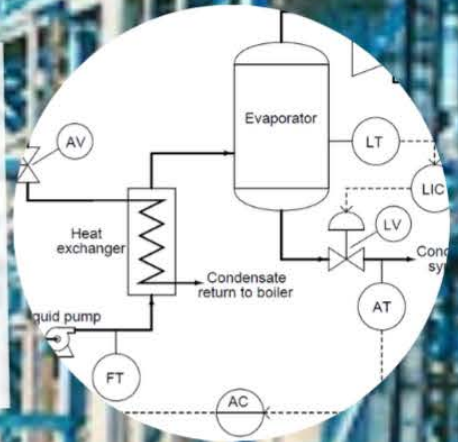


PIPING AND INSTRUMENTATION DIAGRAM



NOR HATINI BAHARIN
ROSNI YUSOFF
ZAIN RETAS





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**NOR HATINI BAHARIN
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ZAIN RETAS**

**Penerbit
Politeknik Tun Syed Nasir Syed Ismail
2021**

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**to a new student who is keen
to fly towards our dreams**

PREFACE

Piping and Instrumentation Diagram is a very important knowledge needed in Oil and Gas Industry. This book is written based on the course structure of Diploma in Mechanical Engineering (Petrochemical) , Malaysia Polytechnic. It will provide students with the fundamental knowledge required to comprehend and read piping and instrumentation diagrams. The first chapter gives the overview of Piping and Instrumentation Diagram. The following chapter discuss about the symbols and their identification in the process diagram. This book also covers the fundamental of control systems which are essential in a plant. It is hoped that this book will assist students in understanding the Piping and Instrumentation Diagram.

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1.0 INTRODUCTION OF PIPING AND INSTRUMENTATION DIAGRAM

Key Learning Points

- Describe the definition in P&ID
- The Importance of in Piping and Instrumentation Diagram to the operation facility
- Characteristic of the Piping and Instrumentation Diagram
- Layout and Information in Piping and Instrumentation Diagram

1.1 Piping and Instrumentation Diagram (P&ID)

Piping and Instrumentation Diagram (P&ID) is one of the basic plant drawings largely used in oil refining and other process industries. It provides an overview of the entire process of the facility. The Piping and Instrumentation Diagram is also known as Mechanical Flow Diagram (MFD). P&ID is defined by the Institute of Instrumentation and Control as follows:

- i. A diagram which shows the interconnection of process equipment and the instrumentation used to control the process.' In the process industry, a standard set of symbols is used to prepare drawings of processes. The instrument symbols used in these drawings are generally based on International Society of Automation (ISA) Standard S5. 1.
- ii. The primary schematic drawing used for laying out a process control installation.

Based on that definition, P&ID depicts the engineering details of the equipment, instruments, piping, valves and fittings as well as their layout. The term “*piping*” means not only “pipe” but also fittings, valves, flanges, and other components that make up a piping system. The physical parts that link the equipment and through which the process streams flow are referred to as piping.

P&ID also shows the instruments and valves that monitor and control the flow of materials through the pipelines. Instrumentation is a term that refers to device that are used to measure, control, and monitor the process variables. These variables can be flow, temperature, pressure, liquid level, viscosity, and others. Control valves and relief valves are also an important part of the instrumentation.

The P&ID is based on the process flow diagram and depicts the technical implementation of a process using graphical symbols representing equipment and piping, as well as graphical symbols for process measurement and control functions. P&ID will serve as a basis for developing the piping drawings and for specifying the instrumentation and control systems. Because it is a detailed document, each P&ID only covers a small part of the process. So, a typical petrochemical unit may have 20 to 30 P&IDs, with bigger facilities having 60 to 100.

1.2 Purpose of Piping and Instrumentation Diagram

P&IDs play an important role for maintenance and modification of the process that it describes. It is critical to demonstrate the physical sequence of equipment and systems, as well as how these systems connect. During the design stage, the diagram also provides the basis for the development of system control schemes, allowing for further safety and operational investigations, such as a Hazard and operability study commonly pronounced as HAZOP. The purposes P&ID are generally as follows:

- Serves as basic document for operation, control and shutdown schemes.
- Provides a basic for maintenance and modification works.
- Gives the regulatory and plant safety requirement.
- Serves as basic guide for start-up and operational data.
- Develop guide lines and standard for facility operation.
- Basic training document to explain the process details to the operators and engineers.

In processing facilities, it purposes as a pictorial representing the details of

- a. Key piping and instrument details
- b. Control and shutdown schemes
- c. Safety and regulatory requirements
- d. Basic start up and operational information

1.3 The Importance of Piping and Instrumentation Diagram to the Operation Facility

The P&ID serves a reference for a various engineering discipline during both the design and the operating phases. It can be used as a communication document for the project.

It provides a lot of information for the manufacturing of the equipment, installation, commissioning, start-up, in hazard and operability (HAZOP) studies, in management meetings, and during project scheduling and planning.

It is also playing an important role in the maintenance and modification of the process described. P&ID is use as training basis for Operational Personnel in before they start work at the plant.

P&ID documents are frequently used by process operators to familiarize themselves with:

- a. Flow schemes
- b. Process/utility interlock system
- c. Control loop identification
- d. Equipment list
- e. Check blinding point locations
- f. To locate process instrument.

1.4 Characteristics of Piping and Instrumentation Diagram

The Piping and Instrumentation should include the following elements:

- Basic operational & start-up information
- Flow direction
- Instrumentation and designation-graphic symbols of equipment
- Equipment numbers and description.
- Piping details (size, identification)
- Line continuation numbers.
- All valves and their identifications
- Valve fitting
- Interconnections reference (from one P&ID to another P&ID)
- Miscellaneous-Vents & drains, special fitting, sampling line, reducers, increasers and swagers.

- Safety relief valves
- Computer control system input-DCS inputs
- Control loop & instrumentation-Control inputs and outputs, Interlocks
- Vendor & contractor interface

The P& ID should NOT include:

- Instrument root valves
- Control relays
- Manual switches
- Primary instrument tubing and valves
- Pressure, temperature and flow data
- Elbow, Tees and similar standard fitting
- Extensive explanatory notes.

1.5 Layout and Information in Piping and Instrumentation Diagram

Figure 1.1 shows the layout of Piping and Instrumentation Diagram. Basically there are six parts of a P&ID namely:

1. Title Block
2. Revision Block
3. Revision Drawing Block
4. Notes and Legend
5. Engineering Drawing / Main Drawing
6. Equipment Description
7. Page Connector

① Title Block

The title block is usually located at the right bottom corner of the P&ID drawing and contains the following information

- a. Drawing title
- b. Drawing number

- c. Revision level
- d. The site
- e. Vendor

The title block includes enough information to identify the drawing and to verify its validity.

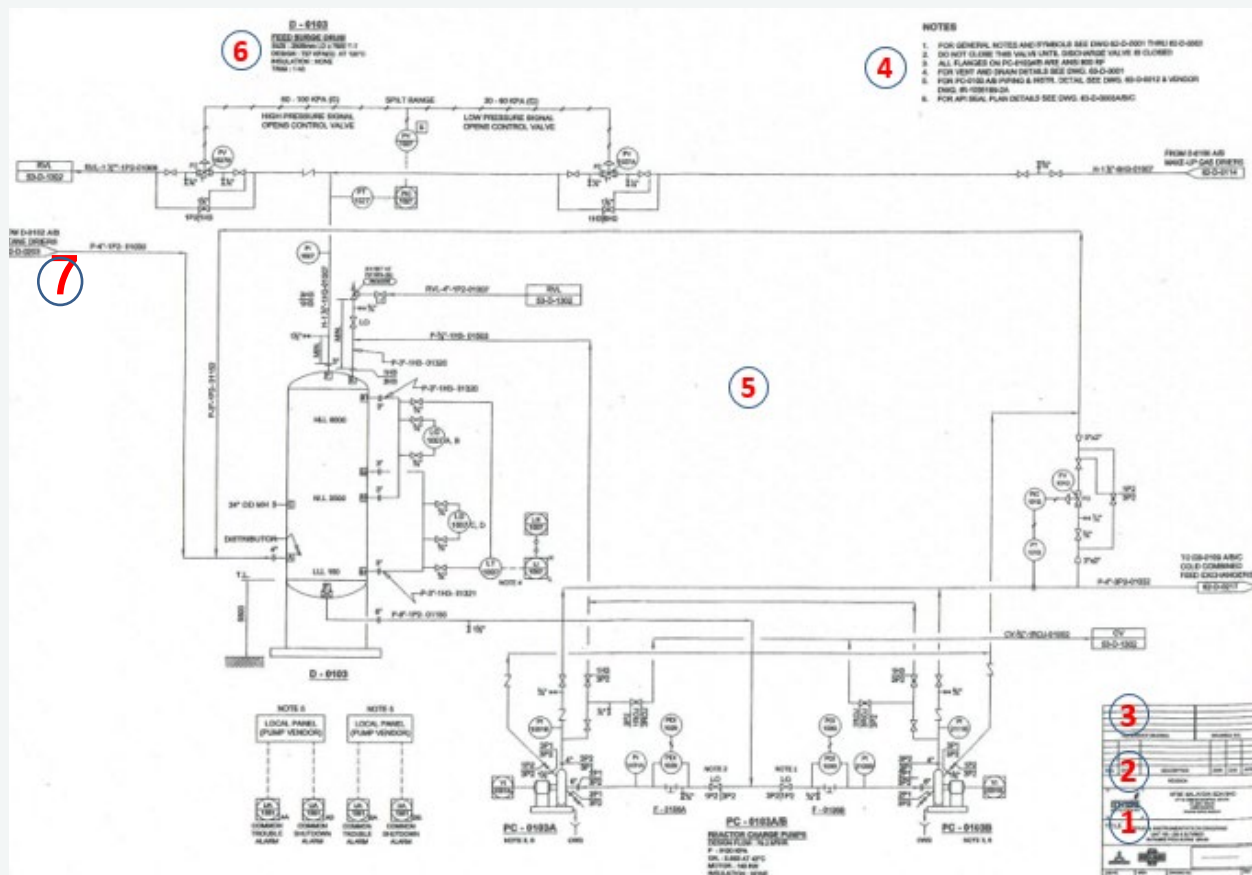


Figure 1.1 : Layout of Piping and Instrumentation Diagram

② Revision block

Revision block shows the revision name and the date of issue. The Revision/ issue descriptions, which are usually above the title block tell us exactly what changes were made with each new issue number.

In some cases, we may observe “cloud”, triangle or hold marker on a P&ID. A “cloud” is sketched in the drawing to indicate the location of the new equipment is. A triangle is used to indicate the changes and the number inside the triangle refers to the issue number for recording the changes. The Hold Marker is simply a special bubble that shows that section is on hold and no work should be done until further notice.

Figure 1.3, below gives a sample of how a note marker, a hold cloud, and a revision change cloud with a revision triangle looks like on a drawing.

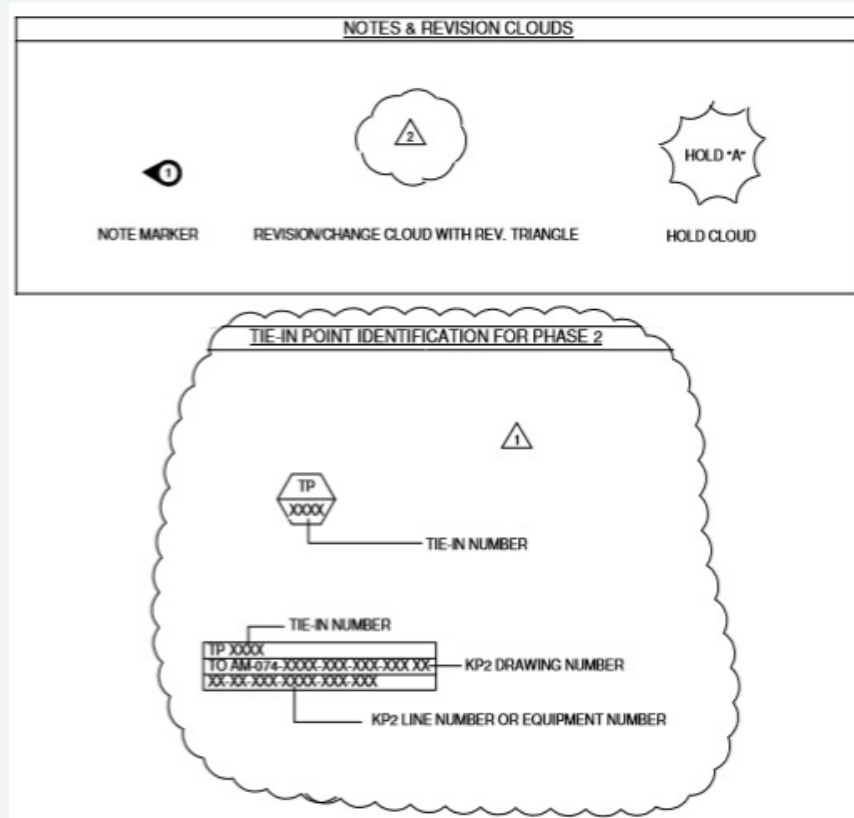


Figure 1 . 2 : Revision change cloud with revision triangle and note marker as well as hold marker

③ Reference Drawing Block

All other drawing which are needed to be studied previously to have a complete understanding of the P&ID. Figure 1.3 shows the example of reference drawing block.

DWG.No.	Reference drawings	REV.
52-27-002	HVAC detail DWG.	A

Figure 1 . 3 : Example of Reference drawing block

④ Notes & Legends

All the information that cannot be displayed as symbols in the main body of a P&ID is stated in the notes area.

Notes can be classified either main body note, side notes , specific notes or general notes and design notes or operation notes.

⑤ Engineering Drawing / Main Drawing

Main drawing or also referred as main diagram is the largest section of the drawing, and contains symbols and lines for:

- a. Equipment
- b. Piping connecting pieces of equipment
- c. Instruments
- d. Lines connecting instruments
- e. Instrument control loops
- f. Line Numbers, Valve Codes etc.

⑥ Equipment Description

The drawing may include descriptions of the equipment shown in the drawing, including the information depending on the type of equipment.

- a. Capacity (Volume, Heat Duty etc.)
- b. Physical Size (Dimension)
- c. Pressure & Temp. information
- d. Horsepower of Pumps/Comp.
- e. Diff.Head of Pumps etc.
- f. Unique equipment number, appearing on each piece of equipment and on the P&ID equipment symbols

Figure 1.4 shows the two samples of equipment descriptions. The sample of Equipment Descriptions show typical information we could see on a P&ID.

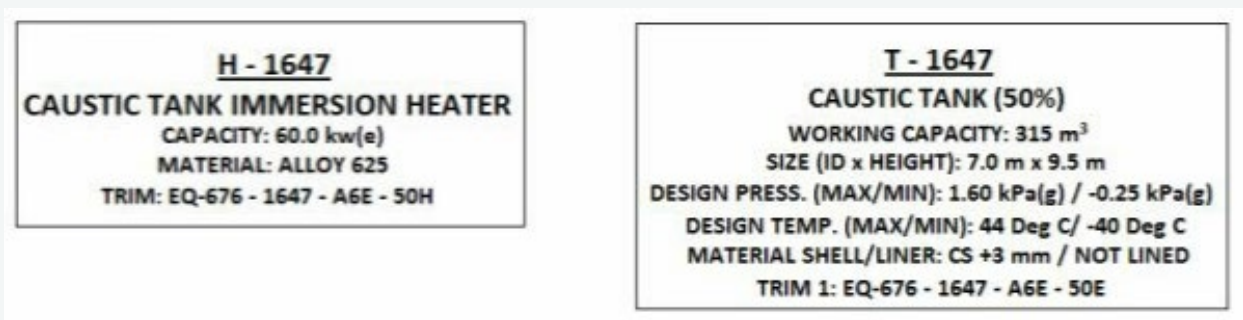


Figure 1 . 2: Sample Equipment description

⑦ Page Connector

A connector used when a process line or signal line continues another drawing. It is not a label but a component includes a label. Figures of 1.5, 1.6, and 1.7 show the example of page connectors labels used in P&ID layout sheet.

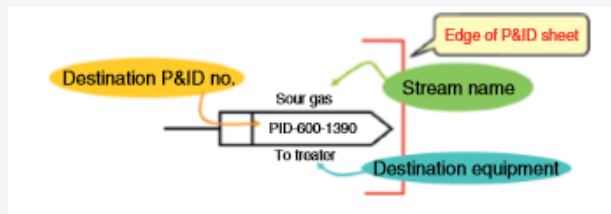


Figure 1 . 3 A leaving off –page connector

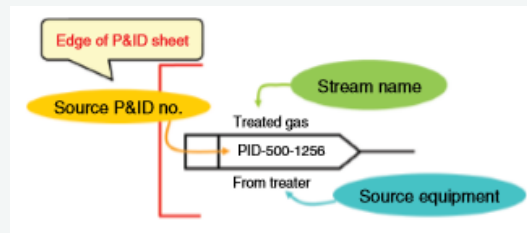


Figure 1 . 4 Incoming off page connector in P&ID

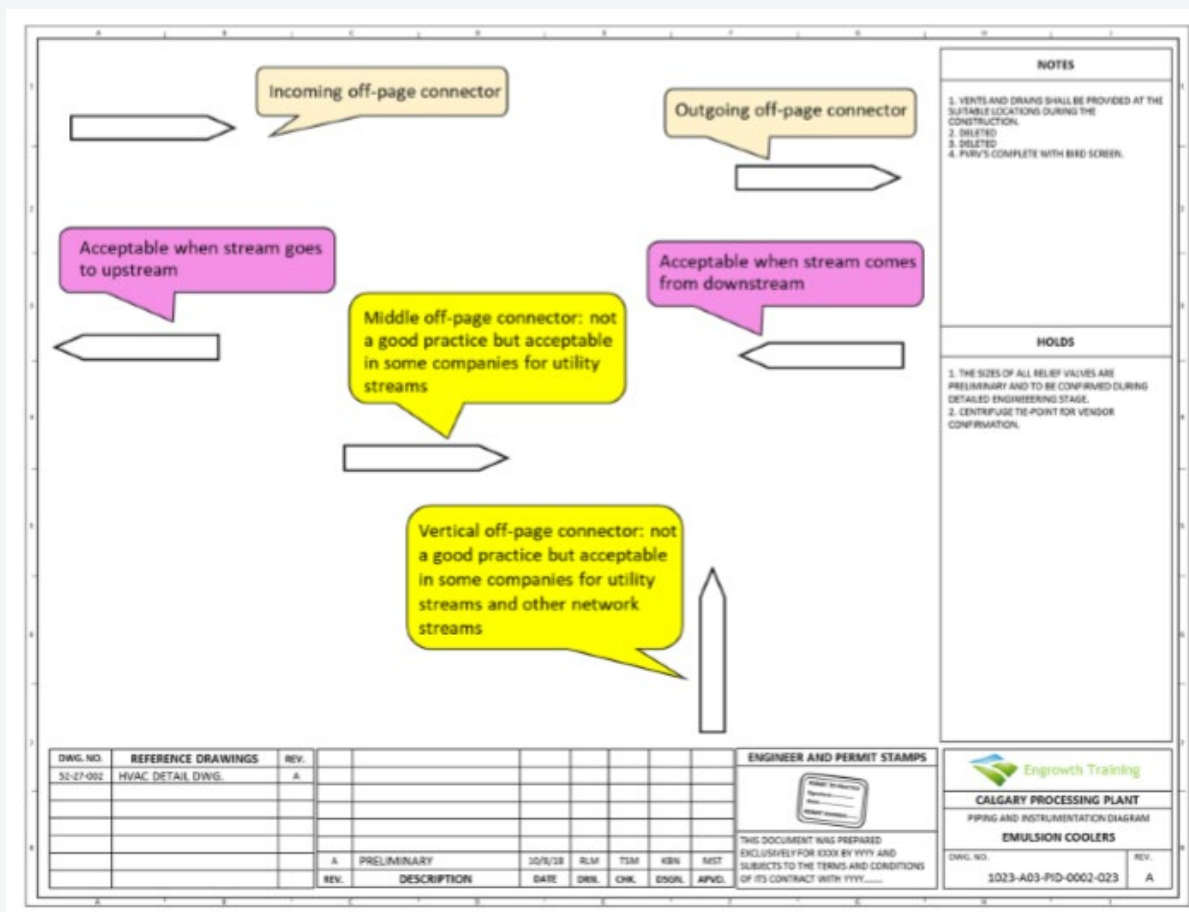


Figure 1 . 5 : Page Connector in P&ID layout

The Function of Main Components in P&ID

- i. Flow path
 - Consists of the main equipment /components and pipe connection.
 - Showing how the liquid flowing from tank to pump and distributed to others in the equipment /components
- ii. Valving
 - Used to isolate, vent, and main equipment /components drain.
 - Explained how the equipment and pipe separable if maintenance is required
- iii. Piping Specialties
 - Including strainers, expansion joint and others component.
 - how fluid is filtered before entering the pump is also included in this section
- iv. Instrumentation and interlocks
 - Devices used to measure, control and monitor the process variables such as flow rate, temperature, pressure, liquid level etc.
 - Safety devices used to protect workers from injury, damage to equipment and give the correct reading

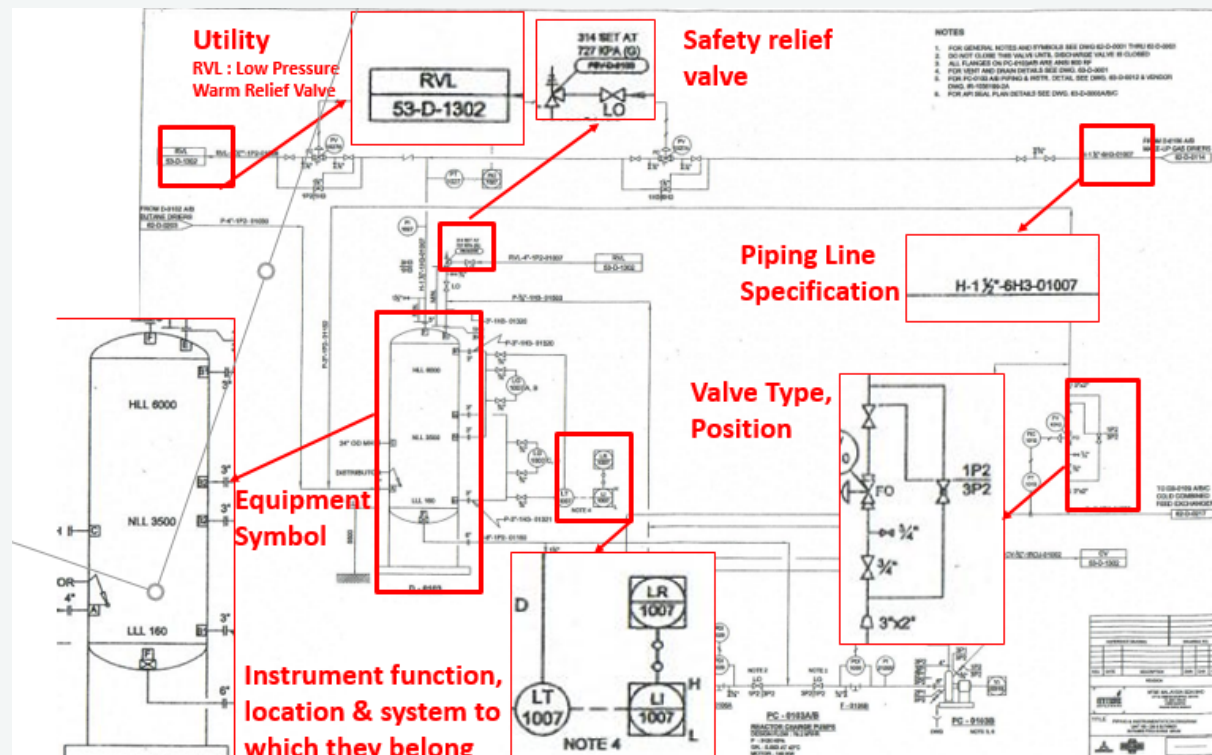


Figure 1 . 6 : Example of information from P&ID

A legend sheet is useful to understand the P&ID shows in Figure 1.9

It defines the symbols with corresponding pipe type, equipment type, valve type, etc.

The information given on the Legend Sheet for a set of P&IDs will vary from site to site depending on who made the drawings and what processes are involved.

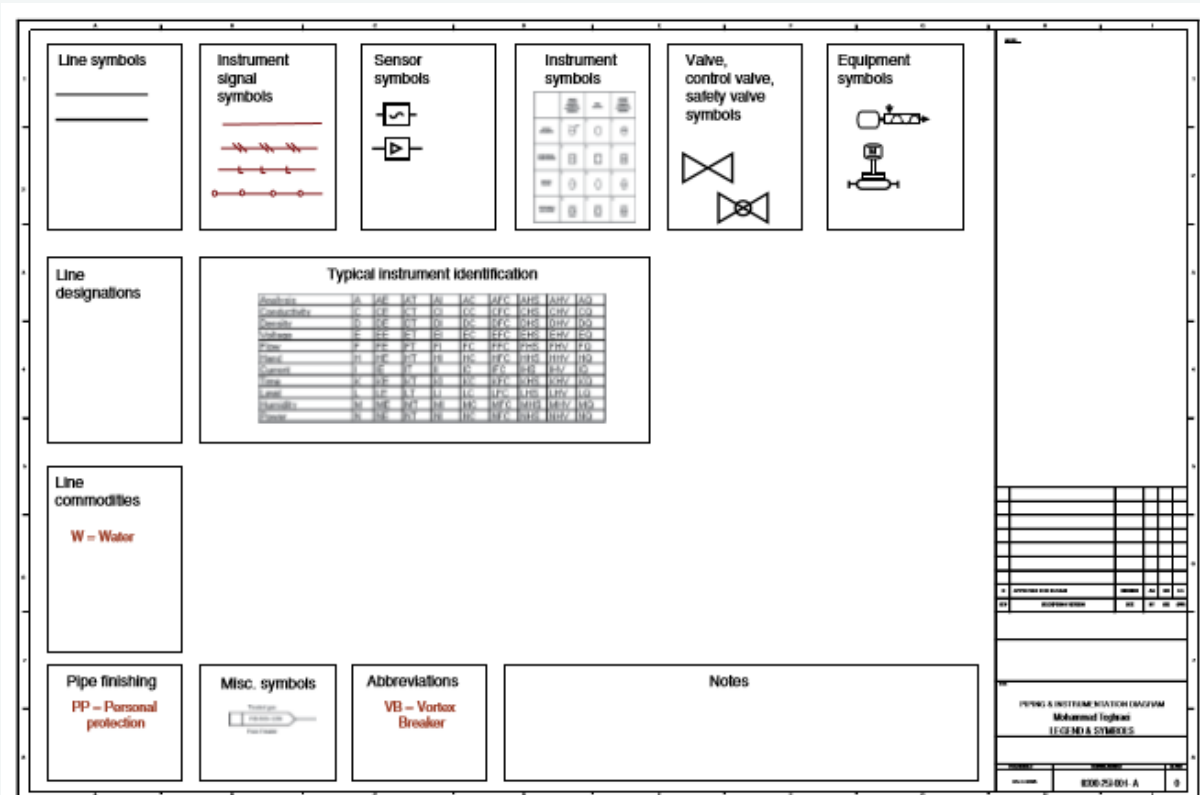


Figure 1.7 : Sample of P&ID Legend Sheet

EXERCISE 1

1. What is piping and instrumentation diagram in refinery and process industry.
2. Give definition of P&ID by the Institute of Instrumentation and Control
3. List the characteristics should have in P&ID.
4. What is the purpose of of P&ID in operation facilities?
5. List the important information needed for process operator in P&ID drawing.
6. Describe layout in piping and instrumentation diagram drawing.
7. List the information in equipment description.
8. Draw a sample of equipment description.
9. How instrumentation symbols shown in a P&ID.
10. List and describe the function of main equipment in P&ID drawing.

2.0 SYMBOLS IN PROCESS DIAGRAM

Key Learning Points

- Symbols of Equipment
- Symbols of Piping Line
- Symbols Piping Fitting
- The Piping Colour Codes
- The Symbols of Instrumentation

Symbol is the basic notation for describing or representing a P&ID. There are hundreds of symbols and diagrams associated with flow process in industries. These process symbols explaining how specific process operates. To read and interpret piping and instrumentation diagram, you must first learn the meaning of the symbols. In general, all the symbols used in P&ID are as per ISA (International Society of Automation) or ANSI (American National Standard)

2.1 Equipment Symbols

The symbols consist of mechanical equipment such as separator, container vessel, pressure vessel, material handling equipment, pump, compressor and blower, drivers / agitator and mixer, heat exchanger and furnace.

a) Separator

Separator is a device for the separation process of solid /liquid / gas particles into several fraction.



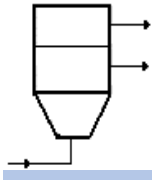
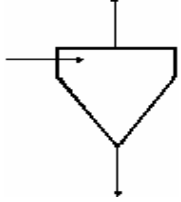
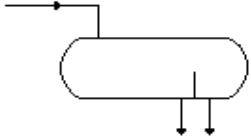
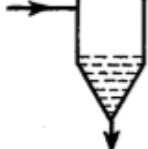
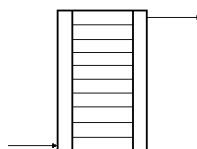
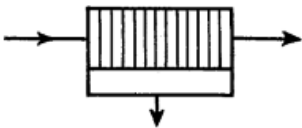
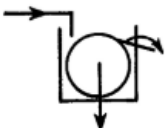
Cyclone separator



Drum settler

Figure 2.1 Separator and Drum settler

Table 2.1 Name, Symbol and Function of Separator

Name and Symbol	Function
Centrifuge 	Particles are separated from a fluid by gravitational forces acting on the particles. The particles were solid, gas, liquid and the fluid was a liquid or a gas.
Cyclone 	Settling device in which the outward force on the particles at high tangential velocities is many times the force gravity. For separation of small solid particles or mist from gases. The gas-solid particle mixture enter the cyclone and enter in a rotating motion. Gas and solid will separate because of the forces
Drum Settler 	To remove the particles from liquid stream so that the fluid is free of particles contaminants
Open Settling Tank 	To remove the particles from liquid stream so that the fluid is free of particles contaminants. Sedimentation.
Electrical Precipitator 	To separate solid/liquid mixture. Sedimentation
Filter Press 	To separate solids and liquid
Rotary Vacuum Filter 	To separate solids from liquid

b) Container and Vessel

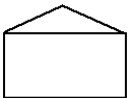
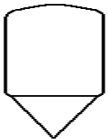
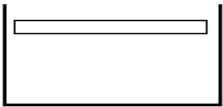
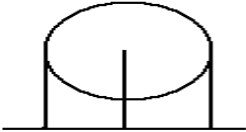
A container or storage tank and vessel, usually to store liquid/gases to its use in the facility , or as holding tanks for partially refined product awaiting further processing or to collect a finished product prior to its delivery or pick-up by a customer.

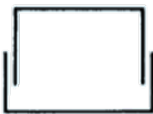
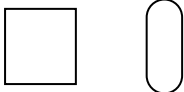
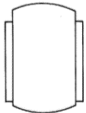
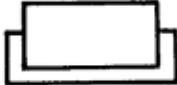


Figure 2.2 Container and Vessel

Process Pressure Vessel is used to store the material (solid/liquid/gas) a with pressure and at the same time, other process occurs in the vessel, example process for this equipment is distillation, separation process.

Table 2.2 Name, Symbol and Function of Container and Vessel

Name and Symbol	Function
Atmospheric tank (cone roof) 	An atmospheric tank is a container for holding a liquid at atmospheric pressure.
Cone bottom bin (bulk storage) 	It is used to gain storage and ease of unloading and used for liquid, solid, slurry and silo.
Floating roof tank 	A storage tank commonly used to store large quantities of petroleum products such as crude oil or condensate. Roof will float on the surface of the stored liquid. Roof rises and falls with the liquid level in the tank. It eliminates breathing losses and greatly reduces the evaporative loss of the stored.
Open top bulk storage (non- pressure) 	Use for collection systems, temporary liquid storage or as secondary containment for vertical tanks in indoor or outdoor installations.
Pressure Storage (sphere or spheroid) 	A pressure vessel is a closed container designed to hold gases or liquids at a pressure substantially different from the ambient pressure.

Name and Symbol	Function
Close top bulk storage (non-pressure) 	Use for collection systems, temporary liquid storage or as secondary containment for vertical tanks in indoor or outdoor installations
Gas holder 	A gas holder provided storage for the purified, metered gas. It acted as a buffer, removing the need for continuous gas production.
Horizontal Drum / Vessel 	Use as a storage vessel for handling the material with pressure
Vertical Drum / Vessel 	Use as a storage vessel handling the material with pressure
Jacketed Vessel 	A vessel with a heating or cooling jacket. Jacket maybe on straight shell, on bottom, head on top head or any combination as required to match the actual process vessel.
Jacketed Vessel (Partial) 	Use as a storage vessel handling the material with pressure

Distillation Tower is used for separation of mixture into its fractions based on the differences in volatilities. Packing or trays may be shown to indicate type of distillation tower.

Distillation tower

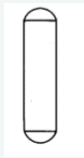
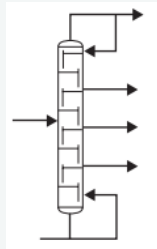
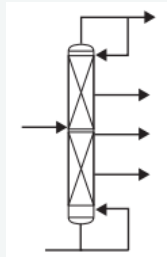


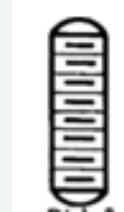
Plate Distillation Tower



Packed Distillation Tower



Disc & Donut Distillation Tower



Sectioned Distillation Tower

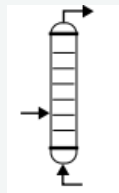


Reactor is a vessel used to carry out a chemical reaction.

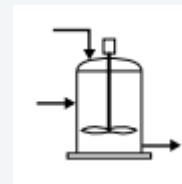
Reactor



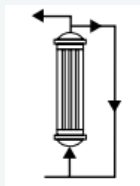
Fluidized reactor



mixing reactor



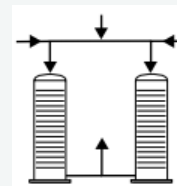
Tubular reactor



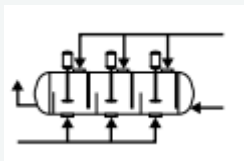
Fluid coking



Hydrocracking



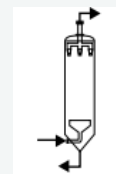
Alkylation



Reformer



Fluid catalytic cracking



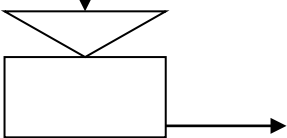
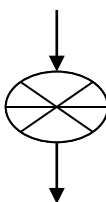
c) Material Handling Equipment

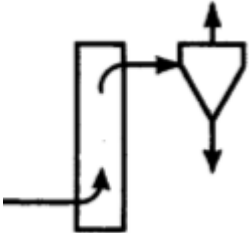
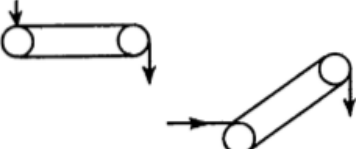
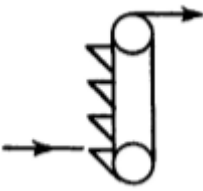
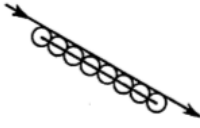
An equipment uses to handle /transfer the material from another component.



Figure 2.3 Material Handling Equipment

Table 2.3 Name, Symbol and Function of Material Handling

Name and Symbol	Function
Feeder & Hopper 	• as a temporary storage. • to transport material from one unit to another • the material in slurry, liquid, silo, solid (small particles)
Rotary Feeder 	• to discharge and isolate the material • Used to packaging according to the volume and weight. • Material in powder, crystals, or pellet, granules

Name and Symbol	Function
Air Lift 	It is used to suck small object, sand and mud from the sea bed and to transport the resulting debris upwards and away from its source.
Belt or Shaker 	Belt / Shaker is used to transport materials either in a straight direction or through directional changes and elevation.
Bucket or Flight Conveyor 	Flight conveyor is used to move powdered, granular, flaked or pelletized materials.
Screw Conveyor 	screw conveyor uses a rotating helical screw blade to move liquid or granular materials
Roller Conveyor 	Roller conveyors are used in material handling applications such as on loading docks or on assembly lines among many others

d) Size Reducing Equipment

This equipment is to make the grain materials into a smaller piece.

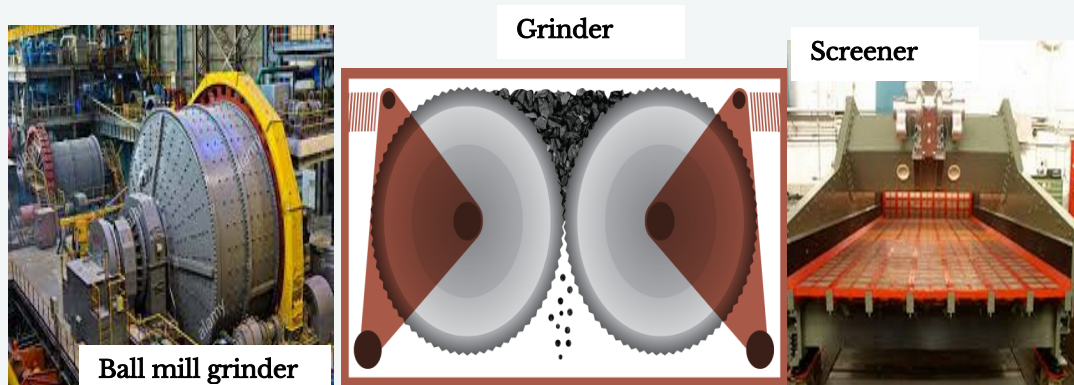
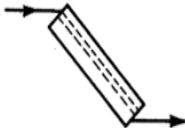


Figure 2.4 Size Reducing Equipment

Table 2.4 Name, Symbol, and Function of Size Reducing Equipment

Name and Symbol	Function
Ball Mill 	Ball mill is a cylindrical device used in grinding (or mixing) materials like ores, chemicals, ceramic raw materials, and paints.
Grinder 	It is used for grinding
Roller Crusher 	To crush friable material
Screener 	• To filter the material according to the screener size. • For the separation process

e) Processing Equipment

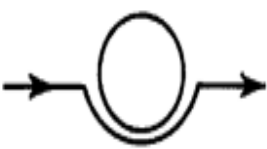
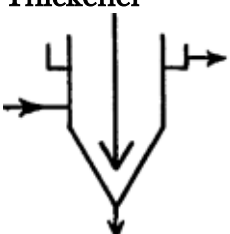
Processing equipment is primary part in symbols of P&ID diagrams.



Figure 2.5 Processing Equipment

Table 2.5 Processing Equipment, symbol and Its Function

Name and Symbol	Function
Mixer 	It is used to mix two or more different components until it reaches a homogeneous state.
Settler 	Used to separate material from unwanted material. The unwanted material will precipitate at the bottom of the settler.
Extractor 	Used to separate a desired substance when it is mixed with others.

Name and Symbol	Function
Autoclave 	The pressure vessels used to process parts and materials which require exposure to elevated pressure and temperature
Kettle Jacketed 	It is used to supply rapidly and uniformly heat to processing temperatures where steam is injected into a thin jacket that surrounds the bowl of the kettle.
Rotary Film Dryer or Flaker 	To reduce or minimize the liquid moisture content of the material it is handling
Jet Mixer Injector / Ejector/Eductor 	Ejector is a simple type of pump which works on the 'venturi effect' to pump out air, gas or liquid from a specified area
Thickener 	It is a machine that de-waters slurry, separating the liquid from the solids

f) Dryers

Dryers are used to remove moisture thermally from a liquid / solid mixture.

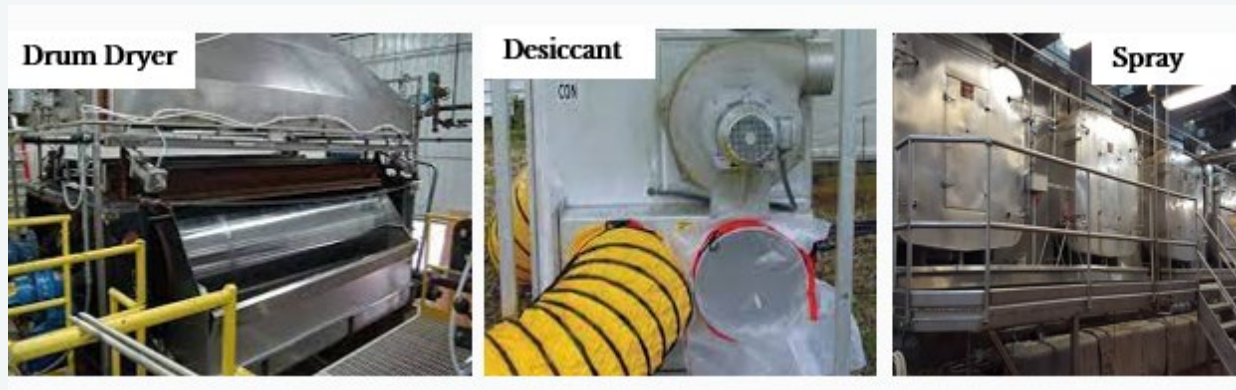
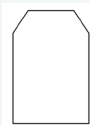


Figure 2.6 Dryers

The following figure are the dryer symbols

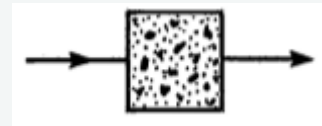
Dryer (general)



Spray Dryer



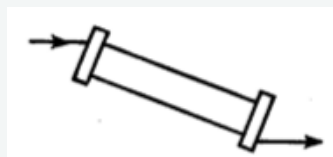
Desiccant



Dryer -oven



Rotary Drum Dryer or
Kiln



Fluidized bed dryer



Figure 2.7 Example of Dryers and It Symbols

g) Pump

Pump is mechanical devices that uses suction or pressure to raise, compress or move fluids in and out of other objects.

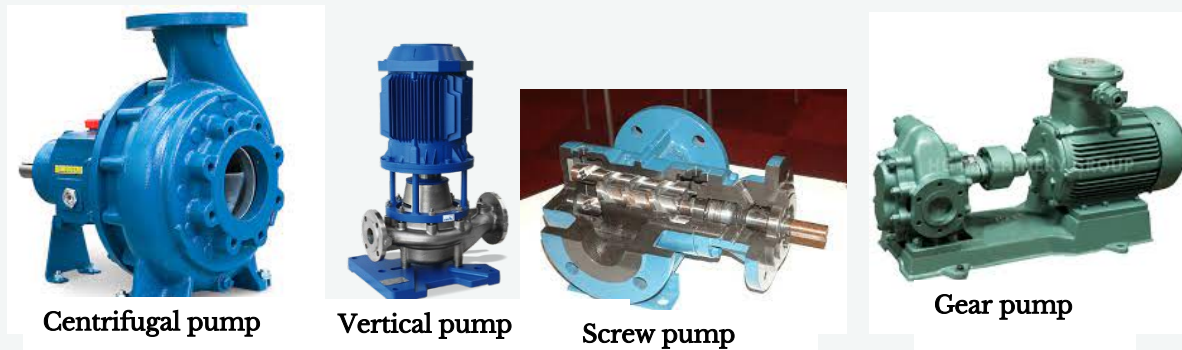
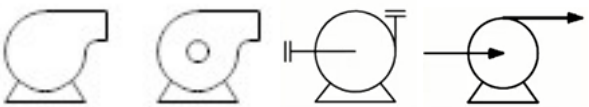
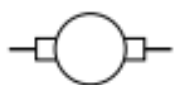
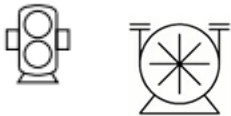
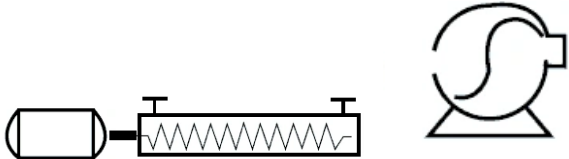


Figure 2.8 Typical type of pumps

Table 2.6 Name, Symbol, and Function of Pump

Name and Symbol	Function
Centrifugal Pump 	Most common pump used in the oil and gas industry. The centrifugal pump is used mainly in constant pressure / variable volume service.
Vertical Pump  Vertical can vertical inline	It is vertical axis centrifugal pump which includes stages of rotating impeller and stationary bowls to process the guide vane. It use wherever the water level is under the volute centrifugal pump limits.
Vacuum Pump 	This pump is used to create a vacuum (sub-atmospheric pressure) on its inlet side. It does this by removing gas molecules from a sealed volume in order to leave behind a partial vacuum.

Name and Symbol	Function
Gear Pump 	A gear pump uses the meshing of gears to pump fluid by displacement. They are one of the most common types of pumps for hydraulic fluid power applications. Gear pumps are also widely used in chemical installations to pump high viscosity fluids.
Screw Pump 	It is a positive-displacement pump that use one or several screws to move the fluids along the screw axis.

h) Compressor and Blower

The equipment that uses energy to move a gas is called a compressor or a blower. A compressor is similar to the pump, but it is designed to move air, gases, or vapors rather than liquids. This machine reduces volume or compressed gas or liquid by creating high pressure. In contrast, a blower is to move air at a moderate pressure to simply blowing air/gas.

Table 2.7 Name, Symbol and Function of Compressor and Blower

Name and Symbol	Function
Centrifugal Compressor 	The most common type of compressor found in oil and gas industry. The compressor may be used in almost any service. The centrifugal compressor is used mainly in constant pressure or variable volume services/
Rotary Compressor 	In a typical rotary air compressor, there will be two interlocking helical rotors contained in a housing. Air enters through an inlet valve and is then taken into the space between the rotors. As the screws turn, they reduce the volume of the air, thus increasing the pressure – which we call Compression

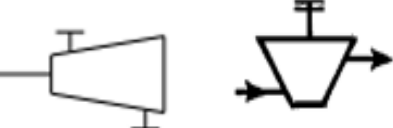
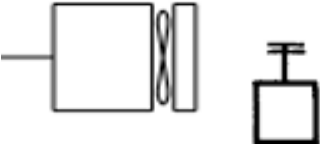
Centrifugal Blower

The Blower basically blows air. Some call it a Centrifugal Fan or Centrifugal Blower. This is mechanical device for moving air or other gases.

i) **Drivers / Agitators / Mixer**

All pumps require a starting device to function. These devices are known as drivers. The driver is connected to the pump via a rotating shaft. An agitator is a piece of equipment that is often associated with vessels.

Table 2.8 Name, Symbol and Function of Drivers, Agitator and Mixer

Name and Symbol	Function
Electric Motor 	An electric motor is the most commonly used driver
Turbine Driver 	an alternative to electricity and as a back-up to the electric motor, a steam turbine is often employed
Diesel Engine 	A diesel engine is used during times of emergency. When piping systems are shut down, diesel engines provide power to operate firewater systems and other essential services
Agitator / Mixer 	An agitator agitates or mixes material contained in a vessel

j) Heat Transfer:

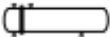
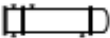
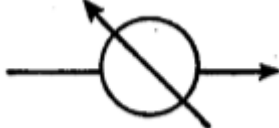
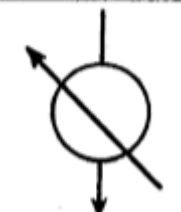
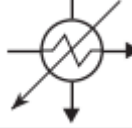
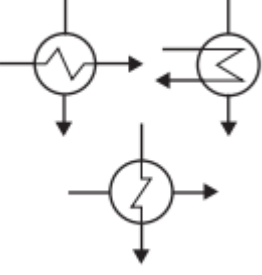
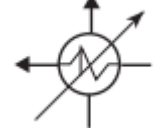
Equipment which is specifically designed to exchange heat between two substances. They will be called coolers, heaters, chiller, reboilers etc depending upon their function



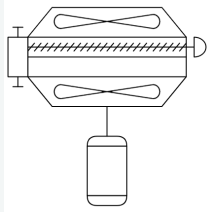
Figure 2.9 Type of Heat Exchangers

There are flows through the heat exchanger devices, inlet and outlet flow can be distinguished by arrow illustrations in the following symbols in Table 2.9:

Table 2.9 Name and Symbol of heat exchanger

 TEMA TYPE BEM  TEMA TYPE BEU  TEMA TYPE AEM  TEMA TYPE AEL  TEMA TYPE NEN  TEMA TYPE BKU	Water Cooled Exchanger  Water Cooled Condenser  Heater 	Shell and Tube Exchanger  Condenser 
--	---	--

Air cooled heat exchanger



Hairpin Heat Exchanger

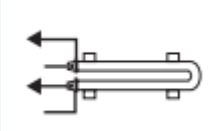
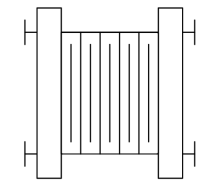
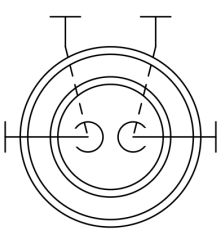


Plate and Frame Heat Exchanger



Spiral Heat Exchanger



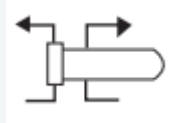
Heat exchanger



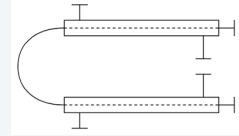
Kettle type heat exchanger



U-tube Heat Exchanger



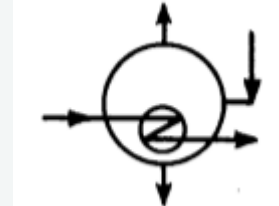
Double Pipe Heat exchanger



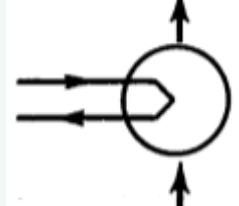
Cooling Tower



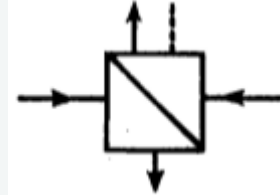
Reboiler (Kettle Type)



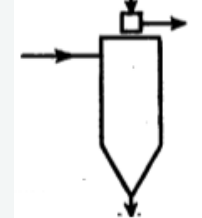
Reboiler (Thermo Siphon)



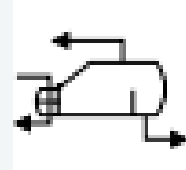
Superheater (Reheater)



Barometric Condenser



Reboiler



Box Cooler (Single Coil)



k) Furnace and Boilers

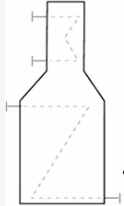
Furnace and boiler symbols use to boil water and produce high, medium or low-pressure steam. All the designs are neatly enclosed inside a refractory -line shell designed to reflect heat back into the furnace.



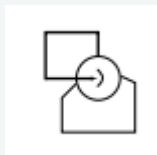
Figure 2.10 Furnace and boiler

Symbols of these furnace and boiler are as follows:

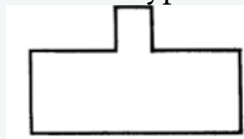
Furnace
(general)



Boiler



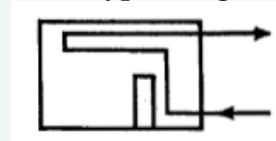
Box Type



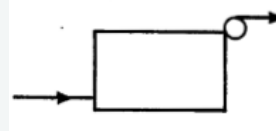
Fired Heater



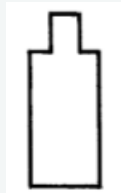
Radiant Type (Single Coil)



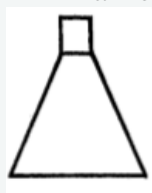
Boiler Fired or Waste Heat



Vertical



"A" Frame



2.2 Piping and Process Line Symbols

Piping and connections are represented with several different symbols as shown in Figure 2.11

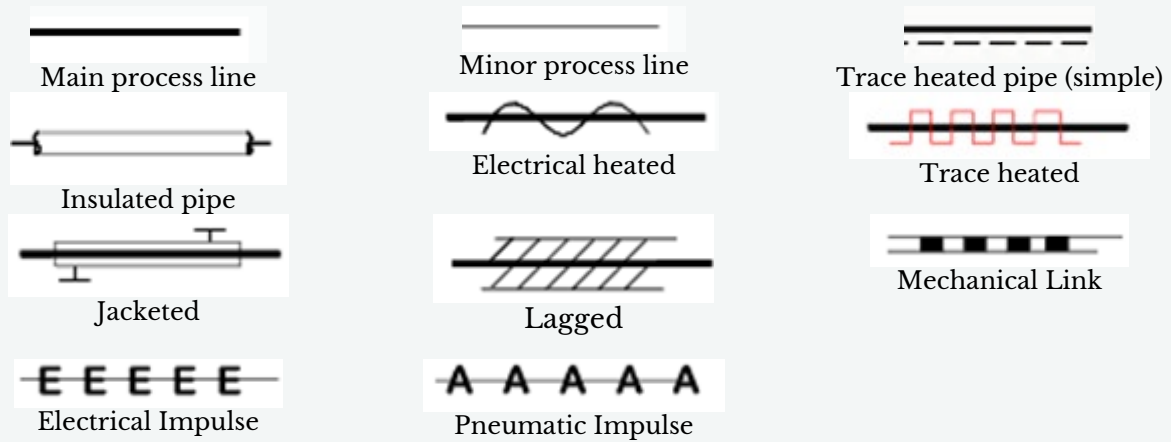


Figure 2.11 Pipe line symbols

Example of pipeline with tracing and it's symbol are shown below




Trace heated pipe

This figure shows the pipe with the heat tracing

The designation symbol of instrument lines are shown below. It indicate what type of signal being used.

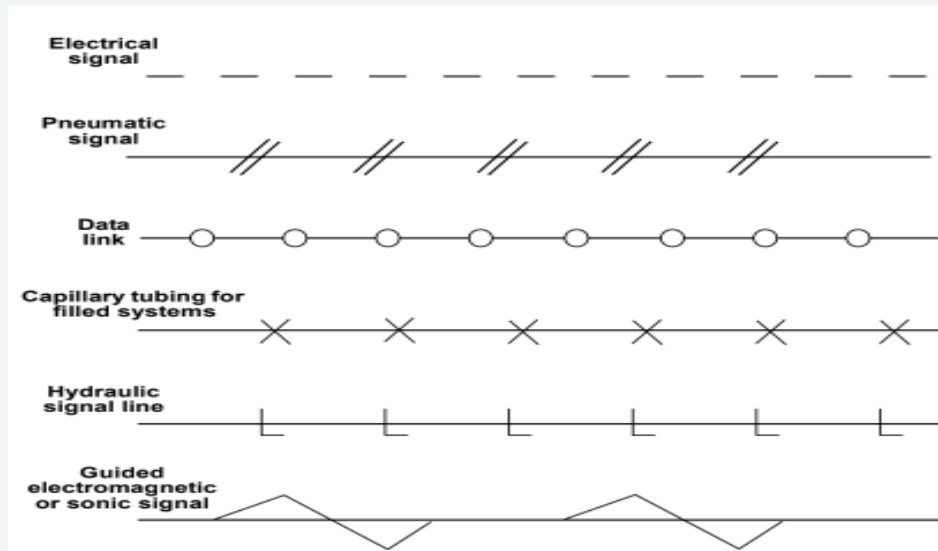


Figure 2.12 Instrument line symbols

2.2.1 Piping special symbols

There are various types of piping specialities use the P&ID drawings based on it purposes. Some general items are as follows:

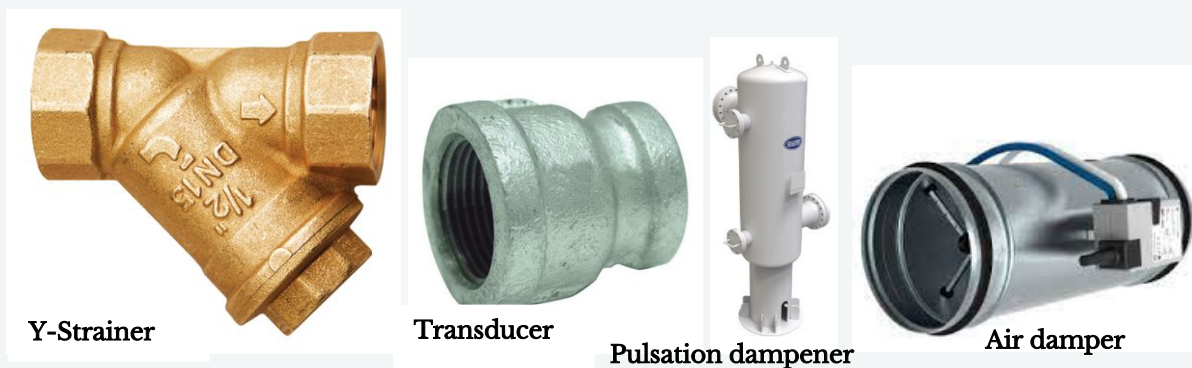
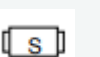
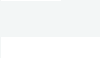
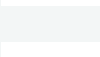


Figure 2.13 Type of Piping fitting

Symbols of piping specialties are as follows

	Detonation arrestor		Temporary strainer		Rotary valve
	Flame arrestor		Steam trap		Excess flow valve
	Duplex strainer		Basket strainer		Pulsation Dampener
	Exhaust head		Filter		Ejector / Eductor
	In line silencer		Vent cover		Removable spool
	Vent silencer		T type strainer		Cone strainer
	Y type strainer		Diverter valve		Flexible hose
	In line mixer		Damper		Expansion joint
	Desuperheater		Reducer		Breather

2.2.2 Piping Fitting

Piping systems require fittings to change direction and connect to all the equipment and devices required to make them function. Most of the examples given below will be found somewhere in oil and gas production and treatment plants.



Flange



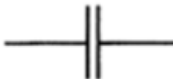
Blind

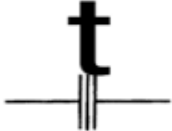
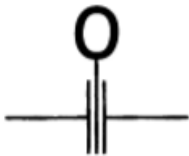
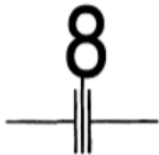


Blind flange with valve

Figure 2.14 Common Type of Fittings

Table 2.10 Name, Symbols and Function of Pipe Fittings.

Name and Symbol	Function
Flange 	A flange is a fitting which is welded or screwed on to the end of the pipe. The flange allows the pipe to be joined up to another pipe, a pipe fitting or item of equipment.
Two Flange 	The flanges are joining two pipes. A gasket placed between the two flanges ensure that the joint is sealed.
Blank Flange with Valve 	Used to terminate a pipe in situations where there may be a reason to extend or fit something to the end of pipe in the future, but in situations where it may not be possible to depressurise the pipe or take it out of service.

Name and Symbol	Function
Hose Connection 	Used to terminate a pipe in situations where there will be a regular requirement to connect a hose to the pipe
Pipe Spade / Blind 	Flat solid plate. Fitted in location where a positive isolation is required to prevent flow through the pipe
Insulated Flanges 	Insulating gaskets, bolt sleeves and washers are installed to insulate one flange from the other. Fitted to sections of pipeline which are protected from corrosion by impressed current cathodic protection systems or where a difference in metallurgy could start the corrosion process.
Pipe Cap 	Used to terminate a pipe in situations where there are no plans to extend or fit anything to the end of the pipe in the foreseeable future.
Blank Flange 	Used to terminate a pipe in situations where there may be a reason to extend or fit something to the end of the pipe in the future
Ring Spacer 	Flat plate with central hole. Fitted in locations where the installation of a pipe spade blind may be required.
Spectacle Blind 	A combined pipe blind and ring spacer. Fitted where frequent positive isolation may be required.

2.2.3 Piping Colour Codes

Colour coding of pipeline and piping materials are standard industry practice. The use of colour will make it easier to identify raw materials and fluid that are transported via pipe. The systematic colour coding of pipeline and piping is important to reduce the safety hazard, reduce the possibility of mistake in identification and accidents associated with wrong identification of pipeline during the emergency.

There is various international standard that provides the guidelines for uniform colour coding in industries.

- a. ANSI/ASME A13.1 – Scheme for the Identification of Piping Systems
- b. BS 1710 – Specification for Identification of Pipelines and Services

The purpose of ASME/ANSI A13.1 Standard is to establish a common system that assists in the identification of hazardous materials conveyed in piping systems and their hazards when released into the environment. ASME A13.1 – 2015 edition has six fixed colours and 4 users define colours that can be used to identify the hazardous material. In this standard, following category are used as illustrated in Figure 2.12.

COLOR CODE Material Properties	Letter color on Field color	Example
FLAMMABLE Fluids which are a vapor or produce vapors that can ignite and continue to burn in air	Black on Yellow	→ HYDROGEN →
COMBUSTIBLE Fluids that may burn but are not flammable	White on Brown	→ ACETIC ACID →
TOXIC & CORROSIVE Fluids which are corrosive or toxic or will produce corrosive or toxic substances	Black on Orange	→ NITRIC ACID →
FIRE QUENCHING Water and other substances used in sprinkler fire-fighting piping systems	White on Red	→ HALON →
OTHER WATER Any other water, except for water used in sprinkler and fire-fighting piping systems	White on Green	→ BOILER WATER →
COMPRESSED AIR Any vapor or gas under pressure that does not fit a category above	White on Blue	→ COMPRESSED AIR →
DEFINED BY USER	White on Black	→ DEFINED BY USER →
DEFINED BY USER	Black on White	→ DEFINED BY USER →
DEFINED BY USER	White on Purple	→ DEFINED BY USER →
DEFINED BY USER	White on Gray	→ DEFINED BY USER →

Figure 2.15 Pipe Color Codes Based on ANSI/ASME A13.1 2015

2.3 Valve Symbols

A valve regulates, directs or controls the flow of a fluid by opening, closing or partially obstructing passageways in a piping systems. This category includes rotameters , orifice and other types of valves.

There are 3 main services which the valve maybe required to perform.

a. ON/OFF SERVICE

- Ensure full flow when fully open & a leak free shut off when fully closed
- E.g : Ball valve, Plug valve, Wedge Gate valve, Diaphragm valve, Orbit valve

b. CONTROL SERVICE

- Able to control the flow of fluid through the valve accordance with the requirement of the design. Able to give a leak free shut-off when it is fully closed.
- E.g : Butterfly valve, Globe valve, Needle valve, Angle valve, Choke valve

c. ONE WAY SERVICE

- Ensure the flow is maintained in only one direction. They should allow free flow in the direction required and a leak free shut off in the reverse direction
- E.g : Check Valve

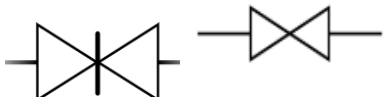
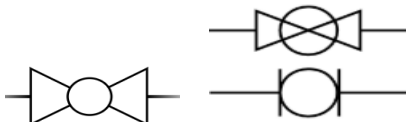
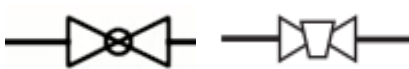
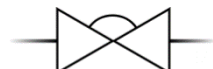
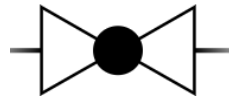
Valves used for One Way service are called check valves, non-return valves or one way valves.

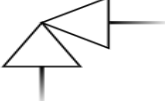
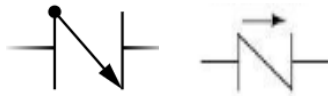


Figure 2.16 Common valve types

The numbers of valve symbols are illustrating as below.

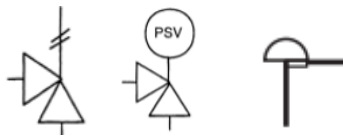
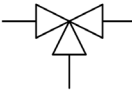
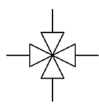
Table 2.11 Symbols Valves and Its Function

Name and Symbol	Function
Gate Valve 	Most common of all valves. Used at all pressure to control the flow of liquids and gases
Ball Valve 	Used for liquid and gas service. It used for on/off or throttling application
Plug Valve 	Mainly used in medium and low pressure service. Best used for on/off applications rather than throttling
Diaphragm Valve 	Used mainly in low pressure dirty service (liquids containing grit or suspending particles or those that may be corrosive or form scale).
Butterfly Valve 	Mainly used in low pressure and low pressure drop services. It is being used for manual or process control, on/off or throttling.
Globe Valve 	Used at all pressures to control or stop the flow of liquid or gas through a pipe. The most common of all control service valves
Needle Valve 	Used at all pressures. Used for very fine flow control.

Name and Symbol	Function
Angle Valve 	Mainly used at high pressures. Reduce turbulence within the valve gives better flow than the globe valve
Check Valve 	Also known as one way valve to prevent backflow of a fluid

In other processing, valve is also used for “special duties” such as the following functions.

Table 2.12 Symbols of special-duties valves and Its Function

Name and Symbol	Function
Pressure Safety Valve (also called as Pressure Relief Valve)  PSV PRV	Pressure Safety Valve (PSV) or Pressure Relief Valve (PRV) is type of device to to relieve pressure in systems in order to prevent damage from overpressure situations.
3 Way Valve 	Use to shut off fluid flow in one pipe while opening fluid flow in another pipe, to mix fluid from two different pipes into one pipe, or to separate fluid from one pipe into two different pipes.
4 Way Valve 	Used to alternately to pressurize and exhaust two working port

2.3.1 Final Control Element Actuator Symbols

Actuator is the part that control the valve. Final control elements are typically automated valves: however, motors or others electrical device can be used. Valve are provided with actuator to increase mechanical advantage by allowing remote operation. Table 2.13 below shows the symbols of actuator.

Table 2.13 Actuator Symbols

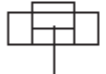
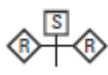
1		Diaphragm actuator	12		Actuator with top-mounted handwheel
2		Diaphragm actuator with positioner	13		Manual actuator Hand actuator
3		Pressure-balanced diaphragm actuator	14		Electrohydraulic linear or rotary actuator
4		Piston actuator	15		Actuator with manual actuated partial stroke test device
5		Piston actuator with positioner	16		Actuator with remote actuated partial stroke test device
6		Rotary piston actuator	17		Automatic reset on-off solenoid actuator Non-latching on-off solenoid actuator
7		Rotary piston actuator with positioner	18		Single solenoid with manual reset
8		Bellows spring opposed actuator	19		Manual and remote reset on-off solenoid actuator Latching on-off solenoid actuator
9		Motor operated actuator	20		Spring or weight actuated relief or safety valve actuator
10		Solenoid actuator	21		Pilot actuated relief or safety valve actuator Pilot pressure sensing line deleted if sensing is internal
11		Actuator with side-mounted handwheel			

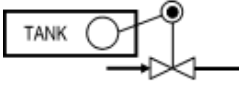
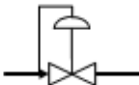
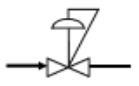
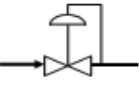
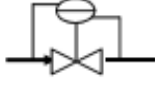
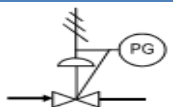
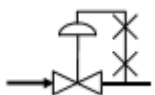
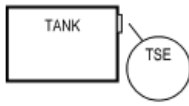
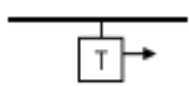
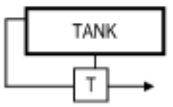


Figure 2.17 Actuator

2.3.2 Self -Actuated Final Control Element Symbols

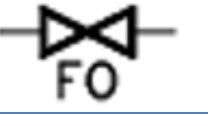
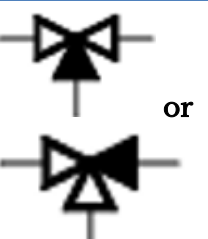
Table 2.14 Symbols of Activated Final Control and Its Description

Symbol	Description
	Automatic flow regulator XXX = FCV without indicator XXX=FICV with integral indicator
	Constant flow regulator
	Flow sight glass
	Flow restriction Single stage orifice plate as shown
	Restriction orifice hole drilled in valve plug

Symbol	Description
	Level regulator Ball float and mechanical linkage
	Backpressure regulator Internal pressure tap
	Backpressure regulator External pressure tap
	Pressure reducing regulator Internal pressure tap
	Pressure reducing regulator External pressure tap
	Differential pressure regulator External pressure taps
	Differential pressure regulator Internal pressure taps
	Pressure reducing regulator w/integral outlet pressure relief and pressure gauge
	Temperature regulator Filled thermal system
	Thermal safety element Fusible plug or disk
	Moisture trap Steam trap
	Moisture trap with equalizing line

2.3.3 Valve Status

Table 2.15 Symbols of valve status

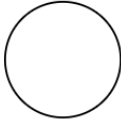
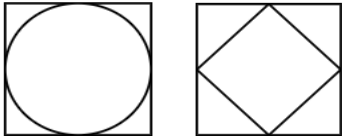
Symbol	Description
	Close Valve
	Open Valve
	Throttled Valve
	Locked Open Valve
	Locked Closed Valve
	Fails Open
	Fails Closed
	Fails As Is
	3-Way Valve with One Port Open , One Closed

2.4 Instrumentation Symbols

An instrument is a device that measures and sometimes controls quantities such as flow, temperature, angle or pressure. The instruments group houses indicators, transmitter, recordings, controller and elements. The symbol used should follow the standard published by the Instrument Society of America (ISA)

The instrument symbols are represented by a 'bubble'. The bubble is a simple circle, square or hexagonal shape.

Table 2.16 Description of Instrument Symbols

Symbol	Description
	Circular bubbles represent discrete instruments . Discrete means it is a stand-alone instrument
	Square bubbles with circle inside represent shared display /shared control Square bubbles with diamond inside represents Programmable Logic Control
	Hexagonal bubbles represent computer systems . Computer systems, as the term implies, are functions, logic and tasks performed by the computer.

The bubbles are further defined by a horizontal line, lines, or lack thereof. These lines specify the location of the instrument and whether it is accessible to the operator or not.

Location:

- a. **No Line** : the device and/or its display are physically located in the field and if it has a display it is only readable locally.
(FIELD MOUNTED)
- b. **Solid Line** : the display is located on a main control panel or video display and is normally accessible and visible to the operator.
(PRIMARY LOCATION , ACCESSIBLE TO AN OPERATOR)
- c. **Dashed Line** : located on a main control panel, located in cabinet behind panel, it is NOT accessible to the operator.
(PRIMARY LOCATION , NOT ACCESSIBLE TO AN OPERATOR)
- d. **Double Solid Line** : the display is located on a secondary or local control panel , situated in a control cabinet in the field that is normally accessible to the operator.
AUXILIARY LOCATION , ACCESSIBLE TO AN OPERATOR
Auxiliary location is an instrument located away from the process equipment it is associated with.
- e. **Double Dashed Line** : the display is located in a secondary control panel, is in a field control cabinet and is NOT normally accessible to the operator.
(AUXILIARY LOCATION , NOT ACCESSIBLE TO AN OPERATOR)

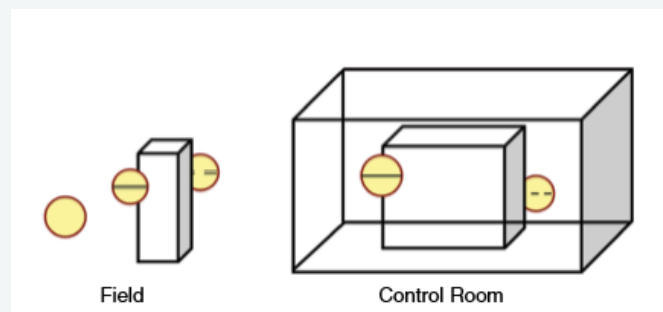


Figure 2.18 Location of the Instrumentation

Location of Instrumentation symbols

Table 2.17 Location of Instrumentation Symbols

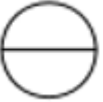
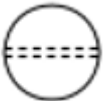
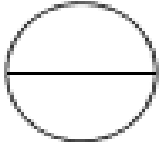
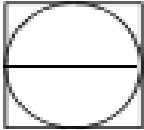
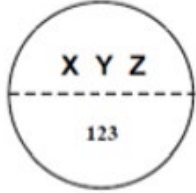
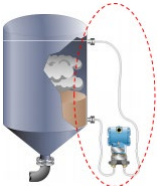
Discrete Instrument	Shared Display /Shared Control (DCS)	PLC (seldom used)	Computer Systems (seldom used)	Location / Accessibility
 Most commonly used symbol	 Used of this symbol can be avoided most of the time	 Used of this symbol can be avoided most of the time	 Used of this symbol can be avoided most of the time	FIELD MOUNTED • In the field or locally mounted • Accessible to an operator at device
 Used in most cases, may be not all	 Most commonly used symbol, always present	 Commonly used	 Rarely used	PRIMARY LOCATION NORMALLY ACCESSIBLE TO AN OPERATOR • On a main panel or screen • Central on the main control room. • Front of main panel or console mounted. • Visible on video display • Accessible to an operator at device or console
 Not usually needed unless there is good reason	 Not usually needed unless there is good reason	 Rarely used	 Rarely used	PRIMARY LOCATION NORMALLY INACCESSIBLE TO AN OPERATOR • Inaccessible, hidden or back / inside panel • Central on main control room. • Rear of panel or cabinet mounted. • Not visible on video display • Not normally accessible to an operator at device or console
 Used from time to time, but will be absent sometime	 Used from time to time, but will be absent sometime	 Commonly used	 Rarely used	AUXILIARY LOCATION NORMALLY ACCESSIBLE TO AN OPERATOR • On a subpanel or remote location • Secondary or local control room. • Field or local control panel. • Front of secondary or local panel mounted. • Visible on video display • Accessible to an operator at device or console
 Rarely used	 Rarely used	 Commonly used	 Rarely used	AUXILIARY LOCATION NORMALLY INACCESSIBLE TO AN OPERATOR • Secondary or local control room. • Field or local control panel. • Rear of secondary or local panel or cabinet mounted. • Not visible on video display. • Not normally accessible to an operator at device or console

Table 2.18 Example of Instrumentation Symbols Description

Symbols			
			
Represent locally mounted instrument / instrument is mounted in the field near the process. (Close to the operator) 	The instrument is board / panel mounted in the control room. (Accessible to the operator) 	Shared Display/Shared Control panel mounted in the control room 	Dashed Line The instrument is mounted out of sight. (Not accessible to the operator)

2.3.2 Instrumentation Identification

Instrument symbol should contain letters and numbers. According to ISA standards, an instrument identification tag consists of the following two parts: a functional identification and a loop number (such as TT-001).

Inside of the shape there are letters and numbers used to represent the property being measured (such as flow rate, pressure, temperature, or level) and the function performed with that measurement. Typical functions are display, record, transmit, and control

Usually, 2 or 3 letters are used for instrumentation identification. First letter indicates a measured or process variable, or a modifier or instrument groups on flow diagram. The

second letter in the instrument abbreviation commonly indicates the instrument function although sometimes it could be a readout/passive function or just a modifier of the first letter (usually the process variable). Again, a third letter could indicate either passive or readout function.

1st letter is the property/variable being measured:

F = flow rate, **P** = pressure, **T** = temperature, **L** = level

2nd letter is a modifier:

D = differential, **F** = ratio. *simply omit if no modifiers apply*

3rd indicates passive/readout function:

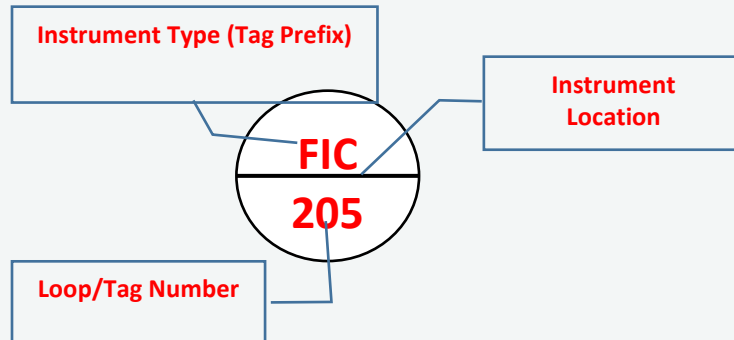
A = alarm, **R** = record, **I** = indicator, **G** = gauge

4th – active/output function:

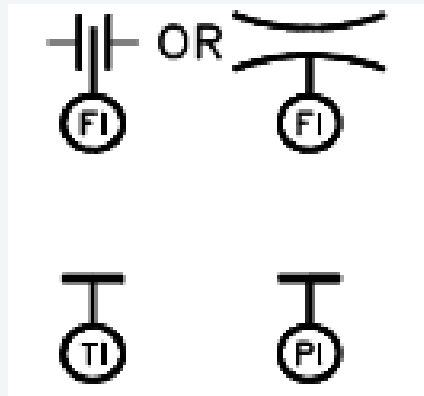
C = controller, **T** = transmit, **S** = switch, **V** = valve

5th is the function modifier:

H = high, **L** = low, **O** = open, **C** = closed. *simply omit if no modifiers apply*



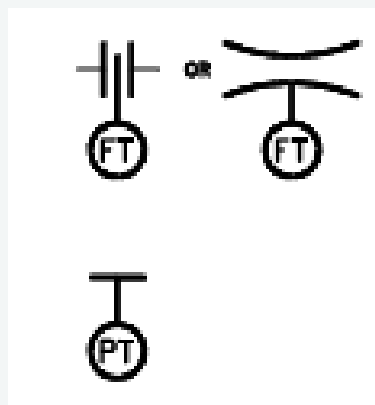
Sensor or detector must be coupled with appropriate modifiers and/or transmitters except for types of local instrumentation having mechanical readouts.



Locally Mounted Flow Indicator

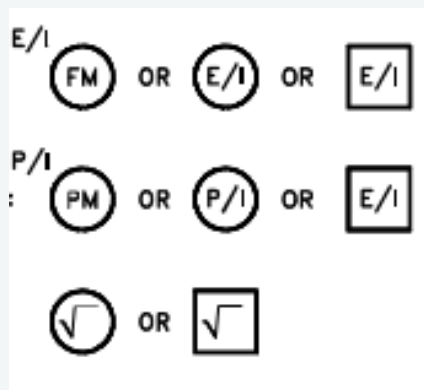
Locally Mounted Temperature or Pressure Indicator

Transmitters are used to convert the signal from a sensor or detector to a form that can be sent to a remote point processing, controlling, or monitoring



Flow Transmitter

Pressure Transmitter



Locally Mounted Voltage to Current Flow Modifier

Locally Mounted Pneumatic to Current Flow Modifier

Locally Mounted Square Root Extractor

Controllers process the signal from an instrument loop and use it to position or manipulate some other system component.



Flow Controller



Temperature Controller



Pressure Controller



Level Controller

There are controllers that serve to process a signal and create a new signal called signal conditioners.



Proportional



Proportional-Integral



Proportional-Integral-Differential



Current to Pneumatic

Table 2.19 List of Letter Combination in Instrumentation Tag

	FIRST LETTER		SUCCEEDING LATTER		
	MEASURED VARIABLE	MODIFIER	READ OUT / PASSIVE FUNCTION	DEVICE OR 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	Electrical Current		Indication		
J	Power	Scan			
K	Time, time schedule	Time rate of change		Control station	
L	Level		Light		Low
M	User's choice	Momentary			Middle,, intermediate
N	User's choice	User's choice	User's choice	User's choice	User's choice
O	User's choice		Orifice, restriction		
P	Pressure, vacuum		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 , presence	y-axis	Relay, compute, convert		
Z	Position, dimension	z-axis	Driver, actuator		

Common instrument abbreviations used in conjunction with P&ID symbols in instrumentation diagrams.

Table 2.20 Instrument Abbreviation

Instrument Abbreviation	Expansion	Instrument Abbreviation	Expansion
FA	Flow alarm	PC	Pressure controller
FAL	Flow alarm low	PDI	Pressure Differential Indicator
FAH	Flow alarm high	PI	Pressure indicator
FC	Flow controller	PIC	Pressure Indicating controller
FE	Flow element	PE	Pressure Element
FI	Flow indicator	PR	Pressure recorder
FIC	Flow indicator and controller	PRC	Pressure recording controller
FR	Flow recorder	PT	Pressure transmitter
FRC	Flow recording controller	PSH	Pressure switch high
FT	Flow transmitter	TA	Temperature alarm
LAL	Level Alarm Low	TC	Temperature controller
LC	Level controller	TI	Temperature indicator
LG	Level gauge	TIC	Temperature indicator and controller
LA	Level alarm	TR	Temperature recorder
LAH	Level alarm high	TRC	Temperature recording controller
LAHH	Level alarm high high	TW	Temperature Well
LS	Level switch	TT	Temperature transmitter
LI	Level Indicator	TY	Temperature relay/transducer
LIC	Level indicating controller	ESD	Emergency Shut down
LRC	Level Recording Controller	SDY	Shut down Relay

EXERCISE 2

1. List the equipment type on a P&ID.
2. Draw the symbols for Drum Settler, Opening Tank, and Cyclone separators.
3. Describe the function for Filter Press and Open Settling Tank.
4. Define Container and Vessel.
5. Draw symbol for Floating Roof tank, Open top bulk storage (non- pressure), Cone bottom bin (bulk storage) and Atmospheric tank (cone roof).
6. What is gas holder and draw its symbols?
7. What is the function of distillation towers?
8. What are four types of Distillation Towers and draw the symbols for each?
9. Draw two types of reactors and define its function.
10. Describe the designation for Jacketed Vessel and draw its symbol.
11. How are instrumentation symbols shown on a P&ID.
12. List three type of material handling in process industries.
13. Define mixer and air lift and draw the symbols for mixer and air lift.
14. Describe the function for dryers.
15. Draw the symbol for Desiccant, Batch Trays, Spray Continuous Tunnel and Rotary Drum Dryer or Kiln.
16. Describe the function for centrifugal pump and centrifugal compressor. Draw each of the symbol.
17. Describe the function of drivers.
18. Draw symbol of Electrical Motor and Turbine Driver.
19. Draw the symbol for agitator.
20. Name and draw the symbol for heat exchangers.
21. Draw the symbol for furnace
22. Draw the symbol for boiler.
23. Draw the symbol for flange and pipe cap.
24. Define the color code for compressed air unit, flammable liquid and water
25. Draw the symbol for gate valve and globe valve.
26. Draw the symbols for solenoid, electric motor and diaphragm.
27. Draw the symbol for close and open valve.
28. Draw the symbol for manually operated valve.

3.0 FLOW DIAGRAM

Key Learning Points

- Block Flow Diagram
- Process Flow Diagram
- Utility Flow Diagram
- Piping and Instrumentation Diagram

Flow diagram is a simple representation that uses process symbols to depict the primary flow path through a unit. It shows the structure and functioning of process plants and is part of a larger set of technical documentation required for planning, assembly, construction, management, commissioning, operation, maintenance, shutdown, and decommissioning of a plant. There are four types of flow diagrams :-

- a) Block Flow Diagram
- b) Process Flow Diagram
- c) Utility Flow Diagram
- d) Piping and Instrumentation Diagram

3.1 Importance of Flow Diagram

- a. To show a process, function and equipment used for specific tasks.
- b. To define the equipment, piping, instrumentation, control system and all process requirements needed to build and operate a process plant.
- c. As a references during the process of maintenance and repair of any damage to the plant.

3.2 Block Flow Diagram (BFD)

Block Flow Diagram (BFD) consists of a series of block a process or process plant that are connected by input and output streams. The block or rectangular frames can represent processes, process steps, unit operations, process plants or group of process plants, plant sections and equipment. The flow lines represent streams of materials or energy flows. A block flow diagram is a non-detail representation of a preliminary or basic processing

concept. It is most useful in early phases of process development and understanding of overall process.

BFD is the simplest form of flow diagram and the easiest to read. It is used to illustrate a process in a simplify form in reports, textbook and presentations but have limited use as engineering documents. It shows what is to be done rather than describe the step to be achieved

Process engineer begins the process design with a block diagram in which only the feed and product streams are identified. Block flow process diagrams often form the starting point for developing a Process Flow Diagram. It shows the main features without getting bogged down in the details.

Block diagram will contain the following information :

- a. Frames or blocks
- b. Ingoing and outgoing materials
- c. Direction of main material flows between blocks

BFD also can contain some additional information such as :

- a. main material flows between the blocks
- b. flow rates or quantities of ingoing and outgoing materials
- c. flow rates or quantities of ingoing and outgoing energy or energy carriers
- d. main material flows between the frames representing energy
- e. characteristic operating conditions

3.2. 1 Characteristic of Block Flow Diagram (BFD)

- a. Composed of only blocks (rectangles) and straight lines
- b. Groups of unit operations or processes may be noted by a single block or rectangle..
- c. Process flow streams flowing into and out of the blocks are represented by neatly drawn straight lines. These lines should either be horizontal or vertical. If lines cross, then the horizontal line is continuous and the vertical line is broken as shown in Figure 3.1.

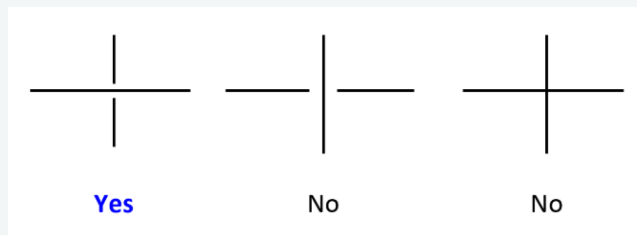


Figure 3. 1 Lines for a process flow; should be in horizontal or vertical, if it is cross, the horizontal line is continuous and vertical line is broken.

- d. The direction of flow of each of the process flow streams must be clearly indicated by arrows.
- e. Unit operations (blocks) should be labeled.
- f. The diagram should be arranged so that the process material flows from left to right, with upstream units on the left and downstream units on the right. (recycles go right to left).
- g. Light stream (gases) toward top with heavy stream (liquids and solids) toward bottom.
- h. Materials in each stream are labelled above or beside the stream
- i. Critical information unique to process supplied. (such as chemical reaction is supplied)
- j. Simplified material balance provided.

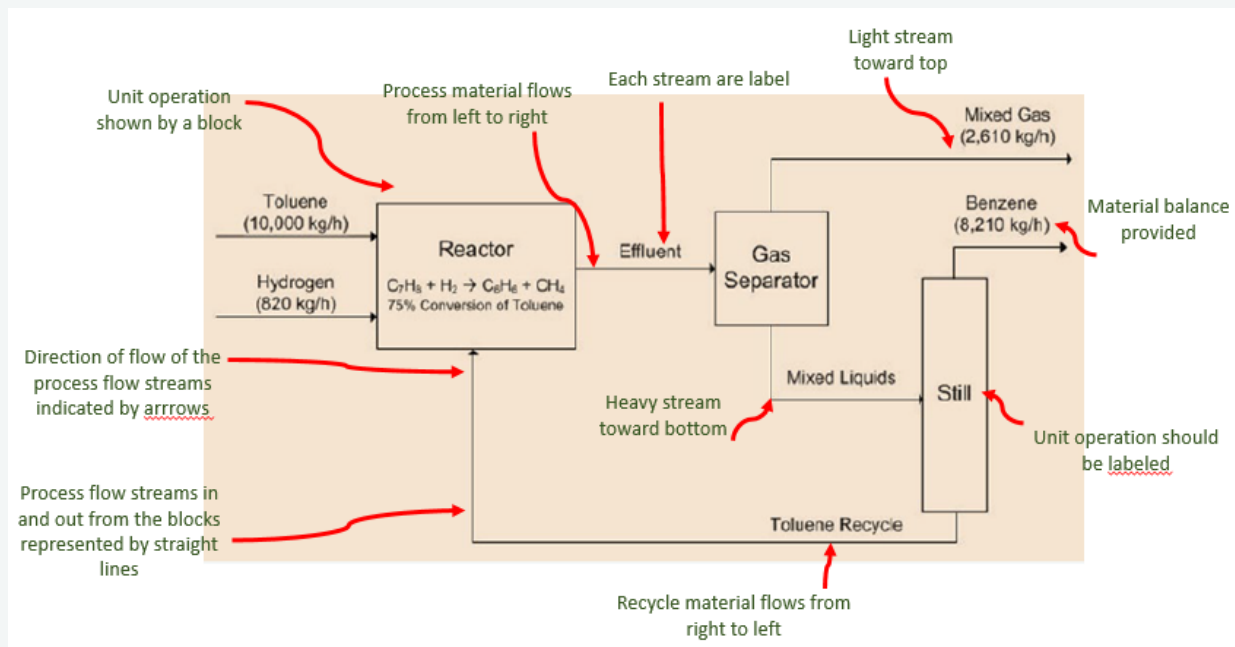


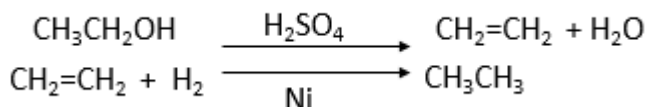
Figure 3. 2 Block Flow Diagram for the Production of Benzene

Figure 3.2 shows the Block Flow Diagram for the Production of Benzene. Fresh feed of toluene containing 10 000 kg/h and hydrogen containing 820 kg/h are converted in a reactor to produce benzene and methane. The reaction does not go to completion, and excess toluene is required. The non-condensable gases are separated in gas separator and discharged. The benzene product and the unreacted toluene in the liquid state are then separated by distillation. The toluene is then recycled back to the reactor and the benzene removed in the product stream.

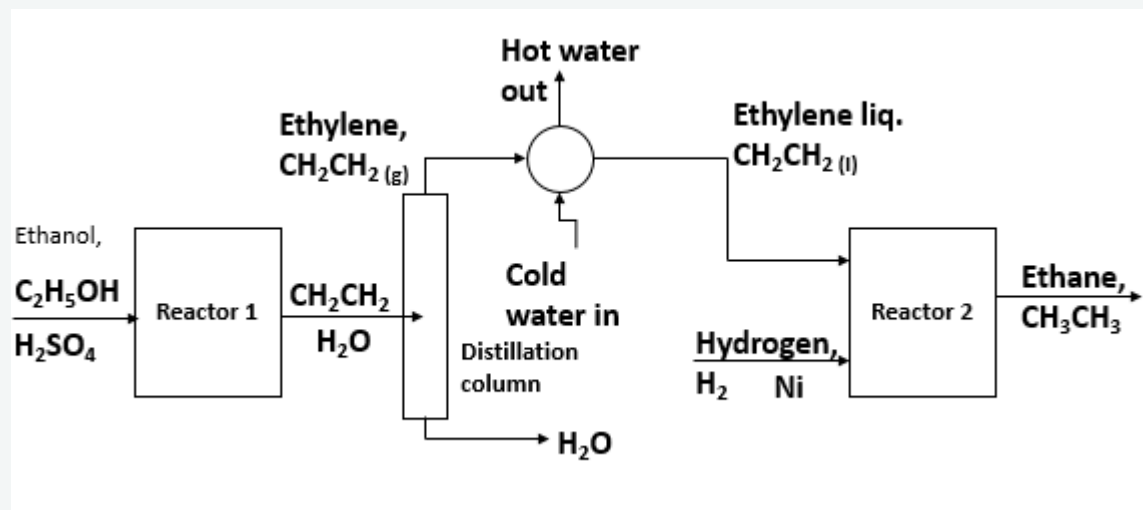
Example 3.1

Production of Ethane from Ethanol

Ethanol is feed to continuous reactor with presence of Acid Sulphuric catalyzer to produce ethylene. Distillation process then will be applied to separate ethylene-H₂O mixture. Ethylene as a top product is then condensate with condenser to perform liquid ethylene. Hydrogenation of ethylene applies in another reactor with presence of Nickel catalyzer to produce ethane as a final product. Develop BFD for these processes.



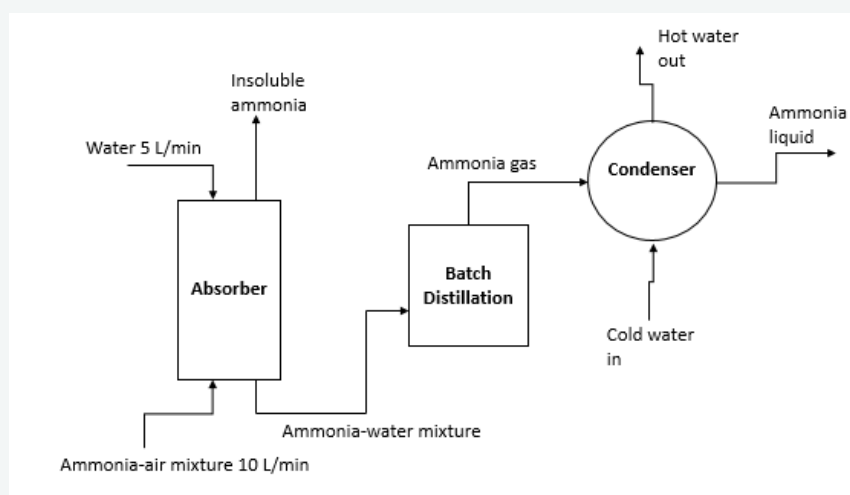
Answer :



Example 3.2

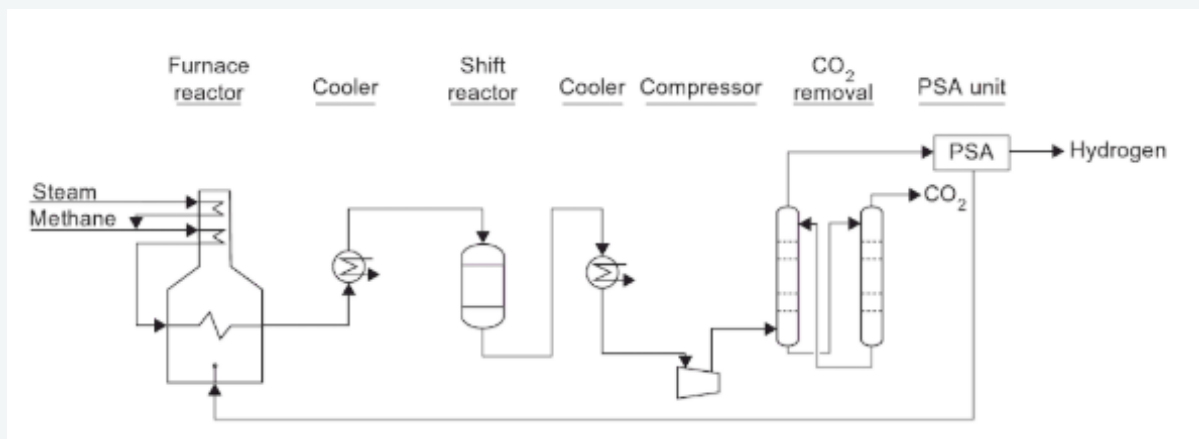
Ammonia-air mixture is feed to the bottom stream of an absorber with flow rate of 10L/min. Water then feed to the upper stream of the same absorber with desired flow rate of 5L/min. There are two outputs from the absorber where upper stream is insoluble NH_3 and bottom stream is NH_3 -Water mixture. This NH_3 -water mixture then feed up to a batch distillation column. The column produces ammonia gas as a top product which this product then will be condensate with a condenser to produce liquid ammonia. Develop Block Flow Diagram (BFD) for this process.

Answer :



Example 3.3

Figure below shows the Block Flow Diagram of the process making hydrogen from methane. Based on the diagram, explain that process.

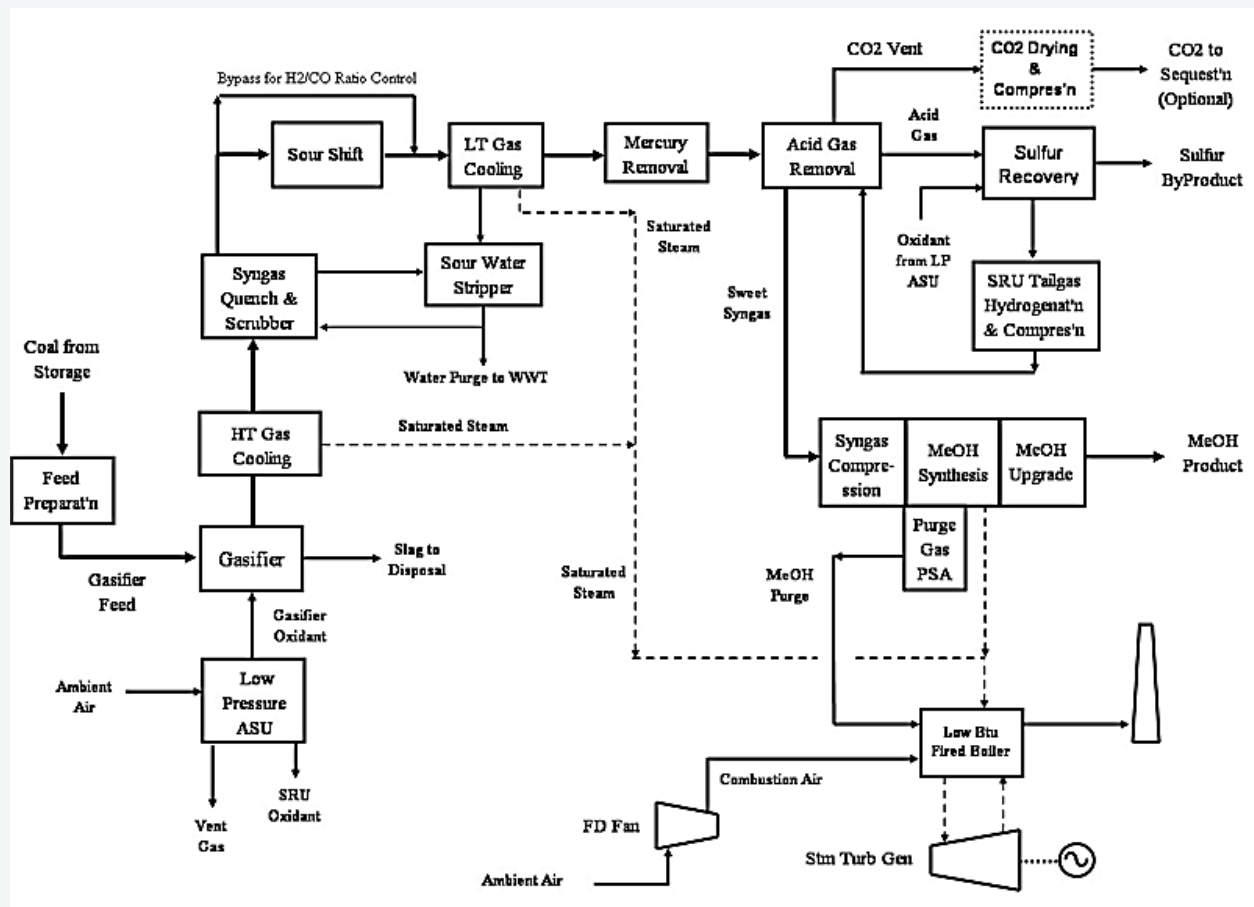


Answer :

The methane feed enters on the left and mixed with steam and preheated in the fired heater. The steam-methane mixture then passes through the reactor tube where the steam reforming reaction takes place. The products from the steam reformer are sent to a shift reactor. The shift reactor product are then further cooled and scrubbed in an absorber to remove carbon dioxide, before being sent to a pressure swing adsorption process that separates hydrogen from carbon dioxide, unconverted methane and water vapour.

Example 3.4

Figure shows a simplified block flow diagram (BFD) of a methanol (MeOH) plant based on coal feedstock. Based on the diagram, explain that process.



Answer :

Syngas from the gasifier is cooled by generating high pressure (HP) steam in the high temperature (HT) gas cooling system before being water quenched and scrubbed to remove fine particulates. The scrubbed syngas then goes through a sour water gas shift (WGS) to adjust the H₂-to-CO ratio to approximately two. Depending on the amount of CO needing to be shifted, supplemental steam injection to the sour WGS feed may be necessary. The syngas from sour WGS is then cooled in low temperature (LT) gas cooling before mercury removal, and followed with hydrogen sulfide (H₂S) and carbon dioxide (CO₂) removal in an acid gas removal (AGR) unit. Sweet syngas from AGR is sent to the MeOH synthesis block where it is highly compressed before going through the MeOH reactor to produce a crude MeOH product. The crude MeOH is then purified to meet product specifications via distillation. Purge from the MeOH reaction system is routed through a pressure swing absorption (PSA) unit to recover H₂ for recycling back to the MeOH reactor. Net low pressure purge gas from the PSA is burned in low-Btu boilers to produce power and steam to meet in-plant power demand. Acid gas from the AGR is sent to the sulfur recovery unit (SRU) to recover sulfur (alternately sulfuric acid) as a byproduct. Since CO₂ is removed and vented ahead of MeOH synthesis, carbon sequestration can be implemented by the addition of a CO₂ drying and compression system.

3.3 Process Flow Diagram (PFD)

Process Flow Diagram (PFD) is a schematic drawing of a plant, or a portion of a plant which shows only the major equipment item and the major process flow streams.

PFD is a simplified flow diagram of either a single process unit, a utility unit, a complete process module or an offsite product storage and loading system

The purpose of the process flow diagram is to depict the fundamental process design, including process flow, process data, unit operations, major equipment and major piping.

A Process Flow Diagram generally includes following information;

- a) Major equipment items including symbols, names and identification system.
- b) Process Piping.
- c) Line to the other sub-plant.

- d) Valve and control system that impact on the process.
- e) Operating conditions of each stream such as pressure, temperature, concentration, etc.
- f) Process stream name/
- g) Major bypass and cyclical trend.
- h) Flows of utilities such as steam, cooling water, brine, hot oil, chilled water, thermal fluid, etc.
- i) Any specific information which is useful in understanding the process. For example, symbolic presentation of a hazard, safety precautions, sequence of flow, etc.

Process flow diagrams generally do not include:

- a) Pipe classes or piping line numbers
- b) Process control instrumentation (sensors and final elements)
- c) Minor bypass lines
- d) Isolation and shutoff valves
- e) Maintenance vents and drains
- f) Relief and safety valves
- g) Flanges

The information of PFD can be classified into :

- a) Process topology
PFD depicts the location of the major equipment as well as the connections made by the process streams between the equipment. The process topology refers to the location and interaction of equipment and process streams.

Figure 3.3 below shows the example of process flow diagram (PFD). In this figure, the equipment is represented by a specific symbol as learnt in topic 2.

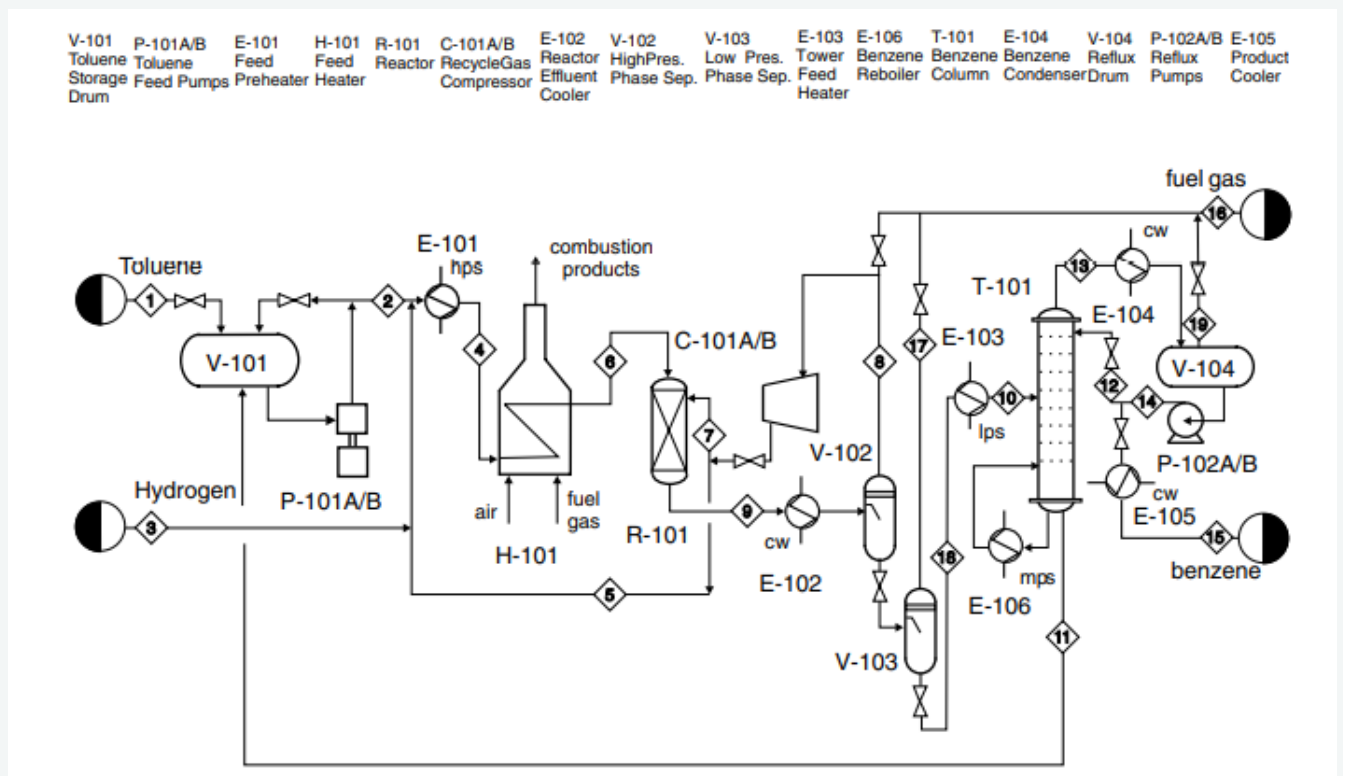


Figure 3.3 : Process flow diagram for the production of benzene

b) Equipment information

Equipment information is a summary of equipment that provides the information needed to estimate equipment costs and serve as the foundation for detailed equipment design.

c) Stream Information / Material Balance

Stream Information is the characteristics of the streams such as temperatures, pressures, compositions, and flowrates can be shown directly on the figure, adjacent to the stream. For a complex diagram only the stream number in a diamond box is provided on the diagram as shown in Figure 3.3. The direction of the stream is identified by one or more arrowheads.

The indexes stream information in diamond box on a flow is summarized by stream table or material balance table, which is often provided below the PFD. Figure 3.4 show the example of material balance for benzene production in Figure 3.4

Material balance or mass balance is a chart/table which shows the balance between what comes into the process and what leaves the process. The chart /table contains :

- i) Line / stream number of Process Flow Diagram
- ii) Product / medium in the streams
- iii) Operating temperature
- iv) Operating pressure
- v) Percentage composition of the product
- vi) Product flow rates
- vii) Product densities

Stream Number	1	2	3	4	5	6	7	8
Temperature (°C)	25	59	25	225	41	600	41	38
Pressure (bar)	1.90	25.8	25.5	25.2	25.5	25.0	25.5	23.9
Vapor Fraction	0.0	0.0	1.00	1.0	1.0	1.0	1.0	1.0
Mass Flow (tonne/h)	10.0	13.3	0.82	20.5	6.41	20.5	0.36	9.2
Mole Flow (kmol/h)	108.7	144.2	301.0	1204.4	758.8	1204.4	42.6	1100.8
Component Mole Flow (kmol/h)								
Hydrogen	0.0	0.0	286.0	735.4	449.4	735.4	25.2	651.9
Methane	0.0	0.0	15.0	317.3	302.2	317.3	16.95	438.3
Benzene	0.0	1.0	0.0	7.6	6.6	7.6	0.37	9.55
Toluene	108.7	143.2	0.0	144.0	0.7	144.0	0.04	1.05

Figure 3. 4: Example of Material Balance of Benzene Production

Stream information also can be added in PFD as shown in Figure 3.5.

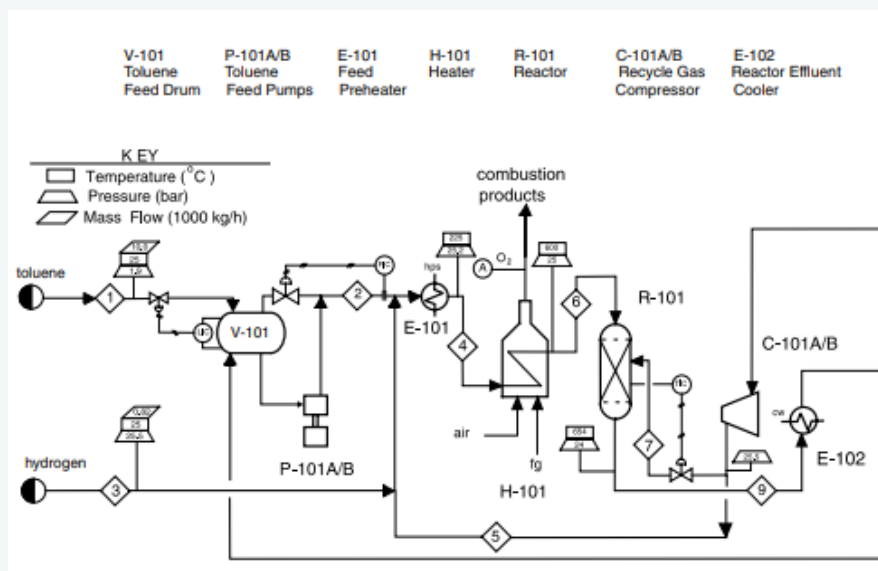


Figure 3. 5 Process Flow Diagram for Benzene Production with stream information in diagram

The shape of the flags indicates the specific information provided on the flag as shown in Figure 3.6

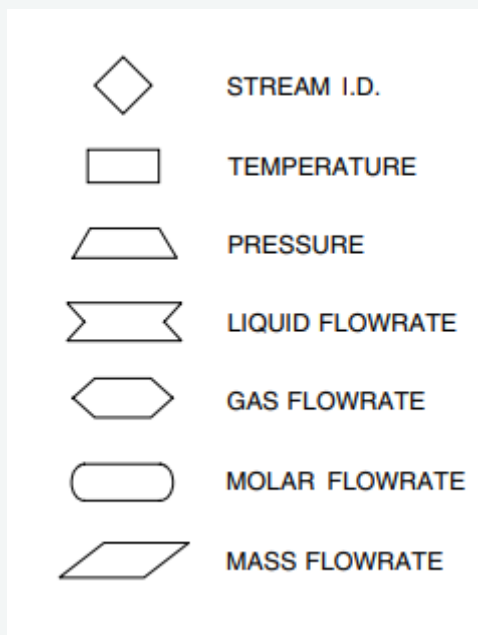
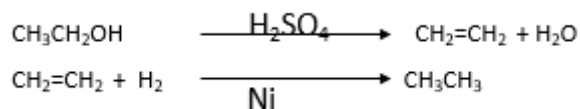


Figure 3. 6 Symbols for stream identification

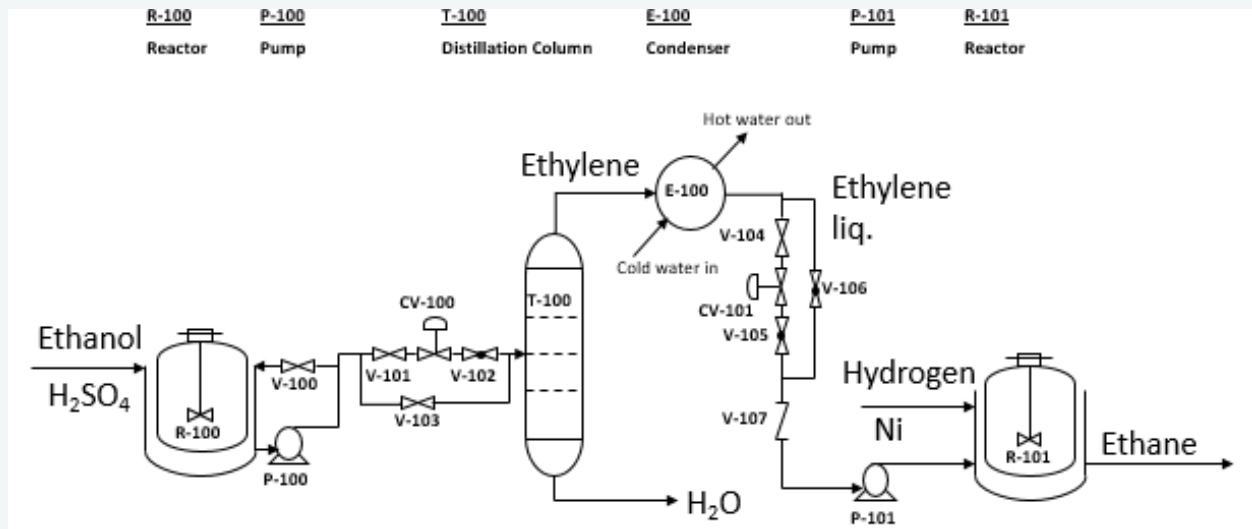
Example 3.5

Production of Ethane from Ethanol

Ethanol is feed to continuous reactor with presence of Acid Sulphuric catalyzer to produce ethylene. Distillation process then will be applied to separate ethylene-H₂O mixture. Ethylene as a top product is then condensate with condenser to perform liquid ethylene. Hydrogenation of ethylene applies in another reactor with presence of Nickel catalyzer to produce ethane as a final product. Develop PFD for these processes.



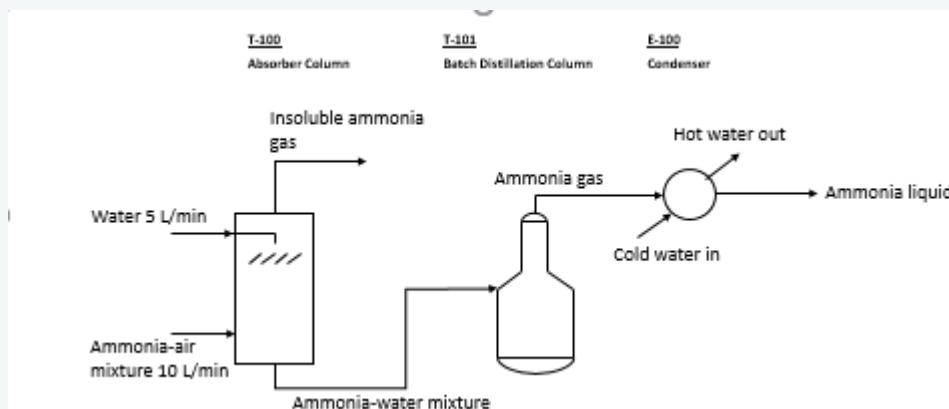
Answer :



Example 3.6

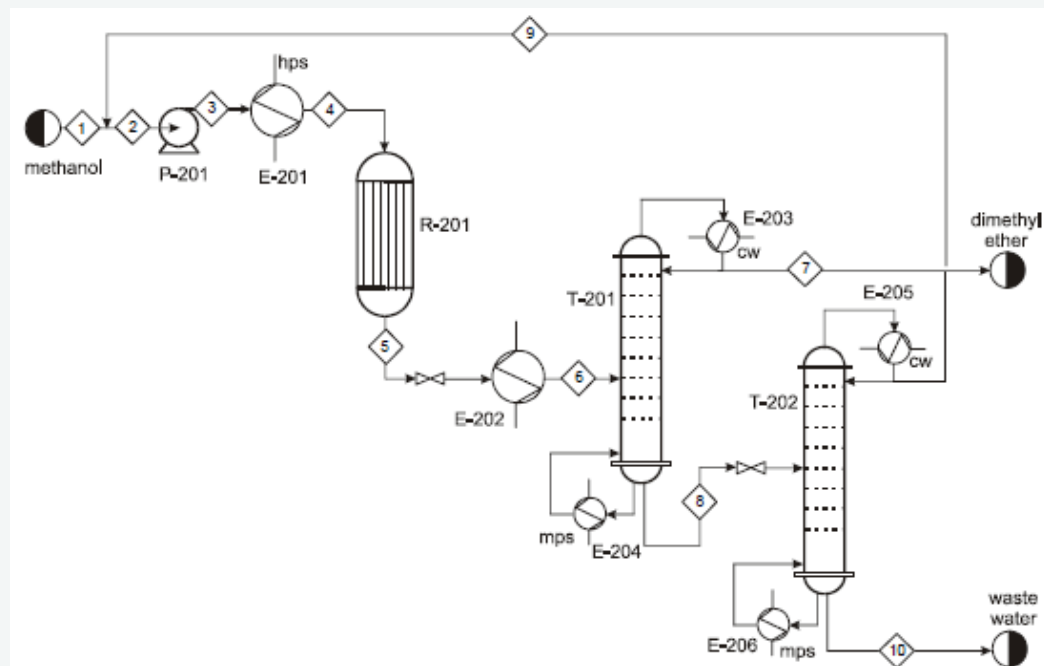
Ammonia-air mixture is feed to the bottom stream of an absorber with flow rate of 10L/min. Water then feed to the upper stream of the same absorber with desired flow rate of 5L/min. There are two outputs from the absorber where upper stream is insoluble NH_3 and bottom stream is NH_3 -Water mixture. This NH_3 -water mixture then feed up to a batch distillation column. The column produces ammonia gas as a top product which this product then will be condensate with a condenser to produce liquid ammonia. Develop Process Flow Diagram (PFD) for this process.

Answer :



Example 3.7

Figure below shows the Process Flow Diagram of the process making hydrogen from methane. Based on the diagram, explain that process.



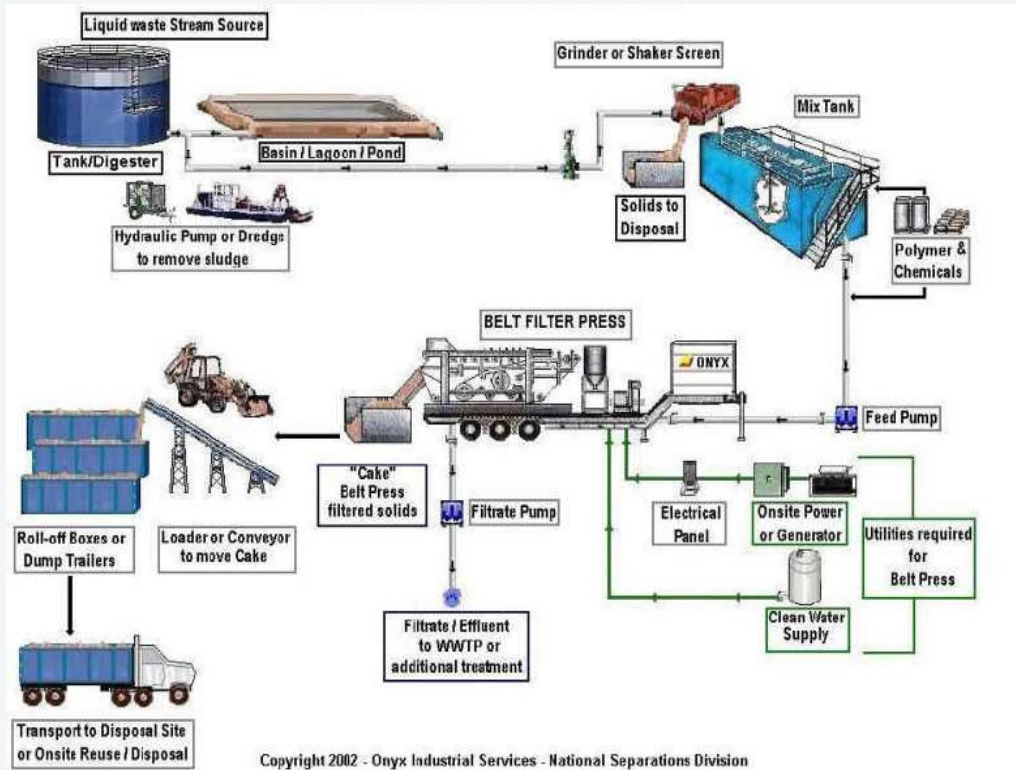
Answer :

Process Description

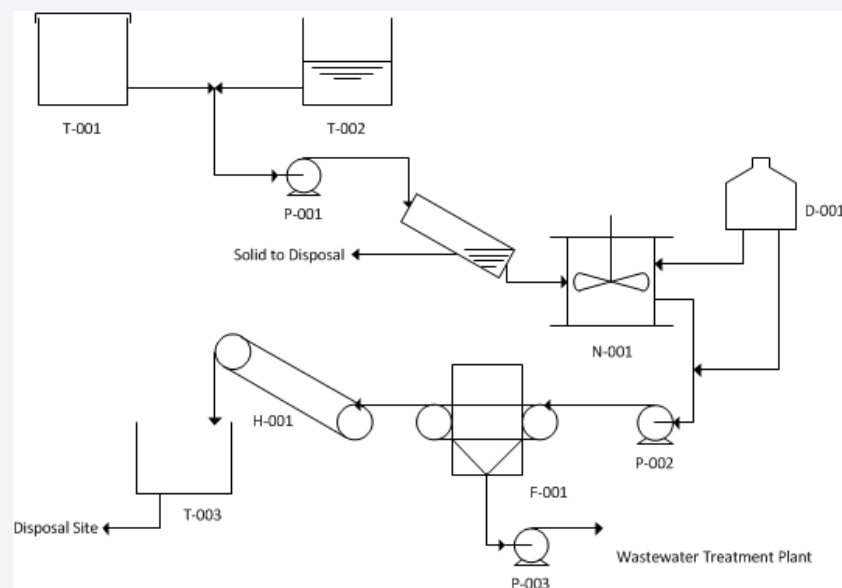
It is a preliminary process flow diagram (PFD) for the dimethyl ether production process. The raw material is methanol, which may be assumed to be pure. The feed plus recycle is pumped in P-201; heated, vaporized, and superheated in a heat exchanger (E-201); and then sent to the reactor (R-201) in which dimethyl ether (DME) is formed. The reaction that occurs is shown below. The reactor effluent is cooled and partially condensed in a heat exchanger (E-202), and it is then sent to the separation section. In T-201, "pure" DME is produced in the top stream (distillate), with methanol and water in the bottom stream (bottoms). In T-202, the distillate contains methanol for recycle, and the bottoms contains waste water. The desired dimethyl ether production rate is 100,000 ton/y.

Example 3.8

Transform the Onyx wastewater liquid treatment schematic flow diagram to process flow diagram using equipment symbols and letters.



Answer :



3.4 Utility Flow Diagram (UFD)

Utilities are services that are essential to the proper function of the plant. Some utilities found in petrochemical facility correspond to some of the same utilities used in a typical house, such as water, gas, and sewer drains. Others that are specific to industrial application such as compressed air to pneumatic tools and steam for high pressure cleaning. Some of the common plant utilities are (application):

- Steam
- Condensate
- Fuel Oil
- Utility Air
- Instrument Air
- Cooling Water
- Drainage Systems
- Flare System

A utility flow diagram (UFD) is a special type of process flow diagram. Utility Flow Diagram is used to summarize and detail the interrelationship of utilities such as air, water, steam, heat transfer mediums, process vents and purges, safety relief blow-down, to the basic process. In other word, it is a diagram that shows the energy utility systems within a process plant, showing all lines and other graphic means required for the representation of transport, distribution, and collection of forms of energy. Figure 3.7 and Figure 3.8 show the example of the utility flow diagram in a plant. The graphical symbols represent equipment and the lines represent flows of mass, energy, or energy carriers.

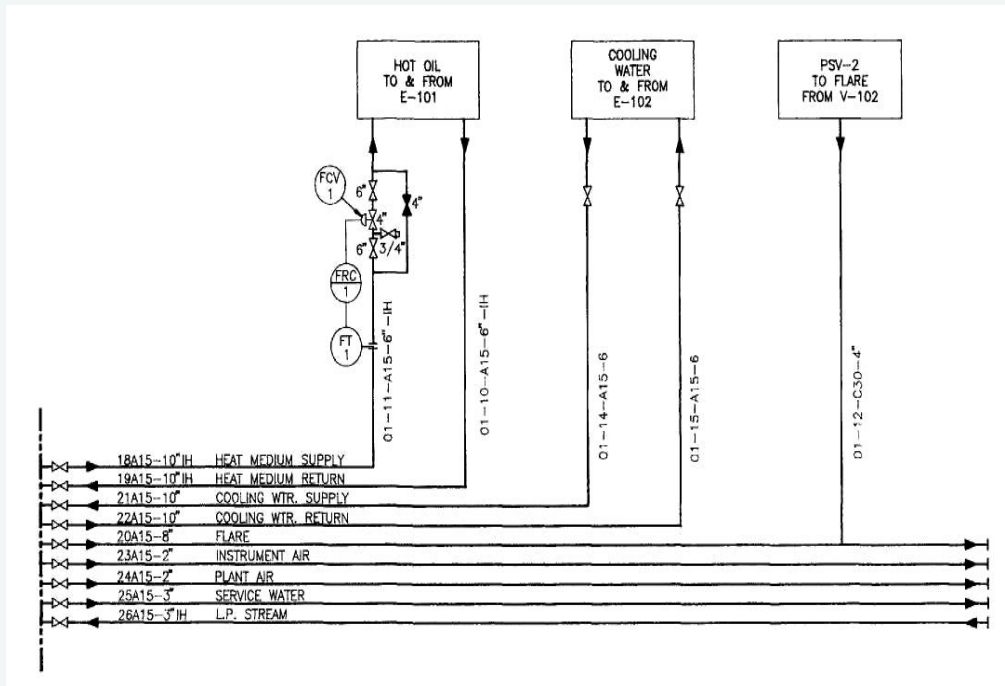


Figure 3.7 : Utility Flow Diagram

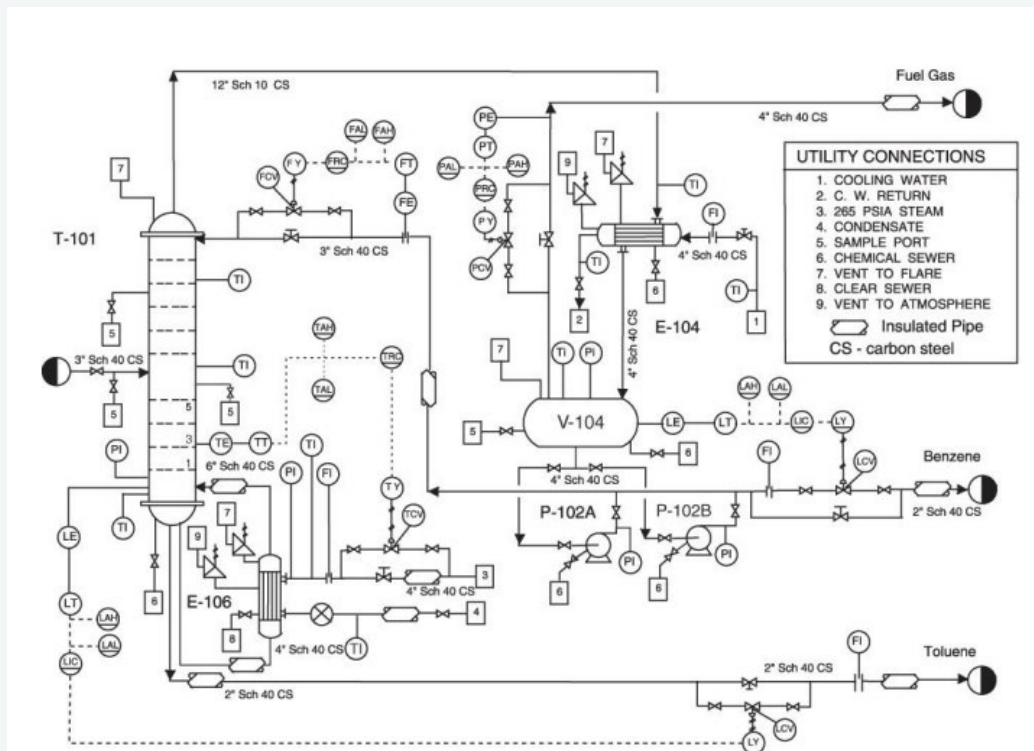


Figure 3.8 : Utility Flow Diagram

3.5 Piping and Instrumentation Diagram (P&ID)

The P&ID is based on the process flow diagram and shows the technical realization of a process using graphical symbols to represent equipment, piping and instrumentation (ISO 10628-1, 2014). In other words, the P&ID shows the interconnection of process equipment and the instrumentation used to control the process. The Piping and Instrumentation Diagram is also known as Mechanical Flow Diagram (MFD).

Piping is the physical elements that interconnect the equipment and in which the process streams flow. Piping comes in different sizes and materials. The process engineer is responsible to specify the size and materials of the piping as well as any the thermal insulation that may be required. The term piping also includes accessories such as elbows, tees, valves, flanges, etc. The most common material is carbon steel. Other metals, such as various grades of stainless steel, and plastic materials, such as PVC, Teflon, are also used.

P&ID schematics also show the instruments and valves that monitor and control the flow of materials through the pipelines. Instrumentation is a term that refers to the devices used to measure, control, and monitor the process variables. These variables can be flow, temperature, pressure, liquid level, viscosity, and others. Control valves and relief valves are also an important part of the instrumentation.

P&ID will be the basis for developing the piping drawings and for specifying the instrumentation and control systems. It is a rather detailed document and for this reason, each P&ID covers only a small part of the process. So, a typical petrochemical unit may have 20 to 30 P&IDs, while larger units may well have 60 to 100.

3.5.1 Uses Of P&ID

- Mainly as a reference for actual plant operation including for maintenance job.
- To specify the actual single unit of instrumentation, control valve, safety valve, flow orifice, electric motor, trip sequence and trip number.
- The connection and type of sensing medium for any controller
- Location of any controller and instrumentation on the pipe line
- To specify the material of pipe line

3.5.2 Classification of P&ID

- Legends and Symbol Diagrams/Standard Details - shows the meaning of the graphical elements and symbols used on the P&ID. (Identification and numbering system, general symbols, equipment symbols, piping symbols, instrument symbols).
- Process P&ID - Process P&ID's define on-plot process unit design, as well as off-plot tankage and shipping systems.
- Utility Plant P&ID - Utility Plant P&ID's define utility units such as cooling towers, air compressors, boilers, unit drain collection systems, fire water systems, and water treatment plants.
- Utility Distribution P&ID - Show the distribution of utilities within a given process. Valving and instrumentation on piping are shown for main headers up to and including branch root valves.
- Interconnecting (Rack) P&ID –They are the connecting link between individual process, utility plant, and utility distribution P&ID's. They are usually prepared for the offsite pipe racks and link the various process and utility plants.
- Vendor P&ID - They are prepared for systems which support major equipment packages.

3.5.3 Characteristic of Piping and Instrumentation Diagram

It includes :

- Basic operational & start-up information.
- Flow direction.
- Graphic symbols of equipment.
- Equipment numbers and description.
- Piping details (size, identification).
- Line continuation numbers.
- All valves and their identifications.
- Valve fitting.
- Interconnections reference (from one P&ID to another P&ID)/
- Vents & drains.

- Safety relief valves.
- Control loop & instrumentation.
- DCS inputs
- Interlocks
- Vendor & contractor interface

It should NOT include:

- Instrument root valves
- Control relays
- Manual switches
- Primary instrument tubing and valves
- Pressure, temperature and flow data
- Elbow, Tees and similar standard fitting
- Extensive explanatory notes

3.5.4 Comparison between PFD and P&ID

PFD	P&ID
Simple representation	A comprehensive representation
Shows major equipment and major process lines	Shows all equipment and all process lines
Shows major operating conditions (flow, temperature and pressure)	Shows piping, valves and instruments that monitor and control the process
Provide a basis for P&ID	Important in the design process

EXERCISE 3

1. List FOUR (4) types flow diagram
2. State the importance of flow diagram in petrochemical plant
3. List the characteristics of a block flow diagram
4. State THREE (3) item description should not be included in P&ID.
5. Based on Figure E3.1 below, convert the block flow diagram into a process flow diagram.

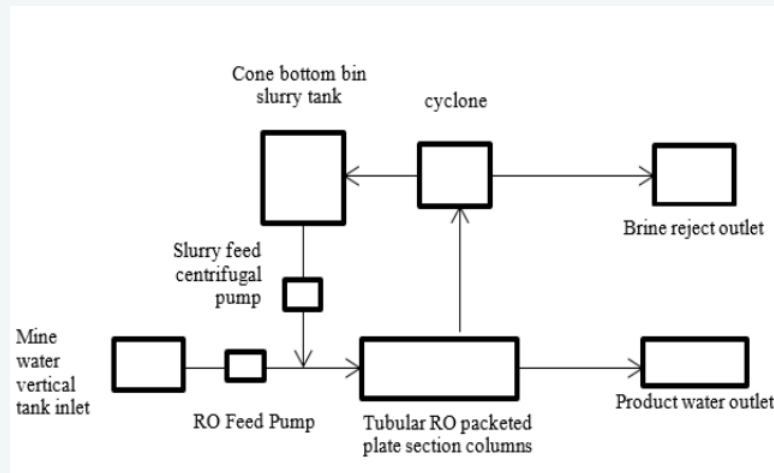


Figure E3.1

4.0 IDENTIFICATION SYSTEM IN PROCESS DIAGRAM

Key Learning Points

- Piping Identification System
- Equipment Identification System
- Instrumentation Identification System

P&ID contains important information, thus it is critical to the process plant apply tags or label to keep track of all the equipment, piping, valves, devices and more. The process equipment, piping and instrumentation are tagged with unit identification code. They contain letter code which describe about the elements and a reference number which is used for identification purposes.

Three main reason for the tagging are :-

- a. To ensure the similar object have unique tags so that identical valves, pumps, instruments etc can be uniquely identified.
- b. Possible to assemble the process plant in a structured manners so that additions, deletions, changes etc are possible from a whole units scale down to a single valve on a pipe at any location.
- c. It is contain scores of metadata that provides or links to more details including specifications, materials of construction, datasheet etc.

4.1 Piping Identification System

Piping is the physical elements that interconnect the equipment and in which the process streams flow. Piping comes in different sizes and materials. It is the duty of the process engineer to specify the size and materials of the piping and also the thermal insulation, if required. The term piping also includes accessories such as elbows, tees, valves, flanges, etc.

The most common material is carbon steel. Other metals, such as various grades of stainless steel, and plastic materials, such as PVC, Teflon, are also used.

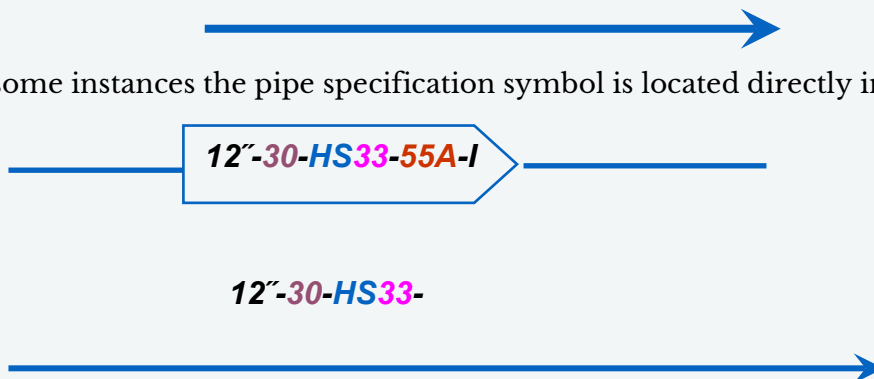
Purposes of Piping Identification System

- a. To ensure that the installation of pipes, insulation of pipes and valves done properly during the construction of the plant.
- b. It helps to make the replacement work properly if there is any damage.

Piping Identification System is shown in the form of letters, numbers and symbols in order:

- Simple
- Easy to read
- Does not take that much space

Pipe line symbol, is used in which to place this information



In other instances the specification information is written above the line

The general rule of the piping identification system will indicate :

- a. Line Size / Pipe Size / pipe diameter
- b. Fluid Code / Line Service (the product which is carried within pipeline)
- c. Pipe Material Specification
- d. Unit Number & Line Number
- e. Insulation (if required)

** A complete list of the designation is given in the P&ID legend sheets*

Sections of Piping Identification System (PIS):

a. Line Size

The Pipe Diameter is either in mm or inch unit.

- unit : mm / A, Example : 150A
- unit : inch(") / B, Example : 8B, 10"

b. Fluid Code (Pipe Service). Table 4.1 should be used as a general reference for a fluid code.

Table 4.1 Abbreviation of Fluid Code

Code	Fluid		Code	Fluid
A	Air		LN	Light Naptha
AC	Acid		LNG	Liquified Natural Gas
AF	Air Foam Solution		LO	Lube Oil
BA	Breathing Air		LS	Low Pressure Steam
BD	Flare and Blow Down		LPG	Liquified Petroleum Gas , Butane
BDH	Hot / Cold Blowdown		ME	Methanol
BFW	Boiler Feed Water and Condensate		MS	Medium Pressure Steam
BRR	Brine Return		NLG	Non Lead Gasoline
BRS	Brine Supply		LSC	Low Pressure Steam Condensate
BW	Ballast Water		N	Nitrogen
CA	Caustic		NG	Natural Gas
CF	Cold Flare		NH	Ammonia

Code	Fluid		Code	Fluid
CH	Chemical Component		NG	Natural Gas
CR	Crude		OW	Oily Water
CS	Chemical Sewer		OG	OFF Gas
CWR	Cooling Water Return		P	Process
CWS	Cooling Water Supply		PL	Process Liquid
DM	Demineralized Water		PG	Process Gas
DO	Diesel Oil		RE	Reformate
DS	Dilution Steam		RG	Regular Gasoline
DW	Domestic Water		RVH	High Pressure Warm Relief Vent
FG	Fuel Gas		RWL	Low Pressure Warm Relief Vent
FO	Fuel Oil		RW	Raw Water
FW	Fire Water		SG	CCR Regen Gas
H	Hydrogen		SO	Seal Oil
HC	Hydrocarbon		SH	Superheated Stream
HN	Heavy Naphta		ST	Saturated Stream
HS	High Pressure Steam		TW	Treated Water
HSC	High Pressure Steam Condensate		UA	Utility Air
IA	Instrument Air		UW	Utility Water
IS	Intermediate Pressure Steam		WW	Waste Water
KE	Kerosene		Z	Solvent

c. Piping Material Specification

The Piping Material Specification will describe the Category of the pipe, type of pipe material and type of service.

Class/Category of Pipe (References)

- Pressure Rating
- Temperature Rating

Type of pipe

- Type pipe material - Carbon Steel, Stainless Steel

Installation

Type of service

- Process, wastewater, gas flare, waste water, steam
- Hydrocarbon, Hydrogen
- Corrosive, Non Corrosive

Table 4.2 below shows some example of Piping Material Specification used in piping.

Table 4.2 : ASME Pressure Rating

ASME Pressure Rating		Code Identifier
CLASS 150		1
CLASS 300		3
CLASS 600		6
CLASS 900		9
CLASS 1500		15
CLASS 2500		25

d. Unit Number & Line Number

- Number of unit /block / process unit
- Number of pipeline

a) Insulation and Tracing (if required)

Installed to the pipe for insulation. Insulation may be an insulation type, thickness and / or an indication of whether the line is heat traced.

The thickness of insulation is measured in units of mm .

Combination of insulation class may also be used. Eg: P/A would indicate that the pipeline required personnel protection Insulation and acoustic protection

Table 4.3 : Abbreviation symbol for insulation type

Symbol	Type of Insulation
A	Acoustic Protection
C	Cold conservation
D	Dew prevention insulation
E	Electrical tracing
ET	Electric Traced and Insulated
F	Fireproof insulation
J	Steam Jacketed line
H	Heat Conservation
L	Cold and acoustic insulation
P	Personnel Protection
S	Steam Trace with termon cement
SJ	Steam Jacketed
ST	Steam Traced and Insulated
T	Steam Trace
TC	Steam trace with cushion
UG	Underground piping
XJ	Jacketed
WT	Water Tracing

The piping identification can be write as the following format ;

A-00- XX -BBCCC-DD-11-EE

00-A-BBCCC-XX-DD-11-EE

Code	Description
00	Diameter of the pipe
A	Service or fluid code
BB	Line/process unit number For unit 100 , Y is 1 For unit 5500, YY is 55
CCC	Line sequencing number. The piping line number assigned with 3 digit number starting from 001 to 999
XX	Piping Material Specification
DD	Insulation type
11	Insulation thickness
EE	Tracing

Example 4.1

Interpret the Piping Identification System below :

P - 2" - 1P2 – 01052

Answer :

- P - Service "PROCESS"
- 2" - Pipe Diameter 2 Inches
- 1P2 - Piping Material Specification
 - CLASS 100/150 lb RATING
 - 29°C TO 399°
 - Pipe Material : Carbon Steel
 - Pipe Is Use For:
 - Process Water, Fuel Gas, Gas Flare, Fire Water Pressure Drains,
 - Service Water, Low Pressure Steam & Steam Condensate, Waste Water
- 01 - Unit Number
- 052 - Line Number is 52

Example 4. 2

Interpret the Piping Identification System below :

P - 18" - 1H3 - 02077 - P – 65

- P - Service "Process"
- 18" - Pipe Diameter 18 Inches
- 1H3 - Piping Material Specification
 - 29°c To 371°C
 - Carbon Steel
 - Hydrocarbon
 - Hydrogen
- 02 - Line Unit Number is 2
- 077 - Line Number is 77
- P - Insulation For Personal Protection
- 65 - Insulation Thickness - 65 mm

Example 4.3

Interpret the Piping Identification System below :

SG - 4" - 1P2X - 07011 - H - 100 - ST

SG	-	Service "Ccr Regen Gas"
4"	-	Pipe Diameter 4 Inches
1P2X	-	Piping Material Specification
	-	- 0°c To 260°c
	-	- Pipe 316 Stainless Steel
	-	- Used In :
		Corrosive Hydrocarbon Process
		Corrosive Water Process
07	-	Unit Number
011	-	Line Number is 11
H	-	Insulation for heat conservation
100	-	Insulation thickness - 100 mm
ST	-	Steam traced & insulated pipe

Example 4.4

Interpret the Piping Identification System below :

200 – P3010 – 3C108 - E - 50

200	-	Pipe diameter is 200mm
P	-	Service 'Process'
3	-	Process unit Number 300
010	-	Line Number is 10
011	-	Line Number is 11
3C108	-	Material Piping Specification, ASME Pressure Rating Class 300
E	-	Electrical Insulation
50	-	Insulation thickness 50 mm

4.2 Equipment Identification

Each item of equipments, will have a unique identification. The identification will consists combination of letters or numbers. The identification of the equipment may differ from project to project. The equipment may be identify by its type, number or by name as the following format :

XX-YYYZZ A/B

Code	Description
XX	One or two letter code that identify the equipment classification or functions (refer to Table xx)
YYY	Consists of one, two or three letter code that identify the process unit. For unit 100 , Y is 1 For unit 5500, YY is 55 For unit 75600, YYY is 756
ZZ	Two digit showing the serial number of the equipment
A/B	To identify the equipment use for the same purpose, identification of parallel unit or back up unit

- General equipment stated as XX-YYYZZ
- Equipment with back up or spare unit or parallel unit stated as XX-YYYZZ A or XX-YYYZZ B

- Any existing which is to be replaced with new equipment in the same service will retain its old equipment number with the exception that a “N” or “R” will be added to the end such as from XX-YYYY to XX-YYYY R or XX-YYYY N.
- Any equipment that is being completely removed from the service, will have its number retired and not reused for another equipment.
- Equipment tag number or identification should be displayed near the symbol used for the equipment.
- The equipment is identified with a classification code and followed by a unique number. Table 4.3 below shows the equipment classification.

Table 4.3: Equipment classification symbol

Symbol	Type of Equipment
A	Special Item
B	Burner, Boiler, Furnace
C	Column,
CT	Cooling Tower
D	Drum,, Silencer
E	Heat Exchanger, De-superheater, Electrical Heater, Condenser, Reboiler, Condenser,
F	Filter, Separator, Ejector
G	Generator, Grinders
H	Conveyor, Scraper, Crane, Hoist, Heater
K	Compressor, Blower, Fan
M	Motor
N	Centrifuge, Mixer, Agitator
P	Pump
R	Reactor, Secondary Reformer
S	Crusher, Screen, Chute
T	Tanks, Tower
U	Vacuum Equipment, Oil Unit
V	Vessel, Stack, Ducts
W	Weigh Scale
Z	Miscellaneous Equipment

Example 4.5

Interpret the Equipment Identification System below :

P-101 A/B

Answer :

- P** : the equipment as a pump.
- 1** : the pump is located in area 100 of the plant. (process unit 100)
- 01** : this specific pump is number 01 in unit 100.
- A/B** : indicates that a backup pump is installed. Thus, there are two identical pumps P-101A and P-101B. One pump will be operating while the other is idle.

Example 4.6

Interpret the Equipment Identification System below :

K-13420A and K-13420B

- K** : the equipment is a compressor.
- 134** : the compressor is located in area 13400 of the plant. (process unit 13400)
- 20** : this specific compressor is number 20 in the same unit (process unit 13400)
- A/B** : indicates two identical compressor (either working in parallel or in series or compressor with single spare)

Example 4.7

Interpret the Equipment Identification System below :

D-2003

Answer :

- D** : the equipment as a drum.
- 20** : the drum is located in area 2000 of the plant (process unit 2000)
- 03** : this drum is number 03 in process unit 2000.

The minimum equipment detail shall be required to be provided in P&ID as shown in Table 4.4.

Table 4.4 : Equipment Description

Equipment	Description
Tanks and Vessels	Height Diameter Orientation Pressure Temperature
Pumps	Pump capacity Differential head Rated power
Compressor	Operating Power
Heat Exchanger	Operating Heat Duty
Heaters	Type Tube Pressure Tube Temperature Duty Fuel Material of Construction

Figure 4.1 show the example of equipment description in Piping and Instrumentation Diagram. The information may be vary depends on the type of equipment.

<i>Template:</i>	<i>Example:</i>
EQUIPMENT TAG	V-200
EQUIPMENT NAME	ACCUMULATOR VESSEL
SIZE/CAPACITY	900mm Ø x 1200 mm T/T
DESIGN PRESS.	30 barg
DESIGN TEMP.	100 °C

Figure 4.1 : Example of Equipment Description

4.3 Instrumentation Identification

Instrumentation Identification System in P&ID is based on the Standard ANSI /ISA 5.1 (Instrumentation Symbols and Identification). The Identification System provides methods for identifying instrumentation required to monitor, control, and operate a processing plant, unit operation, boiler, machine, or any other system that requires measurement, detection, indication, control, modulation, and/or switching of variables or states. Instrument Identification/Tag Numbers are also called Instrument Identification Number, Instrument Tag Number, Instrument Number, or Tag Number. Instrumentation Identification can be written in the following format :

XYX-CZZLL

Code	Description
XYX	Represent the function of the instrument
C	designated the instrumentation area within the plant
ZZ	designates the process unit number
LL	designates the loop numbers

Instruments are identified by as shown in Figure 4.2 :

- a) Their location
- b) Their function
- c) Their Number

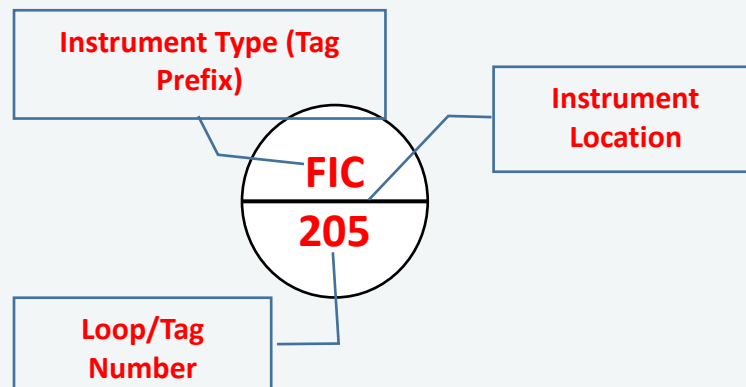


Figure 4.2 : Example of the instrument with identification

Location of Instrument

Location of instrument is defined by a horizontal line, lines, or the absence of lines. These lines specify the instrument's location and whether or not it is accessible to the operator. Refer Table 2.15 in Chapter 2 for more details of symbols to define location of the instrument.

Function of Instrument

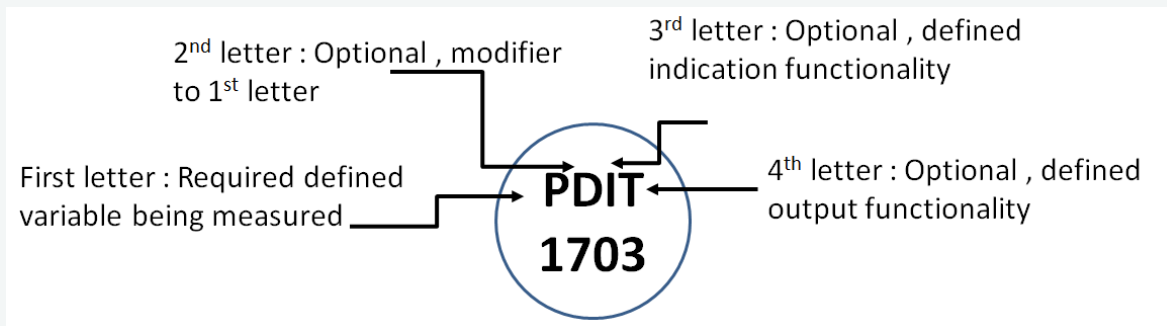
Function of the instrument is indicated by a series of letters contained within the top half of the bubble/ circle. The first letter identifies the measured or initiating variable, the second letter is a modifier, and the remaining letters identify the function.

For example :

LG : Level Gauge

LALL : Level Alarm Low-Low

FIC : Flow Indicator Controller



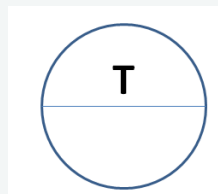
The first letter indicates the types of process variable (variable being measured) the instrument is used for; e.g

P : Pressure

T : Temperature

F : Flow

L : Level

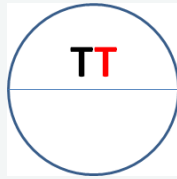


When a symbol contains 2 letter, the 2nd letter indicates the function of the instrument.

C : Controlling

R : Recording

T : Transmitter



This functional identifier represents a Temperature Transmitter

If a symbol has 3 or 4 letters, the 2nd letter provide the information (modifier) of the 1st letter. While 3rd letter indicate the functionality & 4th letter indicate output functionality.

Example : PDAH

P : Pressure

D: Differential

A: Alarm

H: High

Thus, it is Pressure Differential Alarm High

Refer Table 2.18 in Chapter2 to name the function of the instrument.

Typical instrument letter combination are shown in Table 4.5

Table 4.5 : Instrument Letter Combination

First-Letters	Initiating or Measured Variable	Final Element	Controllers				Switches and Alarm Devices ^a			Transmitters		
			Recording	Indicating	Blind	Self-Actuated Control Valves	High**	Low	Comb	Recording	Indicating	Blind
A	Analysis	AV	ARC	AIC	AC		ASH	ASL	ASHL	ART	AIT	AT
B	Burner/Combustion	BZ	BRC	BIC	BC		BSH	BSL	BSHL	BRT	BIT	BT
C	User's Choice											
D	User's Choice											
E	Voltage	EZ	ERC	EIC	EC		ESH	ESL	ESHL	ERT	EIT	ET
F	Flow Rate	FV	FRC	FIC	FC	FCV, FICV	FSH	FSL	FSHL	FRT	FIT	FT
FQ	Flow Quantity	FQV	FQRC	FQIC			FQSH	FQSL			FQIT	FQT
FF	Flow Ratio	FFV	FFRC	FFIC	FFC		FFSH	FFSL				
G	User's Choice											
H	Hand	HV		HIC	HC				HS			
I	Current	IZ	IRC	IIC			ISH	ISL	ISHL	IRT	IIT	IT
J	Power	JV	JRC	JIC			JSH	JSL	JSHL	JRT	JIT	JT
K	Time	KV	KRC	KIC	KC	KCV	KSH	KSL	KSHL	KRT	KIT	KT
L	Level	LV	LRC	LIC	LC	LCV	LSH	LSL	LSHL	LRT	LIT	LT
M	User's Choice											
N	User's Choice											
O	User's Choice											
P	Pressure/ Vacuum	PV	PRC	PIC	PC	PCV	PSH	PSL	PSHL	PRT	PIT	PT
PD	Pressure, Differential	PDV	PDRC	PDIC	PDC	PDCV	PDSH	PDSL		PDRT	PDIT	PDT
Q	Quantity	QZ	QRC	QIC			QSH	QSL	QSHL	QRT	QIT	QT
R	Radiation	RZ	RRC	RIC	RC		RSH	RSL	RSHL	RRT	RIT	RT
S	Speed/Frequency	SV	SRC	SIC	SC	SCV	SSH	SSL	SSHL	SRT	SIT	ST
T	Temperature	TV	TRC	TIC	TC	TCV	TSH	TSL	TSHL	TRT	TIT	TT
TD	Temperature, Differential	TDV	TDRC	TDIC	TDC	TDCV	TDSH	TDSL		TDRT	TDIT	TDT
U	Multivariable	UV										
V	Vibration/Machinery Analysis	VZ					VSH	VSL	VSHL	VRT	VIT	VT
W	Weight/Force	WZ	WRC	WIC	WC	WCV	WSH	WSL	WSHL	WRT	WIT	WT
WD	Weight/Force, Differential	WDZ	WDRC	WDIC	WDC	WDCV	WDSH	WDSL		WDRT	WDIT	WDT
X	Unclassified											
Y	Event/State/Presence	YZ		YIC	YC		YSH	YSL				YT
Z	Position/Dimension	ZV	ZRC	ZIC	ZC	ZCV	ZSH	ZSL	ZSHL	ZRT	ZIT	ZT
ZD	Gauging/Deviation	ZDV	ZDRC	ZDIC	ZDC	ZDCV	ZDSH	ZDSL		ZDRT	ZDIT	ZDT

Instrument Tag Number or Loop Number

Loop Number should be assign to identify the control loop.

Example 4.8

Interpret the instrumentation numbering below

- a. LIC 10003
- b. FRC 82516

Answer

- a. LIC 10003

L = Level shall be measured
IC = Indicating controller
100 = Process unit no. 100 in the area of number 1
03 = loop number 3

- b. FRC 82516

F = Flow shall be measured
RC = Recording controller
825 = Process unit no. 825 in the area of number 8
16 = loop number 16

EXERCISE 4

1. Determine the following PIS
 - a) P - 2" - 1P2 - 01052
 - b) P - 8" - 1P2 - 01004 - P - 50
 - c) CWS - 2" - W1A1 - 01004
2. In unit 8 of the urea plant, a pipe with diameter 75 mm and material specifications 1P2 was found to bring acid into the next unit. The pipe was equipped with 76 mm heat conservation insulation. The line was located at number 100. Construct a Piping Identification System (PIS) for the pipeline.
3. Interpret the equipment identification below :

R-201
 Kettle Reboiler
 Capacity : 40L
 Material : SS304

P-204
 AA Bottom Tank Pump
 Type : Centrifugal
 Nom. Q : 2.0m³/hr
 Max. Head : 27m
 Pwr Supply: 415VAC/3Φ

4. Explain the instrumentation symbols shown in Figure E4.1 below:

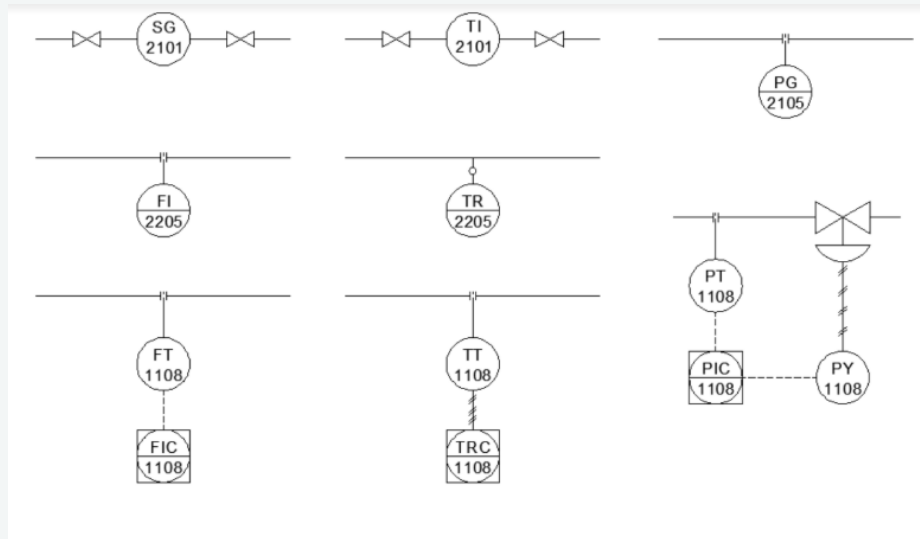


Figure E4.1

5.0 BASIC CONTROL SYSTEM

Key Learning Points

- Introduction of control System
- Advantages of control system
- Manual and automatic control
- Differences between open loop feed back control & feed forward control

5.1 Introduction

Control system are an integral part of modern society. Numerous applications are all around us. We find control system in all sectors of industry, such as quality control of manufactured products, automatic assembly line, machine tool control, power systems robotics, and many others.

5.1.1 Definitions

- Control System is a group of components, plants, processes assembled for controlling.
- A control system is a device or set devices to manage, command, direct or regulate the behavior of other devices or systems.
- In other word, a control a system provides an output or response for a given or stimulus as shown in Figure 5.1.

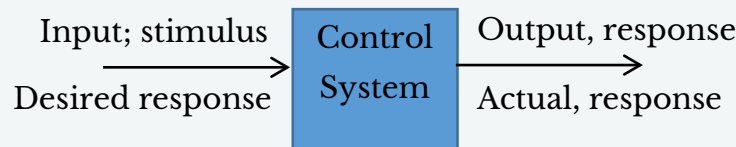


Figure 5. 1 Simplified description of a control system

Example : A control heating boiler is a process that produces heat as a result of a flow of fuel. This process is assembled from subsystem called fuel valves. Fuel valve actuators regulated the temperature of a room by controlling the flow of fuel into the boiler. Other subsystems, such a thermostats act as sensors, to measure the room temperature.

5.1.2 The Importance of Control System

- a. Safe plant operation
 - To keep the process variable within known safe operating limits
 - To detect dangerous situation as they develop and to provide alarms and automatic shutdown systems.
- b. Production rate
 - To achieve the design product output.
- c. Product quality
 - To maintain the product composition within the specified quality standard.
- d. Cost
 - To operate at the lowest production cost, commensurate with the other objectives.
- e. Stability
 - To maintain steady, automatic plant operation with minimal operator intervention.

5.1.3 Terminology in Control System

- a. **Process variable (PV)** is to measure of the process output that changes in response to changes in the manipulated variable. Common process variable include : pressure , flow , level , temperature , density , PH (acidity / alkalinity) , liquid interface, mass , conductivity.
- b. **Setpoint** is a value for a process variable that is desired to be maintained.
e.g : if a process temperature needs to keep within 5°C of 100°C, then the setpoint is 100°C.
- c. **Process Input (Input Variable)** is the outside variable that affects a process, it is can be classified to manipulated or disturbance variables; inputs may change continuously, or at discrete intervals of time.

- **Manipulated input/variable (MV) (control input)** can be adjusted by control system or by a process operator. The factor that is changed to keep the measured variable at setpoint.
 - **Disturbance variable** is a variable that affects the process outputs but that cannot be adjusted by the control system. It cannot be manipulated such ambient temperature.
- d. **Process Output (Output Variable)** —A characteristic of the process that affects the outside world. In a process control loop, this must be measurable and vary in a consistent way with the process input.
 - e. **Measured Output/variable** is a process variables we wish to control – is the condition of the process fluid that must be kept at the designated setpoint. Measured Output /variables are affected by two types of input variable
 - f. **Controller** : The hardware and software which compares the measured process output to the Setpoint, and calculates if the process input needs to change and by how much. (keep the process variable at desired value).
 - g. **Final control element** :last control element in the process control loop that manipulate the process variable.

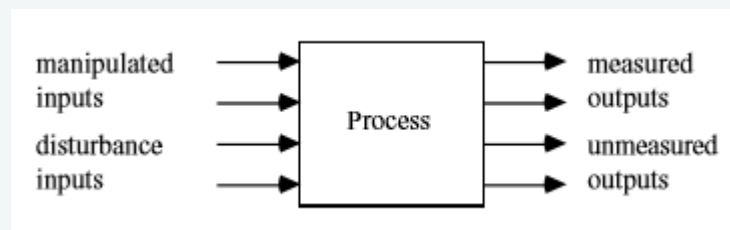


Figure 5. 2 : Input / output representation of control system

5.2 Control Loop Configurations

5.2.1 Open Loop System

In an open loop system, the controller is told what the desired process output and the controller sends a command to the actuator to achieve the output. Output has no effect on the control action. It is a system in which output is dependent on input but control action or input is totally independent of the output or changes in output of the system.

A general block diagram for open loop system is shown in Figure 5.3

- Does not have a loop
- Does not have corrective action.

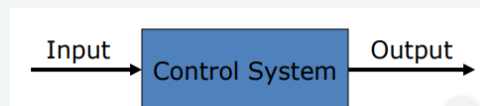


Figure 5.3 : Open loop system

5.2.2 Characteristic of Open Loop System

- Also known as a Manual Loop System.
- A characteristic of the open-loop controller is that it does not use feedback to determine if its output has achieved the desired goal of the input. This means that the system does not observe the output of the processes that it is controlling.
- The value of the controlled condition is continuously shown on an indicator / recorder.
- This type of control requires the operator to control the process variables.
- A reading of the instrument is taken periodically and the control value position is adjusted accordingly.
- The output of measuring element does not play a direct part in actuating the valve.
- Its only to function to provide information.
- This method is simple and low cost but limited applications.
- Its input does not depend on the output
- It does not have a loop

Advantages of Open Loop System

- Simple in construction and design.
- Economical.

- Easy to maintain.
- Generally stable.
- Convenient to use as output is difficult to measure.

Disadvantages of Open Loop System

- They are inaccurate.
- They are unreliable.
- Any change in output cannot be corrected automatically.

5.2.3 Applications Open Loop System

Figure 5.4 shows a block diagram of process control in open loop system for simple heat exchanger process.

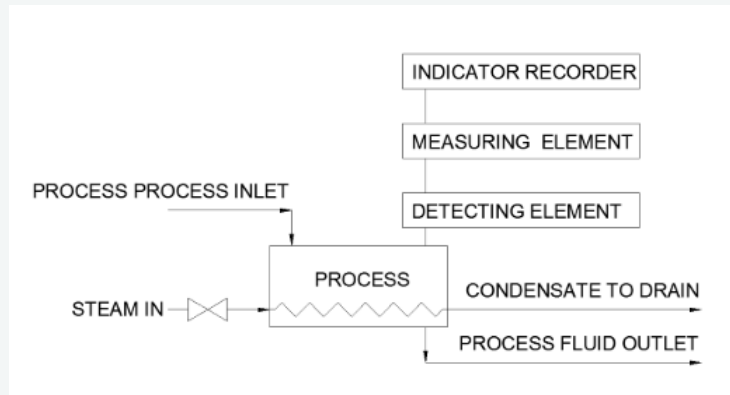


Figure 5.4 : Process control in open loop system

Detecting Element

This element responds directly to the value of the controlled condition.

It is an element which is used as a detector of change of a quantity and provides a response based on the quantity controlled.

Example, thermocouple, resistance thermometer element, Bourdon tube, diaphragm, restriction orifice, and displacer.

Measuring Element

Measuring element is used to measure and compensate for the reading of signals from the detecting element. Example, differential pressure units, manometer, Venturi meter, Rotameter, and potentiometers.

Indicator Recorder

Displays and records the controlled variable reading. Examples, flow meter, pressure gauge indicator and recorder.

Manual Control System

This system requires the operator to perform process control.

The operator will monitor the process and control the variables manually.

Open Loop System : Temperature Control System

Figure 5.5 shows schematically the process manual and automatic control of a heat exchanger process loop.

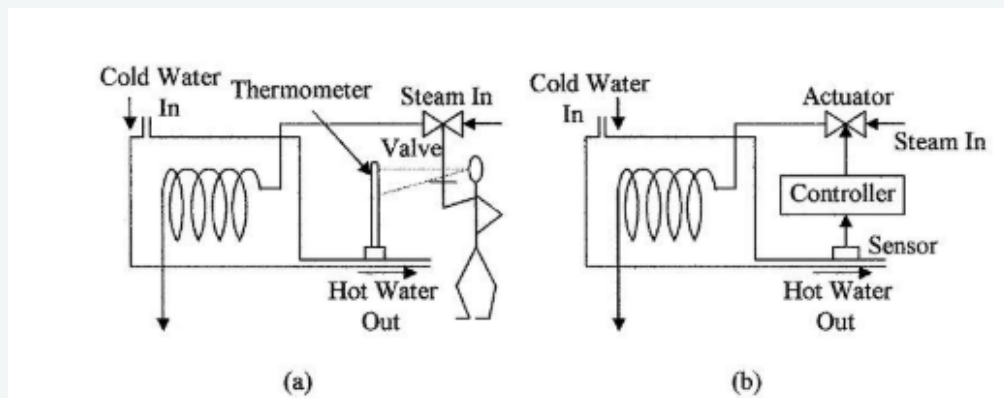


Figure 5.5 : Process control (a) shows the manual control of a simple heat exchanger process loop and (b) automatic control of a heat exchanger process loop.

The process operator serves as a controller, by observing the measured value indicated on the thermometer dial, and adjusting the steam valve accordingly. Provided the operator is present in this capacity, then the closed loop system is formed. The system will change to open when the operator leaves.

Manual Control

Advantages of Manual Control	Disadvantages of Manual Control
• The process is easy and cost-effective • Actions can be performed in circumstances beyond our control. • Suitable for start-up plant.	• Need the operator to observe or monitor • Effect the production quality and • Security limited application

5.2.4 Conventional control system

5.2.4.1 Pressure Control System

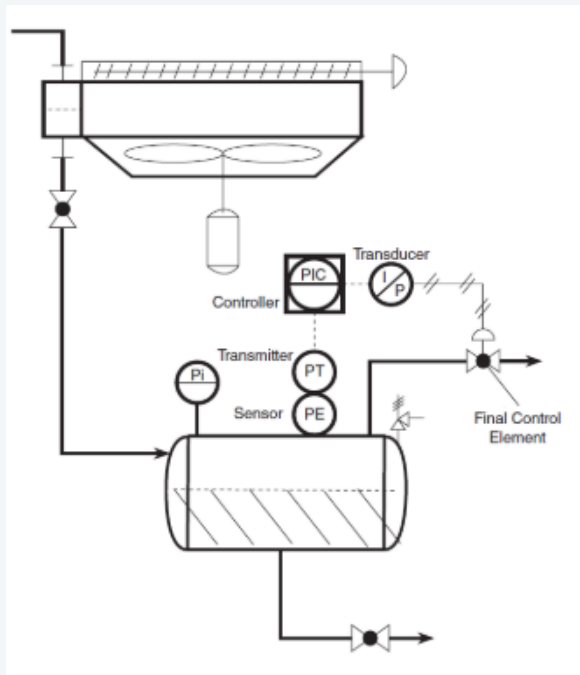


Figure 5. 6: Physical diagram of pressure control system.

- Uses the five elements of the control loop.
- The area to be controlled is a special vapor-disengaging cavity that allows vapors or gases that are compressible to be controlled at a set point.
- The one area that changes consistently is the first primary elements and sensors.
- Use devices to detect pressure changes.
- Pressure changes can effect temperature, level and flow.
- Pressure changes the boiling point of chemicals, reaction rates, and the speed at which fluids flow through piping.

5.2.4.2 Flow Control System

This open loop control strategy is shown in Figure 5.7, where flow control system was presented.

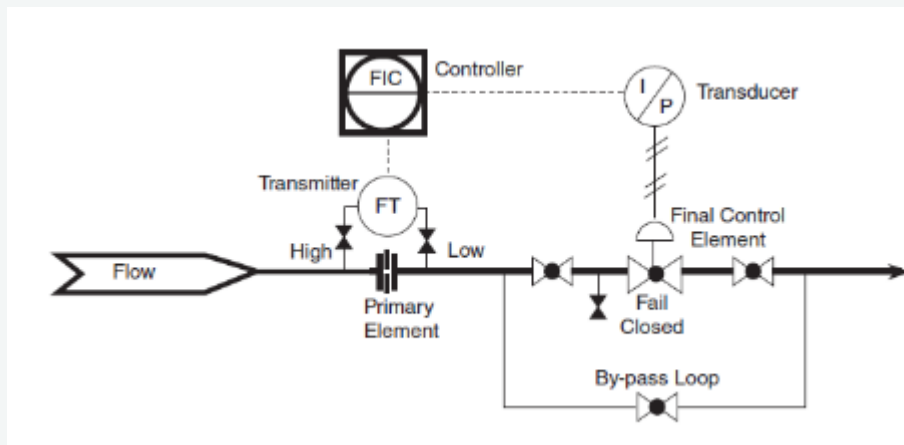


Figure 5. 7: The physical diagram of a control loop flow control system.

Flow control loops are considered fast loops because they respond quickly to changes. Therefore, flow control equipment must have fast sampling and response times.

Are typically designed so that a measurement of the flow rate is taken first and then flow is interrupted or controlled downstream.

Start at the primary element and work their way back to the final control element.

Primary elements:

- Orifice plates
- Flow nozzles
- Pitot tubes
- Magmeters
- Turbine meters
- Mass flow meters
- Nutating disks
- Oval gears
- Venture meters
- Target flow meters
- Integral orifice flow meters
- Annubar pitots

Typically used in conjunction with a transmitter.

5.2.4.3 Level Control System

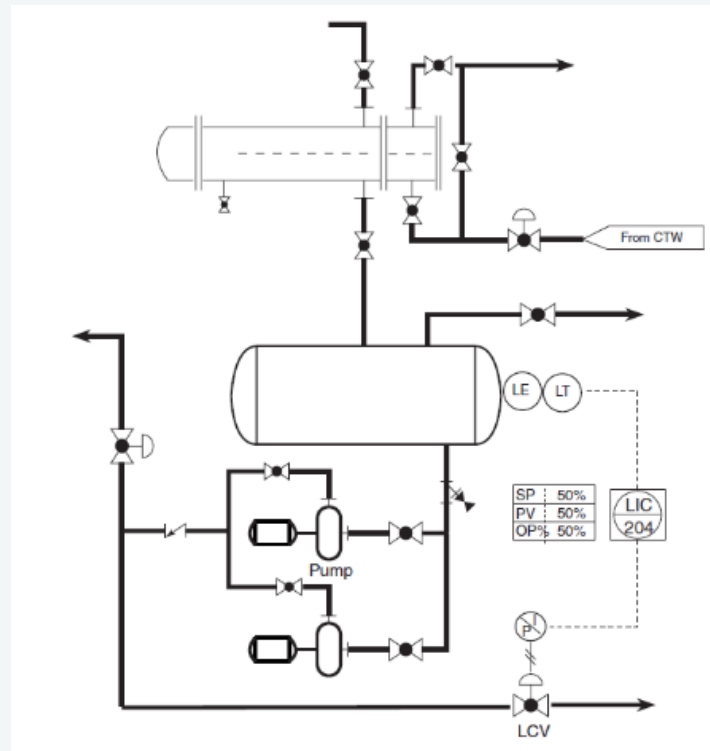


Figure 5. 8: Physical diagram of level control system

- Applied to level control on any vessel or tank.
- The speed of changes in a level control loop largely depends on the size and shape of the process vessel) and the flow rate of the input and outflow pipes
- Uses:
 - ✓ Floats and float gauges
 - ✓ Displacers
 - ✓ Tapes and tape gauges
 - ✓ Differential pressure transmitters
 - ✓ Bubblers
 - ✓ Loas cells
 - ✓ Capacitance probes
 - ✓ Electromagnetic measuring devices
 - ✓ Nuclear measuring instruments

5.2.4.4 Temperature Control System

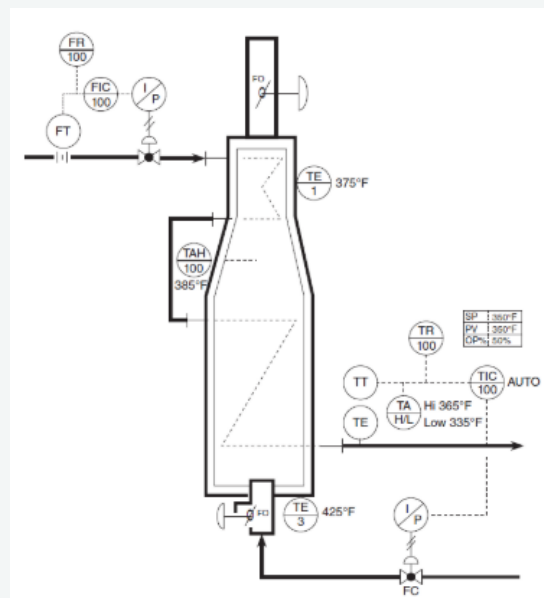


Figure 5. 9: Physical diagram for temperature control system

- Control the amount of heat or cooling a substance is receiving, for example, steam to a kettle reboiler, hot oil to a heat exchanger (preheater) or cooling water to a condenser (heat exchanger).
- Also control the amount of natural gas flowing to a burner.
- Temperature is controlled by reducing or increasing the opening on the valve.

5.2.4.5 Analytical Control Loop

Figure 5.10 depicts an example of how flow can be used to influence a compositional variable. The pH of a cooling water basin may be controlled by adding acid or caustic. When the PPM in the water basin exceeds operational guidelines, the analytical control loops removes a specified percentages of the basin water and replaces it with fresh water. Can be applied to a wide assortment of operational processes.

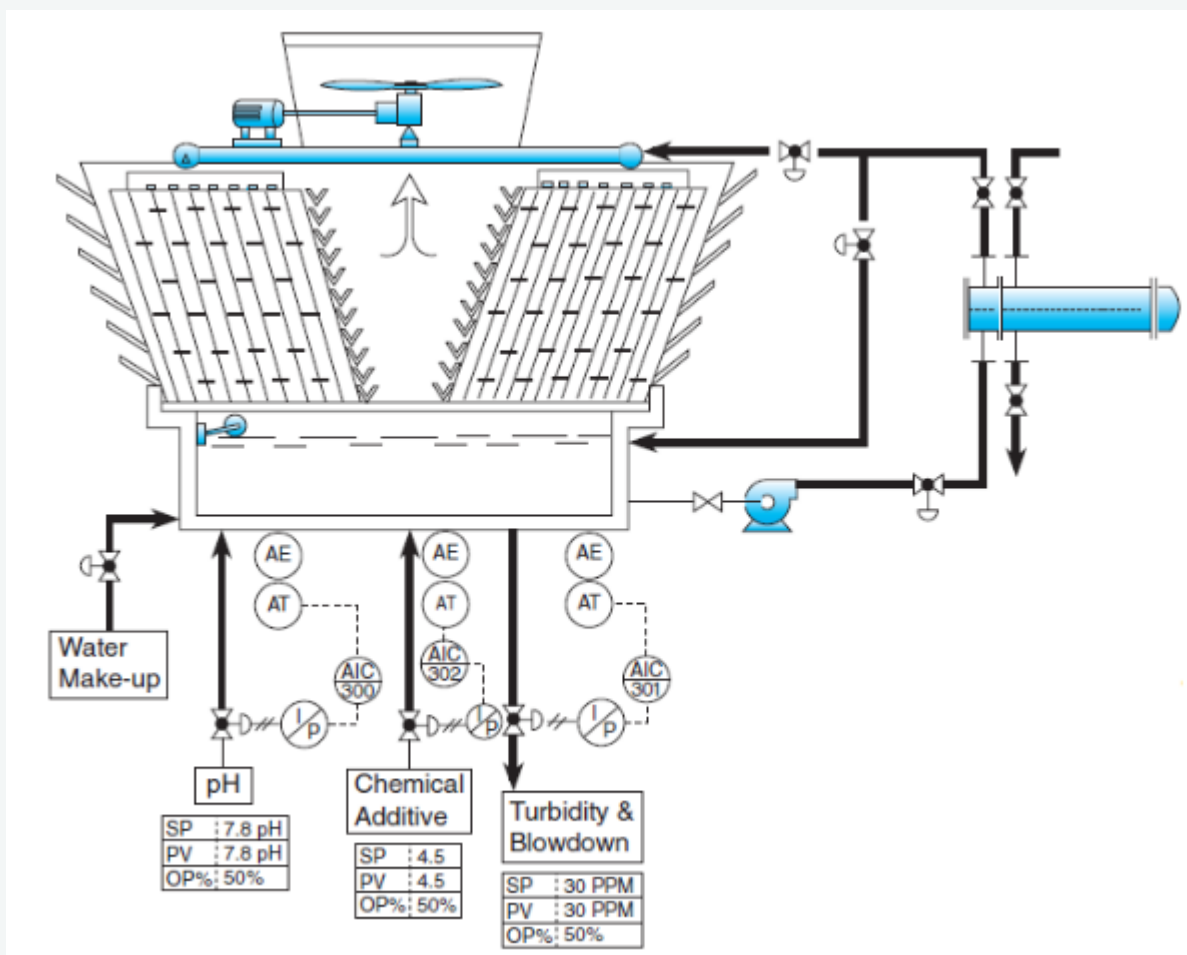


Figure 5.10: Typically designed to use flow to control some compositional variable.

5.2.5. Close Loop System

Figure 5.11 shows a block diagram of process control in close loop for temperature control system.

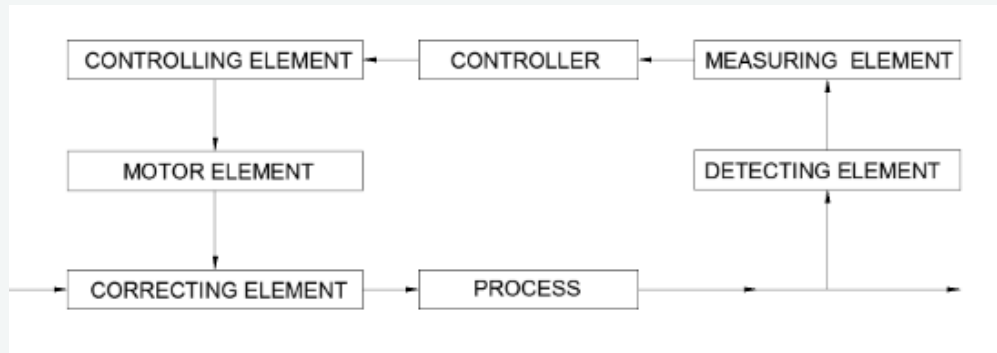


Figure 5. 11: Block diagram :Close Loop System for Temperature Control System.

5.2.5.1 Instrumentation in Close Loop System.

Detecting Element

This element respond directly to the value of the controlled condition.

It is an element which is used as a detector of change of a quantity and controlled.

Examples, thermocouple, resistance thermometer element. Bourdon tube, diaphragm, restriction orifice and displacer.

Measuring Element

As a measure and compensate for the reading of signals from the detecting element.

Examples diaphragm units manometer, Venturi meter, Rotameter and potentiometers.

Comparing Element

As an element to compare between the present value and set point reading.

Controlling Element

It is a signal which serves as a correcting element adjuster that controls the process.

Correcting Element

This element is used to control the processing system.

Typical correcting element for pressure flow level and temperature in a pipeline is control valve.

5.2.5.2. Application close loop system Temperature Control System

Figure 5.12 show a block diagram of process control in close loop for temperature exchanger process. While figure 5.13 represents a structure of close loop system.

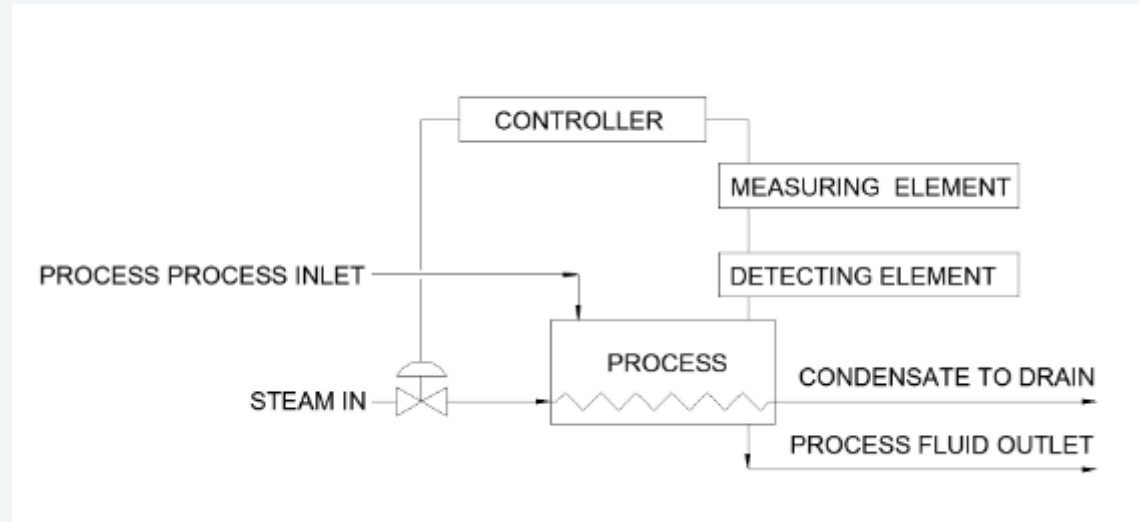


Figure 5. 12 Process control: Close loop system temperature control system

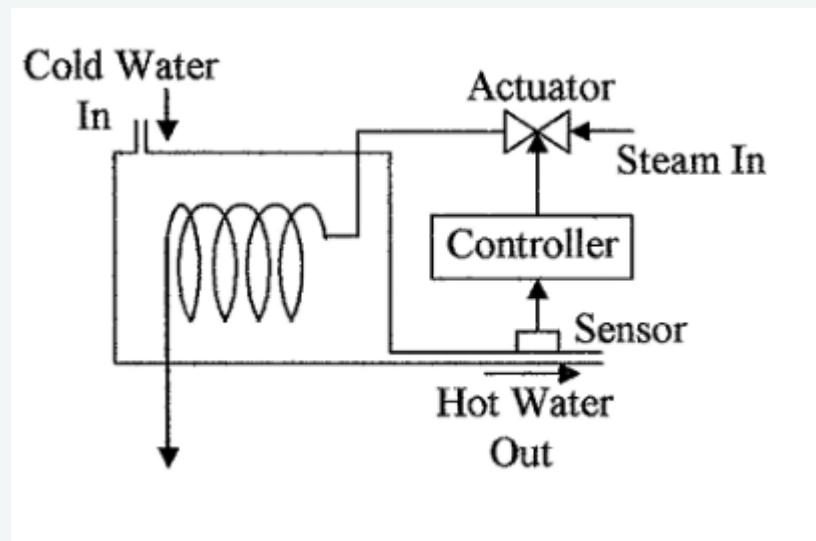


Figure 5. 13 : Structure of close loop system temperature Control System

Automatic Control

Most automatic control installations are closed loop systems.

Advantages of the system, including:

- The process operators are relieved of the more monotonous tasks, thus making better use of manpower.
- Steady conditions reduce the waste of raw materials and fuel.
- The plant can be operated nearer to its maximum capacity than it could with manual control.
- A more uniform product is obtained, conforming closer to the specification.
- Processes can be operated which could not be manually controlled.

Disadvantages of automatic control system are:

- The quality of product affected if not monitored accurately as we; as safety of equipment and personnel issue
- Limited application.

5.3 Feedback and Feedforward Control System

The basic concept of feedforward control is to measure important disturbance variables and take corrective action before they upset the process. In contrast, a feedback controller does not take corrective action until after the disturbance has upset the process and generated non-zero error signal. Simplified block diagrams for feedforward and feedback control are shown in figure 5.14.

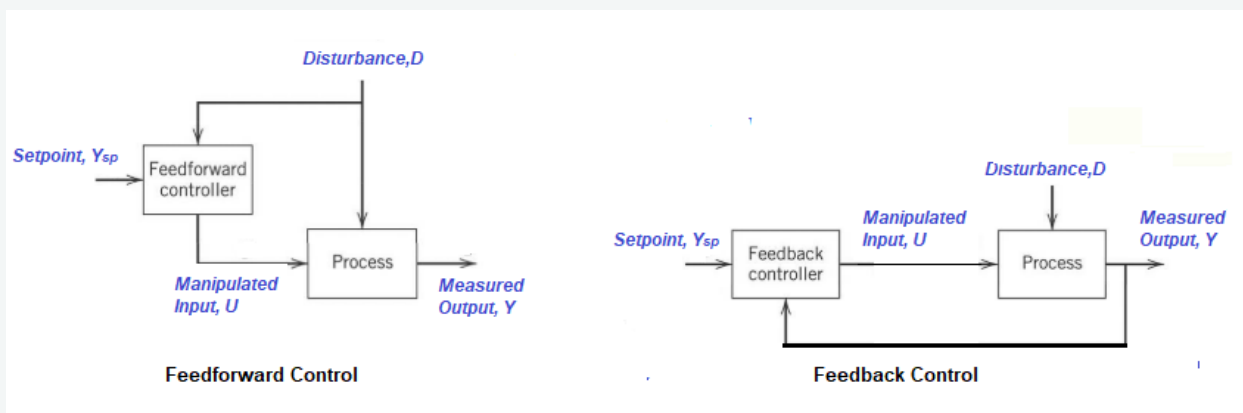


Figure 5.14 : Show a feedforward and feedback control with disturbance.

5.3.1 Feedback Control System

The process variable of interest is measured and the controller's output is calculated based on the process variable and its set point. Although external disturbance often the process variable, they are not used directly for control. Instead, if a disturbance affects the process variable, the control action is based on the process variable and not the disturbance.

Example 5.1 Feedback Control System in Level Control

Surge tanks are often used as intermediate storage for fluid streams being transferred between process units. Consider the process flow diagram shown in Figure 5.15, where a fluid stream from process 1 is fed to the surge tank; the effluent from the surge tank is sent to process 2.

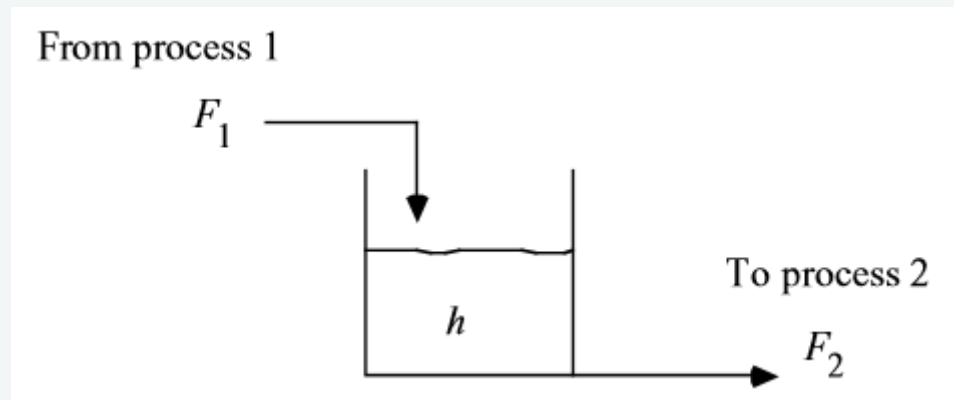


Figure 5. 15 Surge tank to control the level of fluid

The control objective is to maintain the height of the liquid within certain bounds. The set point is the desired height of the fluid in the tank. If it is too high it will overflow and if it is too low there may be problems with the flow to process 2.

The measured variable for a feedback control strategy is the tank height. Which input variable is manipulated depends on what is happening in process 1 and process 2.

Case 1 : Level Control with inlet flow rate manipulated

Figure 5.16 represents a diagram to understand level control process. where F_1 , the inlet flow rate will be use as manipulated variable, F_1 is adjusted to maintain a desired tank height.

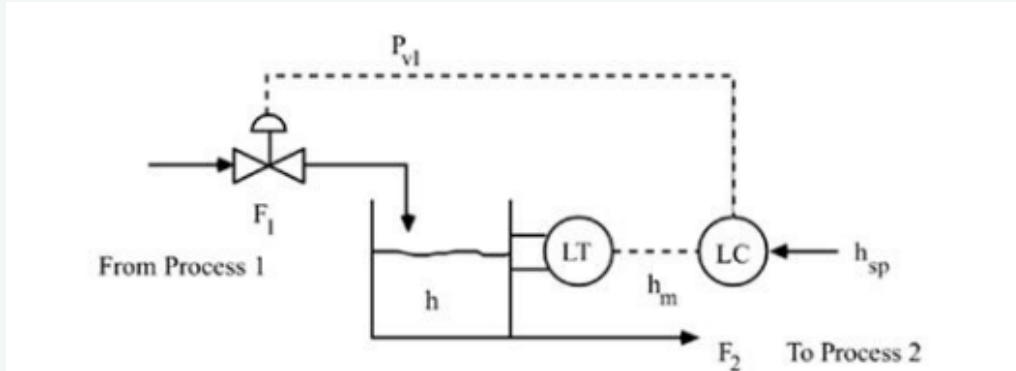


Figure 5. 16: Level control, inlet flow rate manipulated. The transmitter signals are shown as dashed lines. The level transmitter sends a signal to the level control, which sends a signal to the control valve.

Consider the level control shown in the figure 5.16. A level measurement device sense the level, h_m , The level transmitter (LT) sends the measured height of liquid in the tank (h_m) to the level controller (LC). The controller (LC) is comparing the tank height with the desired level, h_{sp} (the height set point) and sending a controller output (pressure signal) to the valve, which changes the valve position and therefore the volumetric flow of stream 1, F_1 . The changes of flow rates bring the tank level close to the desired setpoint .These signals are shown as dashed lines on the figure 5.16.

Case 2 : Level control with outlet flow rate manipulated

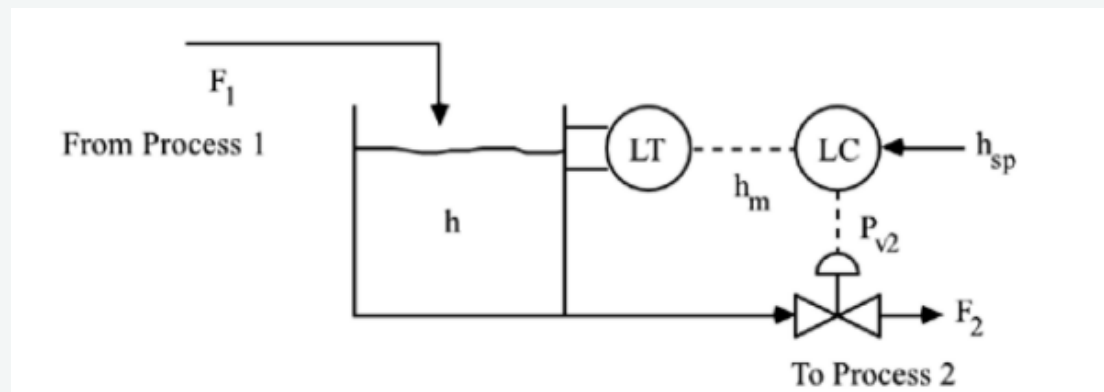


Figure 5. 17 : Outlet flow rate manipulates

The alternative process and instrumentation diagram for previous level control problem shown in Figure 5.17. The only difference between this and the previous instrumentation diagram is that F_2 rather than F_1 is manipulated.

For this feedback strategy, outlet flow rate, F_2 is manipulated while F_1 is a disturbance. Both of the feedback control strategies were based on measuring the output (tank height) and manipulating an input (the inlet flow rate in scenario 1 and the outlet flow rate in scenario 2). In each case the manipulated variable is changed after a disturbance affects the output.

Example 5. 2 Control the Liquid Level in a Boiler Drum

A boiler drum with a conventional feedback control system is shown in Figure 5.18. The level of the boiling liquid is measured and used to adjust the feed water flow rate. This control system tends to be quite sensitive to rapid changes in the disturbance variable steam flow rate as result of the small liquid capacity of the boiler drum. Rapid disturbance changes are produced by steam demands made by downstream processing units.

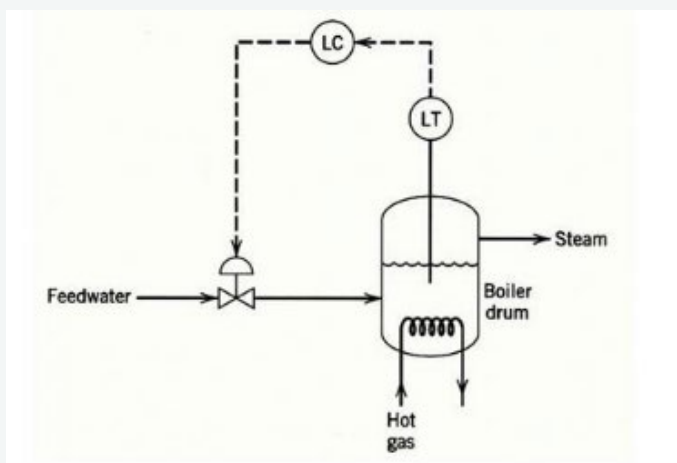


Figure 5. 18: The feedback control of the liquid level in a boiler drum.

For this case, the level of boiling liquid in the boiler is measured, the level transmitter (LT) sends the measured level to the Level Indicating Controller (LC). The LC is comparing the level of boiling liquid with the desired level (set point) and sending controller output to the valve, which changes the valve position and feed water flow rate.

In this system ;

Control Objective : to maintain the level of the boiling liquid at the certain value

Set point : desired level of the boiling the liquid

Manipulated variable : feedwater flow rate

Disturbance variable : steam flow rate

Output variable : level of the boiling liquid in the boiler

Example 5. 3: Control the Temperature in a furnace

Consider the temperature control problem shown in the Figure 5.19. A process furnace heats a process stream from near ambient temperature to a desired temperature. The process stream outlet temperature is controlled by manipulating the flow rate of fuel gas to the furnace.

The outlet temperature of process fluid is controlled by manipulating the valve position of the fuel control valve. Clearly disturbance in the fuel gas header pressure (upstream of the valve). Will end up changing the fuel gas flow rates as well as the process fluid temperature.

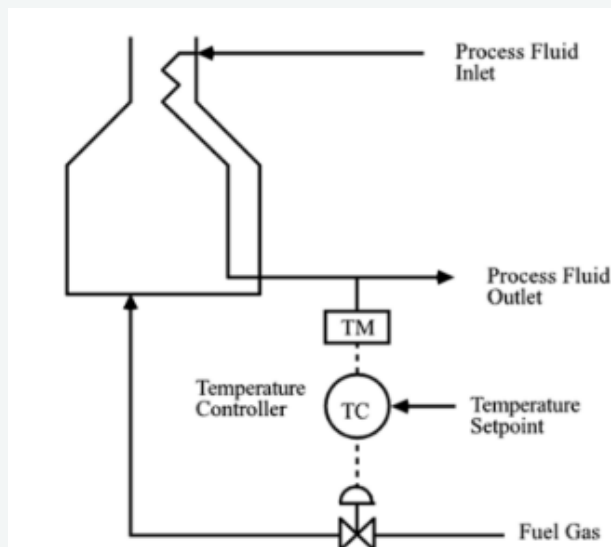


Figure 5. 19 : Feedback control of process outlet temperature

For the above example ;

What is the measured output?

What is the manipulated input?

What are possible disturbances ?

Advantages of Feedback Control System

1. Corrective action occurs as soon as the controlled variable deviates from the set point, regardless of the source and type of disturbance.
2. Feedback control requires minimal knowledge about the process to be controlled; in particular, a mathematical model of the process is *not* required, although it can be very useful for control system design

Disadvantages of Feedback Control System

1. No corrective action is taken until after a deviation in the controlled variable occurs.
2. Feedback control does not provide predictive control action to compensate for the effects of known or measurable disturbances.

5.3.2 Feed Forward Control System

In contrast to feedback control, feed forward control acts the moment a disturbance occurs without having to wait for a deviation in process variable. This enables a feed forward controller produces its control action based on a measurement of the disturbance.

In other word, feed-forward controller measures the disturbance variable and sends this value to a controller, which adjusts the manipulated variable.

When used feed forward control is almost always implemented as an add-on to feedback control. The advantage to a feed forward control strategy is that a disturbance variable is measured and a manipulated variable is changed before the output is affected.

Example 5. 4 : Feed-forward control strategy to control level of the fluid in the tank

Consider a case where the inlet flow rate can be changed by the upstream process unit and is therefore considered as disturbance variable.

If we can measure the inlet flow rate, we can manipulate the outlet flow rate to maintain a constant tank height. This feed-forward control strategy is shown in Figure 5.20, where FM is the flow measurement device and FFC is the feed-forward controller.

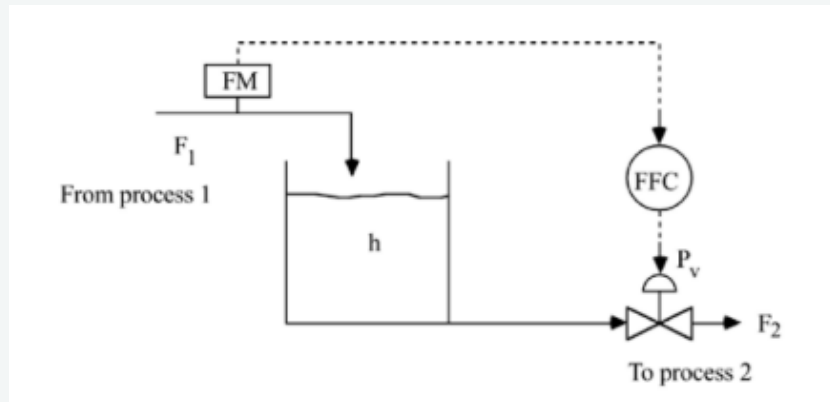


Figure 5. 20 : Feedforward control strategy. inlet flow rate is measured and outlet flow rate is manipulated.

Inlet flow rate, F_1 is the disturbance variable that directly affects the tank height. The value of F_1 is measured by the flow measurement, FM device, and the information is used by feed forward controller, FFC to change the manipulated input, outlet flow rate, F_2 .

Example 5. 5 The feedforward control of the liquid level in a boiler drum

The feedforward control scheme shown in figure 5.21. This provide better control of liquid level. The steam flow rate is measured, and the feedforward controller adjust the feedwater flow rate so as to balance the steam demand. Note that he controlled variable, liquid level , is not measured. As an alternative steam pressure could be measured instead of steam flow rate.

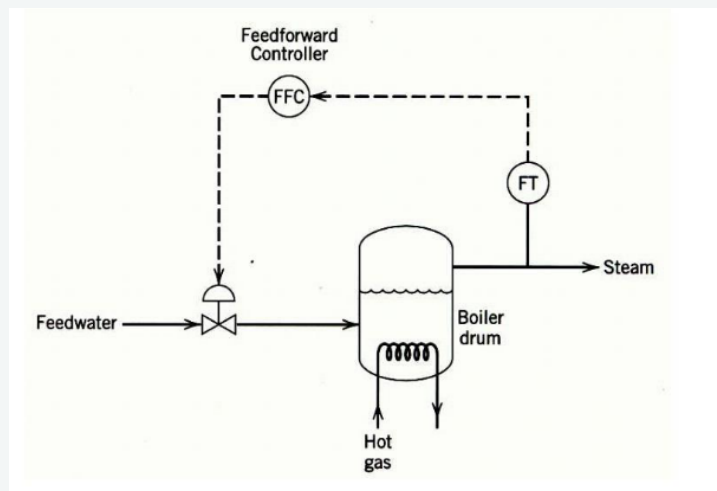


Figure 5. 21 : The feedforward control of the liquid level in a boiler drum.

Example 5. 6 Feed forward control of temperature in the furnace

Consider the furnace system as shown in Figure 5.22. One possible disturbance is the process fluid flow rate; if the flow rate increase 20%, then the required heat duty should also increase by 20%. The purpose of the feed-forward control strategy shown is to immediately change the fuel gas flow rate when a change in the process flow rate is sensed. For simplicity we assume that the fuel gas flow rate is directly manipulated in shown Figure 5.21.

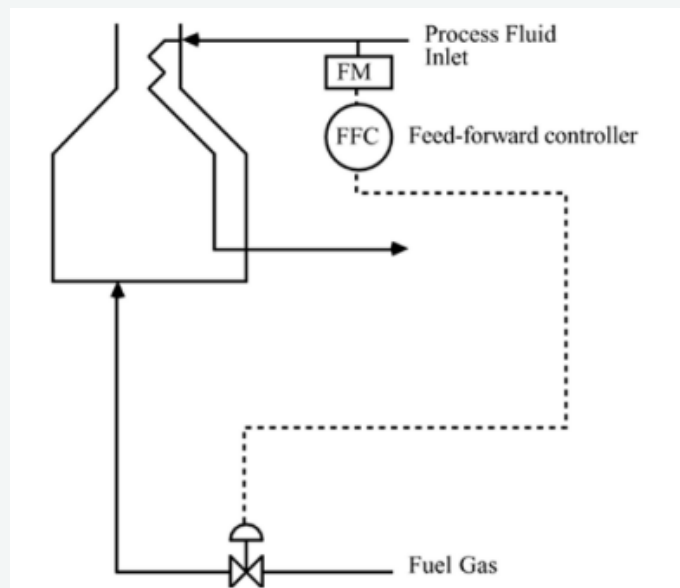


Figure 5. 22 : Feed-forward control of temperature based on the measured process fluid flow rate (disturbance input)

5.3.3 Feedforward-feedback control system

Difficulty of accounting for every possible load disturbance in a feed forward system, feed forward systems are often combined with feedback systems. Controllers with summing functions are used in these combined systems to total the input from both the feed forward loop and the feedback loop, and send a unified signal to the final control element

Feedforward control is used to reduce or eliminate the effects of measurable disturbances, while feedback control trim compensates for inaccuracies in the process model, measurement error, and unmeasured disturbances.

Example 5. 7 The feed forward-feedback strategy for control level of liquid in the tank

Figure 5.23 shows a feedforward -feedback loop in which both a flow transmitter (FM) and a level transmitter (LT) provide information for controlling a valve. The inlet flow rate is the measured disturbance, tank height is the measured output, and outlet flow rate is manipulated.

Feed-forward portion allows immediate corrective action to be taken before the disturbance (inlet flow rate) actually affects the output measurement (tank height). The feedback controller adjusts the outlet flow rate to maintain the desired tank height, even with errors in the inlet flow-rate measurement.

The inlet flow rate is the measured disturbance, tank height is the measured output, and outlet flow rate is manipulated.

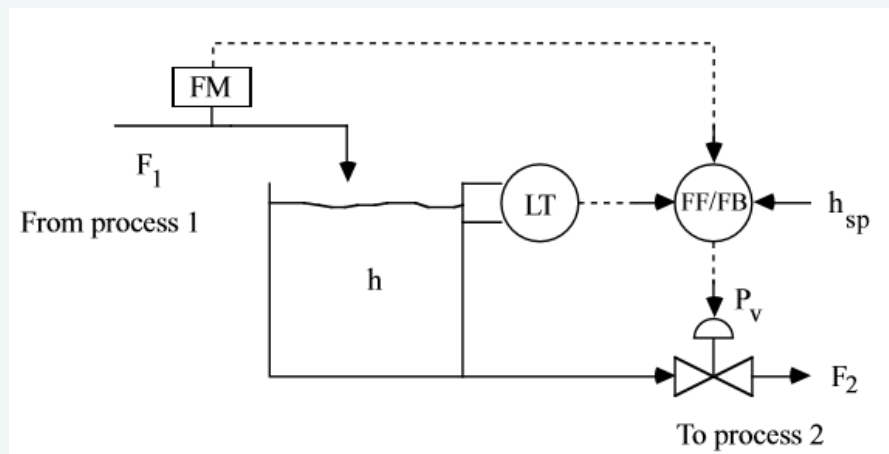


Figure 5. 23: Feed-forward/feedback control strategy

Example 5. 8 : Feedforward-feedback of the boiler drum level control

Figure 5.24 shows a feedforward-plus-feedback loop in which both a flow transmitter and a temperature transmitter provide information for controlling a valve. Controllers with summing functions are used in these combined systems to total the input from both the feedforward loop and the feedback loop, and send a unified signal to the final control element.

Feed forward portion allows immediate corrective action to be taken before disturbance (steam flow rate) affects the output measurement (level of the boiling liquid).

The steam flow rate is the measured disturbance, level of the boiling liquid is the measured output, and feedwater flow rate is manipulated variable.

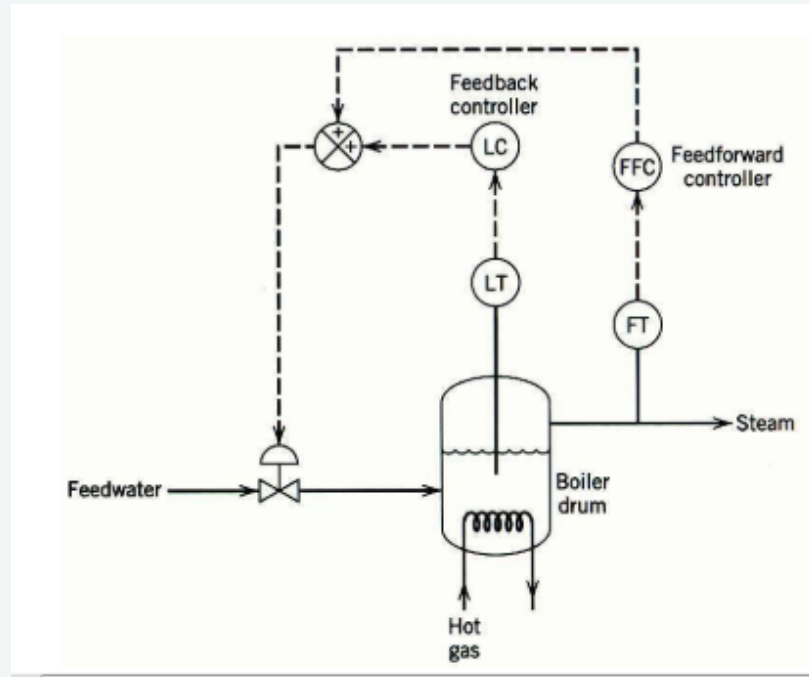


Figure 5. 24 : Feedfoward –feedback of the boiler drum level control.

Example 5. 9 : Feedforward-feedback of the furnace temperature control

Figure 5.25 shows the example of feed forward-feedback control of temperature based on measured process fluid rate (disturbance input). Here, the feed-forward controller compensates for process flow rate disturbances. While the feedback controller compensates for other disturbance (outlet temperature).

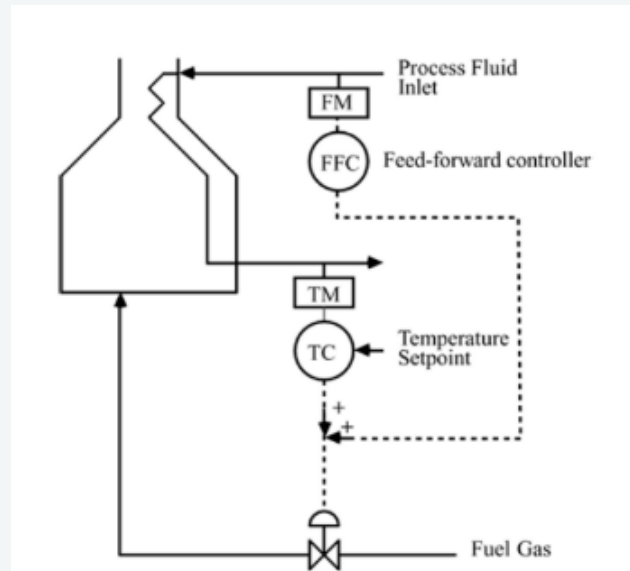


Figure 5. 25 Feedforward-feedback control of temperature based on the measured process fluid flow rate (disturbance input)

Example 5. 10 : Feedforward-feedback control in blending system

An alternative configuration for feedforward-feedback control is to have the feedback controller output serve as the set point for the set point for the feedforward controller as shown in figure 5.26. The feedforward controller set point now denoted as x_{sp}^* . It is generated as the output signal from the feedback controller. The actual set point is used as the set point for the feedback controller.

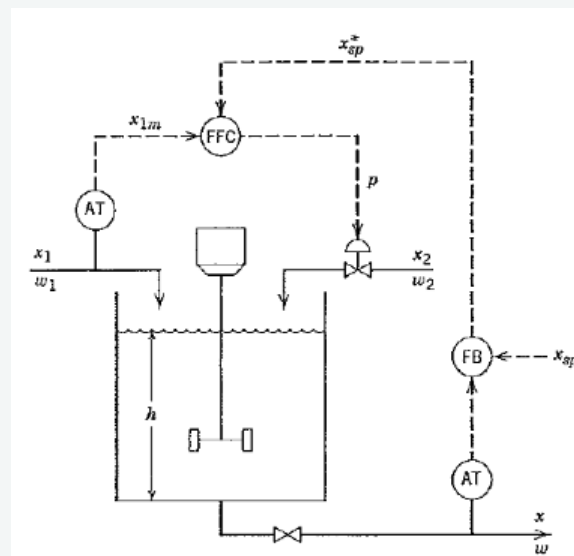


Figure 5. 26:: Feedforward-feedback control of exit composition in the blending system.

5.4 Cascade Control System

The principal for cascade control is to reduce error in a controlled process. Figure 5.27 represent a diagram to understand this process, where a cascade controller consists of two control loops that are inner loop and outer loop that represent primary controller loop and secondary controller loop respectively. In a cascade control arrangement, there are two (or more) controllers of which one controller's output drives the set point of another controller.

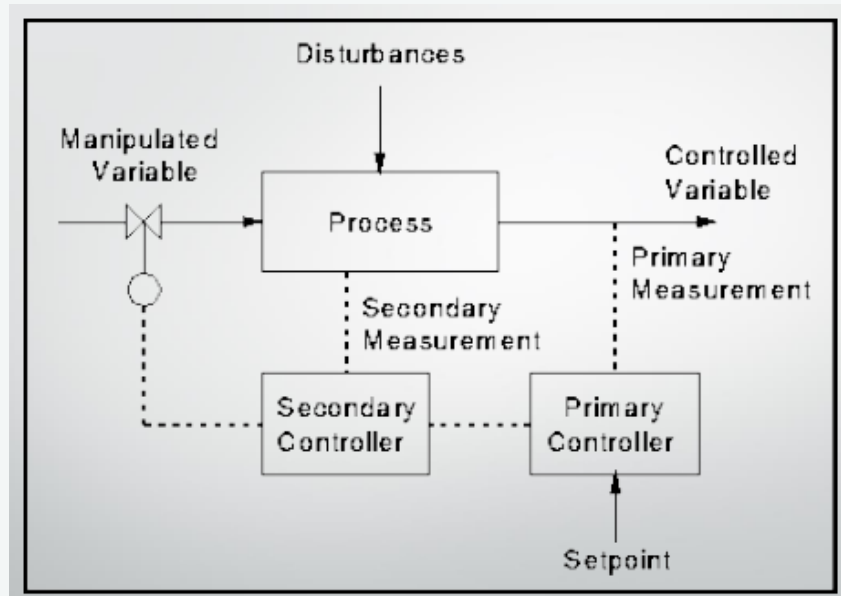


Figure 5. 27 Block diagram cascade controller with disturbance.

The controller of the primary loop (master) determines the setpoint of the summing controller in the secondary loop, while secondary (slave) control loop is set up to control a variable that is a major source of load disturbance for another primary (master) control loop

For cascade control to be effective and worthwhile the secondary loop needs to have a fast process characteristic while the primary loop has a slow process characteristic.

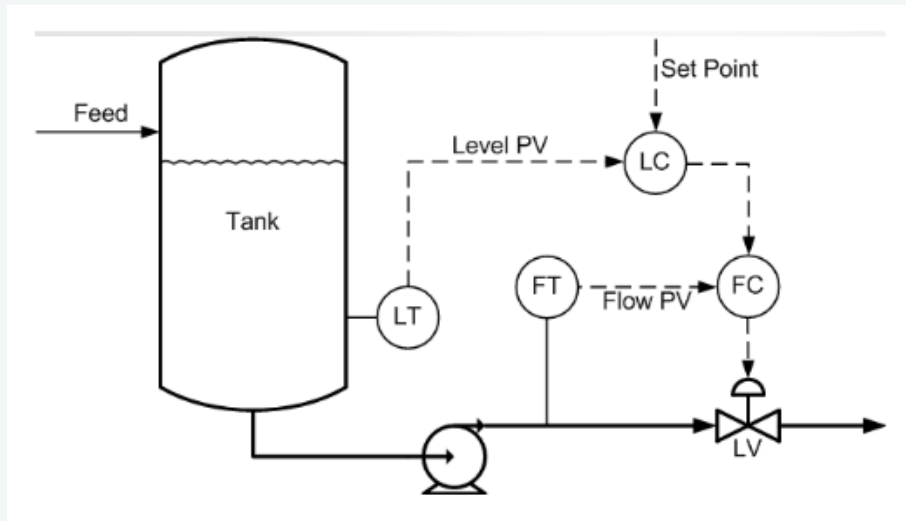


Figure 5. 29: Cascade control arrangement, there are two controllers which is level controller (LC) and flow controller (FC).

Example 5. 12 : Cascade Control System to control temperature in the furnace

Figure 5.30 shows the example of cascade control system to control the temperature in a furnace. The furnace is used to heat the process fluid stream and the outlet temperature of fluid stream is to be controlled. In cascade control, the output of the temperature controller is the setpoint to the fuel gas flow controller. Thus temperature s controller is known as the *primary, master, or outer-loop* in which regulate the temperature of a process fluid exiting from furnace.

The output of the flow controller is the pressure to the control valve, which changes the valve position and, therefore, the flow rate. Thus, flow controller is the *secondary, slave, or inner-loop* controller which corrects the disturbances that affect the fuel gas flow rate before it affects the outlet temperature.

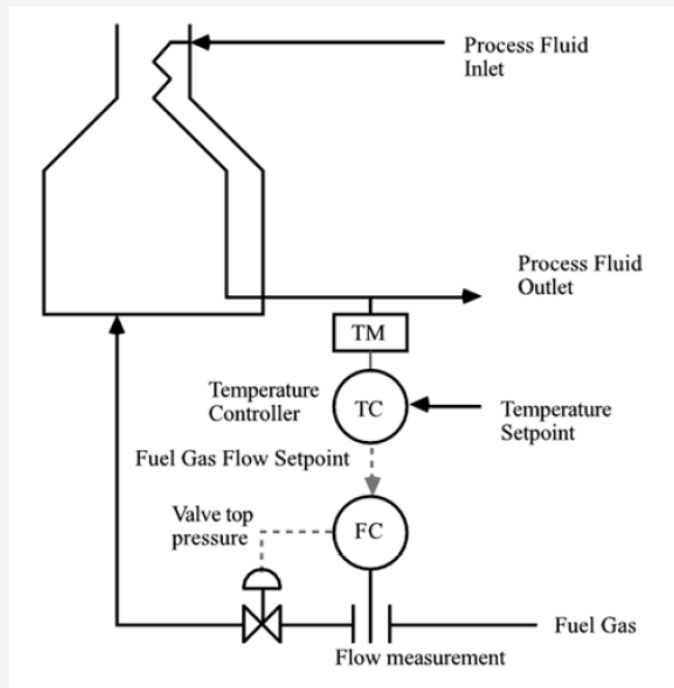


Figure 5. 30 : Cascade control of process outlet temperature

5.5 Ratio Control System

Ratio control system is a special type of feed forward control system where two disturbance (loads) are measured and held in a constant ratio to each other. The objective of ratio control is to maintain the ratio of two process variable as a specified value.

Ratio control system is used to control the flow rates of two streams : wild stream and controllable stream.

- Wild stream (master stream) : the stream which flow rate can be measured but cannot be controlled
- Controllable stream : the stream which can be measured and controlled.

Wild stream may require the controlled stream to have the same flow as itself / a fraction of its flow, a multiplier of it. Ratio control system is usually used in the industrial applications such as :

- Setting the relative amount of components in blending operation
- holding the fuel air ratio to a furnace at the optimum value
- maintaining a stoichiometric ratio of reactants to a reactor
- keeping a specified reflux ratio for a distillation column.

There are two well-known methods that are used in ratio control.

Method 1 Ratio Control

Figure 5.31 shows there is a process with two process variables. The variables are usually flow rates, one is fixed as manipulated stream and the other flow is fixed as the disturbance stream. Whatever the external load disturbance causes the manipulated stream, a ratio control keeps a fixed ratio between the two or more variables irrespective of possible set point change.

The flow of both streams (disturbance/wild flow & manipulated/controlled flow) are measured using flow transmitter and the values are applied to a divider. (ratio, u/d)

The divider calculates the ratio between the two streams, $R_m = u_m/d_m$ and the output of the divider element is sent to the ratio controller.

Ratio controller compares the calculated ratio, R_m to the desired ratio, R_d , and adjusts the manipulated flow rate, u accordingly. If there is an external disturbance in the manipulated or disturbance stream, a proportional change in ratio stabilizes the process.

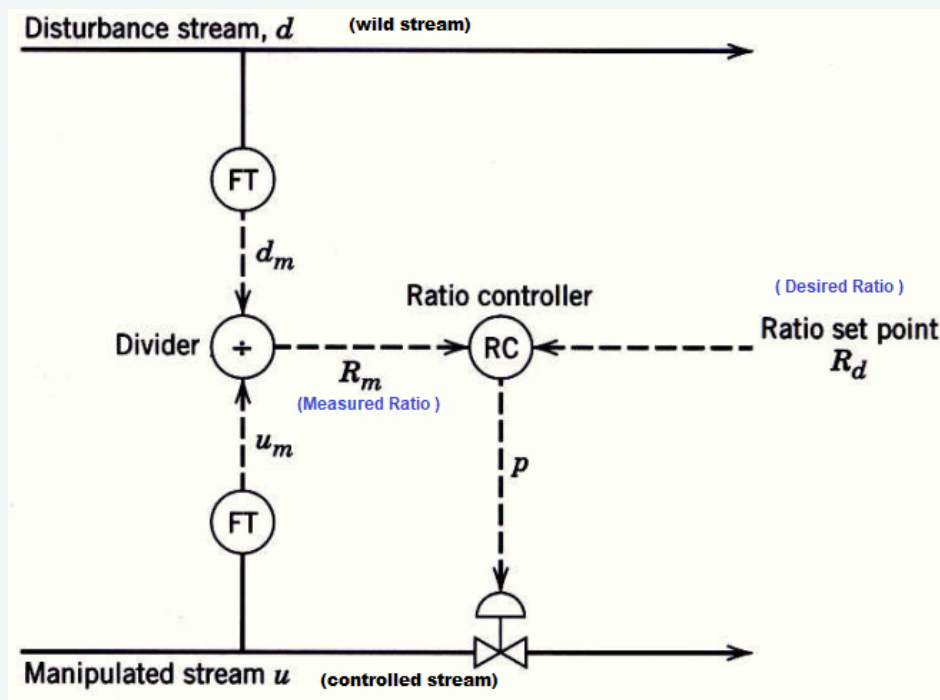


Figure 5. 31: Method 1 of Ratio Control

Method 2 ratio control

Figure 5.32 shows the flow rate of manipulated stream has to be maintained at a constant fraction of flow rate of disturbance stream, irrespective of variation of flow rate of disturbance stream. The flow rate of wild stream (disturbance stream, d) is measured and multiplied by the desired ratio in ratio station,

The output signal from the ratio station is then used as the set point for the flow controller, which adjusts the flow rate of control stream (manipulated stream, u) and fed to the controller that operates the control valve.

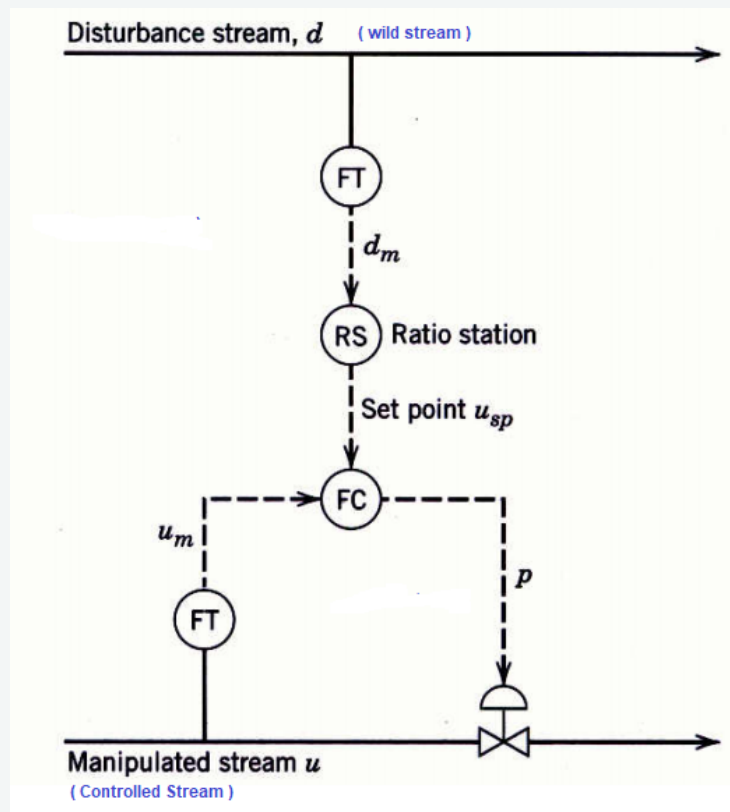


Figure 5. 32 : Method 2 of Ratio Control

Example 5.13 Ratio Control in neutralisation of waste water

A feed of acidic wastewater is to be neutralized by the proper Stoichiometric amount of NaOH in a second feed stream as shown in Figure 5.33. Here, the flow rate of wastewater and the flow rate of NaOH solution are to be maintained at a ratio. The ratio is determined by the pH controller based on the pH value of the effluent.

The product of pH controller output and measured flow rate of wastewater acts as a setpoint for NaOH solution flow controller. The flow controller actuates the control value based on setpoint and measured flow rate of NaOH solution. Thus, the addition of NaOH is controlled and the ratio of two flow rates are maintained.

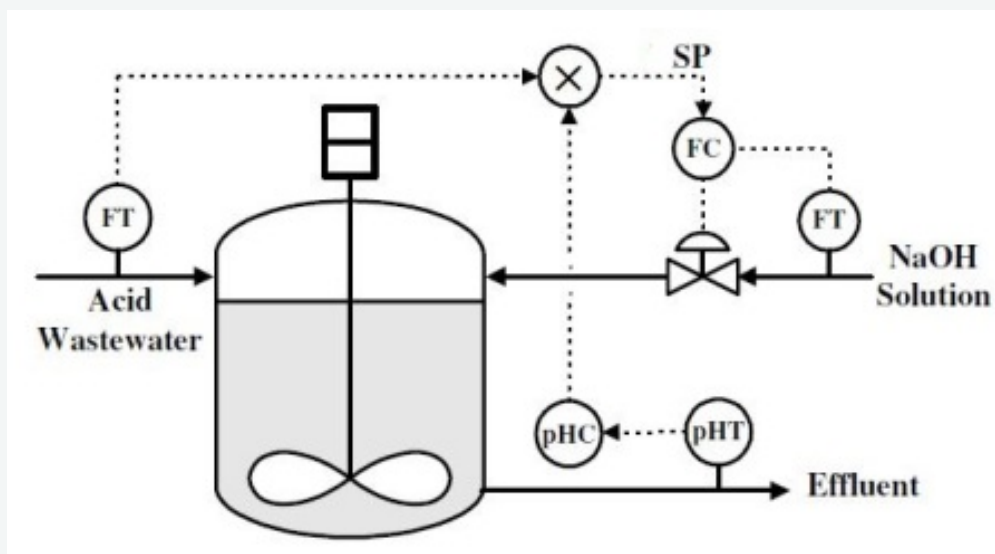


Figure 5.33 : Ratio Control in Neutralisation of Waste Water

Example 5. 14 : Controlling the ratio of combustion air to fuel flow

In figure 5.34 shows the example of controlling the ratio of combustion air to fuel flow. The fuel is the wild flow , while air is the controlled flow.

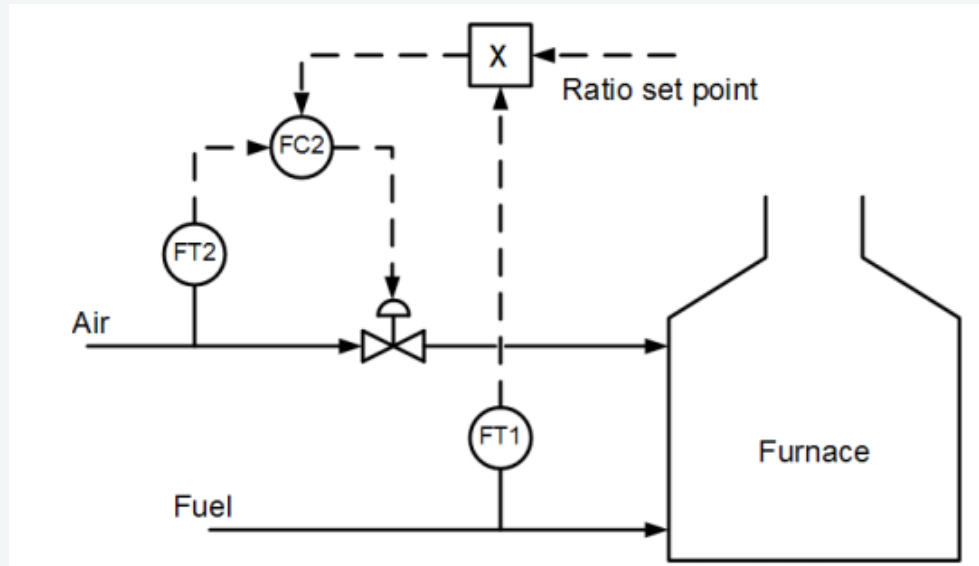
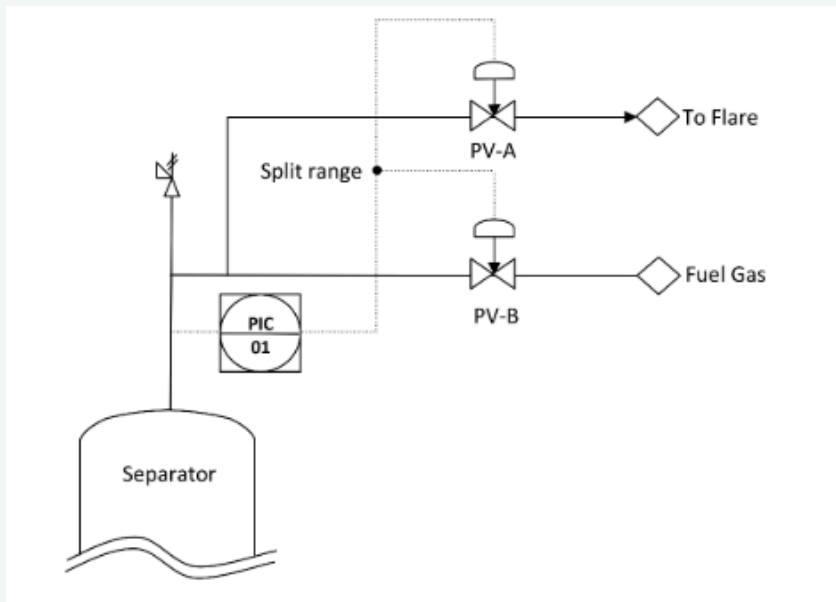


Figure 5. 34 : Controlling the ratio of combustion air to fuel flow

5.6 Split Range Control System

In a split range control loop, output of the controller is split and sent to two or more control valves.

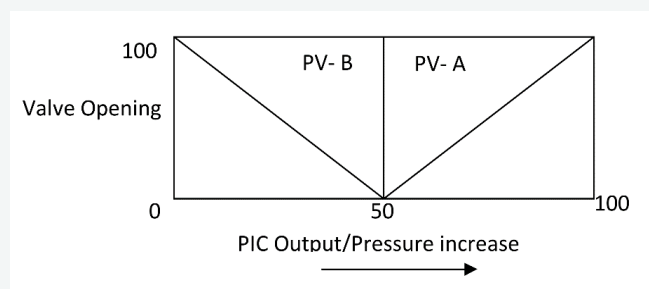


- The splitter defines how each valve is sequenced as the controller output changes from 0 to 100%.
- Control strategy in which one tries to control a process parameter (pressure) by adjusting more than one manipulated variable. In this situation, users might have a single controller and several final control elements (control valve).

Figure 5.35 : Output of the controller is split and sent to two or more control valves.

Figure 5.35 shows PIC-01 controls the pressure of the separator, by mean of a split range controller with the output signal split and sent to two pressure control valves PV-A and PV-B.

Pressure increases beyond set point in range of with 0-50% controller output, PV-B shall close from fully open to fully close. Pressure increases beyond set point in range of with 50-100% controller output, PV-A shall open from fully close to fully open.



Example 5. 15 Split Range Control in Batch Reactor Temperature Control

Figure 5.36 shows the jacket temperature controller has a split range output, where the cold glycol is open during cooling mode and the hot glycol valve is open during heating mode.

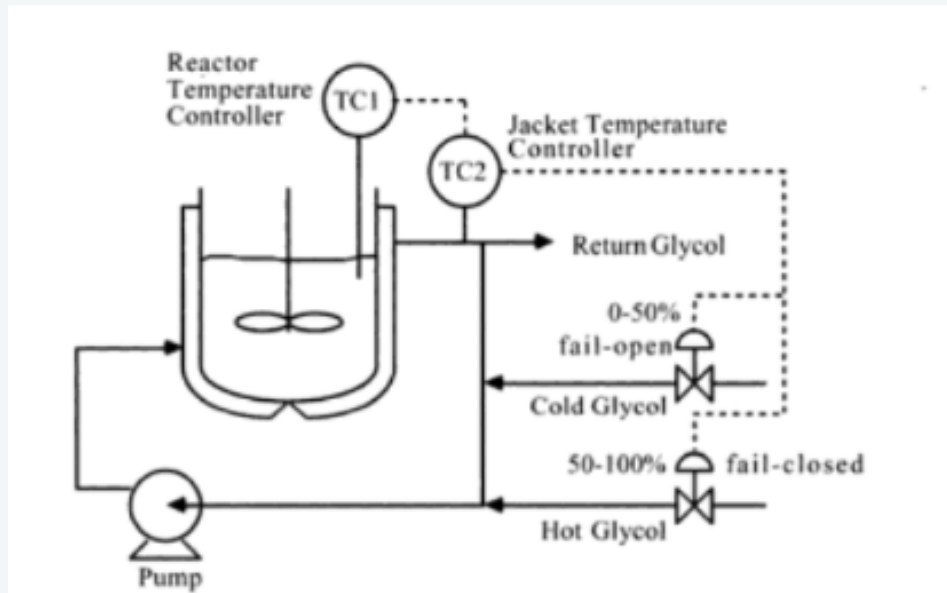


Figure 5. 36 Batch reactor temperature control

EXERCISE 5

1. Sketch a feedback control system used to control liquid level in a tank with all locally mounted basic instrumentation and are pneumatically actuated.
2. A process liquid from preliminary processing unit is required to be store in a closed pressure vessel before it's transferred by a pump to the subsequent processing unit. In the vessel, steam is used to elevate the process liquid temperature to a set point temperature regulating the amount of inlet steam using electrical actuated control valve and locally mounted pneumatic instrumentation and controller. Sketch a piping and instrumentation diagram to show the control and instrumentation for the system.
3. Figure E5.1 shows the boiler system that used to supply hot steam to a turbine. This system need to supply 100 psi hot steam to the turbine where the PCV-100 will be opened when the pressure reached that desired pressure. With using pressure control through temperature measurement in the boiler, draw
 - a. Feedforward loop control loop
 - b. Feedforward-feedback control loop

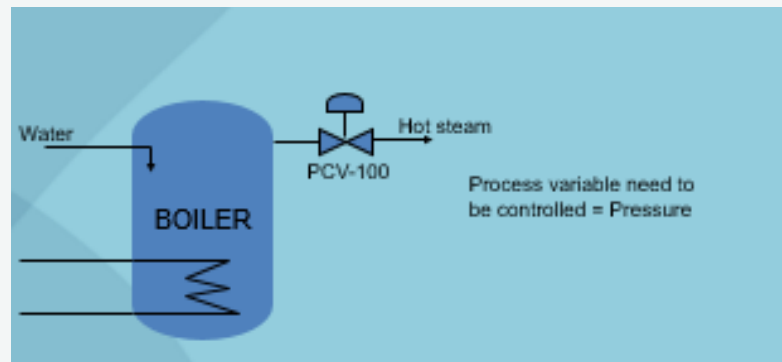


Figure E5.1

4. Answer the following question based on Figure E5.2
 - a. Name type of flow diagram show in Figure E5.2
 - b. Describe the type of control system and instrumentation used in Figure E5.2

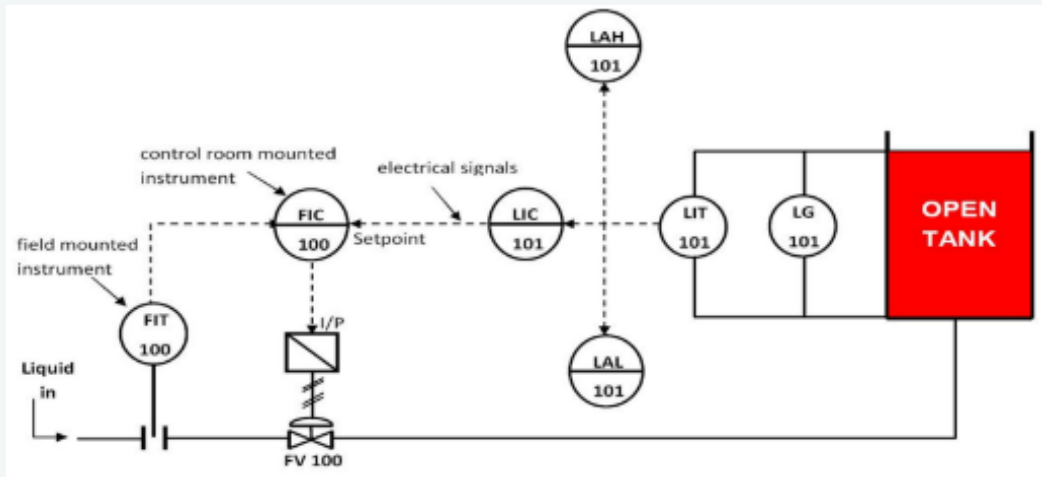


Figure E5.2

5. Identify control loop in the P&ID in Figure E5.3

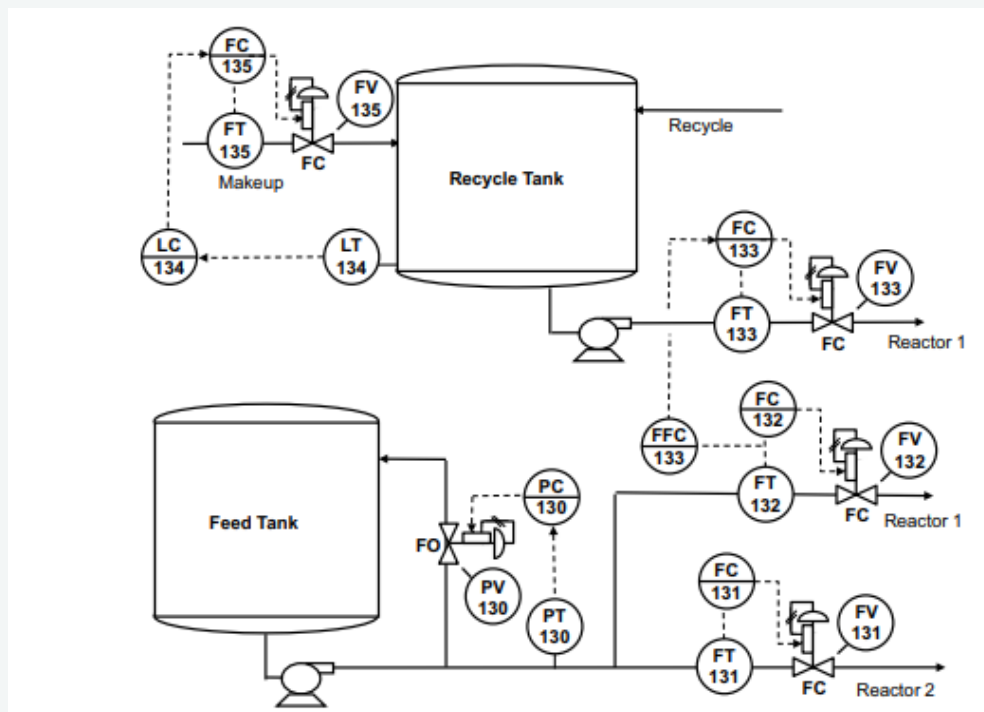


Figure E5.3

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Dunn, W. C. (2005). *Fundamentals of Industrial Instrumentation and Process Control*. USA: McGraw Hill Professional.

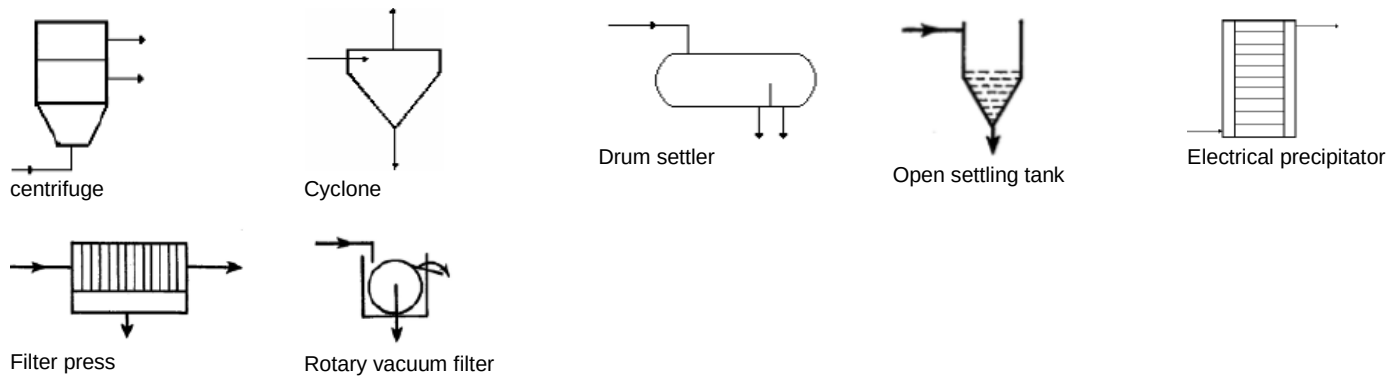
ISO 10628-1. (2014, 9 15). *Diagrams for the chemical and petrochemical industry —Part 1 : Specification of diagrams*. Switzerland: ISO.

Richard Turton, R. C. (2009). *Analysis, Synthesis and Design of Chemical Processes*. USA: Pearson Education.

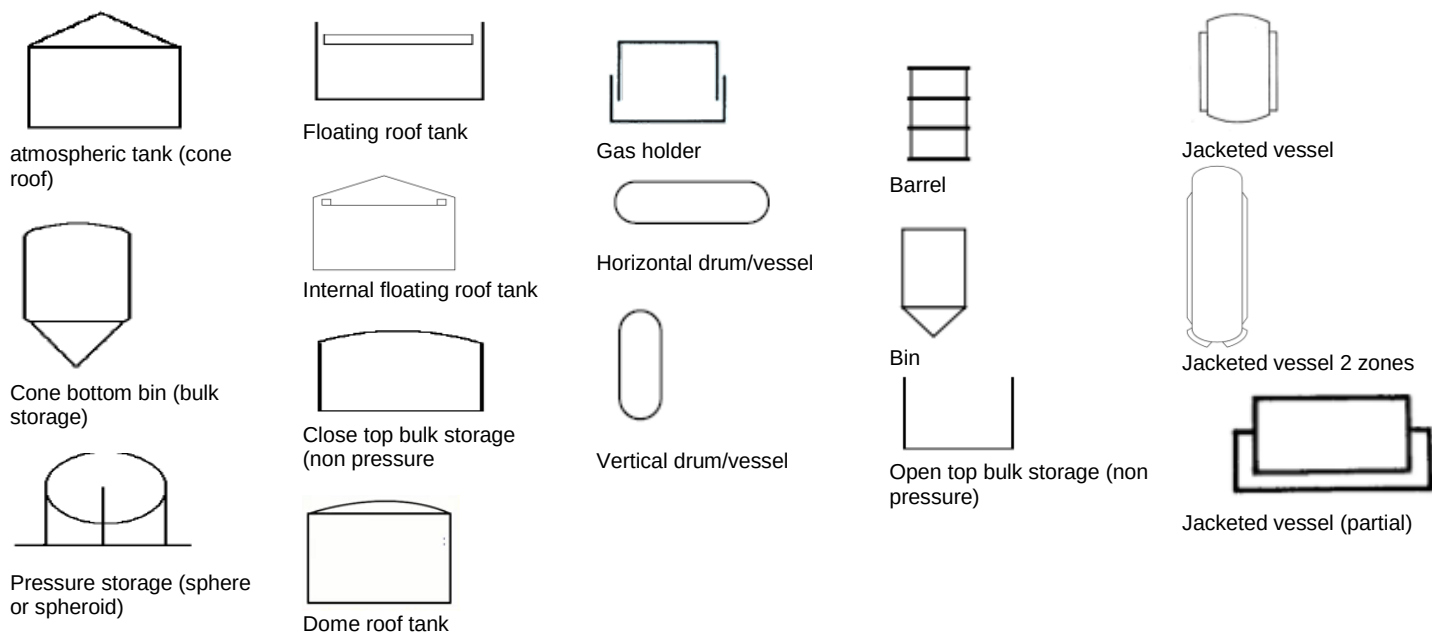
Toghraei, M. (2019). *Piping and Instrumentation Diagram Development*. USA: John Wiley and Son.

Appendix : P&ID symbols

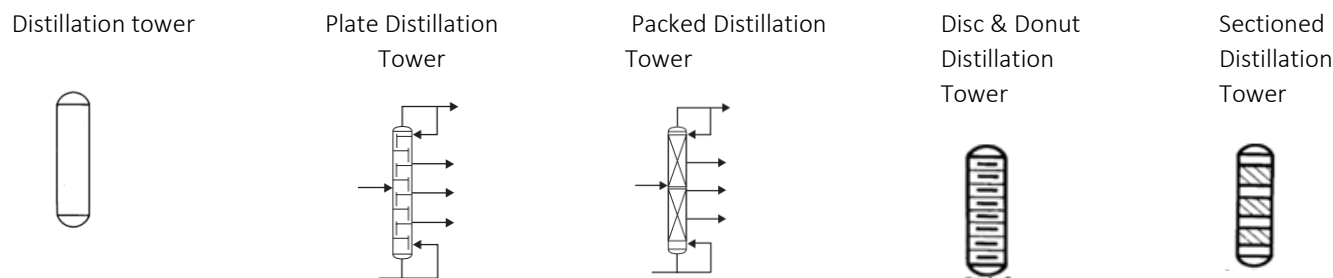
Separator



Vessel



Distillation tower



Reactor

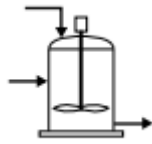
Reactor



Fluidized reactor



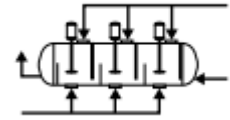
mixing reactor



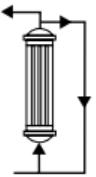
Fluid catalytic cracking



Alkylation



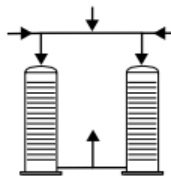
Tubular reactor



Fluid coking



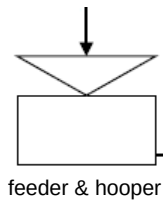
Hydrocracking



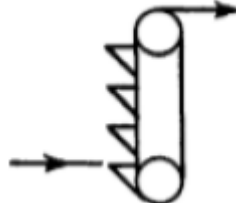
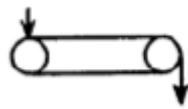
Reformer



Material Handling



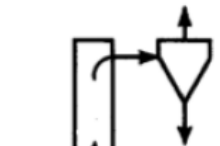
feeder & hooper



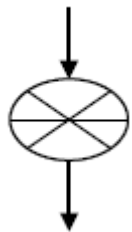
Bucket / flight conveyor



Roller conveyor



Air lift



Rotary feeder



Belt / shaker



Screw conveyor

Size Reducing Equipment



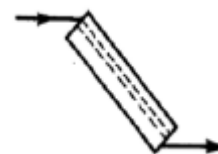
Ball mill



grinder

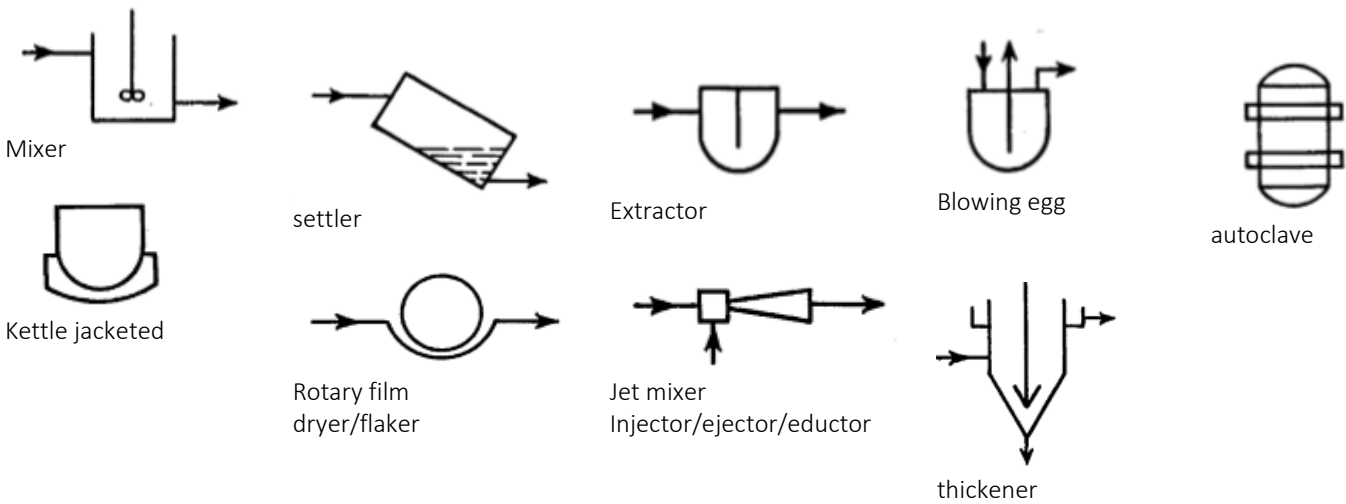


Roller crusher



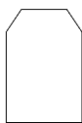
screener

Processing Equipment

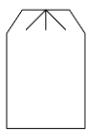


Dryer

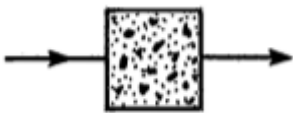
Dryer (general)



Spray Dryer



Desiccant



Fluidized bed dryer



Dryer - oven



Roller conveyer belt dryer



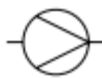
Rotary Drum Dryer or Kiln



Moving Shelf Dryer



Pump (ISO)



Pump



Liquid pump



Centrifugal Pump



Diaphragm pump



Gear pump



Progressive pump



Positive displacement pump

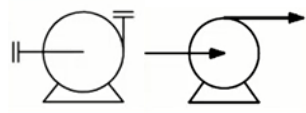


Reciprocating piston pump

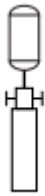


Screw pump

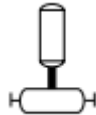
Pump



Centrifugal pump



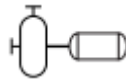
Vertical can pump



vertical inline pump



Vacuum pump



Horizontal pump



Rotary gear pump



Gear pump



Positive displacement pump



Screw pump

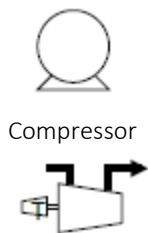


Progressive cavity



Reciprocating pump

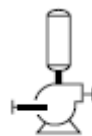
Compressor and Blower



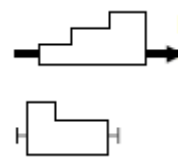
Compressor



Rotary compressor



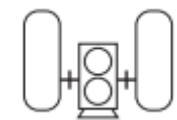
Centrifugal blower



Reciprocating compressor



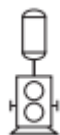
Axial compressor



Rotary compressor and silencer



Rotary screw compressor



Positive displacement blower

Centrifugal compressor

Compressor (ISO)



Compressor



Ejector compressor



Centrifugal Compressor



Diaphragm compressor



Piston compressor



Roller vane compressor



Rotary compressor



Ring compressor



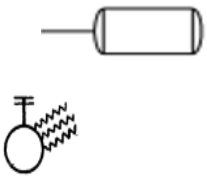
Screw compressor



Turbo compressor

Drivers/ Agitators / Mixer

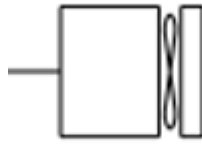
Motor



Electric motor



Turbine driver



Diesel engine



Agitator / mixer

Heat Transfer

TEMA TYPE BEM

TEMA TYPE BEU

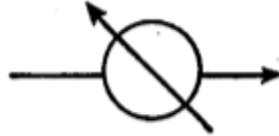
TEMA TYPE AEM

TEMA TYPE AEL

TEMA TYPE NEN

TEMA TYPE BKU

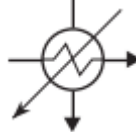
Water Cooled Exchanger



Water Cooled Condenser



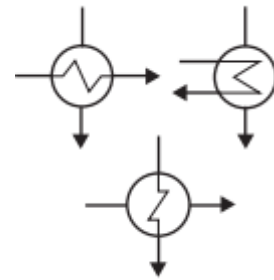
Heater



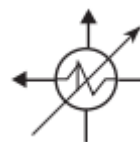
Kettle type heat exchanger



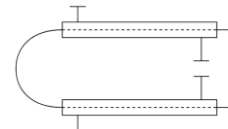
Shell and Tube Exchanger



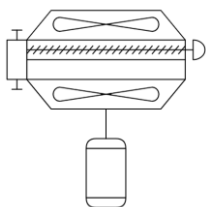
Condenser



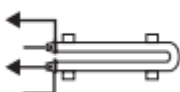
Double Pipe Heat exchanger



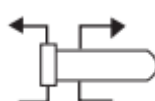
Air cooled heat exchanger



Hairpin Heat Exchanger



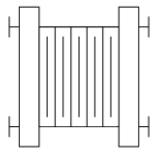
U-tube Heat Exchanger



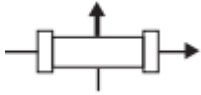
Cooling Tower



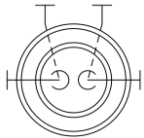
Plate and Frame Heat Exchanger



Single Pass Heat Exchanger



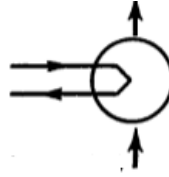
Spiral Heat Exchanger



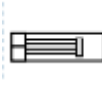
Heat exchanger



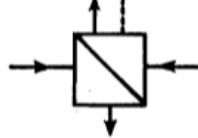
Reboiler (Thermo Siphon)



Floating Head Exchanger



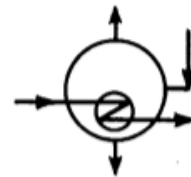
Superheater (Reheater)



Box Cooler (Single Coil)



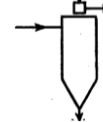
Reboiler (Kettle Type)



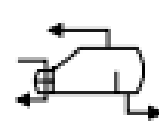
Straight Tubes Heat Exchanger



Barometric Condenser

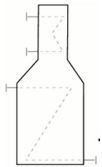


Reboiler



Furnace and Reboiler

Furnace (general)



Boiler



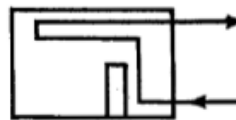
Box Type



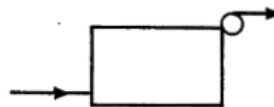
Fired Heater



Radiant Type (Single Coil)



Boiler Fired or Waste Heat



Vertical



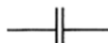
"A" Frame



Piping Fitting



Flange



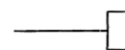
Two Flange



Blank Flange with valve



Blank flange



Hose connector



Ring spacer



Pipe spade / blind



Spectacle blind

Piping Special symbols

	Detonation arrestor		Temporary strainer		Rotary valve
	Flame arrestor		Steam trap		Excess flow valve
	Duplex strainer		Basket strainer		Pulsation Dampener
	Exhaust head		Filter		Ejector / Eductor
	In line silencer		Vent cover		Removable spool
	Vent silencer		T type strainer		Cone strainer
	Y type strainer		Diverter valve		Flexible hose
	In line mixer		Damper		Expansion joint
	Desuperheater		Reducer		Breather

Valve

Gate valve	Pug valve	Butterfly Valve	Pressure safety valve	Check Valve
Ball Valve	Diaphragm Valve	Globe Valve	Angle valve	Needle valve
3 way valve	4 way valve	Pinch valve	Stop check valve	Pressure relief valve
Angle blowdown valve	Plug /cock valve	Knife valve	Fail closed valve	Fail open valve

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PIPING AND INSTRUMENTATION DIAGRAM

This ebook of Piping and Instrumentation Diagram explains the basic introduction of pipelines and process piping equipment and how its symbols use in the Piping and Instrumentation Diagram sheet (P&ID). Block Flow Process (BFD) and Process Flow Diagrams (PFD, as well as Utility Flow Diagram (UFD) are covered. Simple basic control systems in processing flow loops are discussed in detail. It is useful for a new student who is encouraged in the fluid transportation field.

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