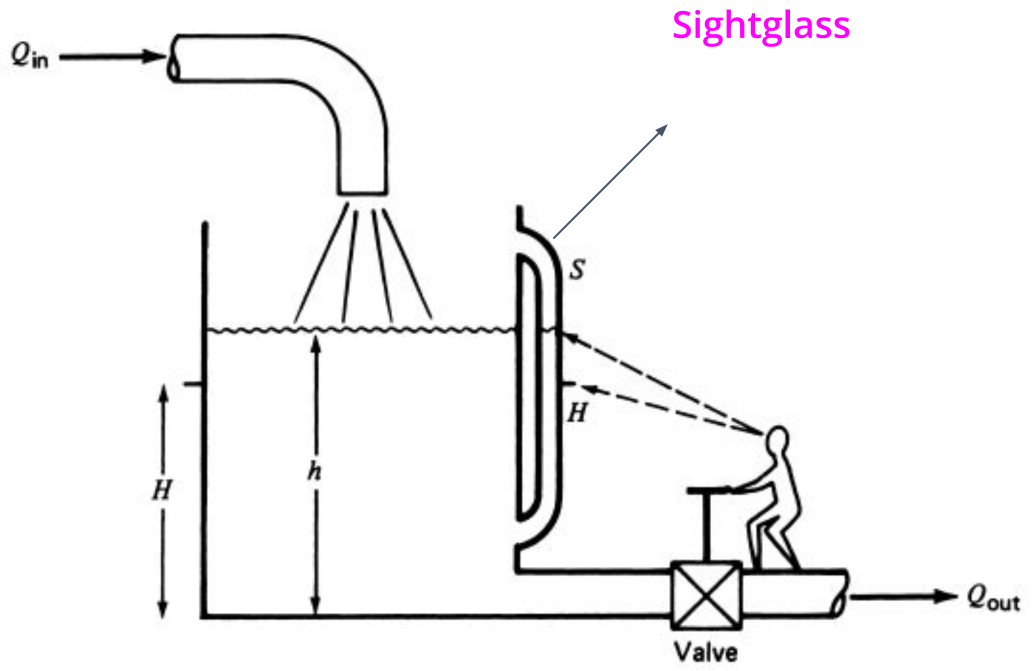


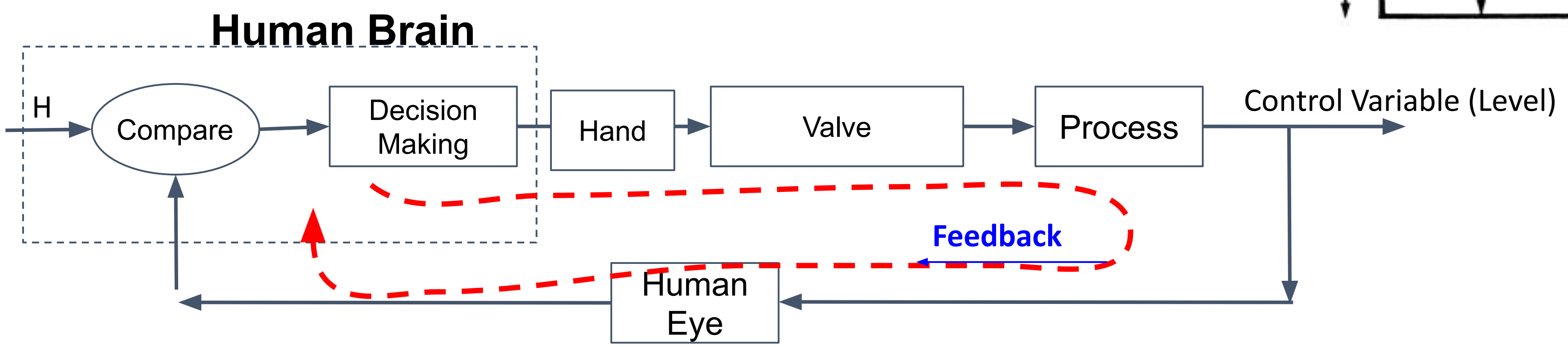


Closed Loop Control System Definition

When feedback is used in the control system to control a parameter, the control system is referred to as Closed Loop Control.

In figure below you can see the red dashed arrow illustrates the loop in the block diagram in Closed Loop Control.





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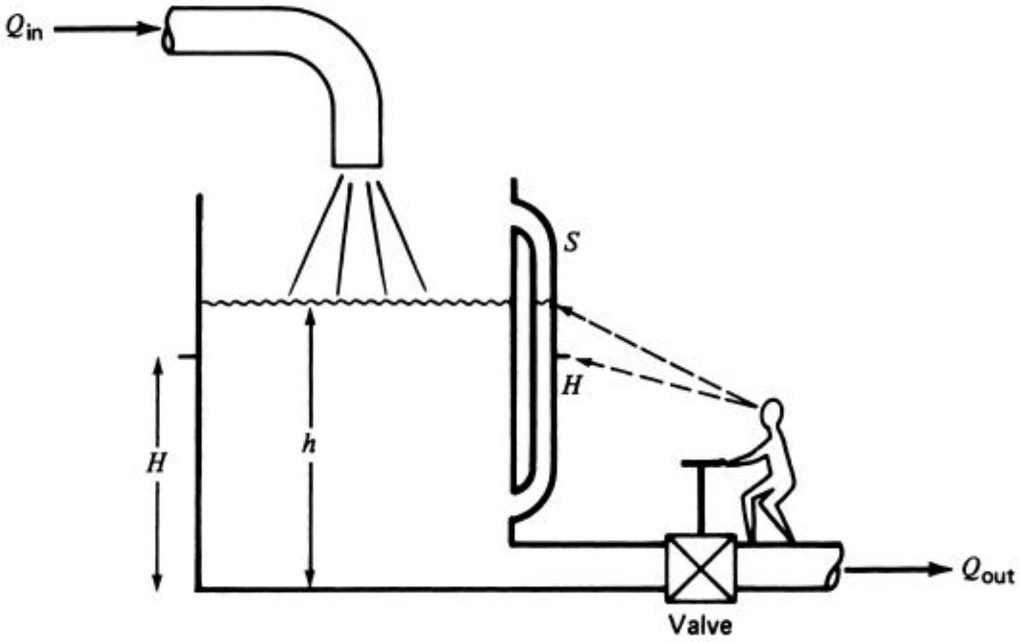
Manual Control

- The operator can open and close the valve to adjust the level at H. they can make decision to open or close the valve based on the water level.
- This type of control which involve the human is called *manual control*.
- If the incoming water rate changes a few times a day, the operator can adjust the tank level by the valve. What if the incoming water rate changes frequently? he has to stand there all the time and open and close the valve.



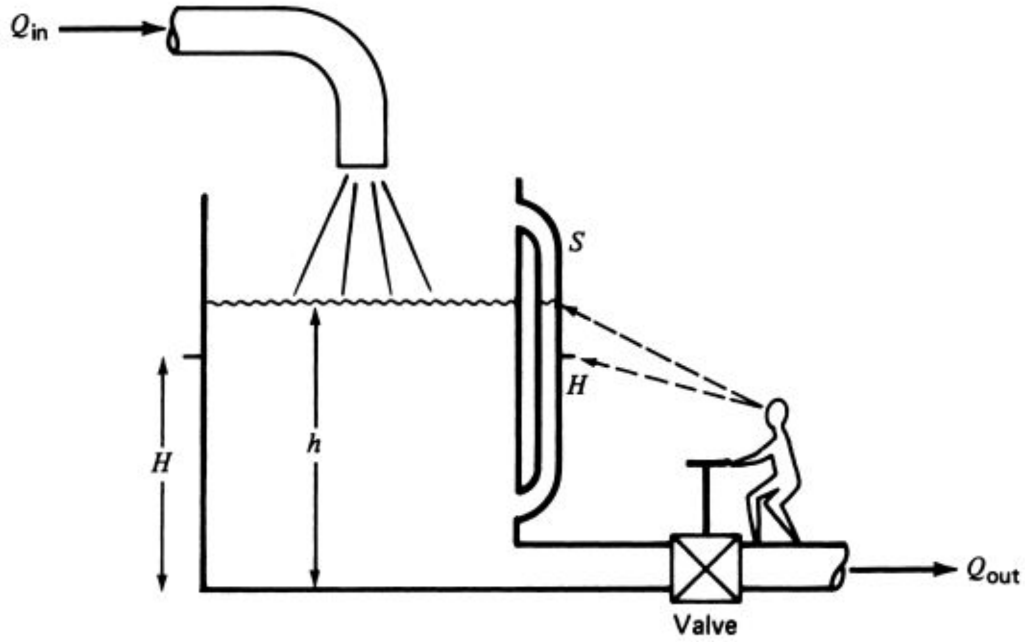
How can we help him?

Automatic Control

How can we help him?

In order to relieve individuals from tedious and repetitive tasks, we can develop a control system that eliminates the need for human intervention in opening and closing the valve. To achieve this, we replace the human function in manual control with devices that perform the necessary tasks.

This type of control, which excludes human involvement, is commonly known as automatic control.



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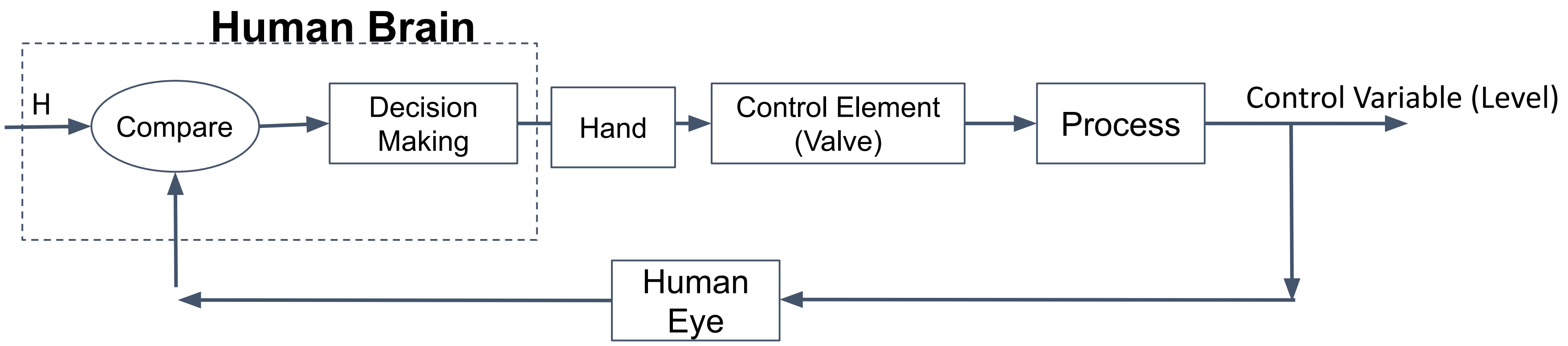
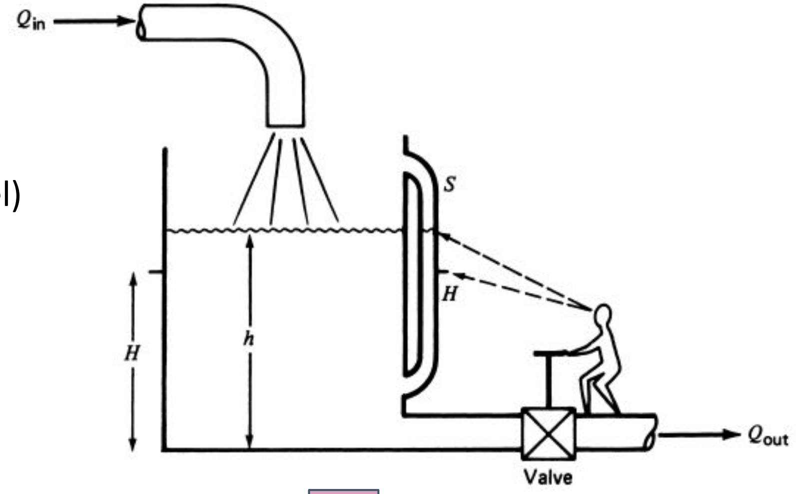
Automatic Control Development

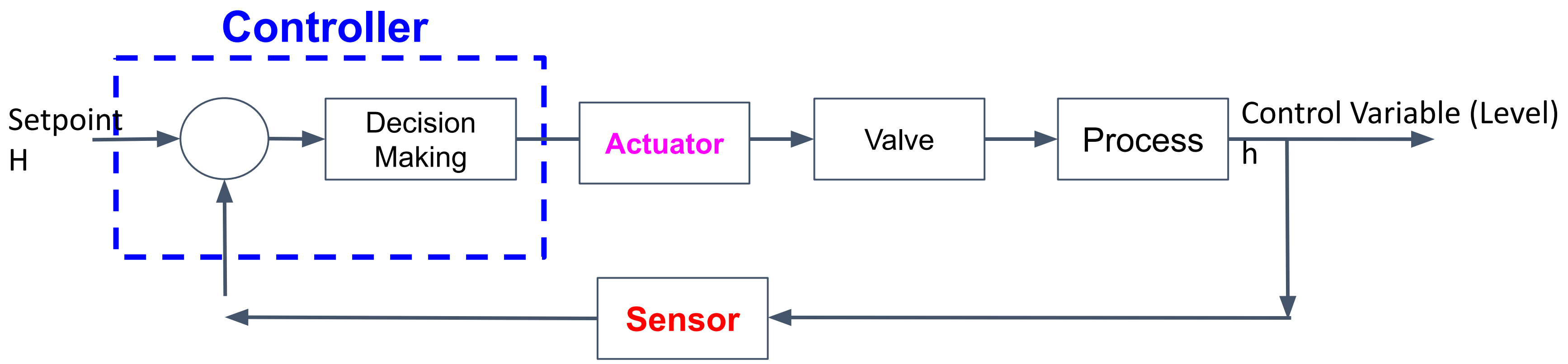


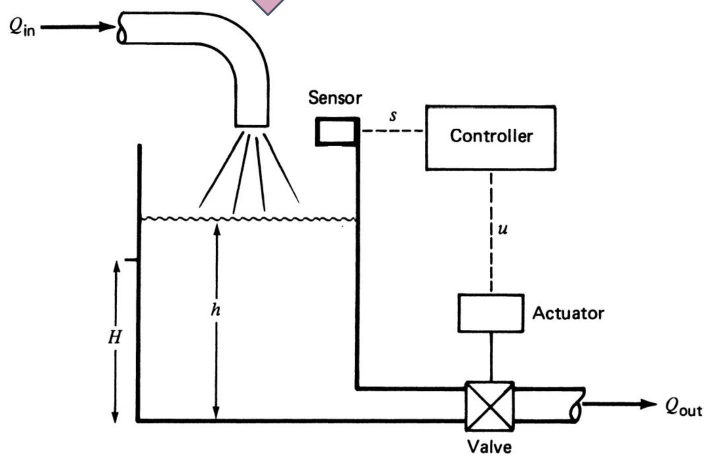


Controller instead of brain

Actuator instead of Hand

Sensor instead of Eye for feedback





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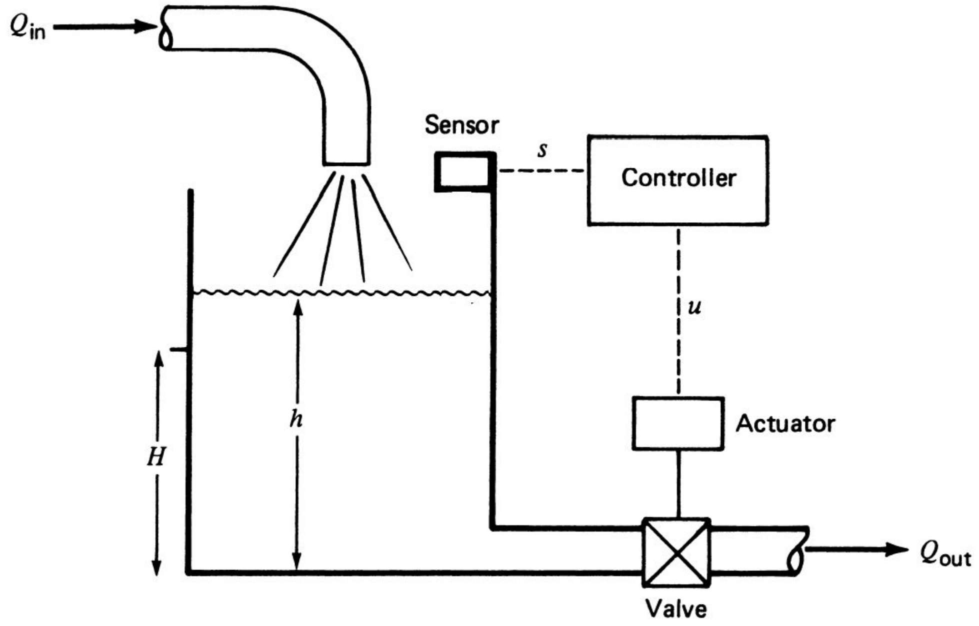
Automatic Control Building Blocks

- **The three general components of an automatic closed loop control system are:**
  - **Sensors**
  - **Controller**
  - **Control element**
- **Sensors and Control Elements are generally referred as instruments.**
- **In this course the instrumentation refers to Sensors for sensing and measuring function**

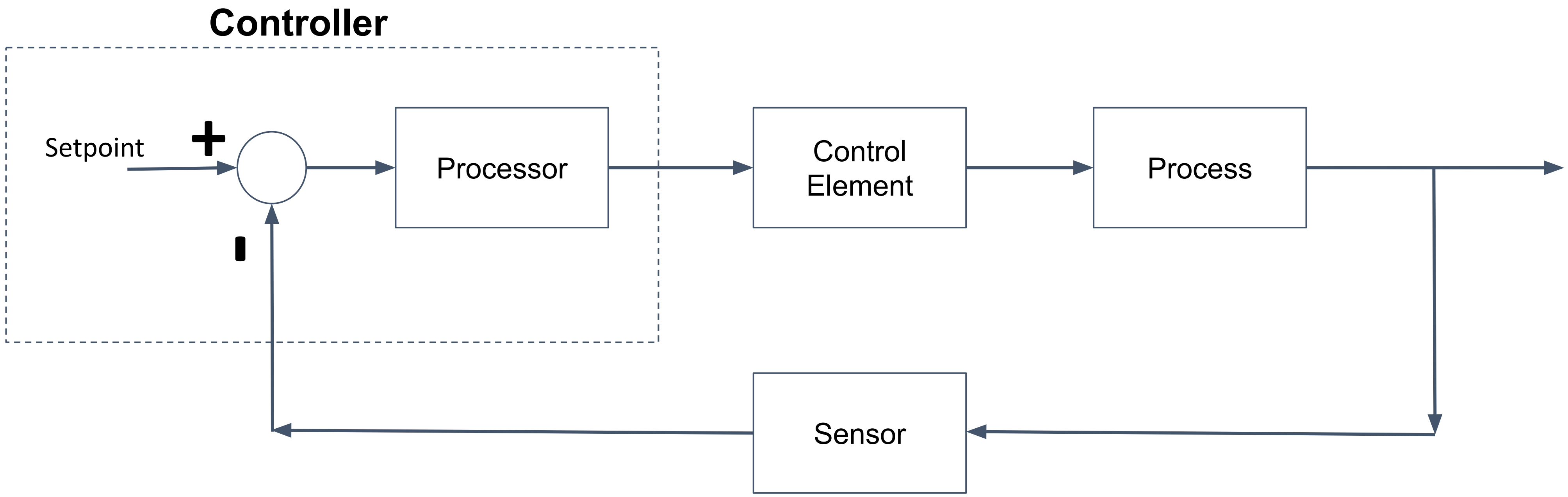
Sensors

Controller

Control Element



General Control System Block Diagram



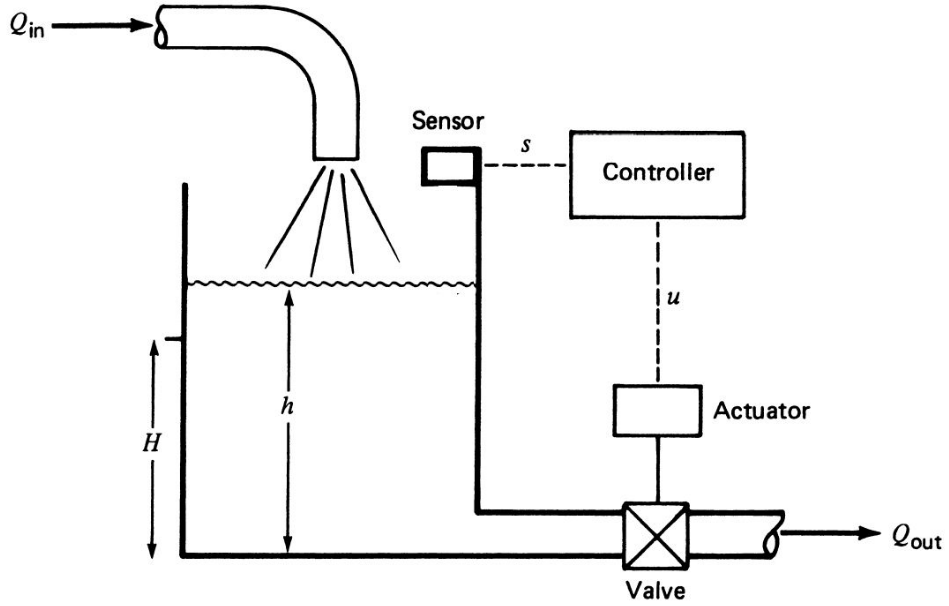
Control System Components

➢ Sensor for detection and measurement

- Oxford Dictionary for measurement: The act or the process of finding the size, quantity or degree of something.
- In general, a measurement refers to the conversion of the environment parameter into some corresponding variable, such as a pneumatic pressure, an electrical voltage or current, or a digitally encoded signal.
- The sensors are also referred to as transducers or transmitters.

➢ Controller

- The measurement information sent by sensors is received by the controller. This information will be processed, such as comparison with a setpoint, and then an appropriate output will be provided to the control element. The control element will act based on the received signal from the controller.



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Control System Components

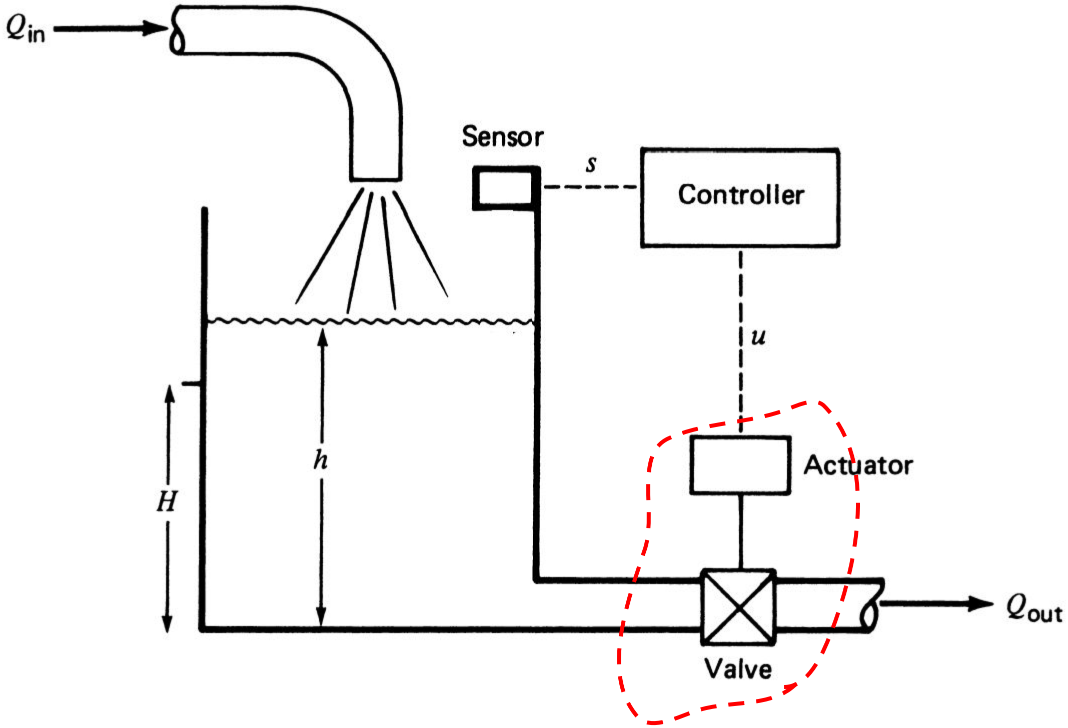
➢ Control element

- Control element could be made of two subcomponents:

  Actuator + Final Element

- The final element in the process-control operation is the device that exerts a direct influence on the process; In front example the valve is the final element.

- Sometimes an intermediate operation is required between the controller output and the final control element. This intermediate operator is referred to as an actuator as it utilizes the controller signal to operate the final control element. The actuator translates the small energy signal of the controller into a larger energy to act upon the process and influence it.



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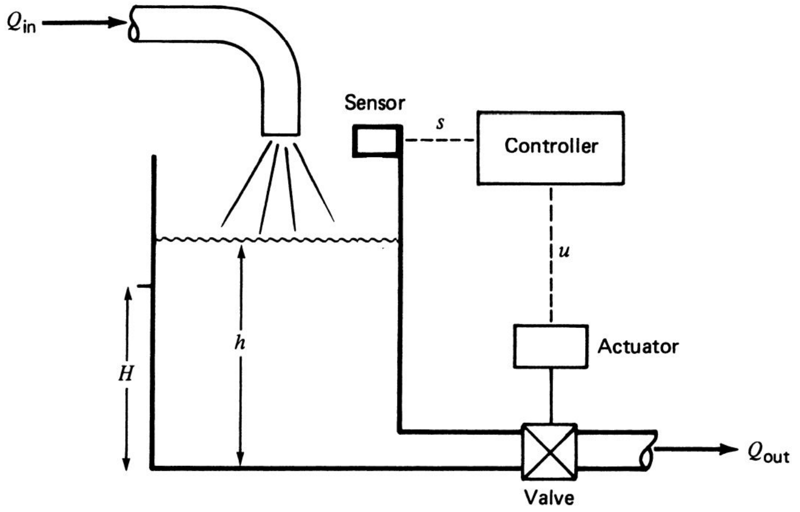
Control System Variables

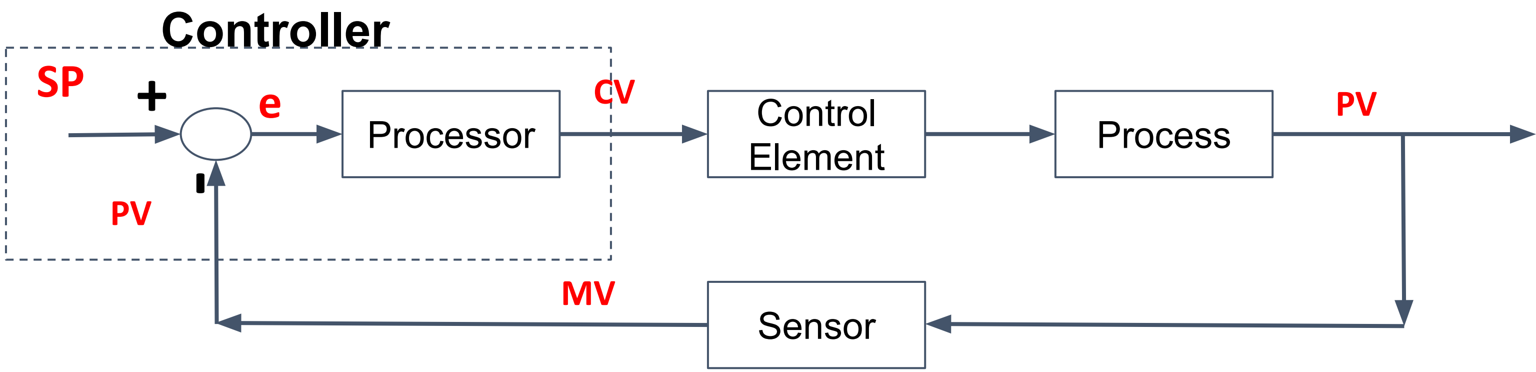
- **PV : process variable,** is the value which is going to be controlled. In the front example level of the tank denoted by h



- **CV : Control variable** or manipulated variable is produced by controller and applied to process to change its behavior. In the front example denoted by u
- **SP: Setpoints**, is desired value from the system. H in the front example
- **MV: Measured value,** the process value measured by the sensor.

  Usually it is assumed the PV and MV are the same.

- **e : Error value=** SP- PV (By assuming MV=PV)



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Application Example

In the front figure, you can see a pipe with a fluid. A control system is implemented to control the flow rate. Let's assume the setpoint is 10 liters per minute. The orifice plate and DP cell pressure sensor is used to measure the actual flow rate. Answer following questions:

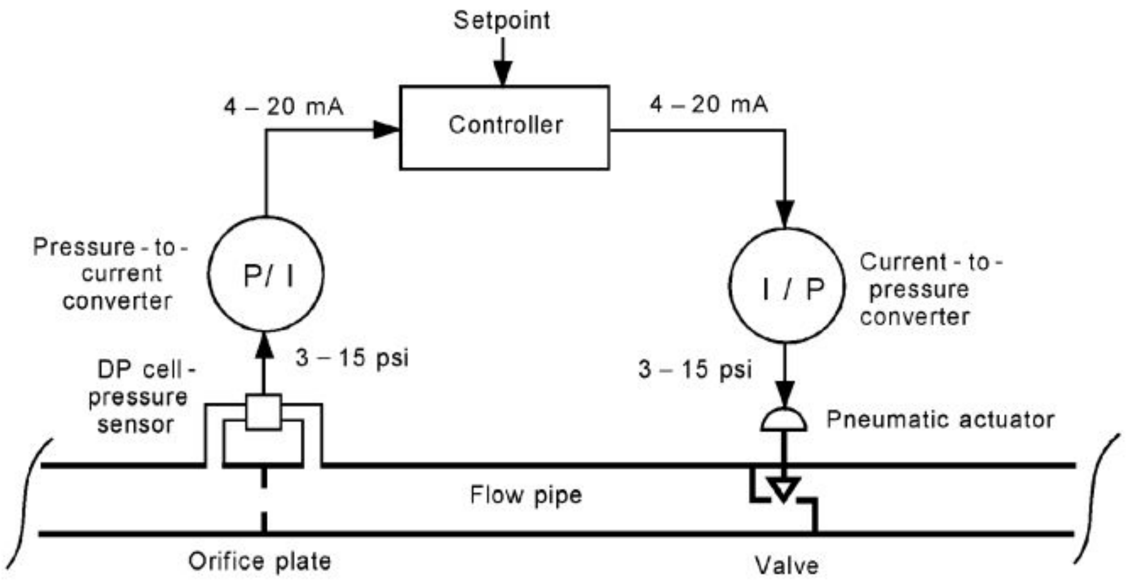
1- Name the process component?

2- When the flow is measured to be 12 L/m what should happen to valve to reduce the flow rate? (Process dynamic)

3-Name the control system components and find them in front system

4- Draw the control system block diagram for the front control system

5- Draw a circle around the feedback loop on the front figure to identify it.



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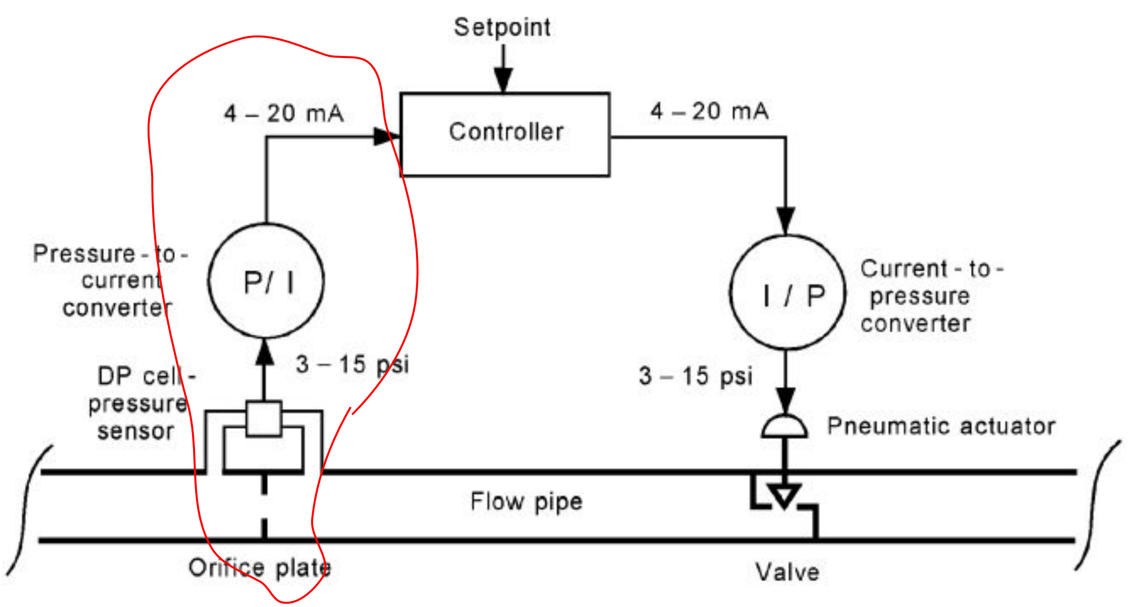
Application Example

Question 5



In the front figure you can see a pipe with a fluid. A control system is implemented to control the flow rate. Let's assume the setpoint is 10 Liter per minute. The orifice plate and DP cell pressure sensor is used to measure the actual flow rate. Answer following questions:

1- Name the process component? Pipe and Flow

2- When the flow is measured to be 12 L/m what should happen to valve o reduce the flow rate? (Process dynamic) The valve should close to reduce the flow going through

3- Name the control system components and find them in front system:

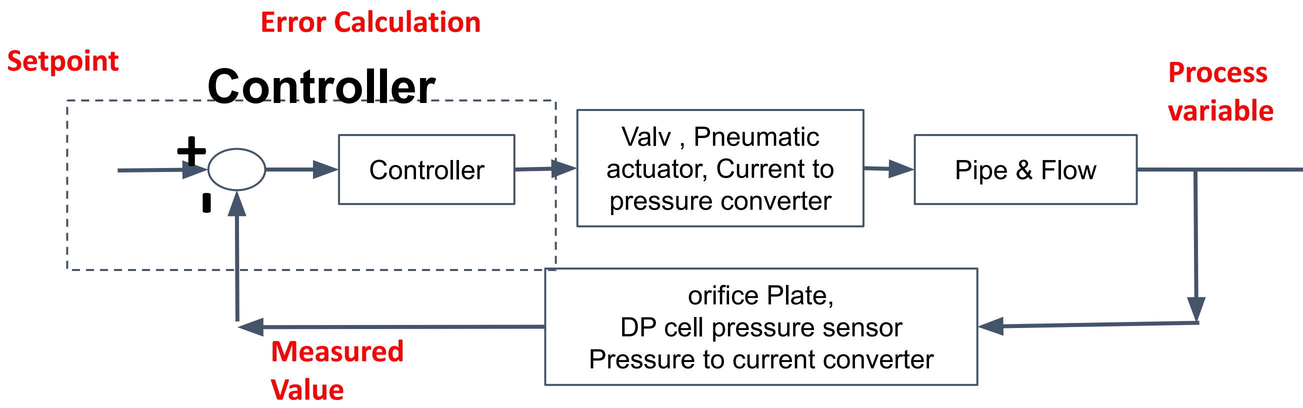
1- Sensor: orifice Plate, DP cell pressure sensor ,Pressure to current converter

2- Controller

3- Controle element: Valv , Pneumatic actuator, Current to pressure converter

4- Draw the control system block diagram for the front control system

5- Draw a circle around the feedback loop on the front figure to identify it.



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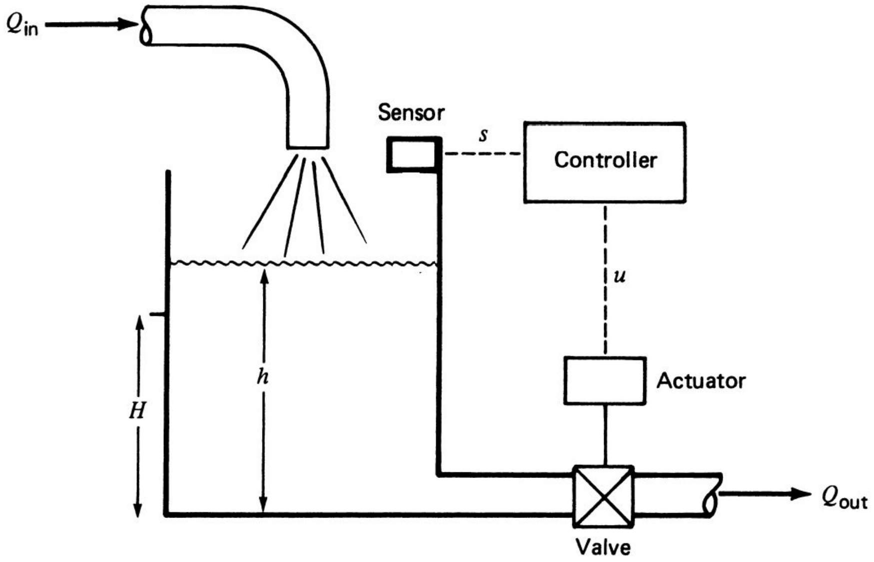
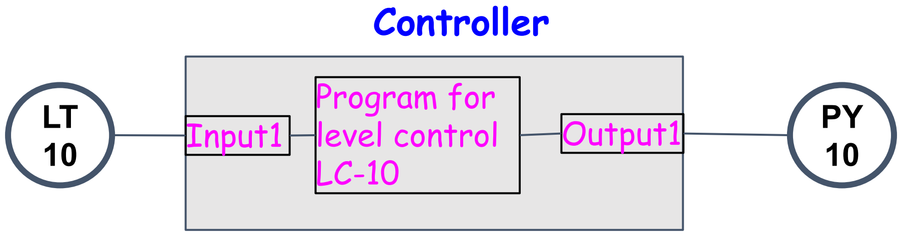
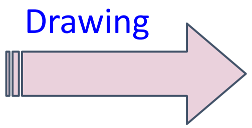
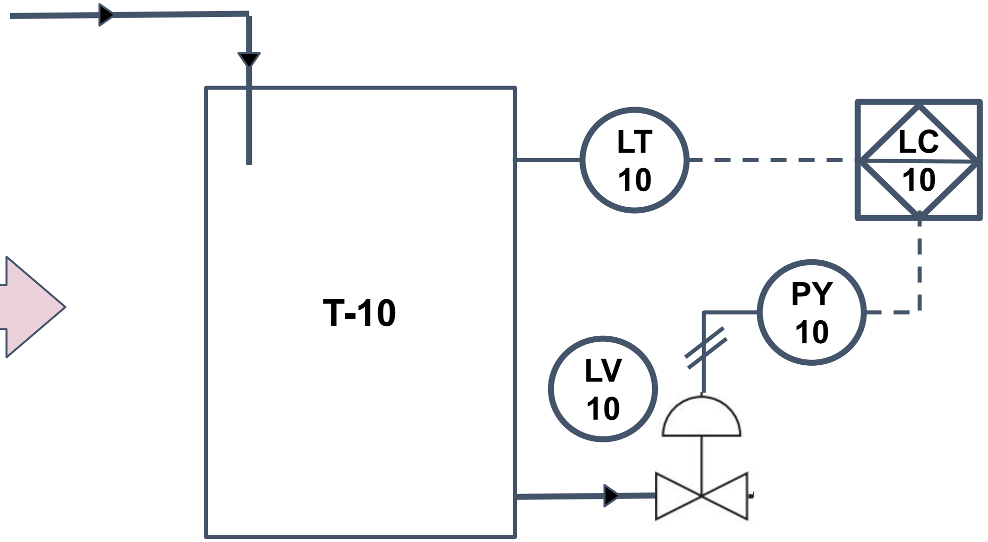
P&ID
Piping & Instrumentation Diagram

Drawing Example









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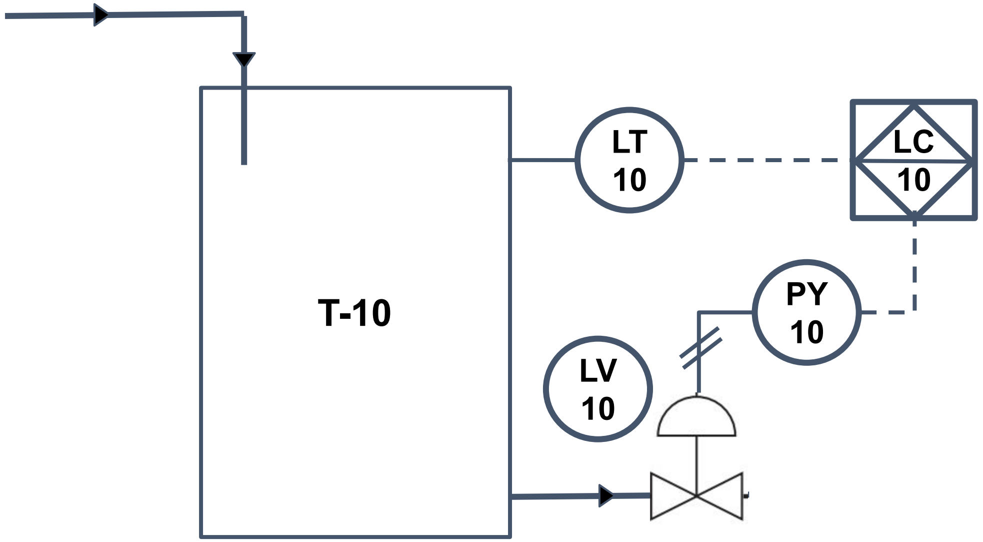
P&ID

The drawing that illustrates the relationship between instruments, controllers, and processes is known as a P&ID, an acronym for Piping & Instrumentation Drawing. To facilitate mutual understanding of these drawings, a set of standard symbols is utilized.

The standard for P&ID drawing were established by the Instrumentation, Systems, and Automation (ISA) society and are designated as ISA S5.1-2009, Instrumentation Symbols and Identification.



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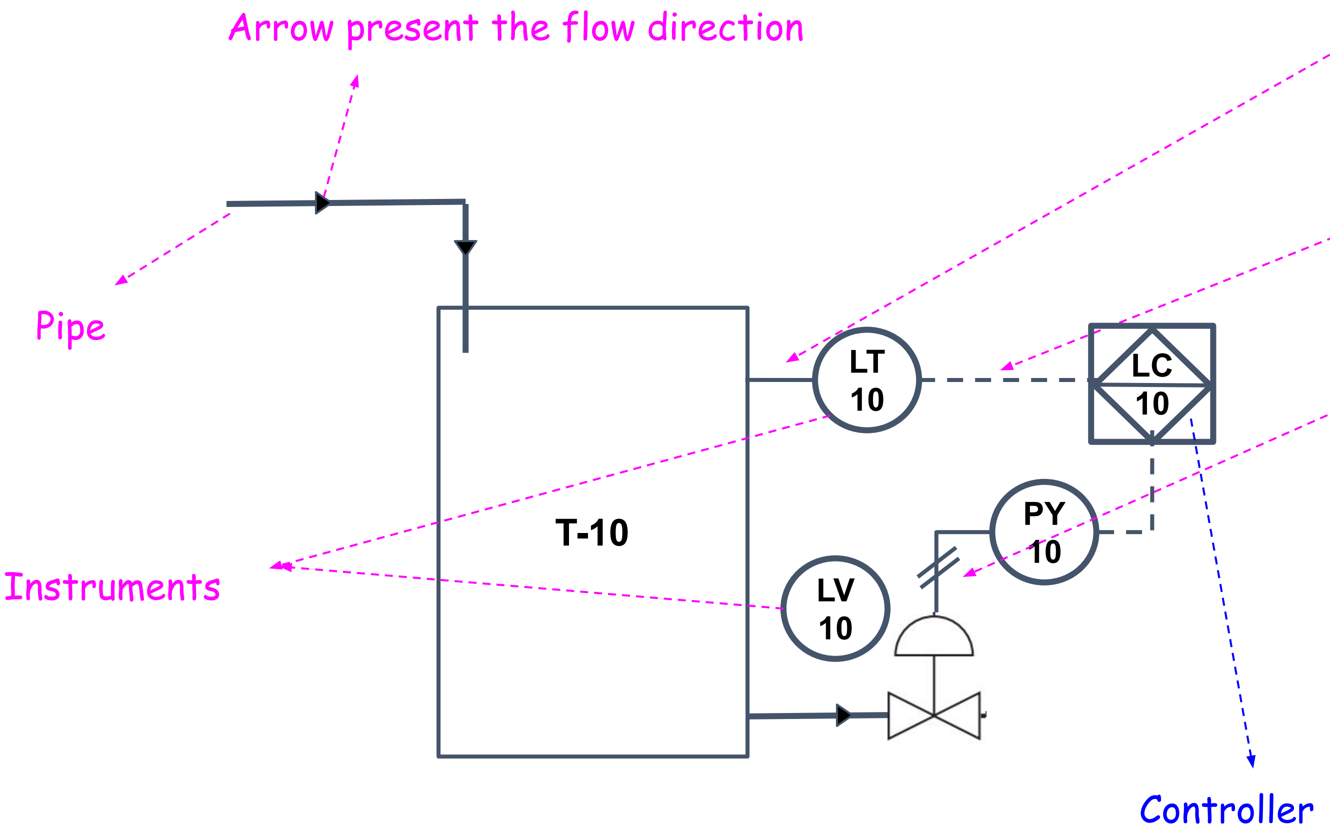
P & ID Instruments Connections



Process line, connection to process or instrument supply	
Electric signal	or
Pneumatic signal	
Hydraulic signal	
Capillary tube	
Guided EM/sonic signal	
EM or sonic, not guided	
Internal system link (computer signal)	

P & ID Symbols for Instruments

The front symbols are employed to represent sensors, controllers or control elements.

The symbols can be either hollow, or filled with a solid or a dash line line in the middle.

A hollow symbol indicates the instrument is located in field.

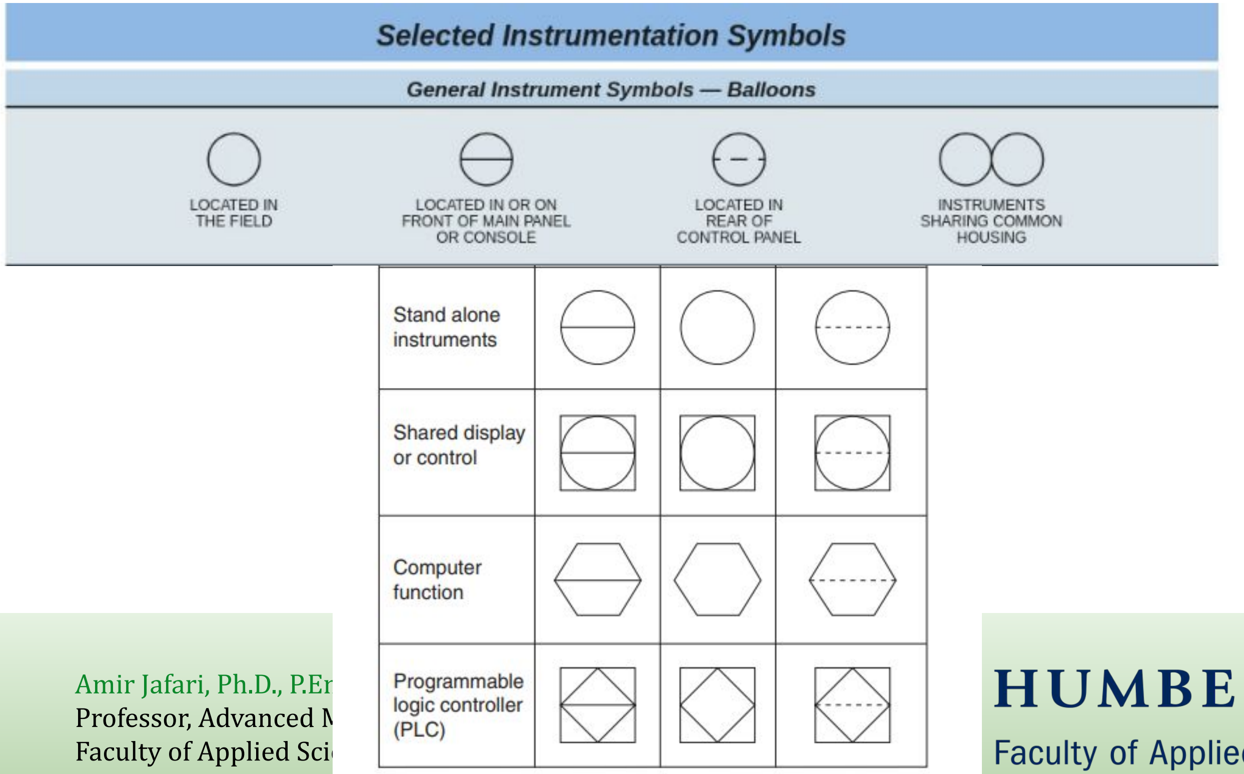
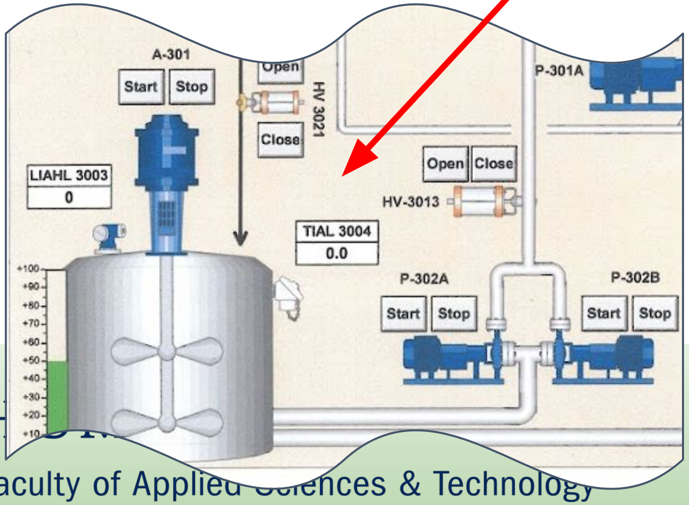


Table 5.1.1 — Instrumentation device and function symbols

Note: Numbers in parentheses refer to explanatory notes in Clause 5.3.1.

No.	Shared display, Shared control (1) A Primary Choice or Basic Process Control System (2)	Shared display, Shared control (1) B Alternate Choice or Safety Instrumented System (3)	C Computer Systems and Software (4)	D Discrete (5)	Location & accessibility (6)
1					• Located in field. • Not panel, cabinet, or console mounted. • Visible at field location. • Normally operator accessible.
2					• Located in or on front of central or main panel or console. • Visible on front of panel or on video display. • Normally operator accessible at panel front or console.
3					• Located in rear of central or main panel. • Located in cabinet behind panel. • Not visible on front of panel or on video display. • Not normally operator accessible at panel or console.
4					• Located in or on front of secondary or local panel or console. • Visible on front of panel or on video display. • Normally operator accessible at panel front or console.
5					• Located in rear of secondary or local panel. • Located in field cabinet. • Not visible on front of panel or on video display. • Not normally operator accessible at panel or console.

Field - Field (Local) Control Panel - Control Room - Main Control Panel



SCADA

Shared Display

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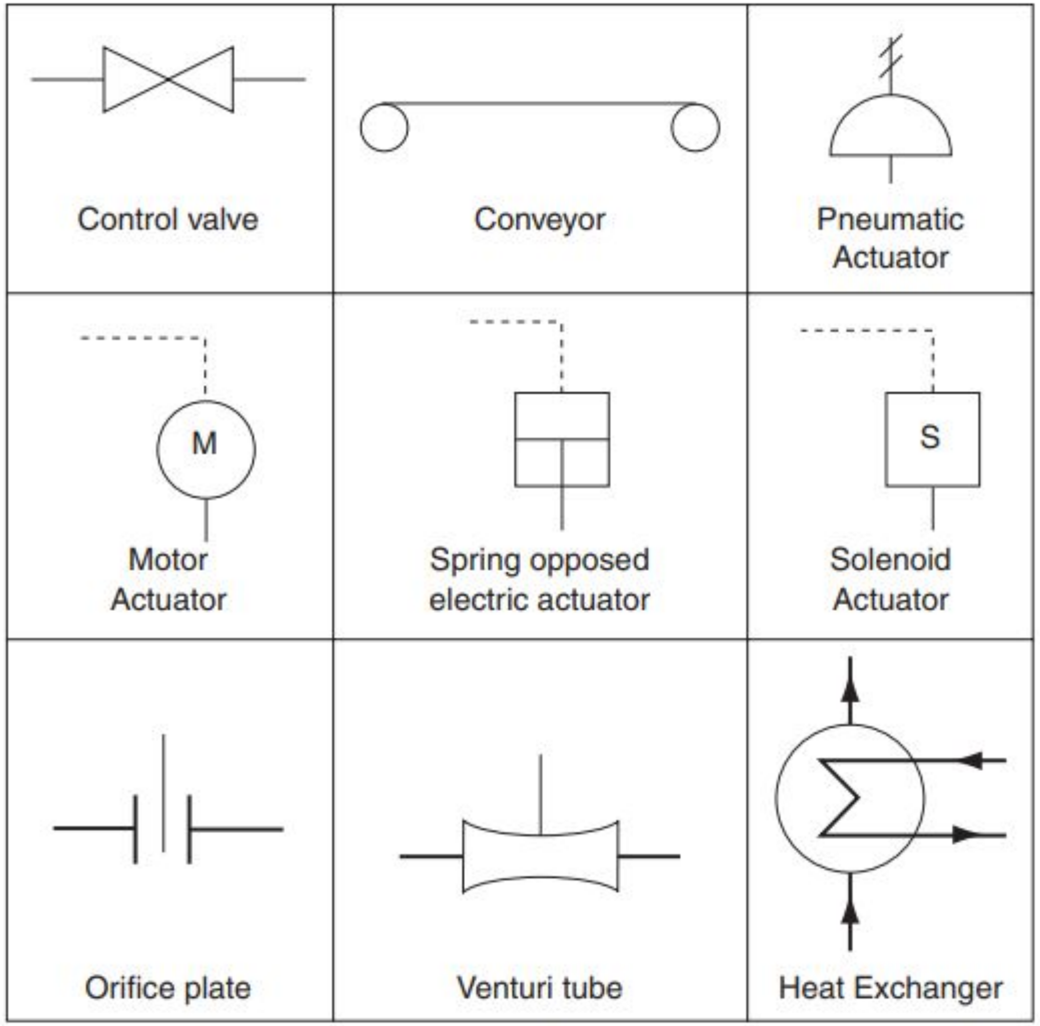
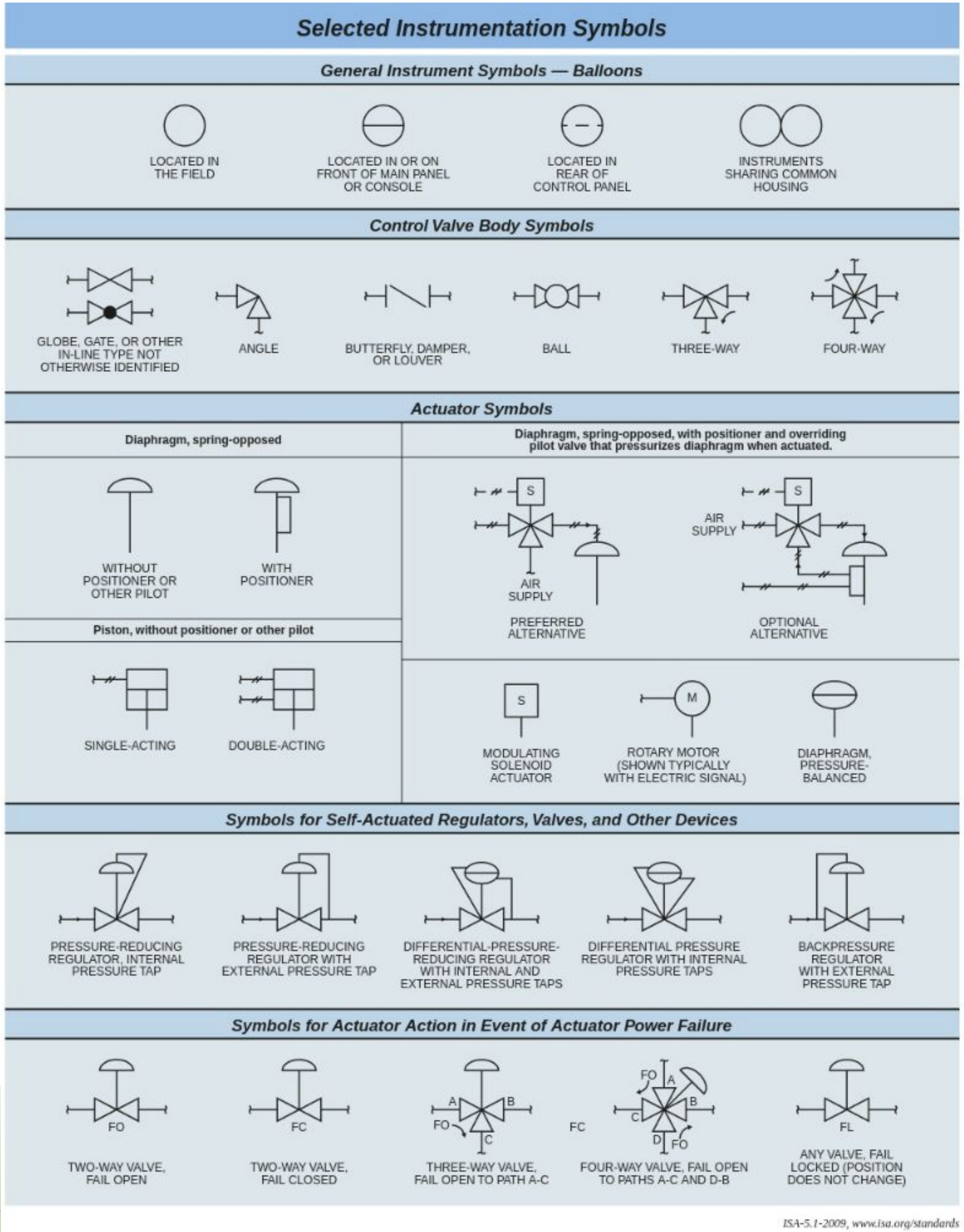
P&ID Control Element Symbols





Instruments Tags in P&ID

In P&ID drawings, each instrument is assigned a unique tag as its identifier. These tags are utilized in various contexts such as mechanical engineering drawings and designs, electrical panel drawings, documentation, manuals, the purchase department's bill of materials, programming (as names for sensors or actuators), and even in casual conversations among individuals.

It is crucial for instrument tags to be distinct and unique, meaning that no two instruments can share the same tag. Failure to maintain uniqueness would result in confusion and disorder. According to ISA standards, instrument tags typically follow the format ABCD-####, combining letters and numbers. The convention for forming these tags takes into account the instrument's type and its role within the control system.

Therefore by learning to read the tags, a person would be able to say for example what the control loop is about, what the sensor supposed to do or the sensor is associated to which control element.

Instruments Tags in P&ID (1)

ABCD-####A

First Letter

Succeeding (Second) Letters

The first letter represent the measured quantity or the quantity which is controlled.

The second letters, could be one or more letters, are about the intended functionality of the instruments.

As example if the instrument tag is

LSH → Level Switch High

LT → Level Transmitter

TI → Temperature Indicator
FC → Flow Control
HV → Hand Valve
LV → Level valve (a valve which is used to control the level)
…

Instrument Tag Identification

	First Letter		Second Letter		
	Measured or Initiating Variable	**Modifier**	**Readout or Passive Function**	**Output Function**	**Modifier**
A	Analysis		Alarm		
B	Burner Flame		User's Choice	User's Choice	User's Choice
C	Conductivity (Electrical)			Control	Close
D	Density (Mass) or Specific Gravity	Differential			Deviation
E	Voltage (EMF)		Primary Element		
F	Flow Rate	Ratio (Fraction)			
G	Gaging (Dimensional)		Glass, Gauge, Viewing Device		
H	Hand (Manually Initiated)				High
I	Current (Electrical)		Indicate		
J	Power		Scan		
K	Time or Time Schedule	Time Rate of Change		Control Station	
L	Level		Light (Pilot)		Low
M	Moisture or Humidity				Middle or Intermediate
N	User's Choice		User's Choice	User's Choice	User's Choice
O	User's Choice		Orifice (Restriction)		
P	Pressure or Vacuum		Point (Test Connection)		
Q	Quantity or Event	Integrate or Totalize	Integrate or Totalize		
R	Radioactivity, radiation		Record		Run
S	Speed or Frequency	Safety		Switch	Stop
T	Temperature			Transmit	
U	Multivariable		Multifunction	Multifunction	
V	Viscosity, Vibration			Valve, Damper, or Louver	
W	Weight or Force		Well, Probe		
X	Unclassified	X-axis	Unclassified	Unclassified	Unclassified
Y	Event or State	Y-axis		Auxiliary Devices	
Z	Position	Z-axis		Drive, Actuate, or Unclassified Final Control Element	

ISA-5.1-2009, www.isa.org/standards

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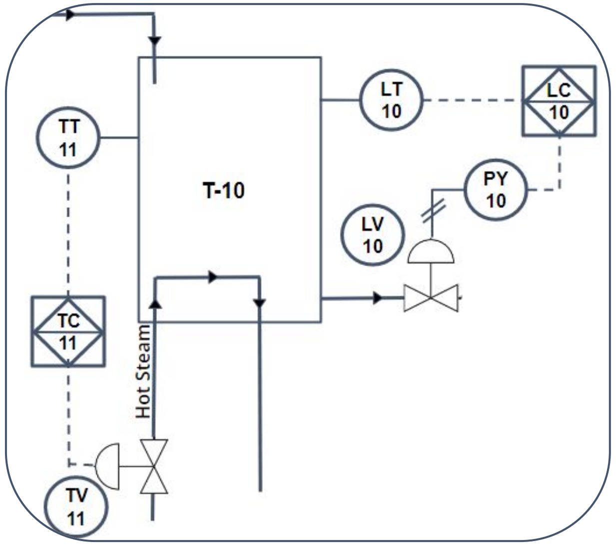
Instruments Tags in P&ID (3)



ABCD-$\underbrace{\text{####}}$A

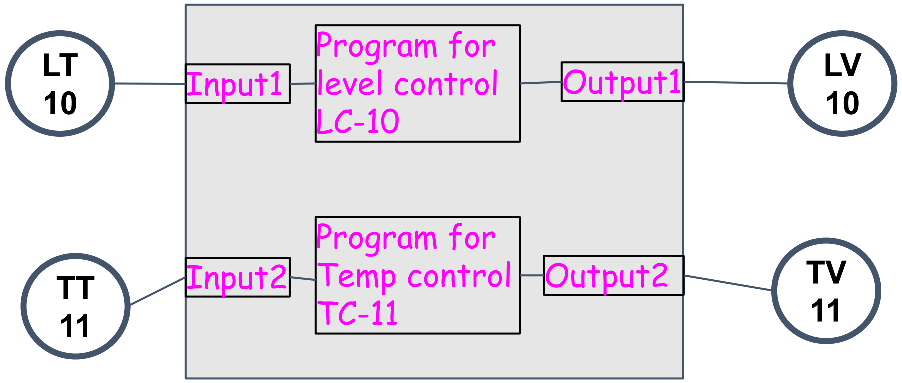
Numbers - Loop Identifier

The number include the control loop number.

Control loop number?

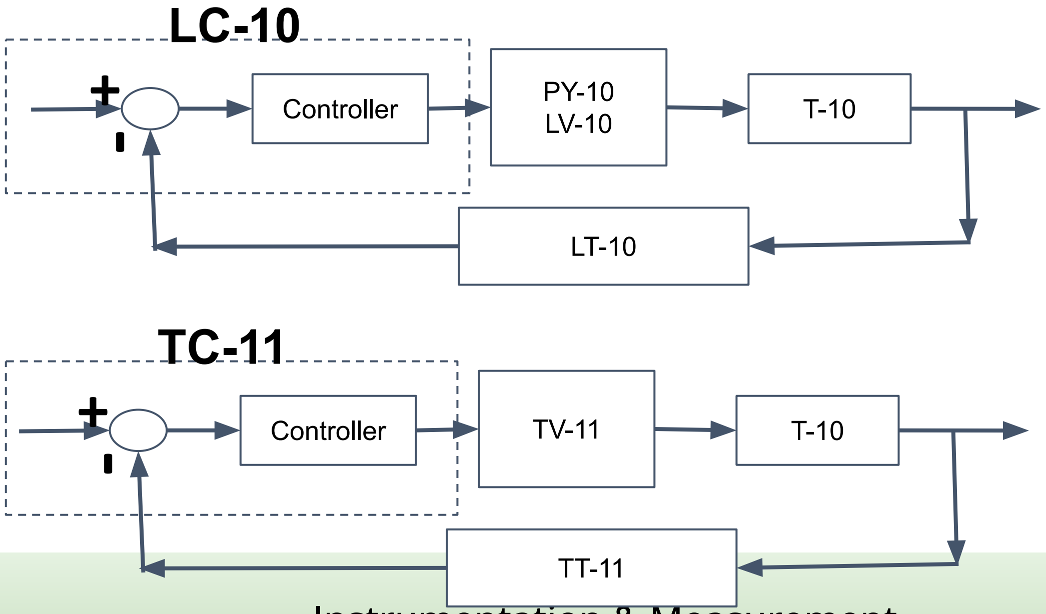
Control System Block Diagram

Controller (PLC)



Loop 10 - Controlling level

Loop 11 - Controlling Temperature



Instruments Tags in P&ID (4)

ABCD-####A

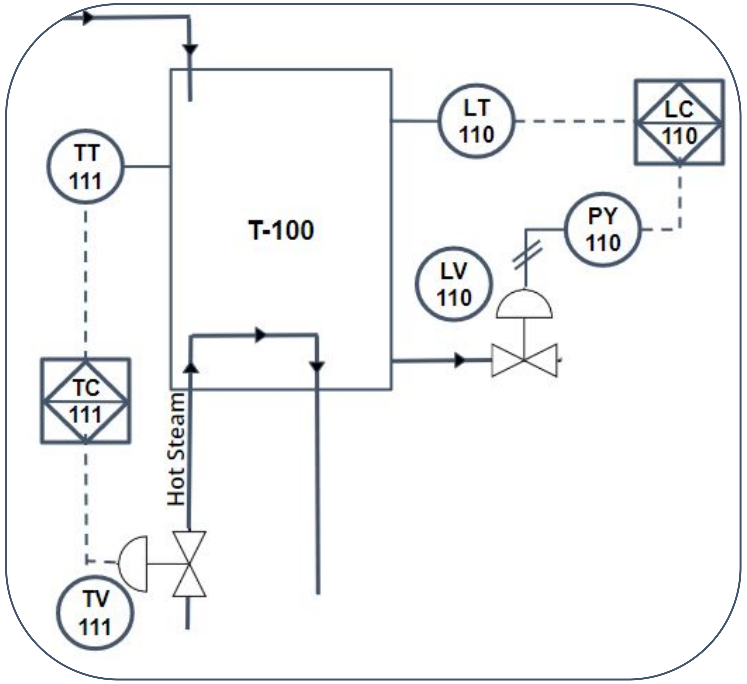
Numbers - Process Identifier

Numbers can also be used to differentiate and identify processes or zones. Similar to room numbers in high rises building. For instance, room 322 indicates room 22 is in third floor. Similarly, if there are different processes or zones they can be presented on the instruments tags. Consequently, hrn we examine the sensor tags, we can easily determine the application or area to which they belong.

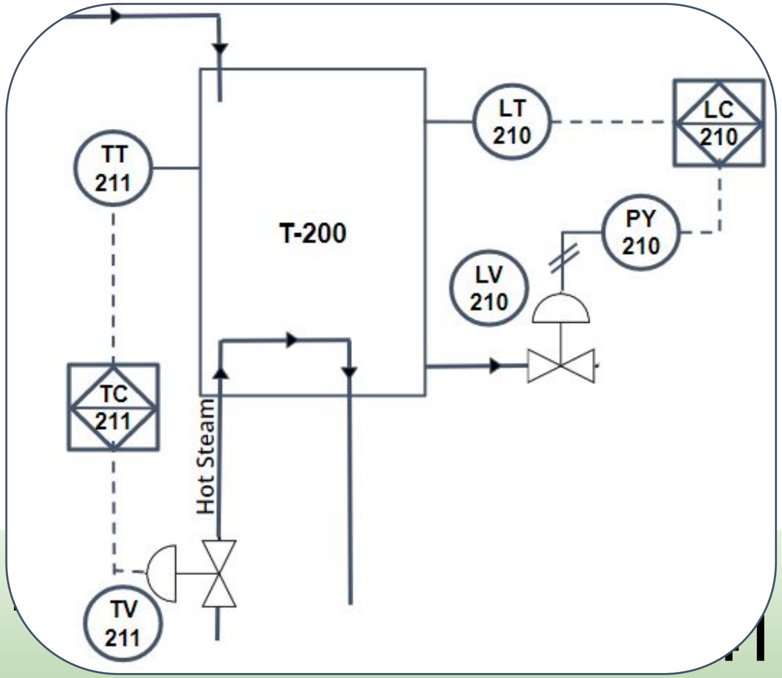
Let's consider an example. Suppose there two identical processes running in parallel. By incorporating a third digit as an identifier for the tank, the instrument tags can tell us on which tank it is installed.

For instance TV-211 tells us this is a valve which is used to control temperature on the second tank (Tank-200) by the control loop 11.

Process 1



Process 2



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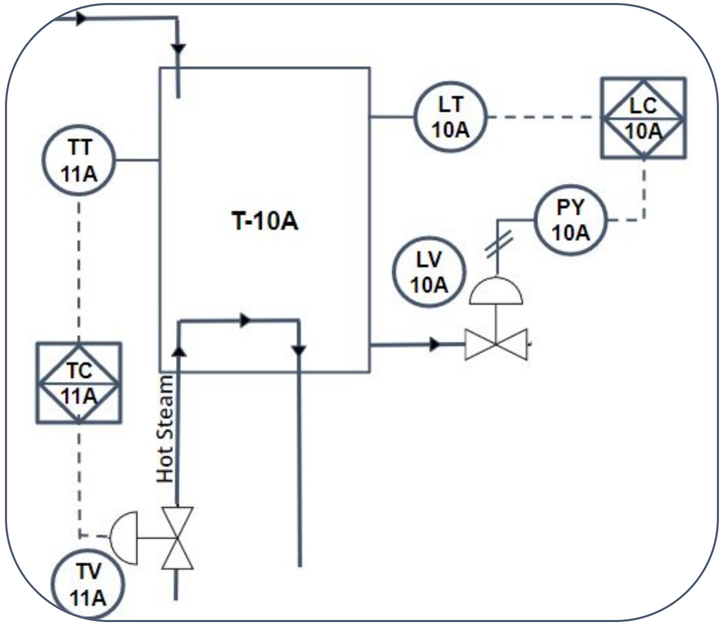
Instruments Tags in P&ID (4)

ABCD-####A

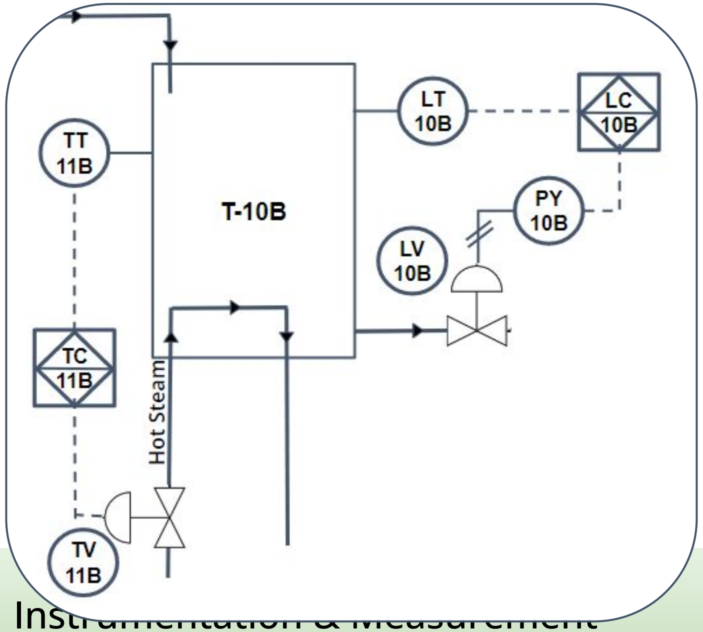
Suffix

Sometimes two identical processes are differentiated by letter such as A or B , in this case the instruments tags can take suffix to present respective process. Nevertheless this is one example of employing the suffix and its employment is not limited to this case.

Process A



Process B



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P&ID Example

1) Identify control loop 100?
2) What is controlled by loop 100?
3) Identify the control loop elements for this control loop?
4) The setpoint of this loop comes from which instrument?
5) A control valve is connected to PY-103. This control valve is on the inlet of the Heat exchanger or outlet?
6) What is connection type between:
   a) PT-104 and the vessel?
   b) PT-104 and PC-104?
   c) PC-104 and CC-100?

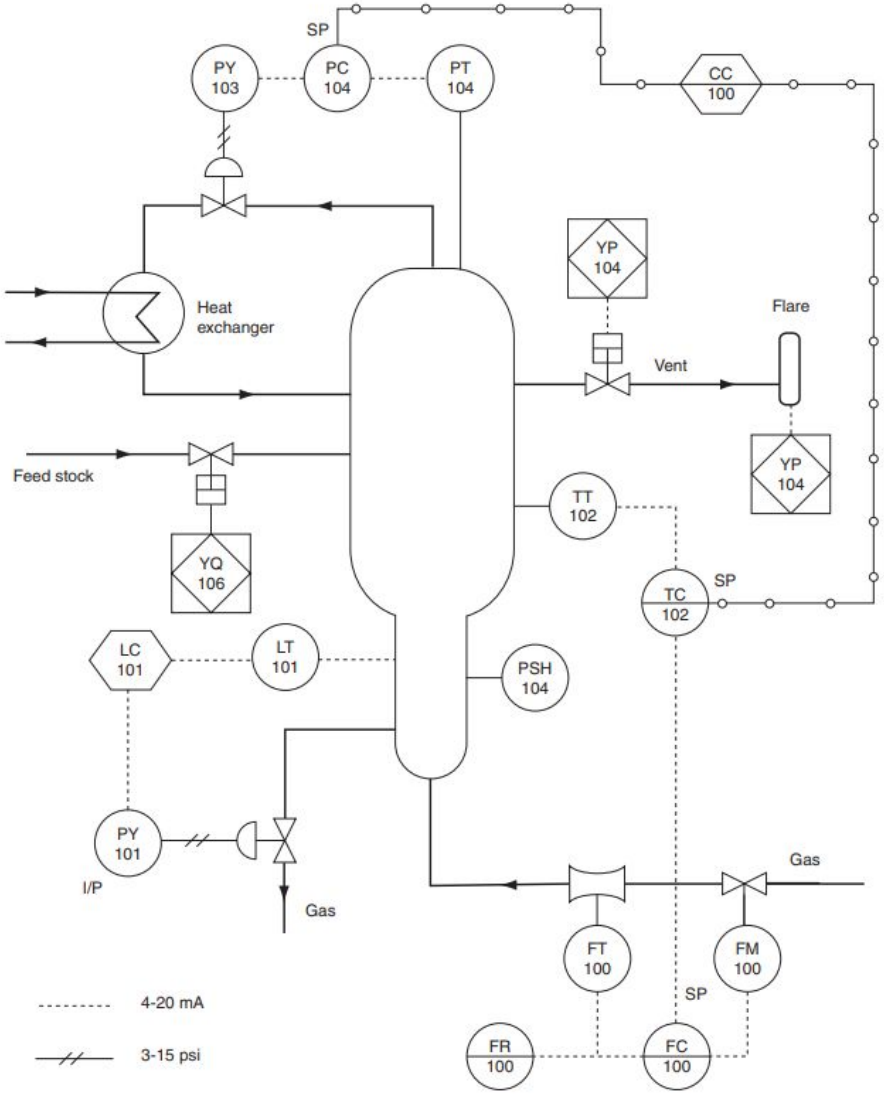

FIGURE 6
Illustration of a P&ID for a chemical process.

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P&ID Example

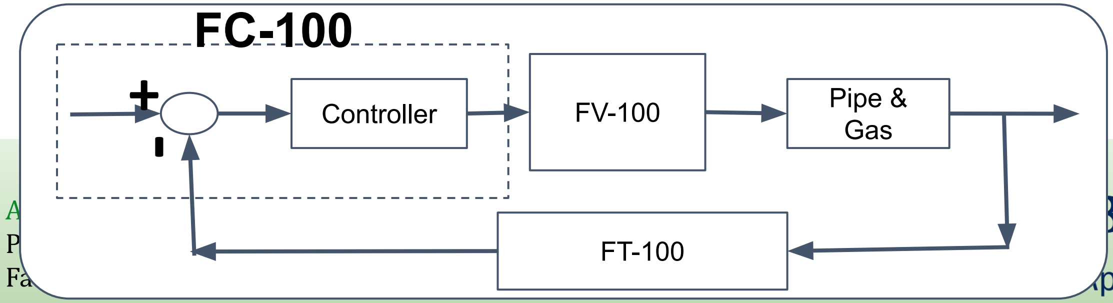
1) Identify control loop 100?
2) What is controlled by loop 100? Flow
3) Identify the control system components for this control loop? what are the tags stand for?

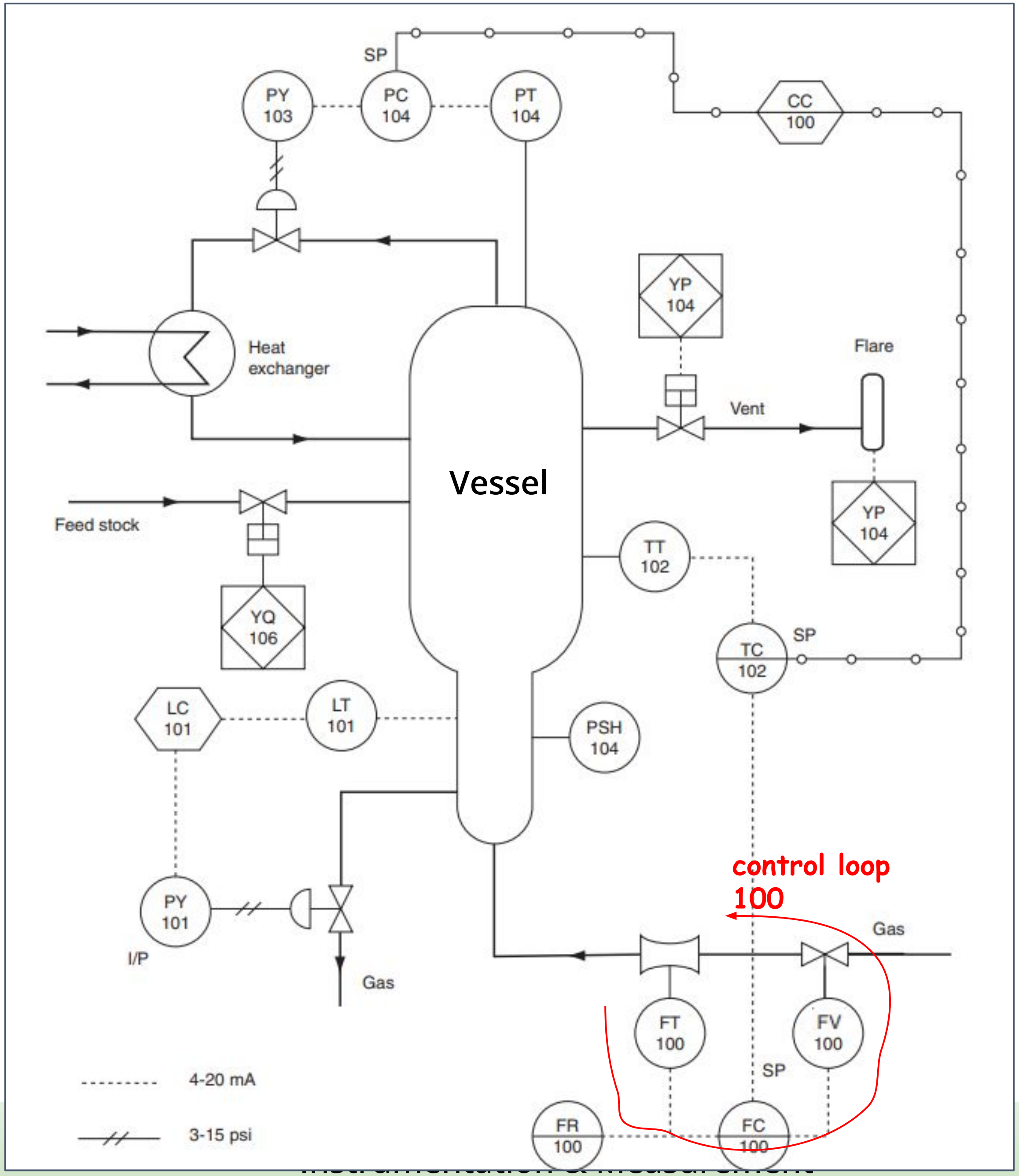
   Sensor → FT-100 stands for Flow Transmitter

   Controller → FC-100 stands for flow control

   Control element → FV-100 stands for Flow valve

4) The setpoint of this loop comes from which instrument? TC-102
5) A control valve is connected to PY-101. Opening this valve will fill or empty the vessel? empty
6) What should be the tag for the valve connected to PY-101? LV-101
7) What is connection type between:
   a) PT-104 and the vessel? Mechanical mounting
   b) PT-104 and PC-104? electrical
   c) PC-104 and CC-100? Computer network
8) Draw Control block diagram for loop 100





P&ID Reading

1- Which instrument provides alarm when the electrical current of the pump M-3-P-4 is too high?

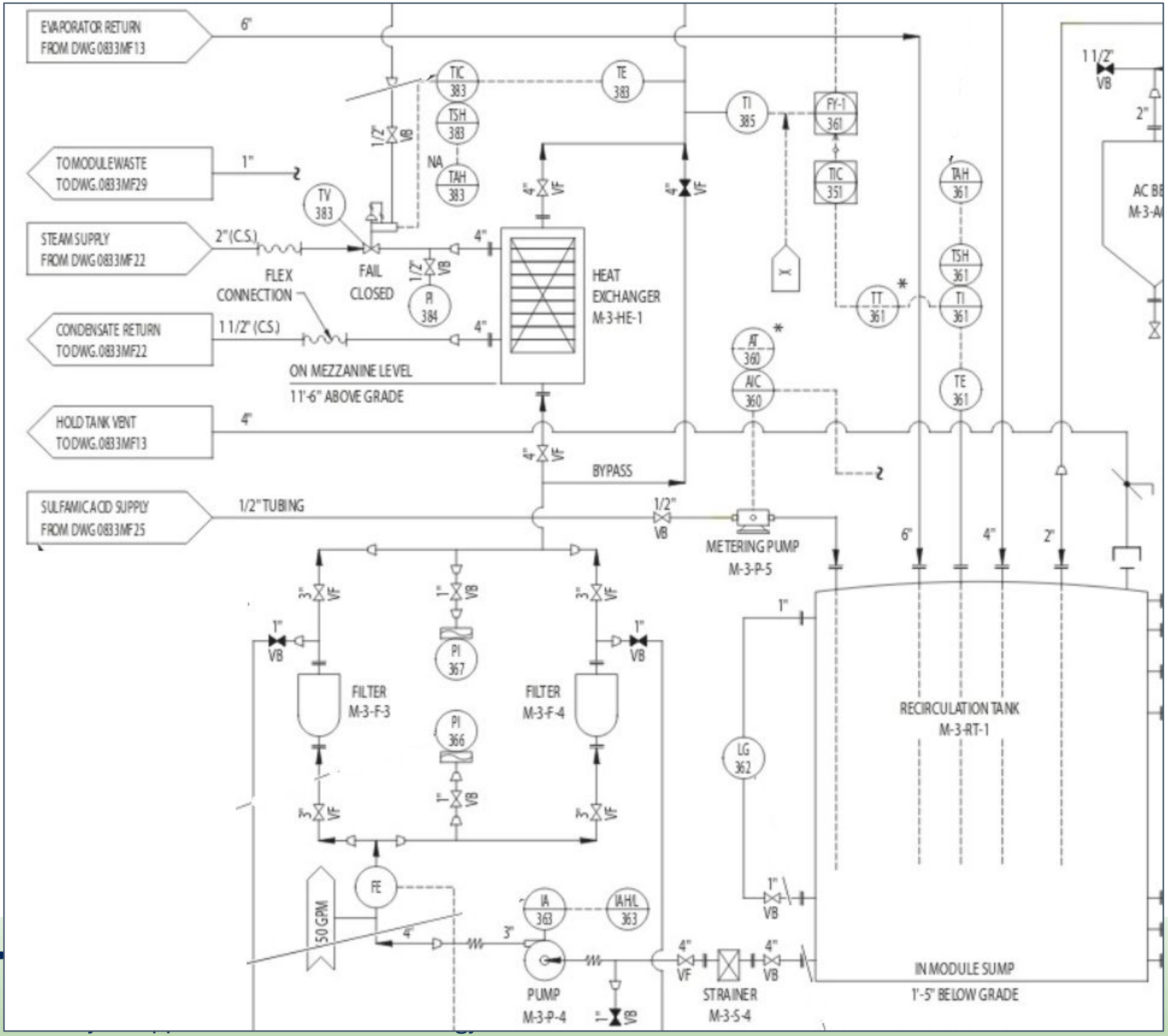
2- Which instruments shows the level of the tank M-3-RT-1? Is it possible to see the level of the tank in control room?

3- Which Instruments indicates the pressure at the inlet of Filter M3-F-4?

4- Which instrument is used to measure the temperature of the tank M-3-RT-1?

5- Which element indicates the temperature of the tank M-3-RT-1?

6- Which instruments provide an alarm when the temperature of the tank M-3-RT-1 is high?



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P&ID Reading

1- Which instrument provides alarm when the electrical current of the pump M-3-P-4 is too high? IAHL-363

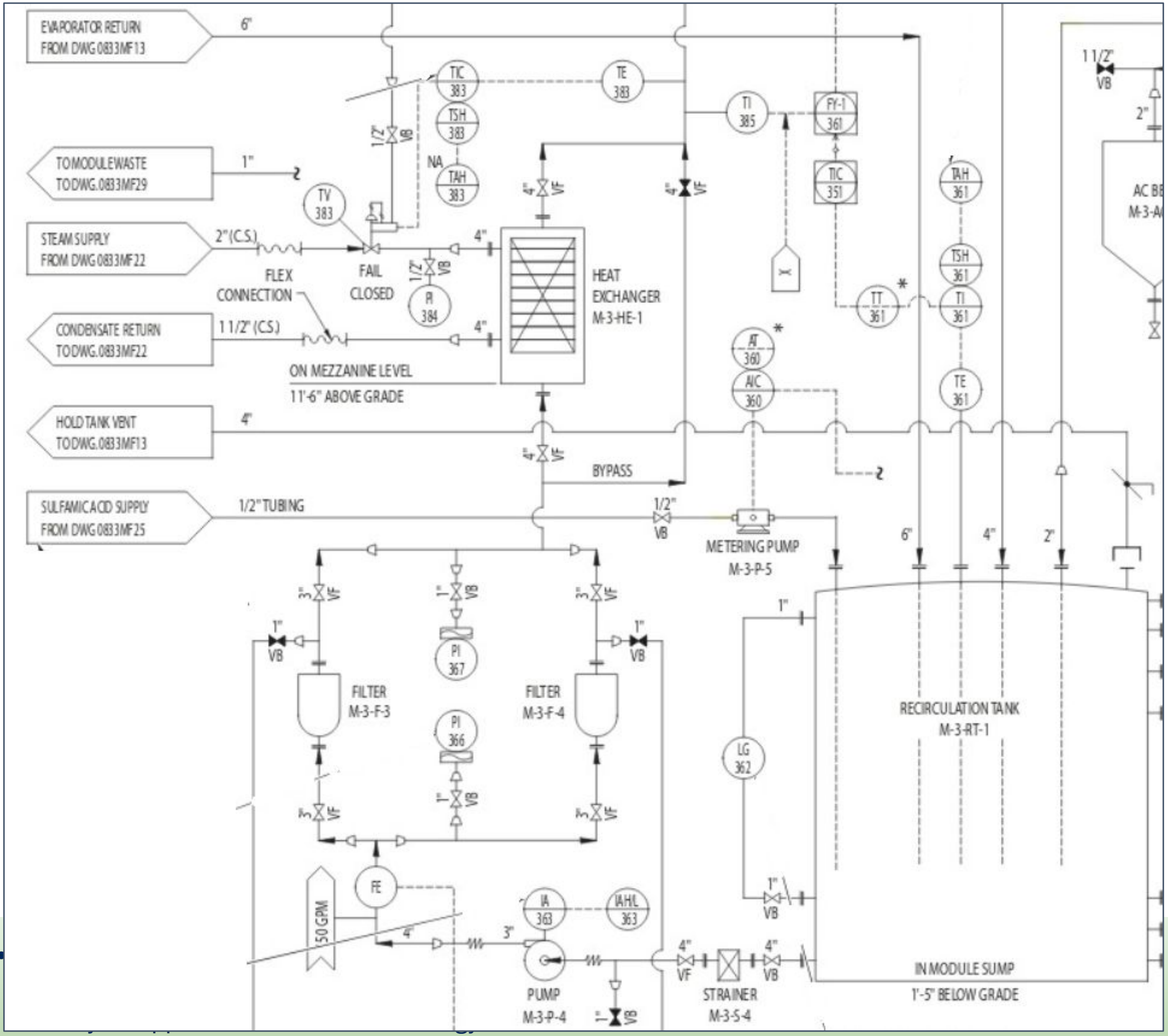
2- Which instruments shows the level of the tank M-3-RT-1? Is it possible to see the level of the tank in control room? LG-362 , no the symbol shows that it is installed in field

3- Which Instruments indicates the pressure at the inlet of Filter M3-F-4? PI-366

4- Which instrument is used to measure the temperature of the tank M-3-RT-1? TE-361

5- Which element indicates the temperature of the tank M-3-RT-1? TI-361

6- Which instruments provide an alarm when the temperature of the tank M-3-RT-1 is high? TAH-361



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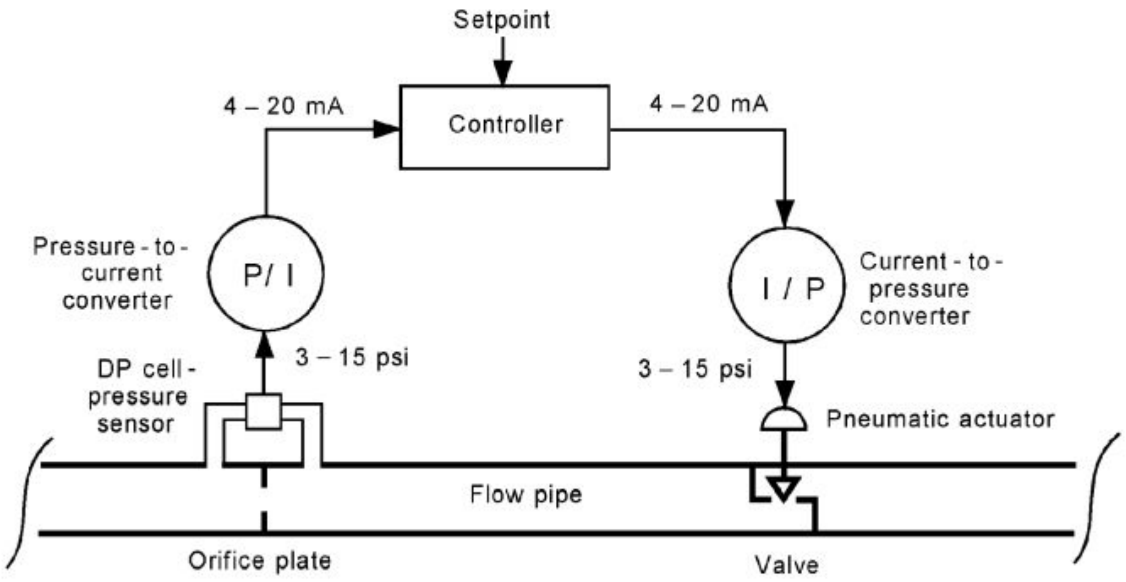
Thank you for your attention!

Homework

For the front process draw the P&ID?



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