Plant Design and Economics
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Lecture - 03
Flow Diagrams

Welcome to lecture 3 Plant Design and Economics. They say to describe a process you put a picture, a picture is worth a thousand words. So today's lecture, we will see how we can pictorially represent a chemical process. In other words, we will be talking about flow diagrams that chemical engineers use to describe a chemical process.

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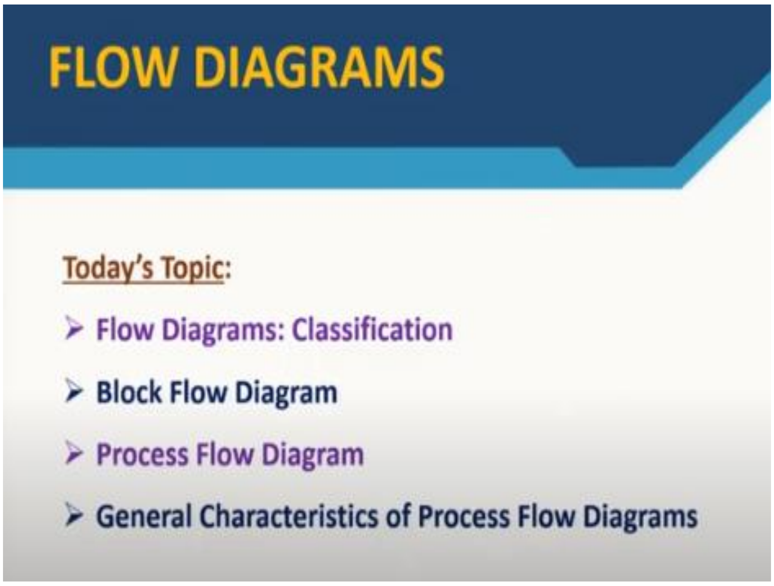

So this will be today's topic. We will talk about various classification of flow diagrams. We will talk about block flow diagram and process flow diagram in today's lecture and general characteristics of process flow diagram. There are other flow diagrams, which we will talk about in later classes.

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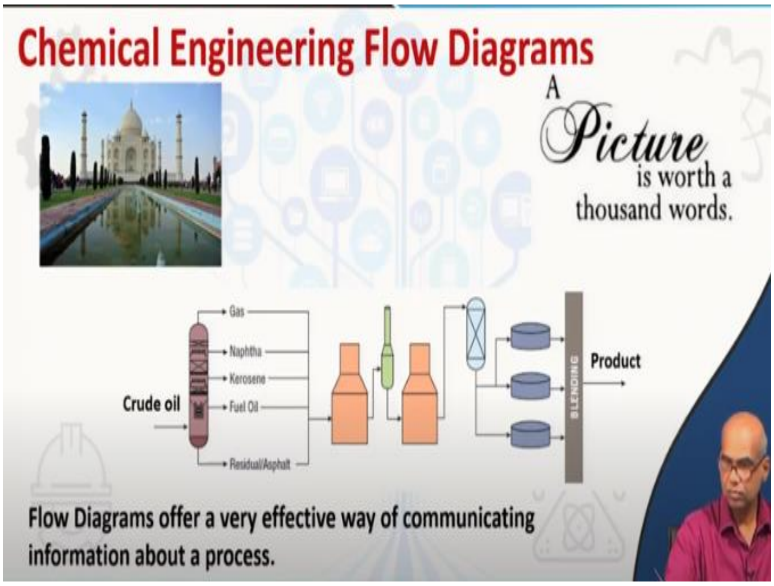

So without much description, a chemical engineer can understand that in this picture crude oil is being fractionated and then these different fractions are undergoing some conversions. In fact it is done to add values and then these are being blended to get the final product. So without much description just by these pictorial representation it is possible for us to represent a chemical process. So this is what we will see in today's lecture.

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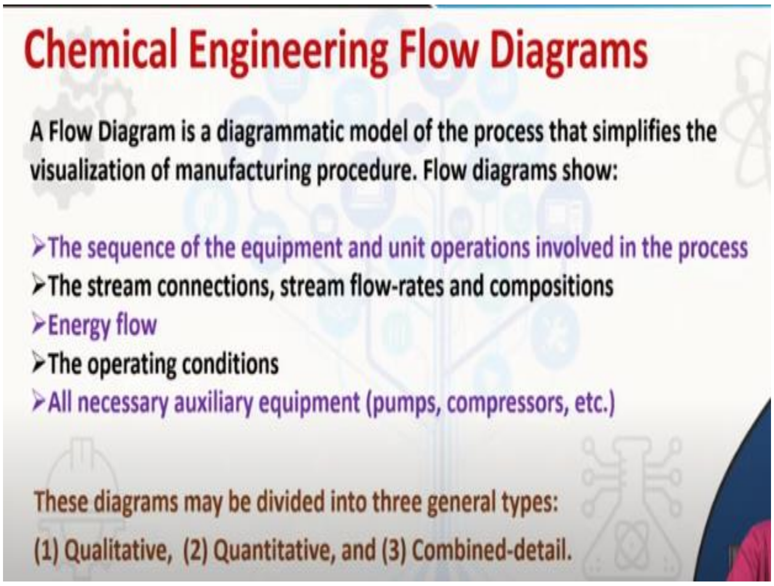

So what is chemical engineering flow diagrams? A flow diagram is a diagrammatic model of the process that simplifies the visualization or manufacturing procedure. So flow diagram is a diagrammatic model of the process that simplifies the visualization of manufacturing procedure. Flow diagrams will show you the sequence of the equipment and unit operations involved in the process.

The stream connections, stream flow rates and compositions. The energy flow in the process, the operating conditions and also all necessary auxiliary equipment such as pumps, compressors, turbines, etc. Now depending on whether such diagrams contain qualitative informations or quantitative informations or both, we can classify these flow diagrams into three general categories, qualitative flow diagrams, quantitative flow diagrams and combined detail.

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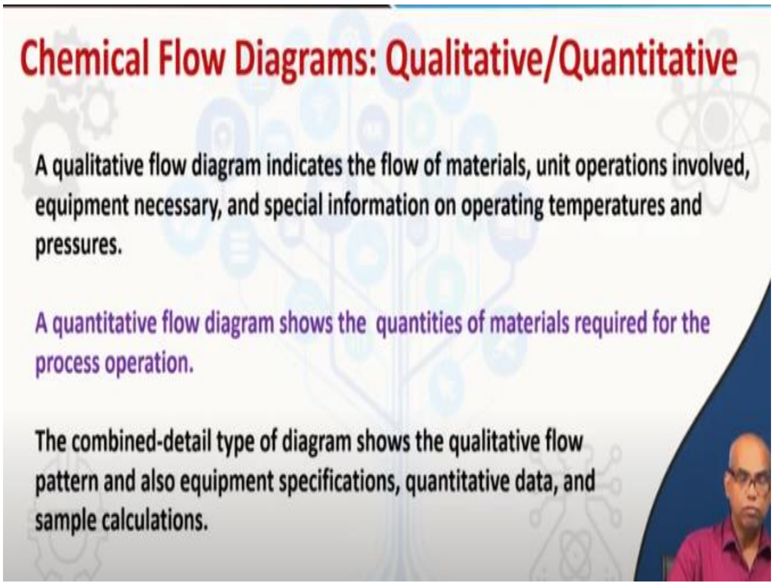

A qualitative flow diagram indicates the flow of materials, unit operations involved, equipment necessary and special information on operating temperatures and pressures. A quantitative flow diagram shows the quantities or materials required for the process operations. So the quantitative flow diagram will tell you the quantities of materials that are involved in the process.

The combined-detail type of diagram shows the qualitative flow pattern and also equipment specification, quantitative data and sample calculations. So this is basically a combination of qualitative flow diagram and quantitative flow diagram.

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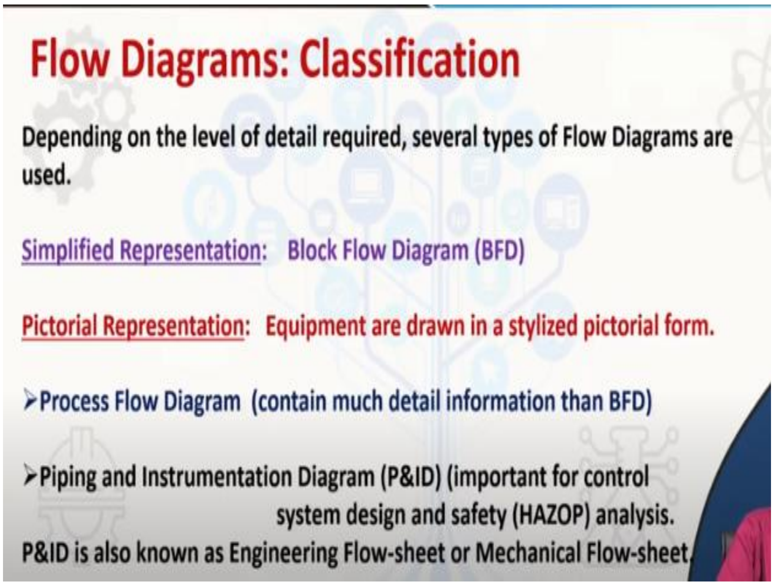

Now chemical engineers use several types of flow diagrams. Depending on the level of detail required several types of flow diagrams are used. There are three major types of flow diagrams that chemical engineers use. Block flow diagram, process flow diagram and piping and instrumentation diagram. Block flow diagram is a very simplified representation of the process.

Whereas process flow diagram and piping and instrumentation diagram are much more involved and they pictorially represent the chemical process. They contain much more detailed information than block flow diagram does. So block flow diagram is a very simplified representation of the process, a process is represented in terms of blocks whereas, process flow diagram and piping and instrumentation diagram represents the process pictorially.

So equipment are drawn in a stylized pictorial form. Piping and instrumentation diagram is very important for control system design and safety analysis. Piping and instrumentation diagram commonly known as P&ID diagram also known as engineering flow sheet or mechanical flow sheet. So most commonly chemical engineers will use process flow diagram and P&ID diagram.

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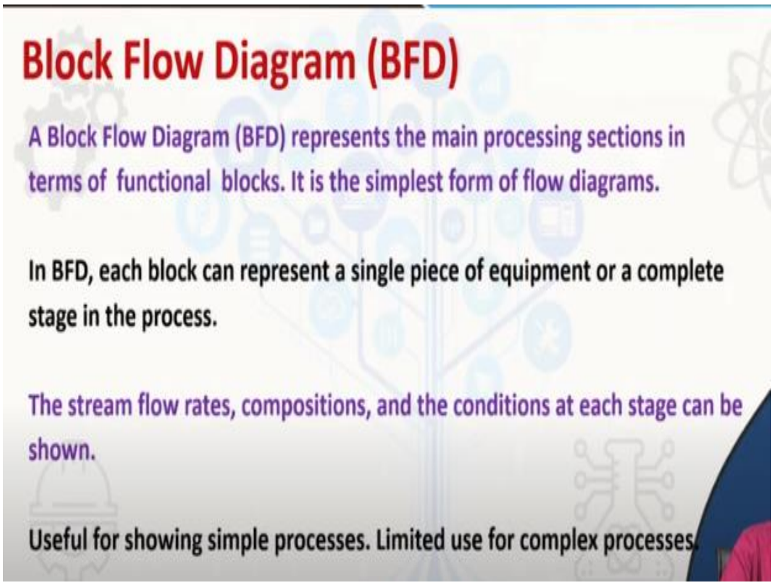

Now let us learn little bit more detail about this flow diagrams. Let us start with block flow diagram. A block flow diagram represents the main processing sections in terms of functional blocks. So it is the simplest form of block diagrams. In block flow diagram each block can represent a single piece of equipment or a complete stage in the process. The stream flow rates, compositions and the conditions at each stage can be shown.

A block flow diagram is more useful for representing simple processes. For a very complex process, it will have limited use because it will be very difficult to use a large number of blocks to represent the process. So maybe we have to use one block to present several processes and then what will happen is, we will lose the detail of the process. So a block flow diagram is more useful for representing a simple process.

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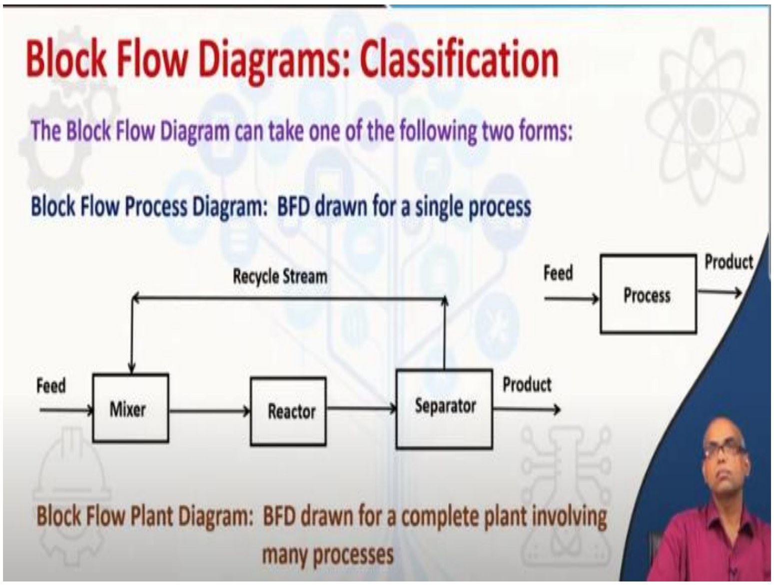

A block flow diagram can be drawn for a single process or block flow diagram can also be drawn for a complete plant involving many processes. But then we will be clubbing the entire process into a single block. What you see is a block diagram for a process with recycle. So there is a mixer, reactor and separator, each is being represented by separate blocks.

We can also use a single block to represent the entire process. So feed goes into the process, product comes out of the process.

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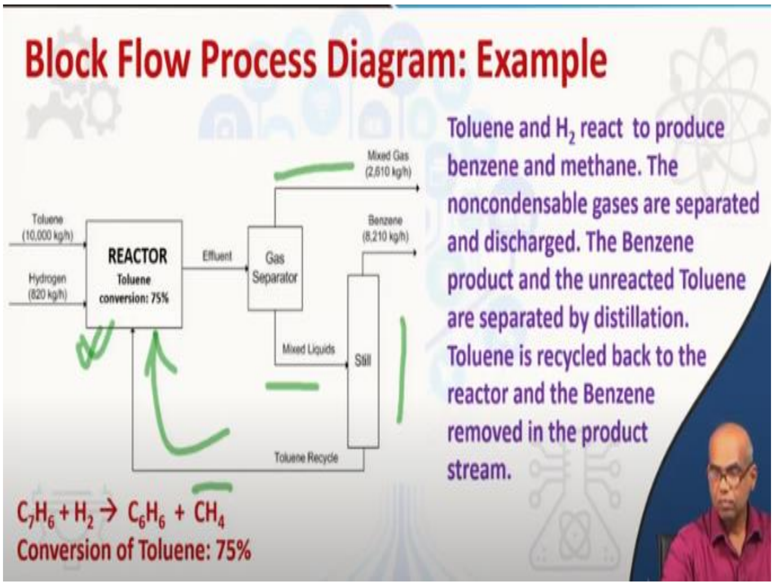

This is an example of block flow diagram of benzene production from toluene and hydrogen. So toluene and hydrogen reacts in a reactor. There is 75% conversion of toluene. So there will be excess toluene, which will be recycled back. So toluene and hydrogen reacts in the reactor. So the effluent stream which will contain a liquid stream and a gas stream. The liquid stream will contain the benzene and the toluene.

And the gas stream will contain the methane and maybe some unreacted hydrogen. So the gas separator separates the gas and the liquid. The liquid stream is being separated into benzene and toluene in a distillation column and the toluene is recycled back to the reactor. So this can be represented by blocks in this block diagram. Note that toluene and hydrogen reacts to produce benzene and methane.

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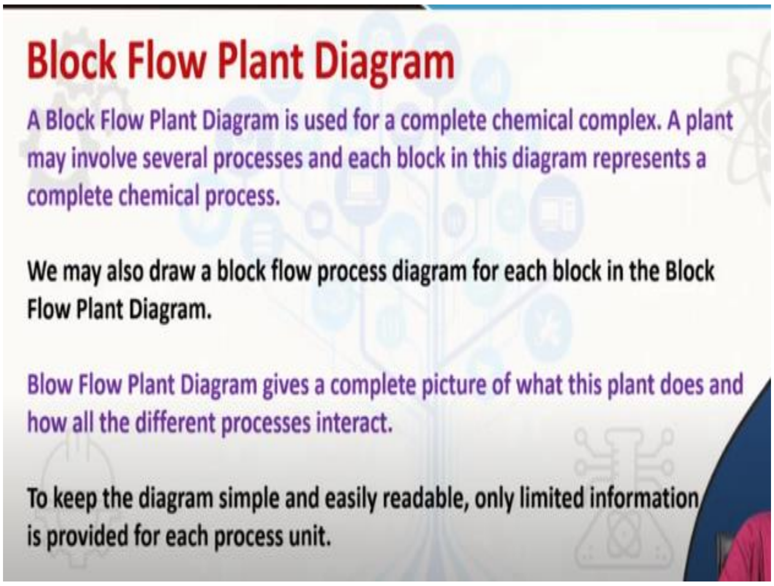

A block flow plan diagram is used for a complete chemical complex. A plant may involve several process and each block in this diagram represents a complete chemical process. We may also draw a block flow process diagram for each block in the block flow plan diagram. Block flow plan diagram gives a complete picture of what this plan does and how all the different processes interact.

To keep the diagram simple and easily readable only limited information is provided for each process unit.

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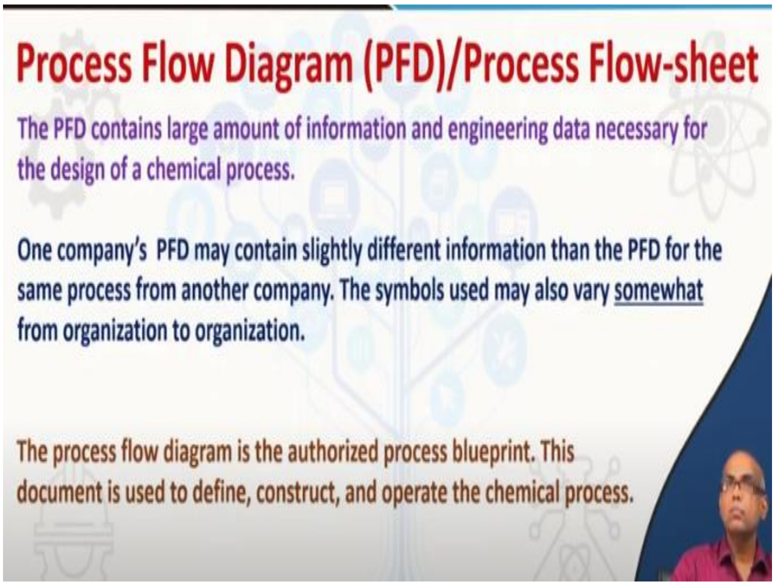

Now let us look at process flow diagram. The process flow diagram is also known as process flow sheet. The process flow diagram contains large amount of information and engineering data necessary for the design of a chemical process. So this flow diagram contains much more detailed information than the block flow diagram does.

And it is a very important piece of document for chemical engineers in the manufacturing plant. Remember, one company's process flow diagram may contain slightly different information than the process flow diagram for the same process from another company. The symbols used may also vary to some extent from organization to organizations.

However, we will try to understand the basic features of the process flow diagram and then it will be easy for you to understand the key features as well as how to read a process flow diagram. The process flow diagram is the authorized process blueprint. This document is used to define, construct and operate the chemical process. It is also used for the training purpose.

It is also used for problem addressing whenever any such occasion arises in the plant.

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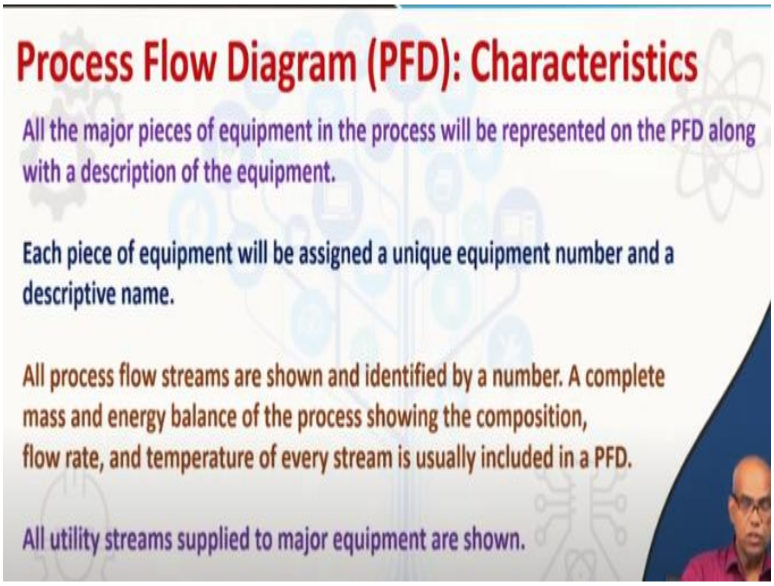

So what does process flow diagram contain? All the major pieces of equipment in the process will be represented on the process flow diagram along with a description of the equipment. So process flow diagram contains all the major pieces of equipment in the process along with a description of the equipment. Each piece of equipment will be assigned a unique equipment number and a descriptive name.

All process flow streams are shown and identified by a number. A complete mass and energy balance of the process showing the composition, flow rate and temperature of every stream is usually included in a process flow diagram. All utility streams supplied to major equipment is shown.

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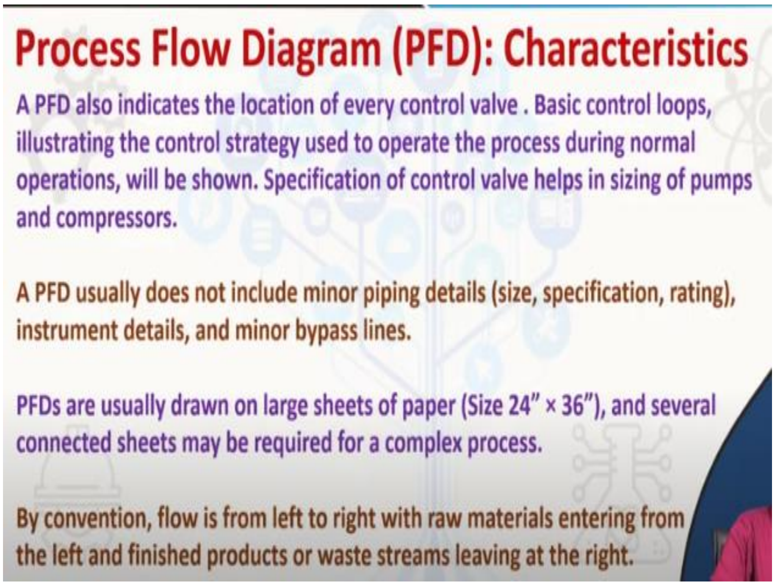

A process flow diagram also indicates the location of every control valve. Basic control loops illustrating the control strategy used to operate the process during normal operations will be shown. It may be noted here that specification of control valve helps in sizing of pumps and compressors. A process flow diagram usually does not include minor piping details such as size, specification, rating etc.

It also does not include instrument details and minor bypass lines. Instrument details are contained by piping and instrumentation diagram. This we will discuss in later classes. Process flow diagram are usually drawn on large sheets of papers. The sizes may be typically 2 feet by 3 feet and several connected sheets may be required for a complex process. It may not be possible to draw the entire process flow diagram on a single sheet.

So for a large chemical process for a large plant it may be necessary that we use several connected sheets. Later on, we will see an example of such connected sheets. By convention, flow is from left to right, with raw materials entering from the left and finished products or waste streams leaving at the right.

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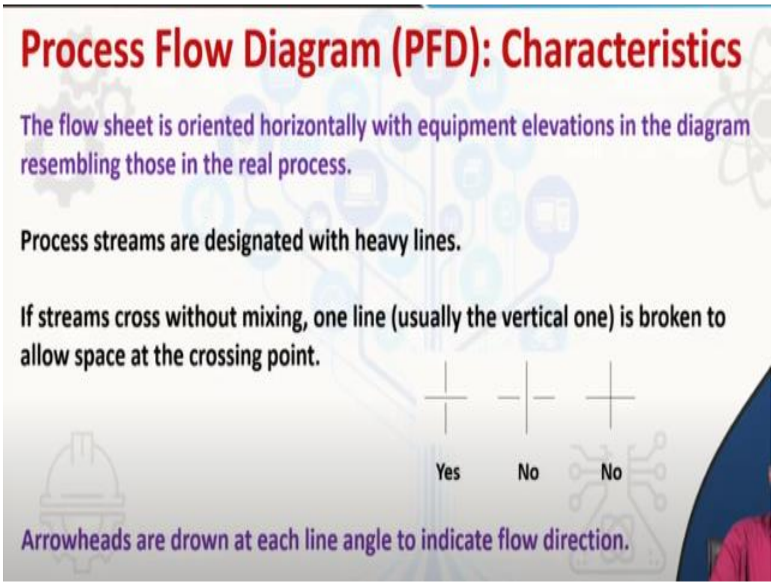

The flow sheet is oriented horizontally with the equipment elevations in the diagram resembling those in the real process. Process streams are designated with heavy lines. If streams cross without mixing, that means two streams cross without mixing then one line is broken to allow space at the crossing point. And it is usually the vertical line which is broken to allow space at the crossing point for the horizontal line.

So what you see in the figure is that the vertical line is broken to allow space for the horizontal line. So that is the accepted norm. Arrowheads are drawn at each line angle to indicate flow direction.

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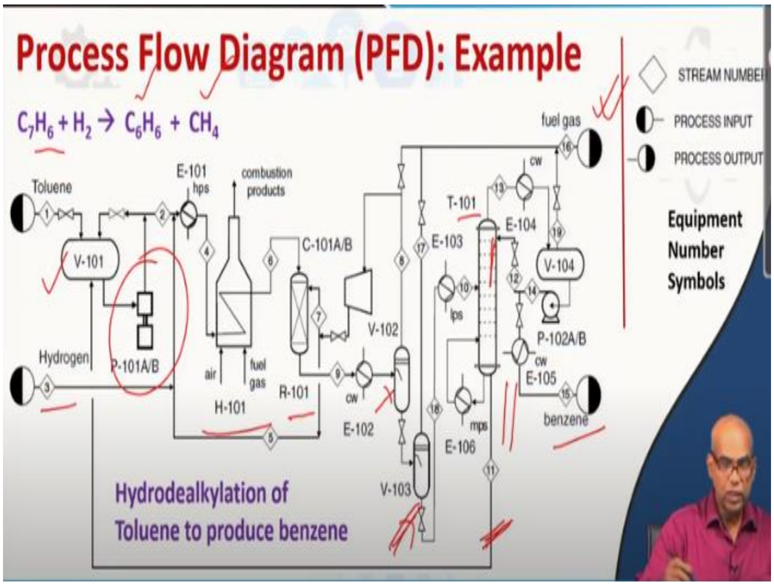

Now what you see now is a process flow diagram for hydrodealkylation of toluene to produce benzene. So toluene and hydrogen they react to produce benzene and methane. What you see is toluene is taken into the vessel V-101. It is pressurized, mixed with hydrogen heated up in the furnace to raise the temperature. The temperature maybe around 600 to 700 degree Celsius at which this reaction takes place.

And then fed to the packed bed reactor represented by number R-101. So in this packed bed reactor toluene and hydrogen reacts to produce benzene and methane. Now there are two separators V-102, V-103. So the first one separates the hydrogen, methane gas. So methane gas and some unreacted hydrogen.

So whatever hydrogen is recovered it will be recycled back and mostly methane and little bit of unrecovered hydrogen will be released as flow gas. The separator V-103, this takes the liquid stream, which is separated into benzene and toluene in the distillation column T-101. The benzene is taken out as product. The toluene is recycled back.

So this is the process flow diagram for hydrodealkylation of toluene to produce benzene. So note in this figure, how every equipment is indicated. Every equipment has a number. Every equipment has a symbol. Also there are diamond symbols which contains numbers for the streams.

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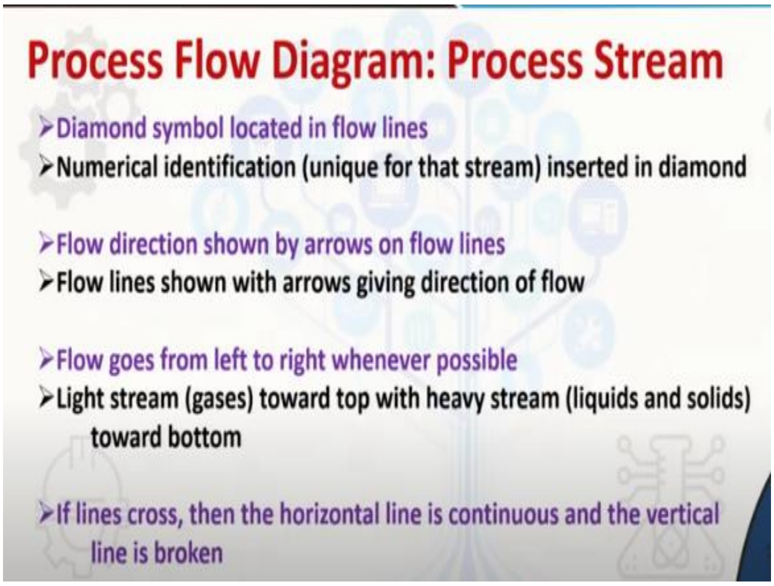

So the diamonds symbols are located in the flow lines. Numerical identification is there for each process stream, it is unique for that stream. And this number is inserted in the diamond symbol. Flow direction shown by arrows on flow lines. Flow line shown with arrows giving direction of flow. Flow goes from left to right whenever possible. Light stream gases toward top with heavy streams, liquids and solids towards bottom.

This is the general convention that the process streams which are light, they will be placed towards top and the liquid and solid stream will be placed towards bottom. If lines cross then the horizontal line is continuous and the vertical line is broken. So these are the features for the process stream. So these we must remember when we represent a process stream.

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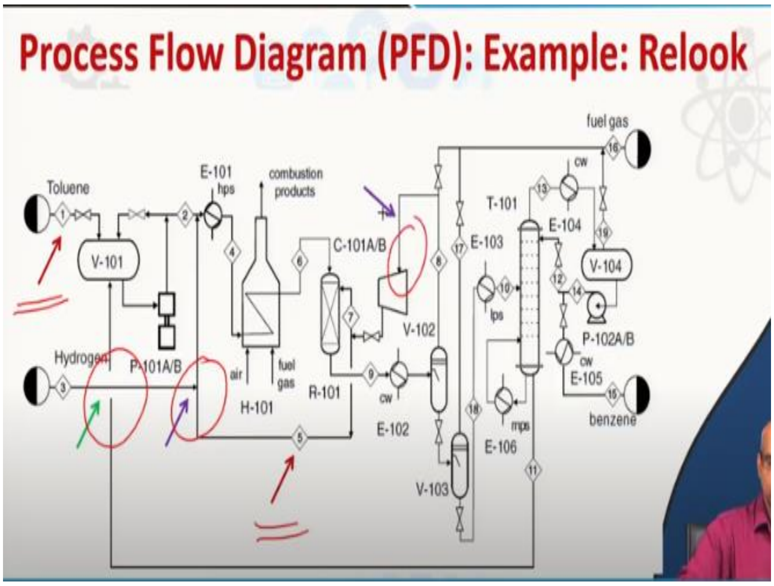

Look at again the same benzene production process flow diagram. Look at the diamond symbol. It contains number 1, is basically for toluene. Similarly, this is another diamond symbol which contains number 5 for the process stream. Here you can see that the vertical line is broken. This shows the arrow for the direction of the flow.

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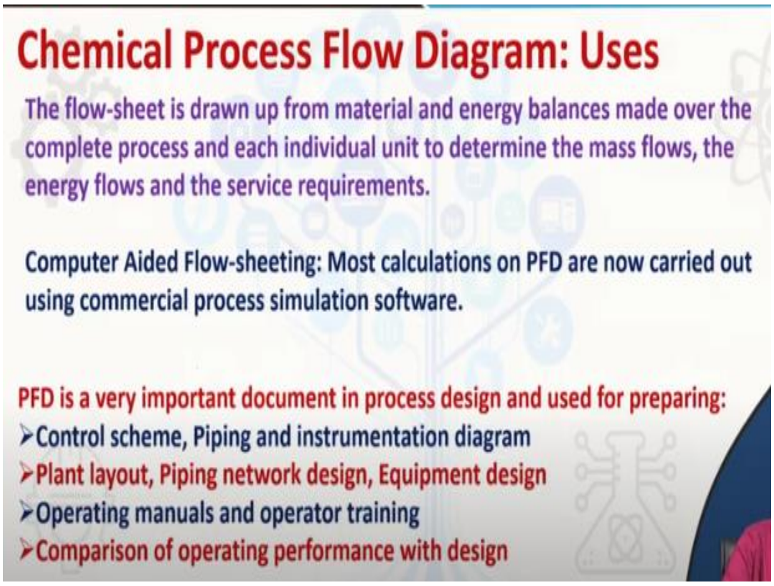

So what are the uses of process flow diagram? The process flow sheet is drawn up from material and energy balances made over the complete process and each individually unique to determine the mass flows, the energy flows and the service requirements. Computer Aided flow-sheeting is normally done these days.

Most calculations of process flow diagram are now carried out using commercial process simulation softwares. Process flow diagram is a very important document in process design. And it is used for preparing control scheme, piping and instrumentation diagram, plant layout, piping network design, equipment design, operating manuals and operator training, comparison of operating performance with the design.

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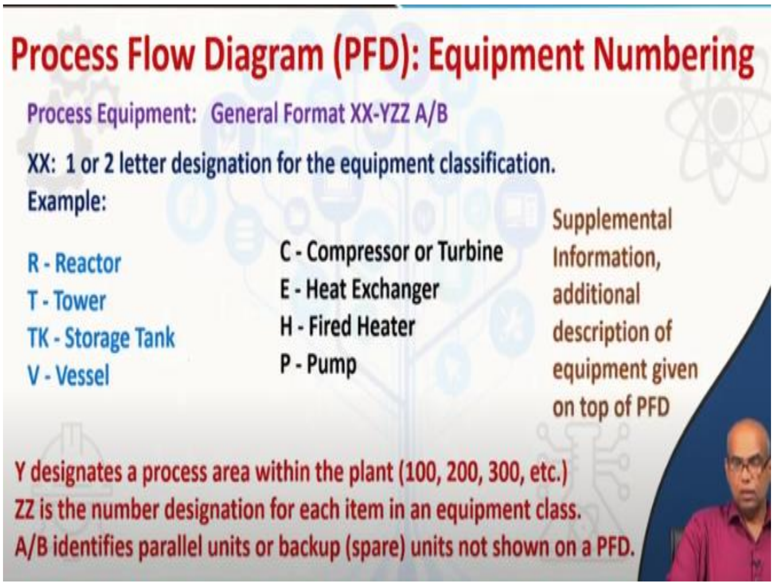

Now let us see how the equipment are numbered in process flow diagram. So the general format is XX-YZZ A/B. So what does it mean? Look at the first symbols XX. One or two letter designation for the equipment classification. So it may be XX-YZZ A/B or it may also be just X. So either it will be XX or single letter X. So this is a designation for the equipment classification.

For example, if the letter is R it usually stands for reactor. T for tower. TK for storage tank. V for vessel. C for compressor or turbine. E for heat exchanger. H for fired heater. P for pump etc. Next comes Y. Now Y designates a process area within the plant. It normally has number like 100, 200, 300 etc. So 100, 200, 300 etc. Then ZZ is the number designation for each item in an equipment class.

So ZZ is the number designation for each item in an equipment class. And finally, A/B identifies parallel units or backup spare units not shown on a process flow diagram. Supplemental information or additional description on equipment given on top of process flow diagram.

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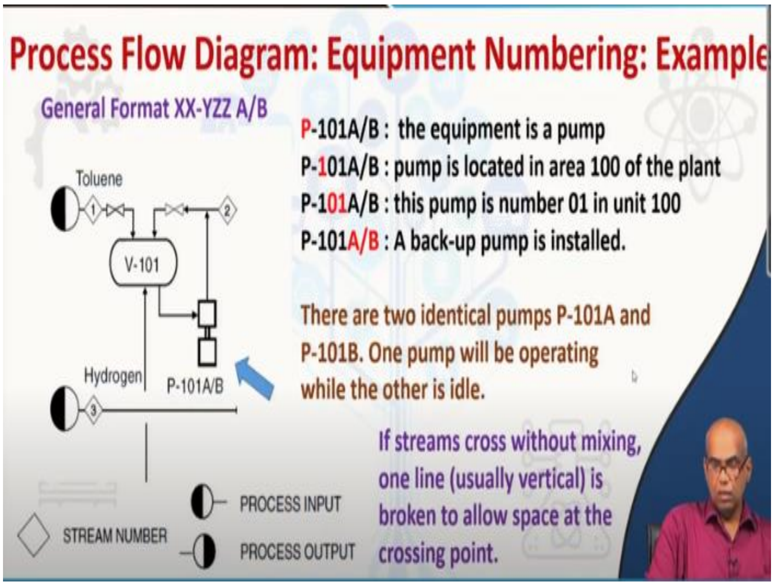

Now let us take an example to understand it better. So what you see is a part of a process flow diagram. Now let us look at the equipment P-101 A/B. What does it mean? Now the letter P means the equipment is a pump. 1 of 101 means pump is located in area 100 of the plant. Then 01. 01 means that this particular pump is numbered 01 in the unit 100. And then finally, A/B represents that a backup pump is installed.

So there are two identical pumps. P-101 A and P-101 B. One pump will be operating while the other is idle. Here note that this also shows that the horizontal line is not broken but the vertical line is broken. Also note the symbols for process input and output. Both are input.

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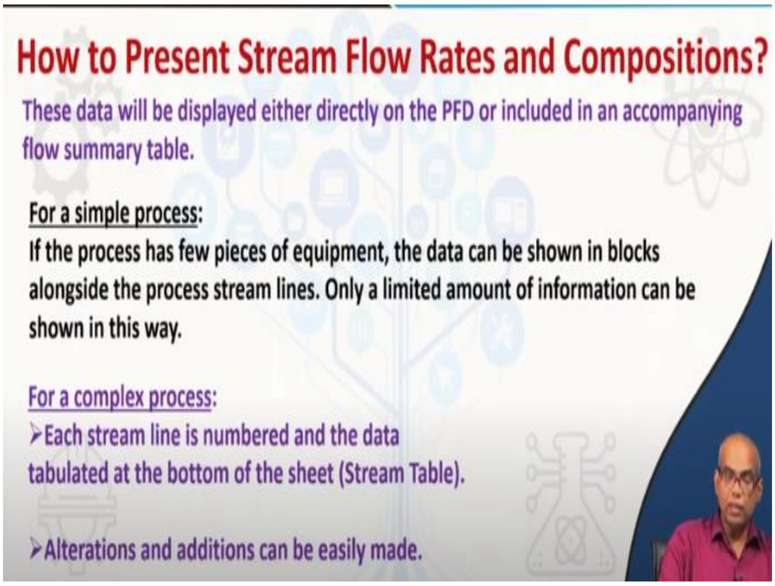

Now how do we represent stream flow rates and compositions on process flow diagram? These data will be displayed either directly on the process flow diagram or included in an accompanying flow summary table. For a simple process, if the process has few pieces of equipment, then the data can be shown in blocks alongside the process stream lines. Only a limited information can be shown this way.

So for a very simple process, you can use a block alongside the process stream and within that block, you can write those informations. But obviously, you cannot write many. Otherwise it will be very difficult to read. For a complex process, each stream line is number and the data tabulated at the bottom of a sheet. It is a stream table. Now the advantage of using stream table is alterations and additions can be done very easily.

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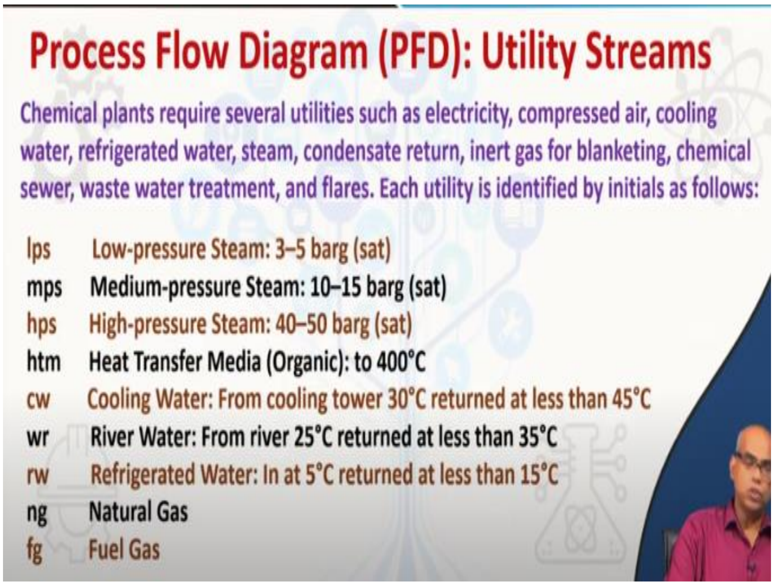

What about utility streams? Chemical plants require several utilities such as electricity, compressed air, cooling water, refrigerated water, steam, condensate return, inert gas for blanketing, chemical sewer, wastewater treatment and flares. Each utility is identified by initials. And these are shown here.

Like lps represents low pressure steam, mps medium pressure steam, hps high pressure steam, htm heat transfer media organic, cw cooling water from cooling tower 30 degrees Celsius return at less than 45 degrees Celsius, wr river water from river 25 degree Celsius returned at less than 35 degrees Celsius, rw refrigerated water, ng natural gas, fg fuel gas etc. So these are the initials that will be used to identify utility streams.

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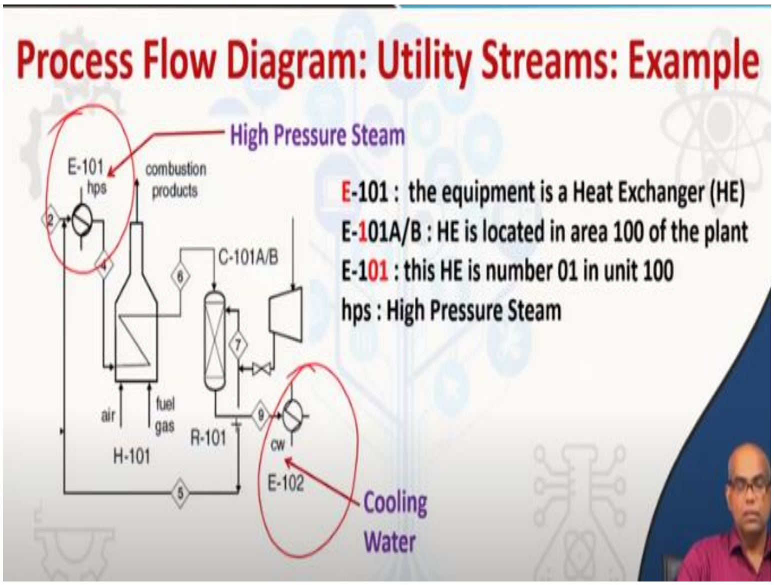

Look at again a part of this process flow diagram. Look at hps high pressure steam with E-101. So E-101 is a heat exchanger and this utility stream is associated with high pressure steam. Similarly the heat exchanger 102 has cooling water. So utility streams are also represented on the process flow diagram using appropriate initials. So E-101 will represent that the equipment is a heat exchanger.

E stands for heat exchanger. 1 for 101 represents heat exchanger is located in area 100 of the plant. And 01 is that this is numbered 01 in unit 100, hps stands for high pressure steam.

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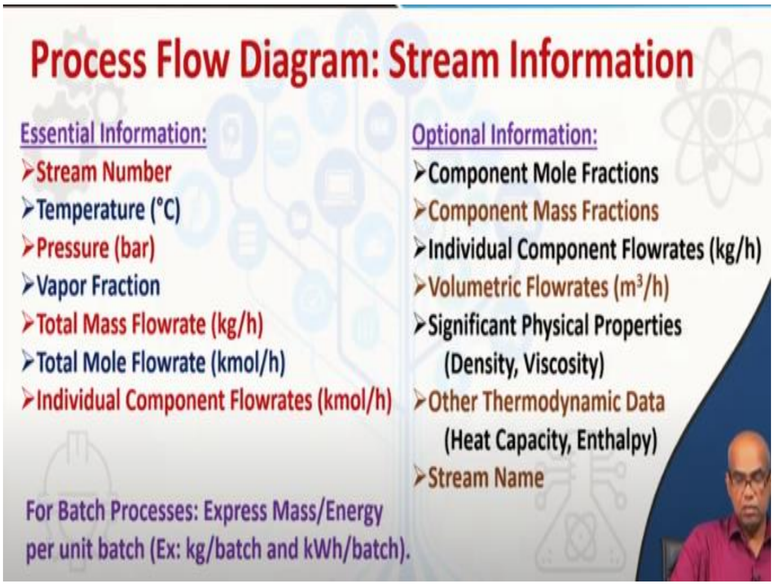

Now in a process flow diagram there are certain informations about streams which are essential information and you must supply. There are certain informations which are optional. So what are the essential information for stream? Stream number, temperature, pressure, vapor fraction, total mass flow rate normally in kg per hour, total mole flow rate normally kilo mole per hour and individual component flow rate normally kilomole per hour.

Optional informations. Component mole fractions, component mass fractions, individual component flow rates, volumetric flow rates, significant physical properties such as density, viscosity etc. Other thermodynamic data such as heat capacity, enthalpy. Also stream name. So there are some essential informations as well as some optional informations. So we talked about continuous processes.

For batch processes we express mass or energy per unit batch. For example, kg per batch for mass. Kilowatt hour per batch for energy. So for batch processes will represent these quantities per unit batch.

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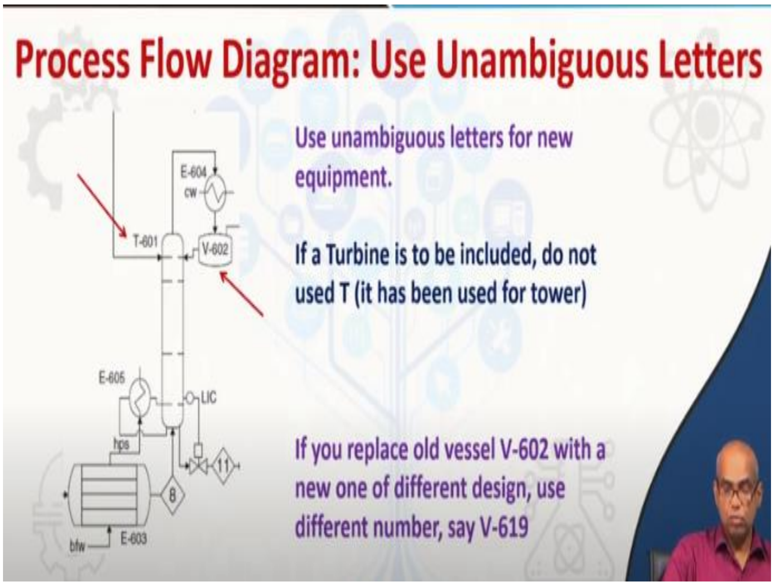

In a process flow diagram always use unambiguous letters. Look at the part of the process flow diagram. Suppose, a turbine is to be included in the process. So you should not use symbol T for turbine. Normally we use C for compressor as well as turbine. But T is already used for towers. So let us not use the T for turbine. If we replace old vessel V-602 with a new one of different design we must use a different number.

Let us not use the same V-602. For example, you may use say V-619 to clearly indicate that it is a new vessel.

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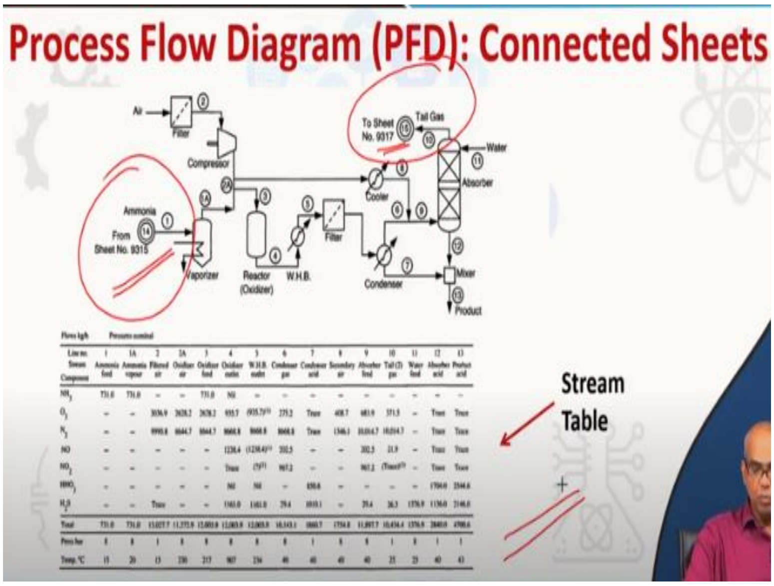

So again here you see is a part of complete process flow sheet and look at here and look at here. So this comes from sheet number 9315 and this goes to sheet 9317. So there are several sheets which are connected and this is how the connected sheets are represented. So it shows from which sheet it is coming and from which sheet to which sheet it is going. And these are the associated streams with the process and the informations about the streams are supplied in terms of stream table.

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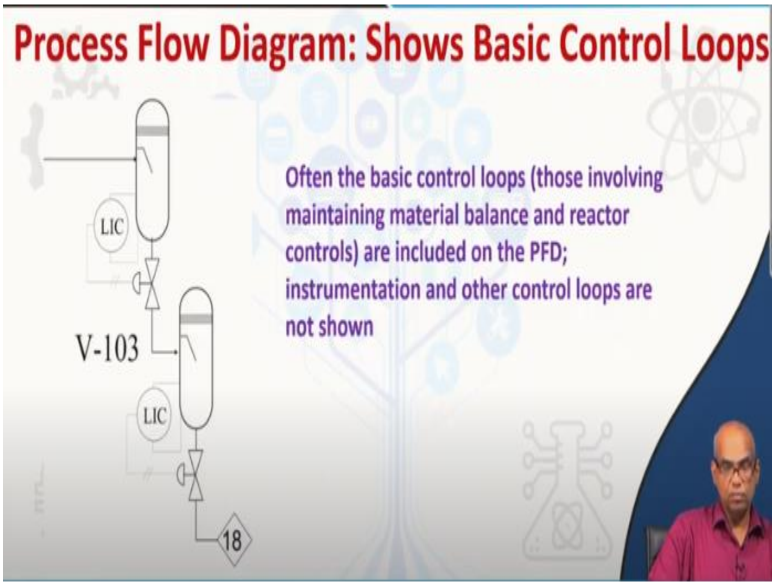

A process flow diagram will show basic control loops. Often the basic control loops those involving maintaining material balance and reactor controls are included on the process flow diagram. Instrumentation and other control loops are not shown. LIC stands for level indicator and controller. So the basic control loop is shown.

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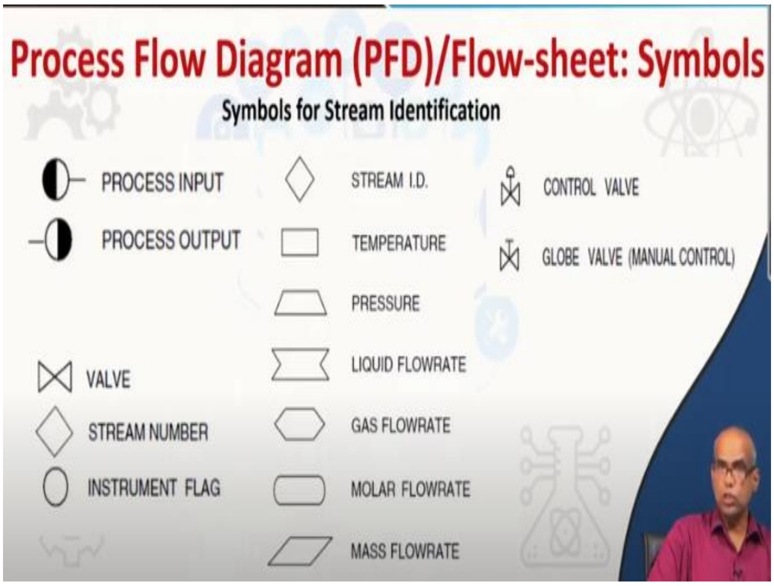

Now we will show symbols that we use to draw process flow diagrams. So what you see is symbols for process input, process output, valve, stream number, diamond symbol, instrumentation flag, blank circle. Then there are various symbols. You have to go through this symbol and try to remember the symbol so that you can identify the symbols when you see a process flow diagram.

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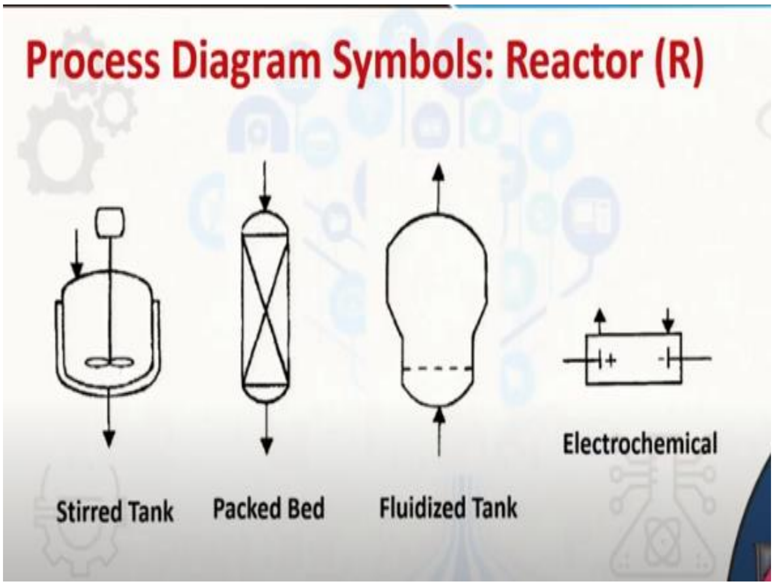

So here are various symbols for reactors. Stirred tank, packed bed, fluidized tank, electrochemical reactor.

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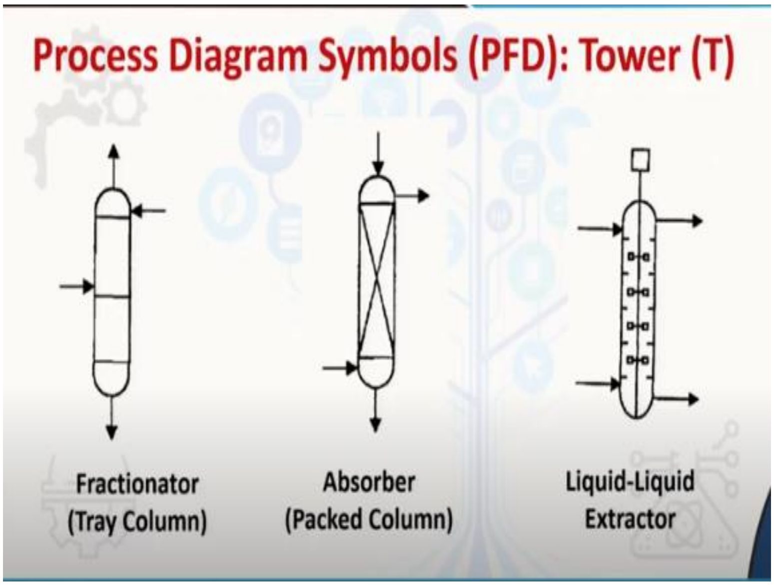

Several towers. Fractionator, absorber, liquid-liquid extractor.

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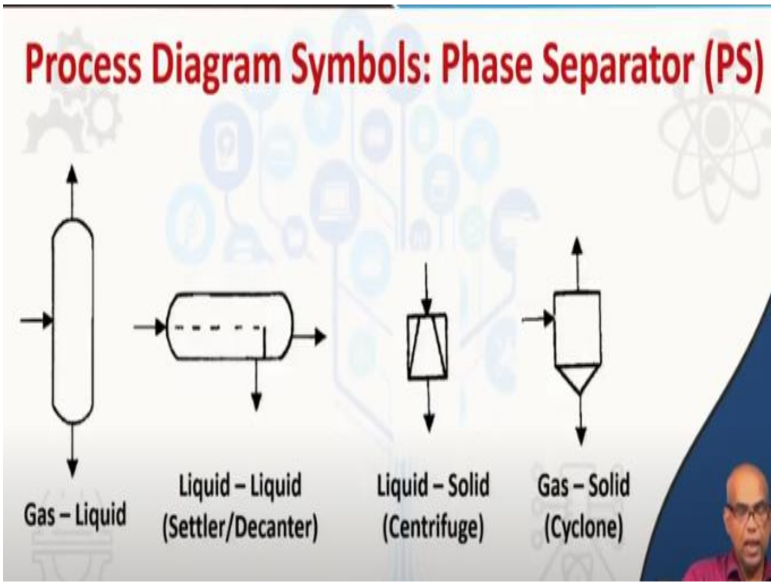

Several phase separators. Gas-liquid, liquid-liquid, liquid-solid, gas-solid.

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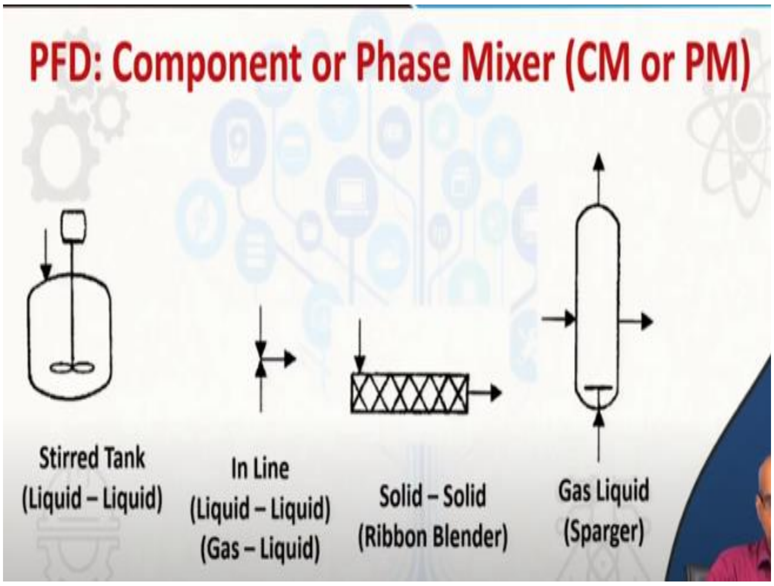

Component of phase mixer, such as stirred tank, in line mixer, solid-solid ribbon type blender, gas-liquid sparger.

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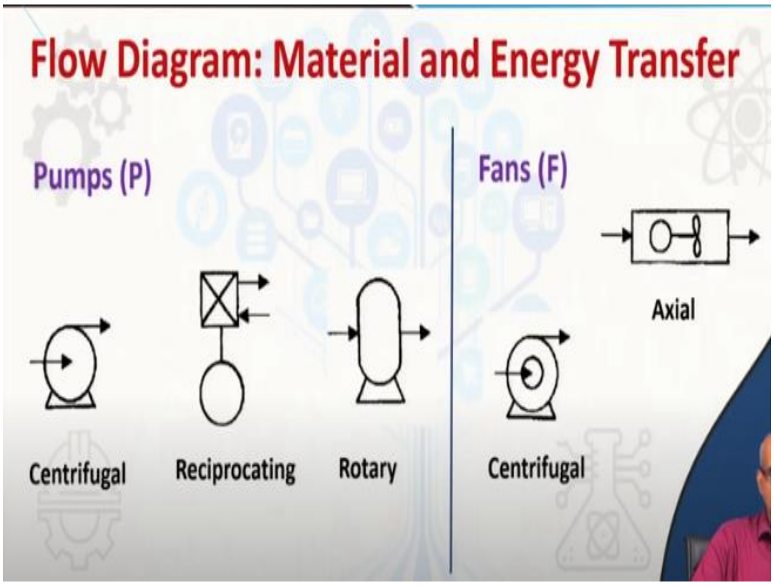

Several pumps such as centrifugal pump, reciprocating pump, rotary pump. Fans such as axial fan, centrifugal fans.

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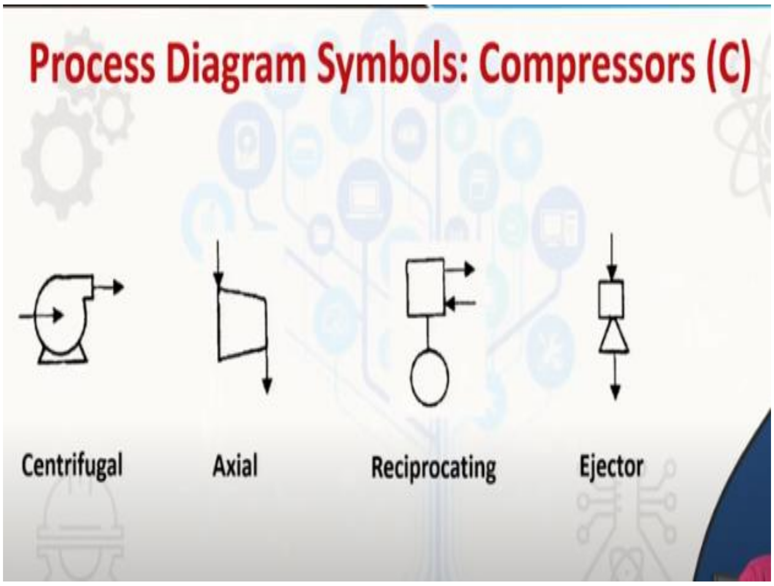

Several compressors. Centrifugal, axial, reciprocating, ejector.

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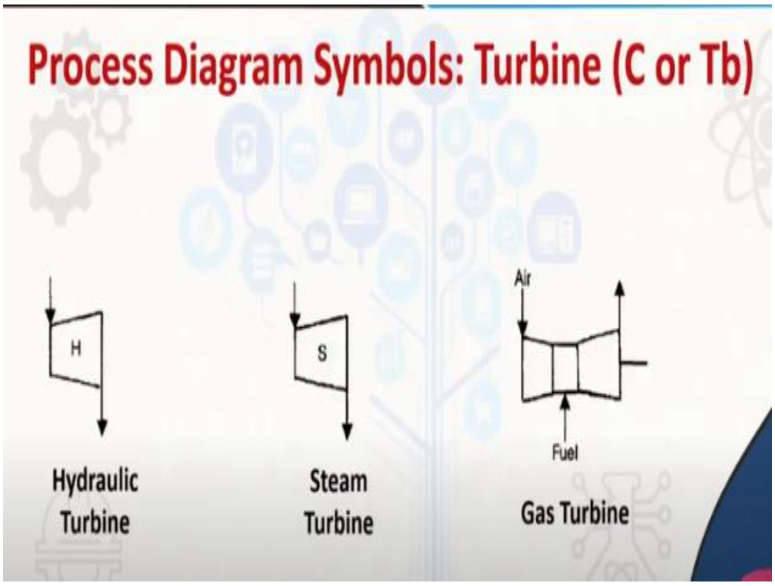

Several turbine. Hydraulic turbine, steam turbine, gas turbine.

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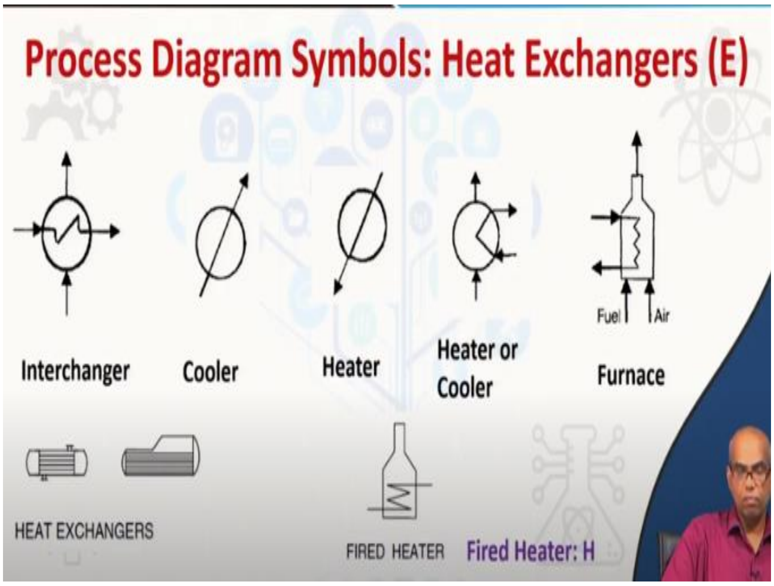

Heat exchangers. Fired heaters. Heat exchanger represented by E. Fired heaters are represented by H. Try to remember the symbols.

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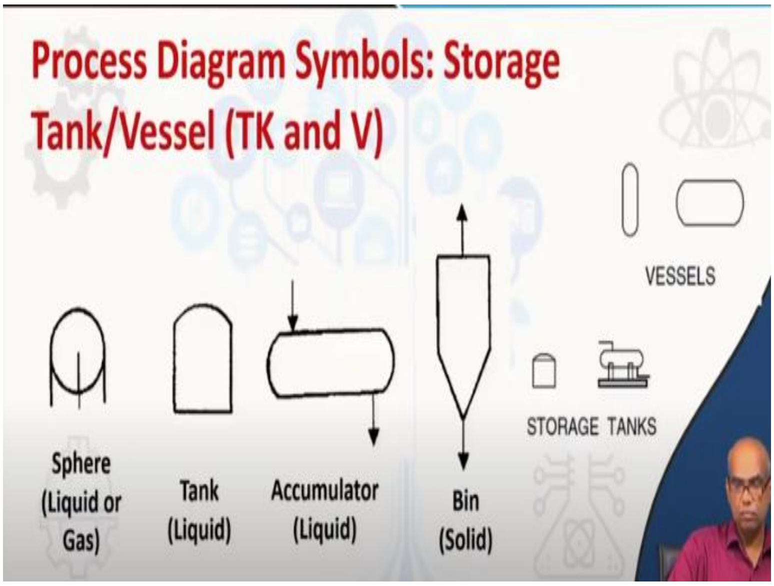

Various storage tank or vessel. Sphere, tank, accumulator for liquid, bin for solid.

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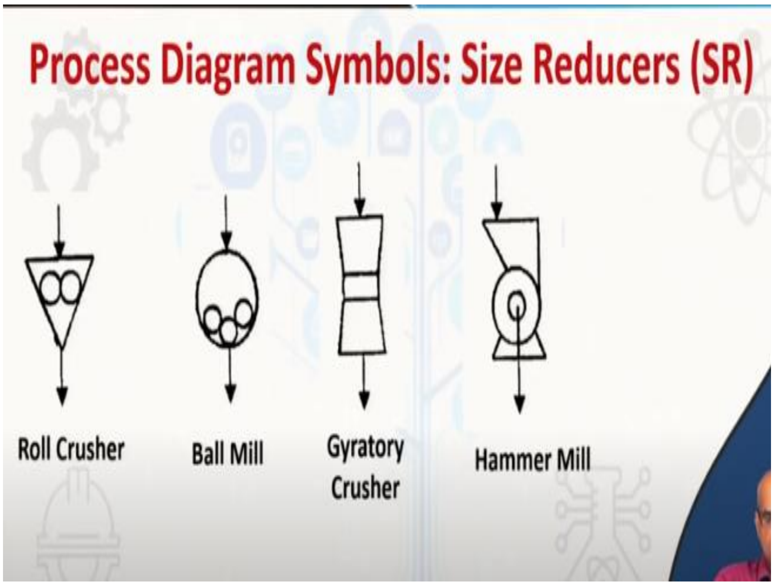

Size reducers such as roll crushers, ball mill, gyratory crusher, hammer mill, etc.

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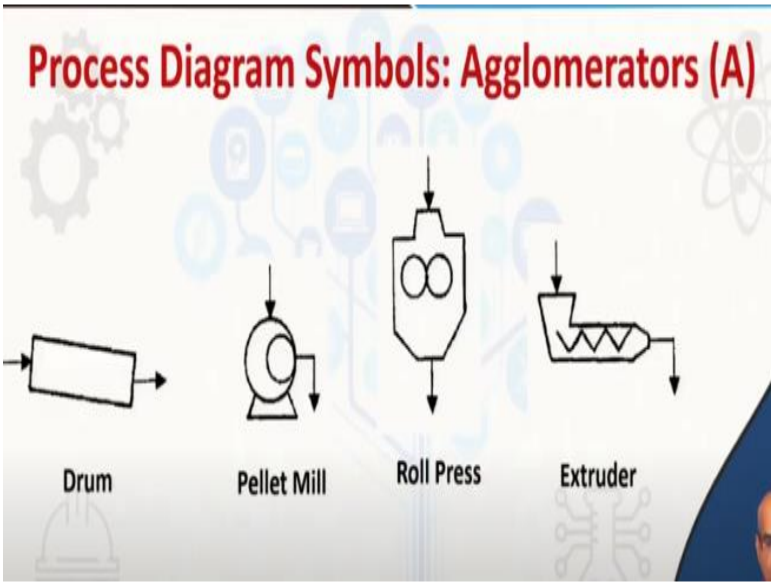

Agglomerators. Drum agglomerator, pellet mill, roll press, extruder.

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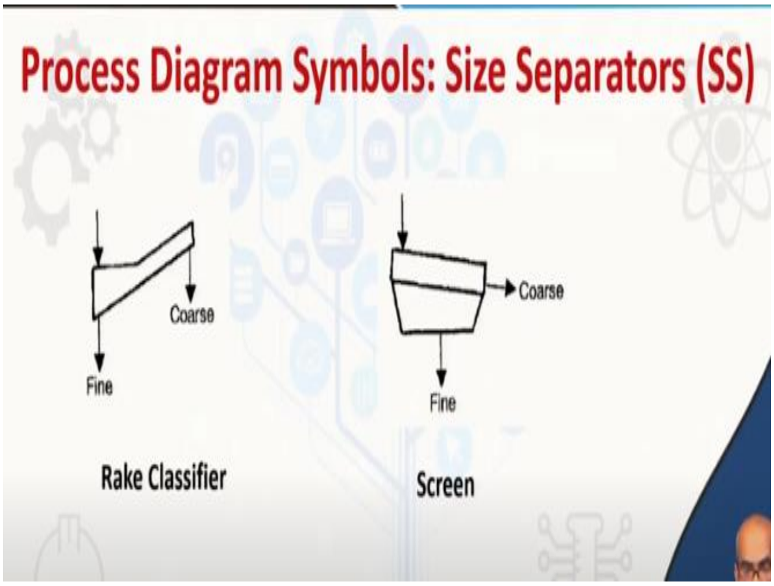

Rake classifier, screen, etc. So there are many more symbols. But these are most commonly used symbols. So you should be familiar with these symbols.

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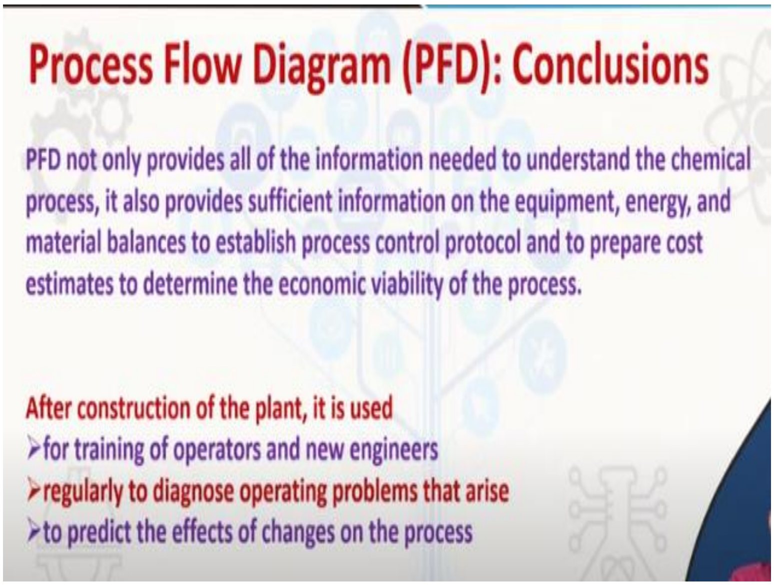

So we will conclude our process flow diagram discussion saying that process flow diagram not only provides all of the information needed to understand the chemical process, it also provides sufficient information on the equipment energy and material balances to establish process control protocol and to prepare cost estimates to determine the economic viability of the process.

After construction of the plant, its job is not over. It is used for training of operators and new engineers. It is used regularly to diagnose operating problems that will arise frequently in a manufacturing plant. It is also used to predict the effects of changes on the process. With this we stop our discussion on lecture 3 here. Thank you for watching.