Process Equipment Design
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Lecture – 1
Introduction

Hello everyone, myself, Shabina Khanum and I am working as Associate Professor in the Department of chemical engineering IIT, Roorkee, and here I am in front of you with an NPTEL l online certification course on process equipment design. As far as this course is concerned, this course is very beneficial for chemical engineers because here we are going to discuss design of important equipment which are used extensively in chemical processes.

So, as you know that the course is on process equipment design, if I ask you that what is a process, what is an equipment and what is design. So, as far as process is concerned that I think being an chemical engineer you all know that process is basically a method or a route through which we can convert raw material into the product. So, that is the basic definition of the process.

Equipment where we convert the raw material into product, so that is basically the unit in which we convert raw material into the product. And design that you all know that design means to decide the dimension of the equipment, to decide the internal structure and accessories which are associated to an equipment all that we have to decide through proper designing and designing means you do not have to draw.

You have to carry out some calculations, some steps so that you can reach to the final dimension of the equipment. So as you know that the course is on process equipment design, this is a 12 week course and today we are starting this course with the first lecture of first week and that is on the introduction. So, here we will first introduce this subject and basically we will make the basis so that you will understand that what is the necessary or what is the necessity for you to study this course.

First of all, we will develop that basis and then we will discuss design of each equipment one by one. So, before starting the design of process equipment, we will first discuss what is process design, where the design of equipment is apart, but where actually you have to focus

on while studying this course or while going through this subject where you can contribute in process design that we have to focus first.

As you already know that we are developing the basis that why you should study this course. So, let me first focus on process design. So, here I would like to mention that I have prepared the slides in slightly detailed manner so that you can get proper study material along with the detailed concepts. So, you may find that some slides may have more content and some slide may have less content.

But my purpose is that I should provide sufficient study material in this course only, in this video only and along with I should speak about the concepts in depth. So, let us start with the process design. Now as far as process design is concerned as I have already told that what is a process it is basically the route to convert raw material into product. So, what is a process design? So, first of all let me read the sentence and then we will discuss the factors or the content available in this one by one.

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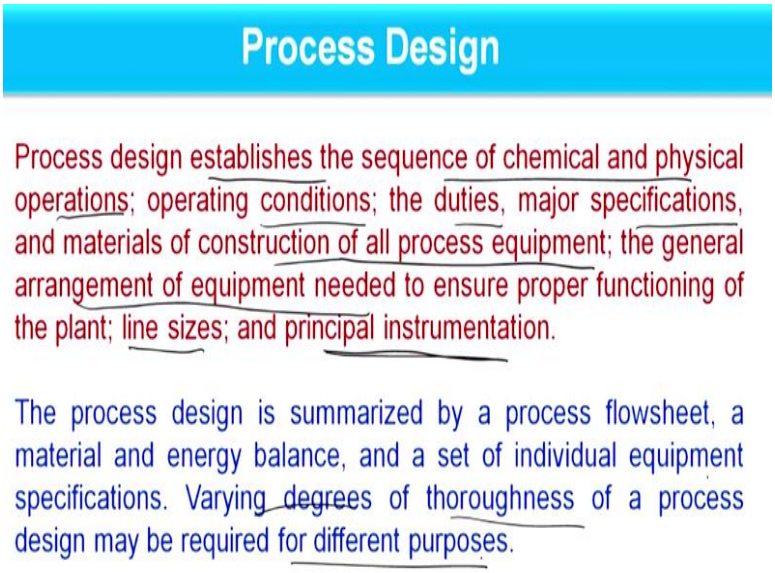

So as far as process design is concerned, it basically establishes the sequence of chemical and physical operations, operating conditions, duties, major specifications, material of construction of all process equipment and arrangement of the equipment needed to ensure proper functioning of the plant, line size and finally the principal instrumentation. So, what is the process design?

Process design basically connects different factors which are associated with the process. For example, the chemical and physical operations. Now, being a chemical engineer, you should understand what is a chemical operation and what is a physical operation. Chemical operation is that operation where we say that property of the material changes. Chemical operation is basically that operation where property of the material changes, what is the meaning of that?

Let us say if I am considering one reactor where component A and B reacts to give let us say C and D. So, property of C and D will definitely be different than property of A and B. It means we entirely get different material when reaction will take place. So, that we call as the chemical operation fine. Now, what is physical operation? Physical operation means property of the material is not changing at all.

To give an example let us say if I have to transport a material in a chemical plant from this location to this location. Now, what will happen? Material which is transporting from this location to this location is not changing. If I am supplying the coal, it will remain the coal till the end. However, what I am doing I am only transporting from one location to another location.

So therefore, it is basically called as physical operation where property of the material is not changing. To give another example, let us say as I have already discussed that A and B reacts to give C and D. Now, if I want to separate C and D, what will happen? I have to carry out some operations so that C and D we can obtain with high purity fine or the quality of C and D will be higher when I am separating that.

So what basically I am doing? I am only doing the physical operation, I am only considering the physical operation over here so that my product C and D will be separated, so that is the physical operation. So, I hope you understand the difference of chemical and physical operation. Now, if I carry out these physical and chemical operation, it will be carried out at certain operating conditions, certain temperature and pressure you can say.

So in chemical process design, we have to decide these operating conditions along with the chemical and physical operations. Now, if I am saying that I am fixing the operating condition what basically I am doing? Where I am fixing that? That fixation occurs in a

chemical equipment or in a chemical unit, fine. Now if I am seeing that chemical unit, it means I have to decide the major specification, means its dimensions.

What should be its height diameter? What should be its internal structure and all that will depend on the duty or the capacity of the equipment. So, if you see what I am doing I am trying to connect all these factors in a single process and therefore I am calling as a complete process or the process design. So, it includes chemical physical operation, it includes units or equipment with a specified capacity with specified duties with the specified operating conditions.

Now, next is what? Next is I have to arrange these equipment in a proper manner. Arrangement means what? Which equipment should come first, which equipment should come later on. To give an example, if I am producing C and D using A and B, so first of all I have to put the reactor where A and B will react and then C and D will be produced and then I can see separate C and D. So, obviously separator will come later than the reactor.

So, how I am arranging different equipment it will basically in such a manner so that the proper functioning of the plant should be ensured because what my aim is I have to get high quality product. To get that product how these equipment will be placed in a chemical plant that we call as basically the arrangement of the equipment. Now, once I am placing those equipment, how I will connect those equipment with each other?

That will be done through pipelines. So, after arrangement we will basically connect the lines or we can call that as pipelines and we will decide the dimension also. Dimension means what? Its length as well as diameter, and finally we will discuss or we will focus on the principal instrumentation that what will be the measuring devices, let us say flow meter etc., or thermocouple where I have to put all these we have to decide with principal instrumentation.

So, you see as far as process design is concerned, we have to focus on all these factors in such a way so that I can get the proper product. I hope it is clear. So, if I focus on the previous discussion what we can conclude? We can conclude that process design basically gives the process flow sheet and that process flow sheet must satisfy material and energy balance.

These are basically the thumb rules to check whether process is in balance or not. So, the basic thumb rule is energy and material balance. So, we have to ensure that each flow sheet should satisfy material energy balance and in which individual equipment must have proper specifications. So, that is the complete flow sheet and my design ends there when I am having a complete flow sheet.

Now further varying degree of thoroughness of a process design may be required for different purposes. So, what is the meaning of varying degree of thoroughness? It means if a process is complicated enough, we have to give sufficient thought before finalizing the flow sheet before finalizing the design. So as complexity of the process increases, we have to give sufficient thought and thoroughness of the process should increase.

So that is basically the step of process design. So, now we will discuss the different steps involved in process design.

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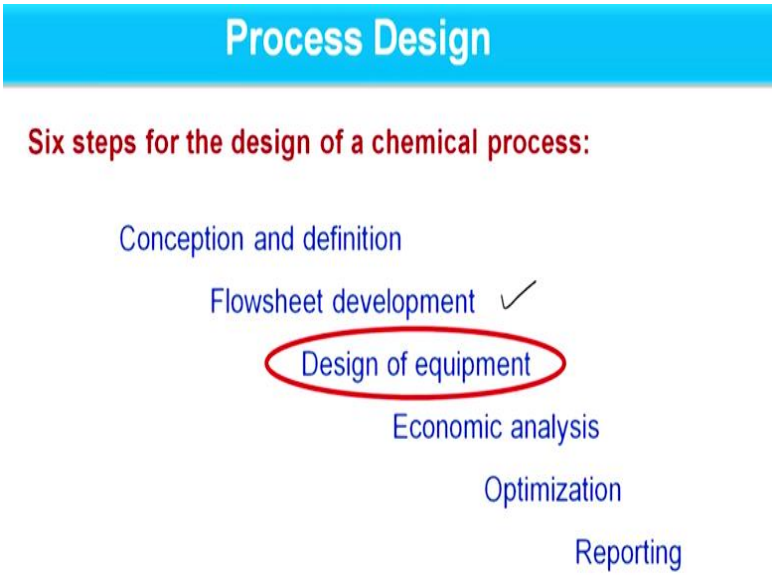

We have usually 6 steps. The first step is the conception and definition. Now, what is this conception definition? When you start design a process first of all you should be clear that what product you want to produce because accordingly you will decide the process, accordingly you will decide the raw material and other factors. So, first of all you have to conceptualize or define that what product we have to develop or we have to produce.

So, once I am having this, second step is the flow sheet development. Now, how we will develop this flow sheet? Let us say if I want to make product A, to make product A we will have different routes, we may have different routes and we have to select the proper route and proper route means what we have to select proper flow sheet. So, in that way we can first conceptualize that I have to produce product A and then accordingly I will decide the proper flow sheet of that.

Next is once I have decided the process flow sheet, I will be aware that what equipment I am including in that flow sheet. So, after deciding the equipment we have to carry out design of each equipment thoroughly so that I can put proper specifications of the equipment in process flow sheet, fine. So, once process flow sheet will be done, we have to design the equipment and after that we will carry out the economic analysis because economic analysis includes operating parameters as well as capital parameters.

Operating parameters means what? Operating cost. Capital parameters means capital cost and these costs cannot be completed until unless I will not complete the design of equipment. So, economic analysis I have to perform once I will complete the detailed equipment design. And if I am considering economic design, why it is important? Because economic analysis gives me the idea that if I sell this product.

Let us say if I am preparing product A, if I sell product A how much profit I have to obtain. If that profit is sufficient for me, then only I will go for production, otherwise I will not install the plant, I will not start the operation in this. So economic analysis is very important, but that will be done once equipment design will be over. Once I am having economic design, once I am having economic analysis, I will optimize the process.

Optimize means what? Optimization means I have to maximize the profit, I have to minimize the losses. Optimization basically considers the condition where I am getting maximum throughput, where I am getting maximum outcome from the process. So optimization usually on which parameter we do? As I have told you that economic analysis is very important, so optimization is usually done on economic analysis only.

To give an example let us say if I am considering operating cost and capital cost, addition of these two operating costs and capital costs gives me total annual cost. As far as optimization

is concerned, this total annual cost must be minimized. So, in optimization we can consider total annual cost minimization as an objective function or let me put in different way we have to consider total annual cost as objective function which I have to minimize, fine.

In any other way if I am saying that profit is very important for me, so I have to consider profit as objective function which I have to maximize, fine. In the similar line I can consider losses also. So, once all these factors, all these steps will be completed, then I will prepare a complete report that this much will be the total production, this will be a complete flow sheet, design of different equipment we have done and this will be the complete economic analysis.

So all that we have to report. Now, in this particular course, we will focus on design of equipment because that is the main aim of this course.

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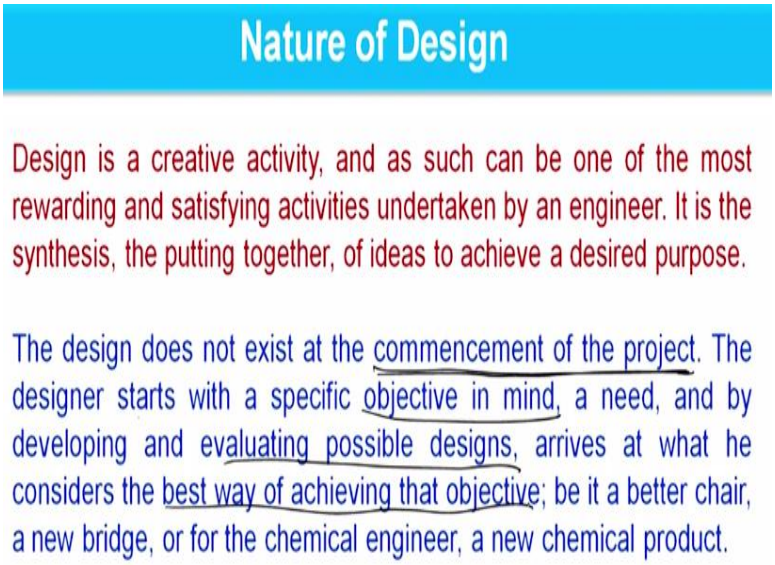

So, I have already discussed the steps involved in process design. Now, we will discuss what is the nature of design. What I am saying that this is a design and here I will focus on definition of design in more philosophical level than the technical level. Now as far as nature of design is concerned, design is a creative activity. Design means what? Design means you are producing something new, which is not available.

Otherwise that will be considered as a repeated activity. However, I am saying that design is a creative activity. It means the imaginative exercise you carry out to do the design. So, first of all, you basically imagine whatever you are going to produce and then you carry out some

analysis, some activity to complete or to address that imagination. So, that is basically you are developing a new thing, which is very satisfying and most rewarding activity.

Now, this is not only related to engineering, it is related to other fields also. Let us say if you are designing a dress, if you are making a statue, whatever you are doing it means you have to first think about that, you have to imagine that so that will become a creative activity. So in the similar line, design a chemical plant is a creative activity. Now, if I am saying that this is a creative activity to what I am doing.

Basically, I am combining the ideas, I am mixing the ideas and putting together the ideas which are related to produce a product. So design means to synthesize the idea properly. So that is basically the nature of design and nature is what this is a creative activity. So if I am considering design, this is design a step is well before then the commencement of the project.

If you see we have to first think and then we can design and then we can start the project. So, if I am asking that what is the work of designer, the work of designer is to set an objective. Objective means depending upon the need and what is that need that I will discuss in next slide. So if you see that what is the work of designer it basically starts with a specific objective, evaluating different design possibilities and arrive at best way of achieving that objective.

It means what he has to think about different combination of limitations, what limitation he has and then accordingly he has to reach to the definite objective, whether it is a chair, whether it is a bridge or it is a chemical product for a chemical engineer that is basically the nature of design.

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Now, next is the design objective. What is the design objective and that I am saying as the need? Now need is what? Need is as far as chemical engineering is concerned, need is basically the public demand. If you see the public demand of a product and that we can consider as a commercial opportunity for a chemical engineer and that commercial opportunity can be decided by sales and marketing organization.

First of all, we will focus on the public requirement, then we will decide that what would be the suitable product for that and then we consider that as a need and that need we are referring as objective. Now, once I am having the objective, I will have some subobjectives also. Subobjective means what? What will be the route to meet that objective? What would be the raw material? What would be the economic conditions?

All these things we consider further when I have decided that the objective and so we are calling that as subobjectives. So, once I am having the objective, I will decide subobjective and then I will carry out the overall process design.

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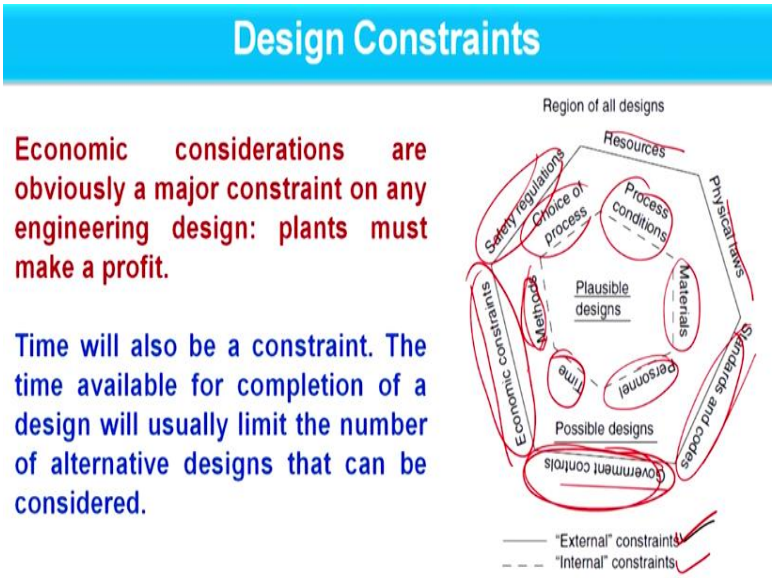

Now, so as I have told you that is it is entirely in the hands of designer that he has to decide what process he has to consider to make the product. I mean there are different constraints. So some design constraints I am discussing over here. If you see this image here I am having external constraints and internal constraints. External constraints are shown with the solid line as you can see the outer periphery.

All these we have the external constraint and similarly dotted line which is the inner periphery it is showing the internal constraints. So, what is basically external constraints and what is internal constraint is external constraints are those constraints which are not in a hand of designer. Internal constraints are basically in hand of the designer. So, what are those external constraints I am discussing a few examples of that.

So first is let me focus on go government control. To give an example if you consider the chemical plant there are strict rules and regulation from the government side that we do not have to discharge waste that is very important guideline. So, designer will do nothing with that, he has to follow that constraint and what is the meaning of that? He has to treat the waste properly, he cannot throw that waste in environment because of the government norms.

Economic constraint, economic constraint is what would be the price of raw material. If some negotiation is possible that can be done but that is very rare. If that price is set by the government, economic constraint will be a crisis criteria for designer to choose a proper process. Safety regulation, he has to follow, he cannot do anything and the standards and codes. It means when he is designing, he has to follow some guidelines.

Let us say if we are going to design the pressure vessel, we have to follow Indian Standard Code that is IS 2825 1969. So, all these constraints he has to follow, he cannot play with this. However, he can consider some constraint which he can vary. For example, method. Method means if he can have the option to choose the manufacturing of the equipment, he can make a choice there.

He can choice the process as I have told you different routes are available to convert raw material into product, so he can choose the proper process to convert that raw material into product. Process conditions he can change, he can make slight changes there. Materials, raw material he can choose. Personnel means how much he can invest or how much he has to take a loan, etc., and time.

Time means what? He has to give the product in definite time. Let us say if I am saying that I am going to design a product which production will start after let us say 4 or 5 years, it will not work for me. So time is very important. Now as far as external constraint is concerned, most important constraint is the economic constraint because everything will depend on that, until unless I am not getting proper profit, I will not make a product.

I will not install a chemical plant and so I will not design. And as far as internal constraint is concerned, time is very important because he has to give the product in a definite time. So, these are basically the design constraints.

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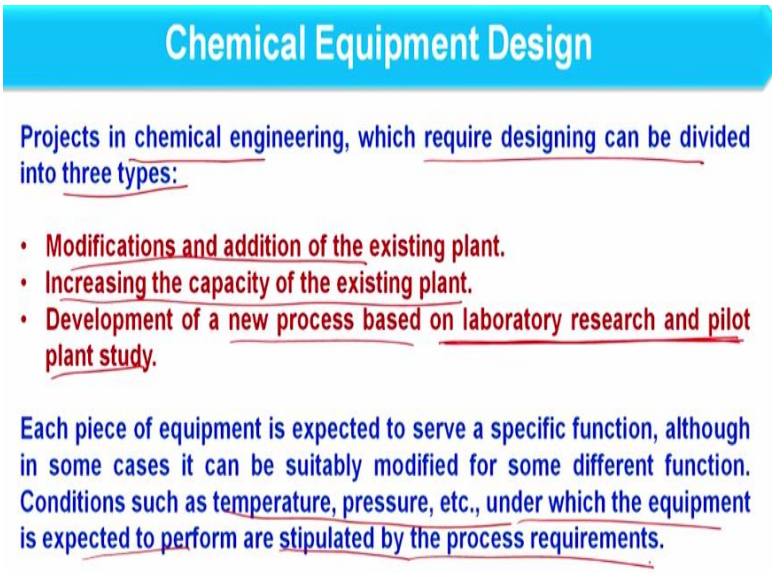

Till now what we have discussed? We have basically discussed factors which are associated with the process design, either it is constrained or different factors were there and now we will focus on chemical equipment design because this is the part of process design. First of all, we have developed the basis of process design and then we are going to discuss chemical equipment design.

So, the projects in chemical engineering which require designing can be divided into 3 types. The first is modification and addition of existing plant, what is the meaning of this? If I have to modify the existing plant, some new technique is available and I have to install that new technique, I have to design the equipment. Addition means what? If I am adding additional product in my existing plant.

Let us say if I am producing C and D in which only C was important to me, I am separating the component focusing on C component only. However, if I am finding that D is also important, so I have to carry out some analysis to make D more, so make D of higher quality, I hope you are getting that. So in that way, I have to design the proper equipment. So chemical equipment design will play a role there.

Second is increasing the capacity of the existing plant. In that case, I have to design the new equipment though those equipment will remain same. I am not changing the equipment because of I am increasing the capacity to, let us say I am having previously one heat exchanger, I am putting another heat exchanger of different capacity like that. So I have to design that heat exchanger.

So, next is development of new process based on laboratory research and pilot plant study. So you see here we have to design the equipment for new plant as well as for existing plant and when I am designing what basically I am doing, I am basically specifying the proper functioning of the equipment and specifying means what we have to decide the operating condition of the equipment.

So that conditions such as temperature and pressure under which equipment is expected to perform are specified by the process requirements. So you can understand over here that at three level we can contribute in designing and designing means what? We have to specify the

operating condition of the equipment and accordingly we have to decide the dimension of the equipment.

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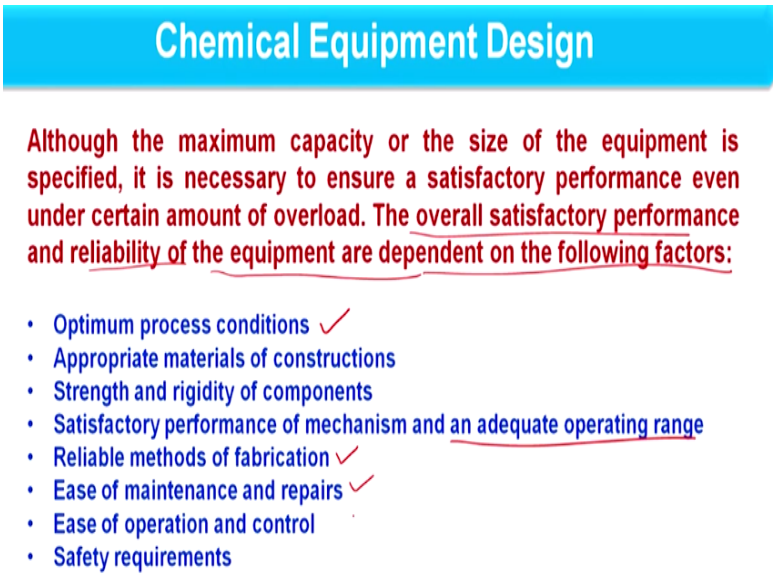

Now, we will ensure that equipment should perform satisfactorily under all possible conditions. For that purpose, I have to design the equipment and I have to test that equipment at maximum possible condition. So, overall satisfactory performance and reliability of the equipment are dependent on following factors and these factors are first is the optimum process condition.

Optimum process condition means where I am getting maximum output. So, equipment should be operated satisfactory really at that optimum process conditions. Next is appropriate material of construction. We have to choose appropriate material of construction, strength and rigidity of the equipment or the component that is very important that it should not fail while carrying out the operation.

Satisfactory performance of mechanism and adequate operating range. So, here you see operating range. So, initially we have discussed that it should operate at maximum optimum condition. So, initially we have discussed that it should operate at optimum condition and then it should be operated in a range because if I am saying that temperature is 20 degrees Celsius that temperature may vary during the operation, it may vary let us say from 18 to 22.

So, that possibility in equipment or that flexibility in the equipment should be there. We have to focus on reliable method of fabrication, then I can say that satisfactory performance can be

obtained from equipment. Ease of maintenance and repair that is very important that maintenance part should be easier in equipment and then we have ease of operation and control that is important and finally the safety requirement.

So, all these factors should meet properly and then only I can say that design is better or design is acceptable. So, that is about the equipment design and process design. So, now you must get the idea that what is the importance of proper design of the equipment and proper design of process. So, now we will focus on that on which plant we should apply that design. So for that I am considering chemical industry, obviously being a chemical engineer we are going to design the equipment for chemical industry.

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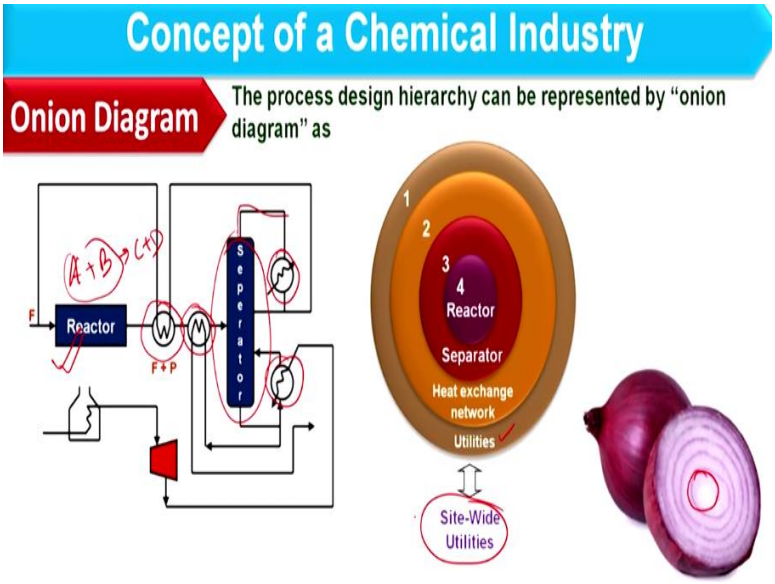

So first of all, let me focus on chemical industry and that I am explaining through onion diagram. Onion diagram you all should know that if I am considering a chemical process where let us say A and B is converted into C and D. So that A and B reaction should be carried out in reactor. So reactor is a core of chemical plant, and if I am considering the onion diagram, it means the innermost section of that we consider as a reactor.

So innermost layer of the union we can consider as a reactor. So, here you see we have the onion and the innermost section is the reactor which we can consider as the core of a chemical process. Now once A and B will be generated, we can produce C and D. So, obviously once I am having C and D I have to separate C and D. So, if you see separator here is the next layer to the reactor.

So, we can say this is the second most inner layer of an onion diagram and once I am having the reactor you see in this diagram whatever stream is exiting it may require cooling, it may require heating, and feed to separator also require heating or cooling, what is the meaning of that? Once I am having the separator, I have to install heat exchanger network, either it is heater cooler or simple heat exchanger.

So heat exchanger network will be the third most layer from inside and finally we can have the utilities because if I am saying that I am installing heater and cooler, there I have to provide definite utility, let us say cooling water or steam and once I am having that utility I have to generate that utility in a chemical plant. So, I have to focus on site-wide utilities. So, these are basically different layers of chemical plant. We can represent that plant effectively through onion diagram.

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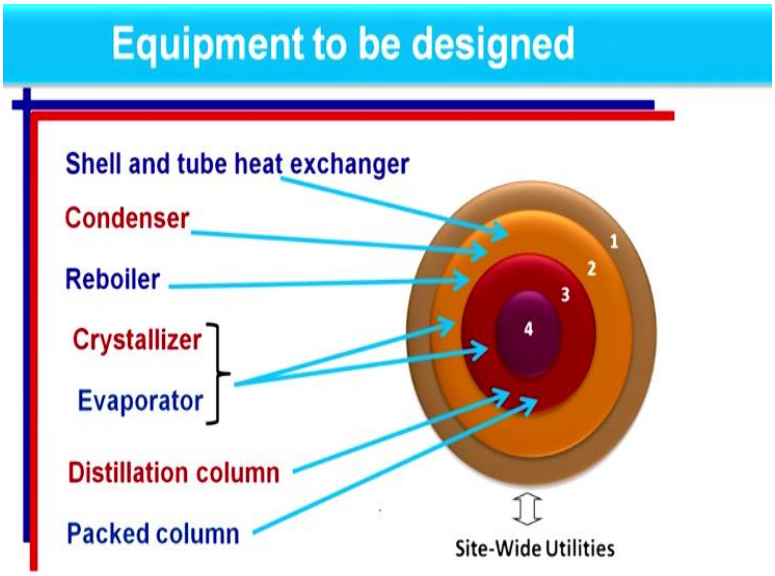

Now, we will discuss that what equipment we are going to design. Till now you must have the basis that why you are studying this course, where you are applying this, I mean at what layer of chemical plant you can address while studying this course and now we will focus on different equipment we are going to design. The first one is shell and tube heat exchanger, very important equipment.

Condenser, reboiler, crystallizer, evaporator, distillation column and packed column. So, if you see almost all important equipment we have considered in this and when I am considering the onion diagram or at which layer you can focus on while designing these

courses. So, while designing these at what layer you can focus on while designing these equipment.

So, as far as shell and tube heat exchanger is concerned, this will come in second layer and condenser is also come in second layer. Reboiler is again a heat exchanger. So, it will be on second layer and then we have crystallizer and evaporator. We can separate here and we can transfer heat also. So, it will focus on two layer, separator as well as heat exchanger. Then distillation column and packed bed in second layer that is a separator.

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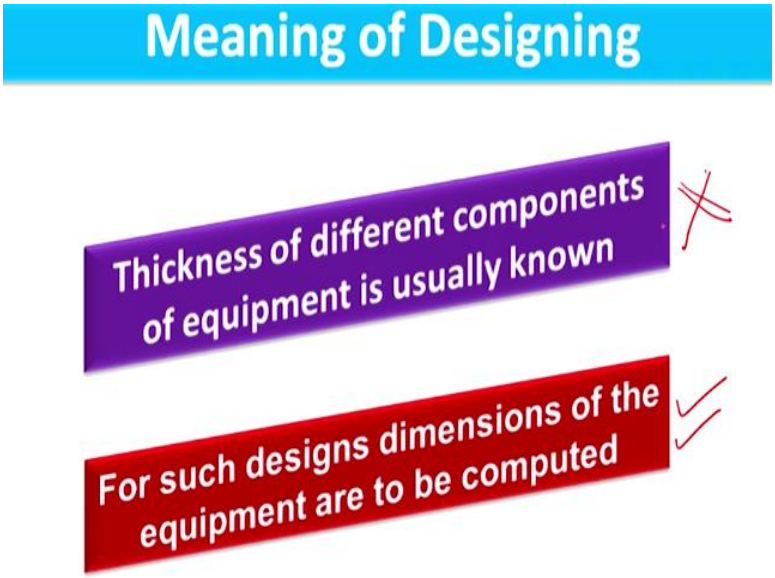

So, what is the meaning of designing? Meaning of designing in this course is to decide the dimension of the equipment to decide the internal structure of the equipment. In this course, I am not focusing on thickness of different components of the equipment because this part I have already covered in my another NPTEL course that is equipment design mechanical aspects. So, for this part 1 you can focus on that, however part 2 I am going to cover in this course only.

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Meaning of Designing

Equipment	Design
Shell & Tube Heat Exchanger	Compute overall heat transfer coefficient and pressure drop
Condenser	
Reboiler	
Crystallizer	Compute height, diameter and residence time
Evaporator	Compute steam consumption and heat transfer area
Packed column	Calculate bed height, diameter and column internal features
Distillation column	Compute ideal number of trays, plate efficiency and plate hydraulic parameters. Mechanical Design

So, as far as meaning of designing is concerned, what is the meaning corresponding to each equipment? First of all, if I am considering shell and tube heat exchanger, condenser and reboiler, all these equipment are basically heat exchangers only. So, what is the meaning of design here is we have to compute overall heat transfer coefficient and pressure drop. We have to compute this and we have to ensure that it should be within the permissible limit.

Crystallizer design means we have to decide the height, diameter, residence time inside the equipment. Evaporator design means we have to calculate the steam consumption and we have to find out heat transfer area and in packed column we have to calculate bed height, column diameter, column internal features, all these we have to decide in designing of packed column.

Now further in distillation column, we have to consider the ideal number of trays that is for the binary system and for multi component system, plate efficiency, plate hydraulic parameters, and finally we will focus on mechanical design. So, here I am considering mechanical design only for the distillation column or tall vessels for other equipment mechanical design course is prepared separately that you can see.

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1	Backhurst, J.R. and Harker J.H., "Coulson and Richardson Chemical Engineering", Vol. II, 5th Ed., 2002, Butterworth-Heinemann.
2	Sinnott, R.K., "Coulson and Richardson's Chemical Engineering Series: Chemical Engineering Design", Vol. VI, 4th Ed., 2005, Elsevier Butterworth-Heinemann.
3	Serth, R.W., "Process Heat Transfer: Principles and Applications" 2007, Elsevier Ltd.
4	Shah, R.K. and Sekulic, D.P., "Fundamentals of heat Exchanger Design", 2003, John Wiley & Sons.

So, I hope you will have a basis to study this course we have discussed different factors associated to the process design and equipment design and here I am having some of the references which you can focus on like we have very important books and all these books you must have read in your chemical engineering courses.

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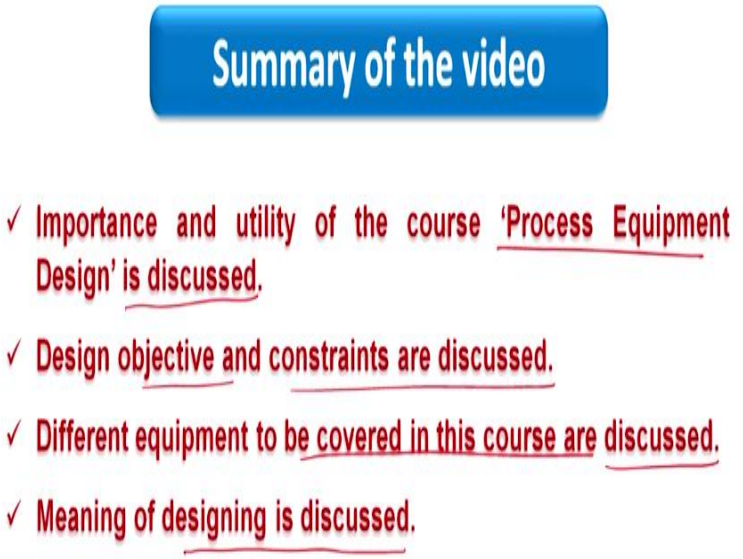

Now I am summarizing this video. In this video, importance and utility of the course process equipment design is discussed. Design objective and constraints are discussed. Different equipment to be covered in this course that we have already described and meaning of designing is discussed associated with different equipment. So that is all for now. Thank you.