Equipment Design: Mechanical Aspects
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Lecture 01
Introduction

Hello everyone, myself Shabina Khanam and I am working as associate professor in the Department of Chemical Engineering – IIT Roorkee. Here, I welcome you all in this course which is entitled as Equipment Design: Mechanical Aspects. It is a four-week course and today we are starting lecture 1 for week 1, and here in this lecture we will introduce the subject. So let us start this.

As you know, the title of the course is equipment design, so I think everyone of us understand the meaning of designing. Design means to compute the parameter for a system, and whatever system I am considering over here is the equipment. So, equipment design means to find out the parameter for a particular equipment, but here my main focus will be on mechanical aspect. So what is mechanical aspect.

Mechanical aspect if I am considering, it means I am focussing on mechanics of the material okay. So mechanical design or mechanical aspects basically deals with the mechanics of the material. So what parameters involved in the mechanics of the material, that we will discuss in the subsequent slides or that we will discuss later on, but here main focus will be on mechanical aspect. So one is mechanical aspect, another will be what. Another will be the process aspect.

So process aspect, it means according to the capacity what should be size of the equipment and what would be the internal accessories for that, which will be used for a particular process to be completed or to carry out, that will come under process aspect. So here, I am not considering process aspect, I am only focussing on mechanical aspect. In other words, we call this design as mechanical design also.

Like here, we are discussing Equipment Design: Mechanical Aspect. So in short, we can call that as mechanical design. So let us start the definition of mechanical design and then we will discuss some of the facts related to that.

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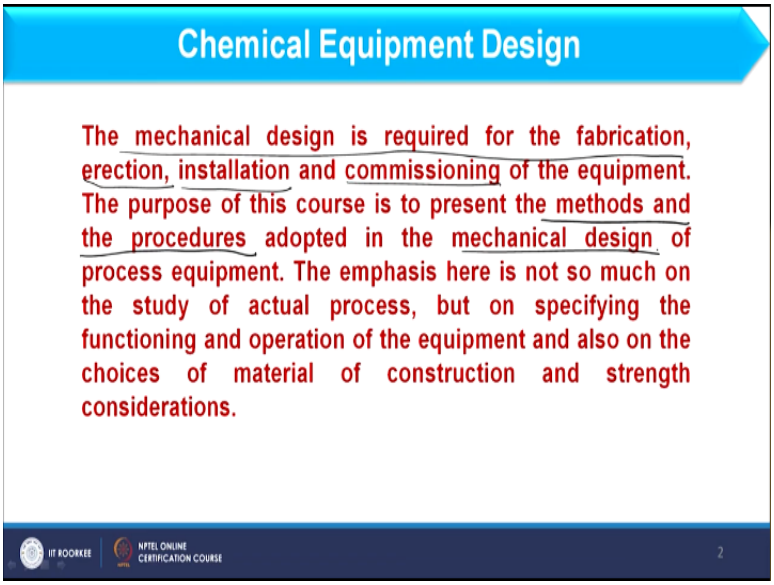

So let us start the discussion on mechanical design. So first of all if you focus on this particular slide, first of all we will see what is written over here and then I will try to explain each terms individually.

So, if you see mechanical design is required for fabrication, erection, installation and commissioning of the equipment. So here if you see mechanical design, we are basically dealing with fabrication, fabrication you understand, this is nothing but the manufacturing of a particular object or particular equipment. Second term we have the erection, erection means I am having different parts which I have to join together or assemble a particular equipment.

Installation, that is to make particular equipment to work, that is to bring it to the working condition in a real environment, so that is basically the installation. And commissioning means to order a particular equipment or on hire basis, if we consider. So all these aspects are coming under mechanical design. Now the purpose of this course is to present the methods and procedure adopted in mechanical design of process equipment.

So here you see, we will discuss different methods or what would be the procedure to design a particular equipment and design we will focus on mechanical aspects. So here you see, we will consider, we will focus on mechanical aspects, and as I have already mentioned next aspect is the process aspect. So in this particular course we will not focus on a particular process or particular equipment related to a particular process okay.

So here we will take one example of distillation column to make you understand what we should consider in the mechanical design. So for this distillation column, I am not going into detail of the process like what would be the feed, what would be the component present in the feed, how many number of trays, what would be top product, what would be the bottom product. All these points I am not going to discuss because that is a part of process. So, while designing the equipment using mechanical aspect or through mechanical aspect we are not going into detail of the actual process which is going on.

So instead of process on what particular subject or what particular factor I need to consider in mechanical design is the operating condition. Operating condition means its functioning as well as what are the parameters, which are kept inside this. For example, if I am considering distillation column that should be temperature as well as pressure, and further we will also focus on material for construction okay. So that material of construction will be decided based on the operating condition.

Therefore, in this particular course that is Equipment Design: Mechanical Aspect, I am only focusing on process condition, not the process in detail. Please see the difference between the two. I am not going into detail of the process, but only I will consider the condition, at which that process is going on and the material of construction. So these parameters or these factors will be considered in design in this particular course.

Now as far as designing is concerned, the main equipment I am considering over here is related to chemical engineering or chemical process. So all projects which are related to design in mechanical aspect point of view have three different categories or we can say that can be divided in three different parts.

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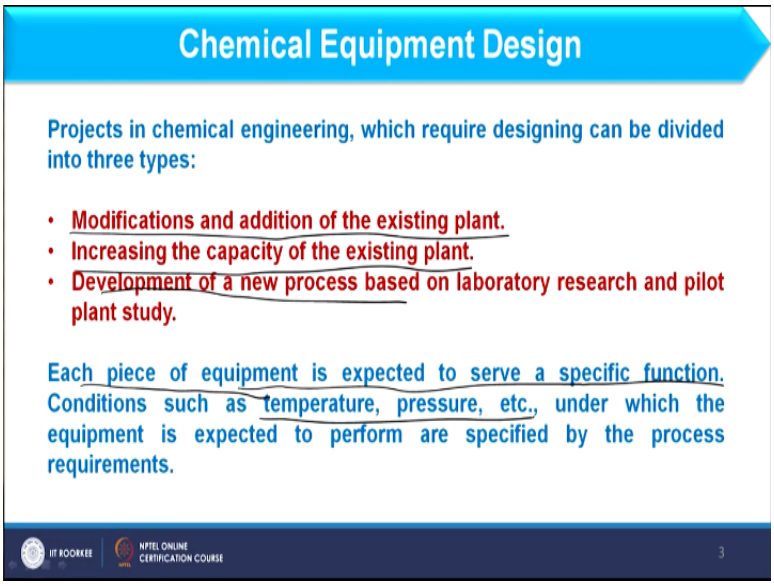

So the first part is modification and addition of existing plant. To make you understand this point, for example if I am considering one industry where obsolete technology is used, and at that place if you want to carry out the process through modern technology. It means some modification will be required, may be some new equipment or may be enhancement in the existing equipment will be required. So in that case or at that stage, mechanical design will play its role.

Second option I am having is, second category you can understand that I am having is increasing the capacity of the existing plant. Now what happens when I need to increase the production capacity of the plant, if I want to enhance the production capacity of the plant, I will also have to increase the raw material requirement in a given ratio. So once the amount of raw material will be increased, in that case I have to use the equipment of larger capacity or we can add a few equipments in a parallel okay. Whatever are existing parallel to that, we can have different equipments.

So again in that equipment we need mechanical design for completing the design aspect or completing the design of that particular equipment. Now the third category in that case is the development of new process okay, based on laboratory research and pilot plant study. So here you see, in this case if I need to install a new plant, so all equipment which are available in that PFD that I need to design, so mechanical design will play its role.

PFD I guess you understand that is the Process Flow Diagram, so considering that diagram I have to design the new equipment. So considering the mechanical aspect of equipment design we can focus on existing plant as well as on new plant. So in both category this mechanical design will play its role.

Further if each piece of equipment is expected to serve a specific function, whatever equipment I am considering that would be for a particular service to provide in a process okay, one equipment cannot provide all services that is used only for a particular service and that depends on temperature and pressure condition okay. So here I am focusing mainly on pressure and temperature condition inside the equipment, not the process in detail.

So along with temperature and pressure we have to decide few more parameters that we will discuss later on. So till now I guess you have idea that at what stages this mechanical design will play its role and whatever equipment I am considering that would be related to chemical industry or chemical engineering. So next I will speak on what should be the chemical industry and at what level in that industry we can contribute while studying this particular course.

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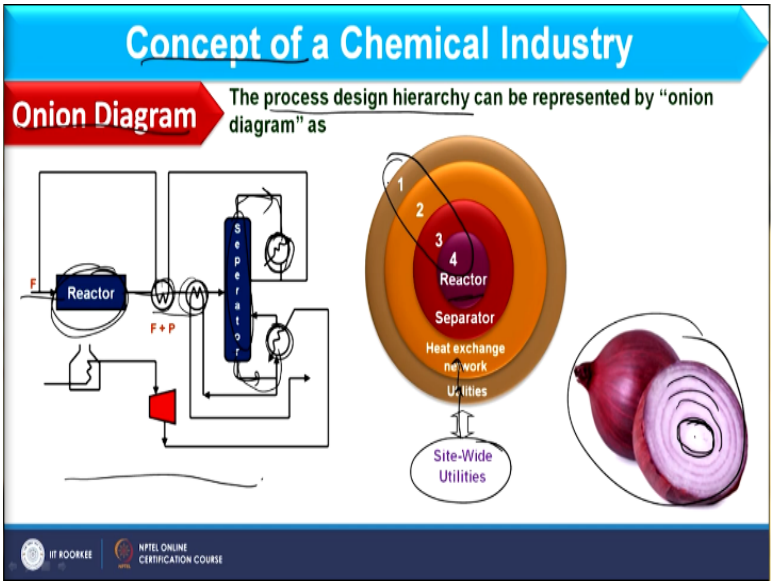

So in this slide we will discuss on concepts of a chemical industry, and to make you understand this concept I am using Onion diagram. What is Onion diagram, that we are going to discuss over here and how it is representing a chemical process that we will discuss. So as far as Onion diagram is concerned, through Onion diagram we can easily show process design hierarchy. So

that hierarchy means what should be the primary equipment, what should be the first stage to be adopted in chemical plant and how these stages will be used at different level okay.

So to make you understand, let us have a brief discussion on what is a chemical process and how this chemical process will be translated to an Onion diagram okay. So here if you see if I focus on this particular process flow diagram, PFD, what happens over here, here I am having the feed, which is entering into the reactor okay. So first of all feed would be the reactor. Now why it is entering into the reactor, because when I am considering chemical process, how you can define a chemical process.

Chemical process can be defined as where raw material is converted into the product okay. So for example if I am having a reaction like A+B = C+D, so here A and B first need to react and then C and D will be produced. So until unless A and B will not react, C and D will not be produced. So what is the meaning of that, that for any chemical process when any reaction is carrying out first of all I need raw material to react with each other and for that reaction we need reactor. So reactor is a basic or most primary equipment used in a chemical process okay.

As we have discussed over here that feed is entering into the reactor. So reactor would be the primary equipment. Now if you focus on this onion, which I have shown over here. So here if you focus, the centre of that onion is basically the core of this onion. Until unless this core will not be present, other layer cannot be formed. Other layer means, these, these, all these layers cannot form until unless I am not having this particular core.

So let us translate that concept into chemical industry like. If I am having a reaction to proceed we need to first design a reactor. So reactor will be the core of an Onion diagram as I have shown over here. So here you see this reactor I am showing and that would be the core of chemical process. And it is resembled to the core of onion, this is the most inner part of the onion, as it is the core of onion okay.

Now once I am having the reaction A+B into a reactor, after that I am having production of C and D. So once if you focus on this particular PFD, here I am having the reactor and then that product whatever are formed that enters into this separator and where the products are recovered

from top and bottom. So once I am having the reactor, formation of product take place and then we have to separate those products.

So what is the representation of that in Onion diagram is that is represented by another layer above the core. Please keep in mind first core would be of or inner most layer would be of reactor as it is the core of onion and above this we have the layer of separator okay. Further, if we focus on this PFD, whatever products are formed that may need some cooling as well as heating okay.

And here also when feed is entering to the reactor, product exits from the reactor and then those products will enter into the separator. So it may be required that separator will accept the feed at a particular condition. So to consider that particular condition we need to exchange heat of this product, which are exiting from the reactor. And similarly separator also needs some heating and cooling requirement.

So the next layer of Onion diagram would be the heat exchanger network. Now why I am calling this heat exchanger network because it may be one exchanger, it may be more than one or number of exchangers. So therefore I am collectively calling this as a heat exchanger network okay. Now you focus on this PFD again, if I am having this heat exchanger network, what happens if you consider these two exchangers it means these two exchangers are satisfy by the heat available in the process only.

However, if you focus on this exchanger as well as in this exchanger, what happens here I have to provide some of the utilities from outside. So what is utility that may be heating requirement or cooling requirement, which will be required from outside of the process. So next layer in Onion diagram will be of utilities okay. So you see here the outer layer would be of utility and once I am having the utility, what can be the example of utility, that may be steam if I am using for heating purpose and that may be cold water if I am using that for cooling purpose okay.

So somewhere in the plant these utilities needs to be generated. For example, if I am considering steam, somewhere I need to generate that steam in the plant and that generation may take place in a boiler house. And in the same line if I want to generate cold water I need cooling tower, so

this cooling water as well as boiler these two are used as a site-wide utility system or in other words we also call that centralized utility system.

So after that utility, we have site-wide utility where utilities are generated and then these are provided in the heat exchanger. So in this site-wide utilities, first utilities are generated and then it will be used in a heat exchanger as you can see from this Onion diagram. Now what happens, here how I have given this numbering, as I have discussed that reactor is the core of chemical industry okay.

So in discussion that comes first okay, but here number whatever I have given is the last number because that would be the innermost part. When you peel onion, you first remove the uppermost part, then you keep on removing till you reach to the core. So numbering I have done from as if you are peeling the onion. So number 1 should be the outermost and then last number would be of core of the onion, okay. So in this way we represent the chemical industry in Onion diagram.

Now, further we will discuss what should be the equipment which we are going to design, or to make you understand that equipment, first of all we will discuss about the equipment classification and then we will choose the equipment which we are considering in this particular course to be designed okay.

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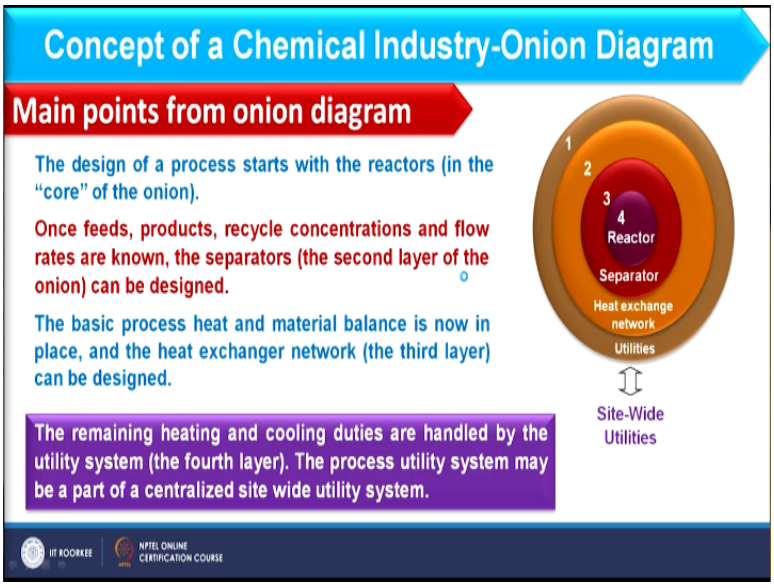

So here if you focus on this particular slide, so here whatever points I am considering over here, these points are basically I have already covered in the last slide and all these layers we have

already discussed how these layers are formed. So this is basically the summary of whatever we have discussed okay.

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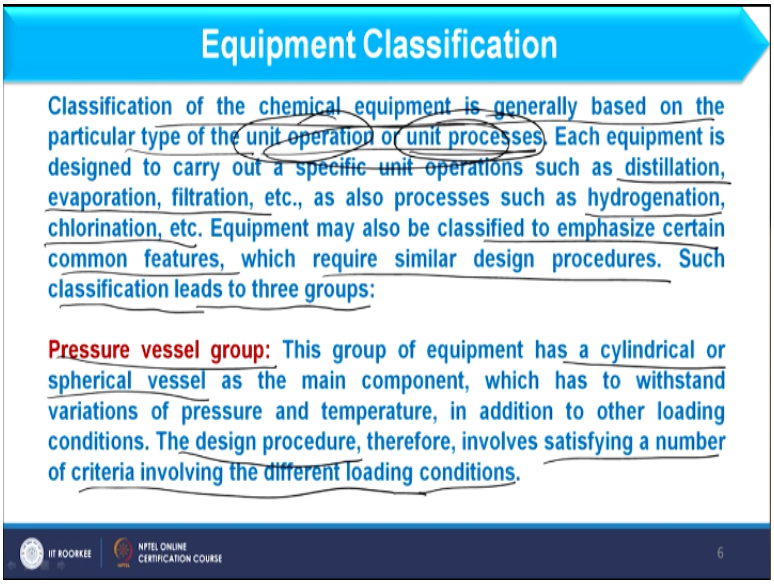

So let us focus on equipment classification. What classification of equipment are having and among this classification what particular classification I am considering in this particular course okay. So let us discuss the classification. So classification of a chemical equipment is generally based on particular type of unit operation or unit processes. Now what is this unit operation and what is this unit processes.

I guess some of you understand the meaning of this unit operation as well as unit process; however, in brief I would like to explain that. Unit operations are used where only physical change occur in the system, physical change occur in the process. For example, if I have to transfer heat from one fluid to another fluid, I will consider heat exchanger for that purpose, but here whatever steams I am considering as hot steam and cold steam, those property I am considering as constant, it means it will not change with the operation.

It means only transfer of heat will take place from higher temperature to lower temperature, but tendency of steam will not change. So here only physical phenomenon occurs, so therefore it is involved in unit operation. Other examples you may consider of distillation column, evaporation, etcetera okay. And what is unit process, unit process are that part in the chemical industry where particular reaction is carrying out okay.

So chemical process deals with the reaction along with transfer of heat that may take place if the reaction would be endothermic, exothermic so accordingly heat will be generated and heat will be required, but reaction should be there once I am defining or once I am considering the unit processes. So this is the basic difference between unit operation and unit process. So each equipment is designed to carry out specific unit operation such as distillation, evaporation, filtration, etcetera.

However, processes we may consider are hydrogenation, chlorination, etcetera. So equipment may also be classified to emphasis certain common feature, which require similar design procedures. So it is not like one equipment will provide service for all, but there may be some resemblance in the equipment. So in that case steps would be followed for designing for all those equipment will be same okay.

So let us start the classification. Classification of the equipment can be done based on three groups okay. So first group will be the pressure vessel group. In this group, the equipment has a cylindrical and spherical vessel as the main component okay. So in pressure vessel group we can consider cylindrical as well as spherical vessels, and these equipment like if it is cylindrical or spherical vessel, these vessels should withstand the condition of the process like temperature as well as pressure okay. And further whatever design procedure we are adopting for these, it involves specifying a number of criteria involving the different loading condition okay.

So here you see we need to define certain criteria for different loading conditions. It means what is that criteria. For example, if I am operating with a particular pressure or temperature, then that particular temperature and pressure should not go beyond the permissible limit. So that permissible limit would be the criteria okay. So in pressure vessel group we have to basically focus on temperature and pressure condition okay.

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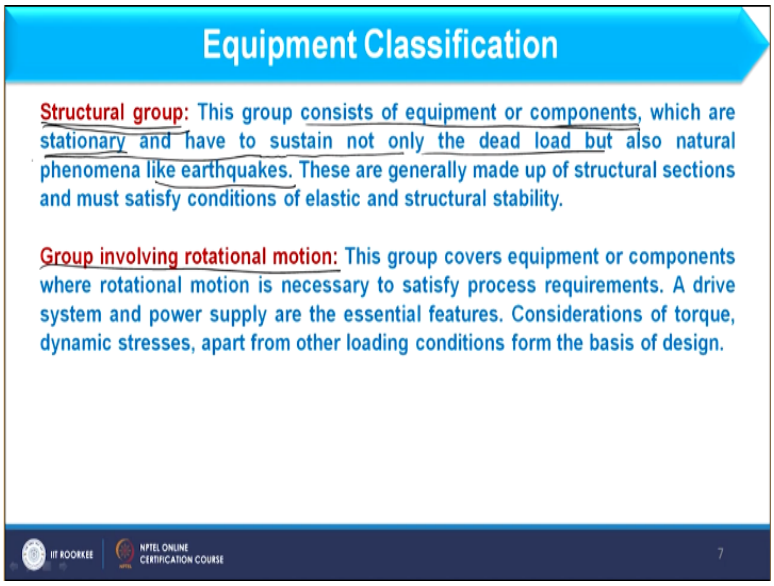

So second group in this classification is the structural group okay. So this group consists of equipment or component, which are stationary and have to sustain not only the dead load, but also natural phenomenon like earthquake okay. So what is this structural group. Structural group basically maintains the shape of the equipment. For example, if I am having a cylindrical equipment, throughout the life of plant, let us say it is 10 years or 15 years that shape should not deform okay.

So this structural group basically provided certain strength or certain accessories in such a way so that the shape of the equipment will be maintained. So that we are discussing in terms of vessel. Now what happens, below this vessel we provide certain support because any equipment will not lie on the floor as it is. To connect that to the floor we need support. So support should be strong enough to bear all dead loads of the vessel along with natural condition like earthquake is there, if very high wind pressure is falling to the vessel. Support should be strong enough so that it should not fall okay. So that comes under structural group.

Now third group I am having is the group involving rotational motion okay. So this rotational motion means what. While carrying out certain process some equipment may need some rotation. So once rotation will be carried out, then reaction or whatever processes are occurring in that that will occur simultaneously with rotation. So to give an example, if I consider sponge iron plant, if I consider cement plant, there we have the rotary kiln, which continuously rotates on the axis and along with this complete process is going on inside the system.

So in that case, apart from temperature and pressure condition, we need to consider that rotation also for designing okay. So if you see here we have discussed three basic classification that is pressure vessel group, structural group and the group which are involving rotational motion. And if I am designing a particular object or particular equipment it may be combination of two different groups okay.

For example, if I am considering the vessel okay, so that vessel will also require support. So along with pressure vessel we need structural support also to complete the design of a particular equipment okay. So here what we can say that any vessel when we design we have different components of that vessel. For example, it has the cylindrical shell, it has the cover, so accordingly we will design all these components separately and then join these components together to complete the design okay.

So here basically we have three classifications and then among these three classifications we will consider pressure vessel group as well as structural group to complete the design. So the next focus will be on defining the pressure vessel okay.

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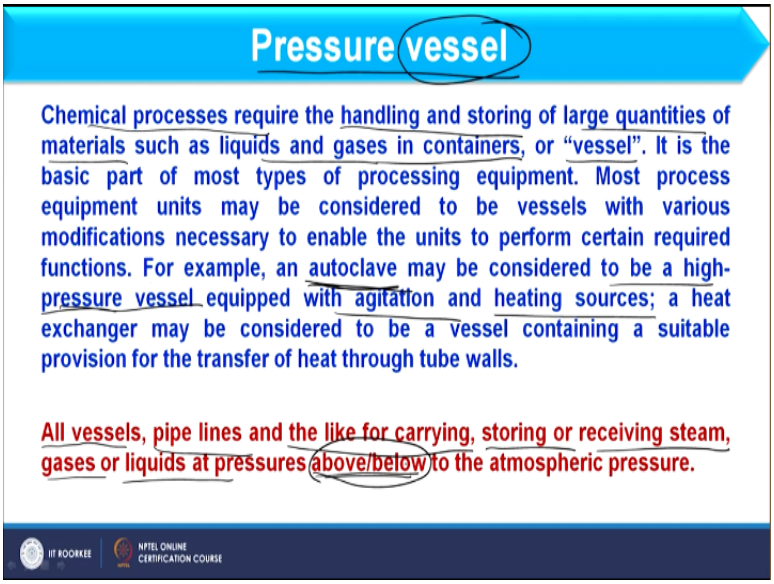

So here I am focusing on pressure vessel. First of all I will discuss what is a vessel and then we will define the pressure vessel. So in chemical processes we need to handle and store large quantities of the material such as liquid and gases in a particular container and those containers

are called as vessels. So what is vessel. Vessel is the equipment in which we can either store or operate large quantity of the material.

So if I am considering vessel, vessel may be empty or vessel may require some assembly okay. So it is not only the empty vessel. For example, if I am going to design distillation column, distillation column will not empty from inside, it has number of trays if it is tray type, it has the packing if it is pack type okay. So in that way we have different accessories, different assembly inside that vessel okay.

So for example, if I am having an autoclave that will be used at very high pressure condition and along with this we need some stirrer or agitation okay. And in the same line another equipment will be heat exchanger if I am considering shell and tube heat exchanger, tubes will be placed inside the vessel okay. So vessel will be container, which may be empty or which may need some accessories inside this okay. So this is the definition of vessel.

Now what is the definition of pressure vessel okay. So let us discuss this. If you see here all vessels, pipelines and the like for carrying, storing, or receiving steam, gases or liquid at pressure above and below to atmospheric pressure. So this is the main focus that pressure vessels are those vessels which are operated either above atmospheric pressure or below atmospheric pressure, but it should not be at atmospheric pressure, then it will not be called as pressure vessel okay. So that may be operated at higher pressure than atmospheric or at vacuum.

So whatever will fall in this, all those equipment will be pressure vessels, like it is not only distillation column, heat exchanger, etcetera. If some fluid is moving inside a pipe at a higher pressure than the atmospheric or lower pressure than the atmospheric that pipe will be considered as pressure vessel okay. So till now you must have the idea that what we are going to design, we are going to design the pressure vessel with structural support to be used in chemical process.

So equipment related to the chemical process will be considered as pressure vessel in this particular course. So as we are focusing on pressure vessel, first of all we will discuss the selection of vessels okay.

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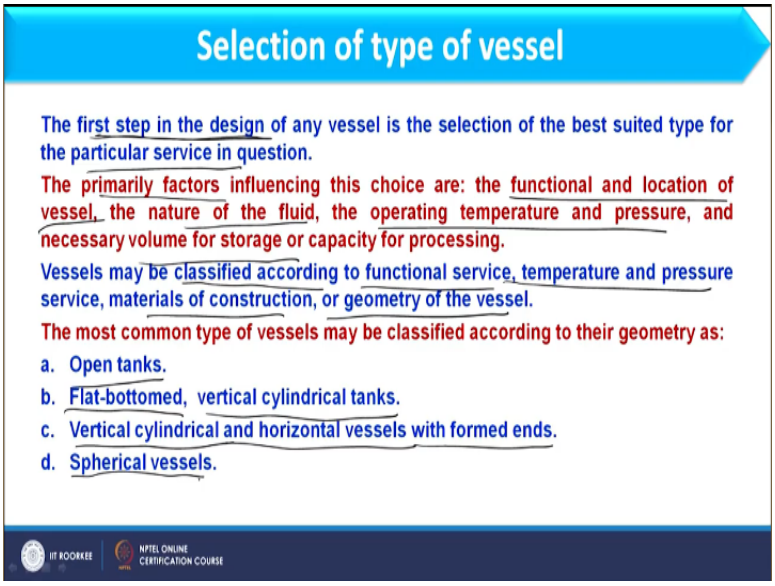

So the first step in design of any vessel is the selection of best suited type of vessel for a particular service in question. So according to the service, need to select proper vessel first of all and then we will design that particular or that proper vessel okay. So on what parameter that selection depends. First of all I need to select, so I have to see the parameters.

So primary factors which influence the choice of or selection of vessel depends on function and location of the vessel, what function I have to carry out in this, accordingly the vessel should be selected. Nature of fluid, it means whether it is toxic whether it is nontoxic, accordingly we select the vessel. Operating temperatures as well as pressure and the volume to be stored or volume to be operated in the equipment okay. So these are few factors based on that we select a particular equipment okay.

So vessel may be classified according to the function of service, we have already discussed, temperature and pressure service, material of construction, yes this is the important point, and geometry of the vessel okay. So main classification will be based on geometry of the vessel, so that all other conditions should be fulfilled okay. So here based on the geometry we will discuss the equipment, which are classified based on geometry and that should incorporate other factors also.

So first classification in that category that is the geometry category is the open tank. Open tank you understand, when something I have kept without covering it that we can consider as open

tank. Next I am having is the flat-bottomed, vertical cylindrical vessel okay. So I am having vertical cylindrical vessel and at both edge or at both end we are providing the flat head okay. And third classification in that category is the vertical cylindrical and horizontal vessels with formed head.

So here again I am considering cylindrical vessel with formed head, formed head means which is not flat okay. If it is either hemispherical type, ellipsoidal type, all that shape will come under formed heads. So we have a detailed discussion on that in a particular lecture. Next shape I am having is the spherical vessel. So here we have cylindrical tank as well as spherical tank. Cylindrical you understand that can be placed horizontally as well as vertically and with formed head, however, that orientation will not be considered in spherical, it has simply the spherical shape and then we cover that with the spherical ends also okay.

So main classification based on geometry are cylindrical as well as spherical okay. So therefore we cannot have a very clear distinction between the equipment, however, we are having some of the guidelines to select a particular vessel for a given operation okay.

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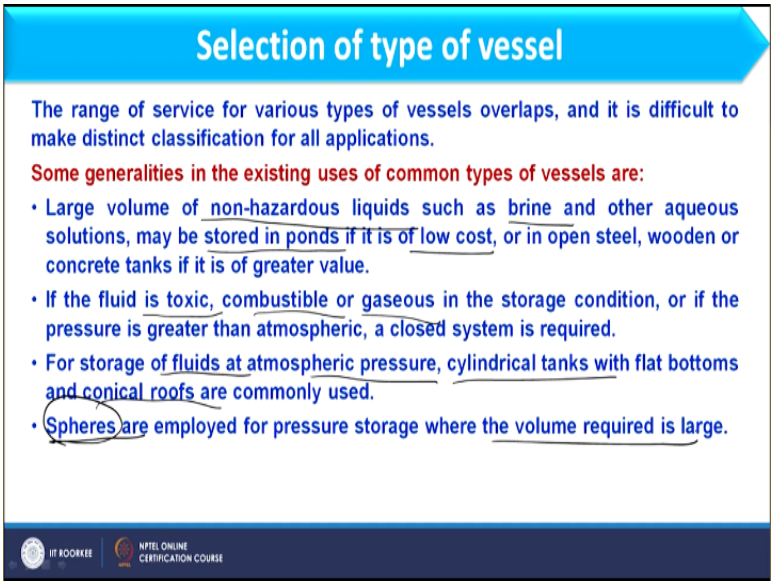

So those guidelines are, if you see, here I am having large volume of nonhazardous liquid such as brine and other aqueous solution may be stored in the ponds if it is of low cost. So that selection depends on the cost also, that is very important factor. If I need to store or operate very low cost

fluid, so obviously for that purpose we can use open tank, where weather condition will not affect significantly okay.

And if that solution is having more cost or it is costly then instead of ponds we can use some wooden vessel, cement vessel or metal vessel like steel vessel also okay. So depending upon the cost of the fluid you can select the type of tanks okay. So here if I am considering open tank or if I am considering covered tank the shape will be cylindrical only okay. So next guideline is if the fluid is toxic, combustible or gaseous okay, then we need to store such fluid very carefully and in that condition we usually use cylindrical vessel with cover okay.

It means closed vessel we need to use and that you can understand why because we are using toxic material that should not be released to the atmosphere okay. Next guideline is for storage of fluid at atmospheric pressure. We can use cylindrical tank with flat bottom and conical roof are also used for that purpose. So if I need to store the fluid at atmospheric condition, we can use cylindrical vessel with flat bottom and conical shape okay.

So next guideline I am having is to use the spherical shape vessel and these should be particularly used for storing large volume of the fluid. So if volume is significantly high instead of cylindrical you can go for spherical vessel okay. If I need to handle a smaller volume, under pressure or over pressure than the atmospheric we can consider the cylindrical vessel with formed end. So here I am having some of the guidelines which I can use to select the particular vessel okay.

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So here you see in these images I am having spherical tank as well as cylindrical tank, so it is looking like this. Now we need to discuss that what equipment we are going to design. Till now you have the idea that we are going to design the pressure vessel okay. And that pressure vessel should be related to chemical process. So what equipment we need to further design and would be the use of those equipment in the chemical industry again I am using the Onion diagram.

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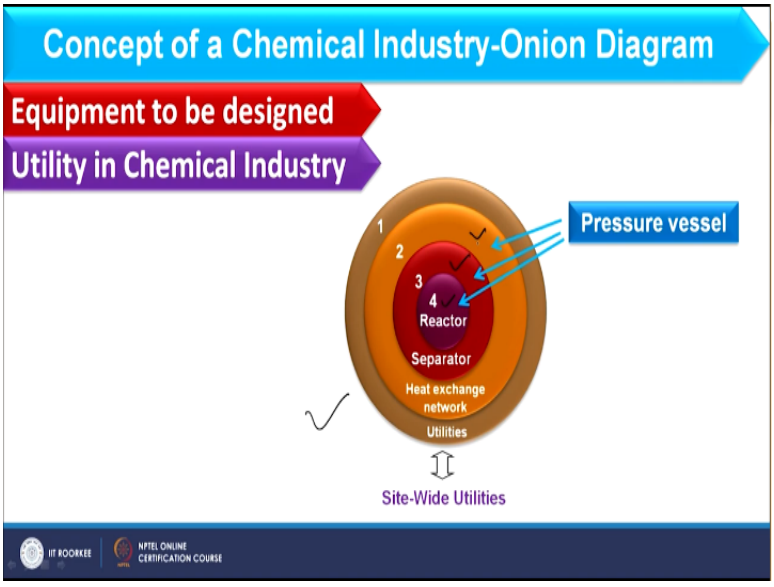

So here you see this is again the Onion diagram, different layers I have already discussed, and as I need to design the pressure vessel, through this pressure vessel we can design reactor, we can design separator, we can design heat exchangers. So this is the main reason of this course that once you study this course you can contribute in these three layers in the Onion diagram okay.

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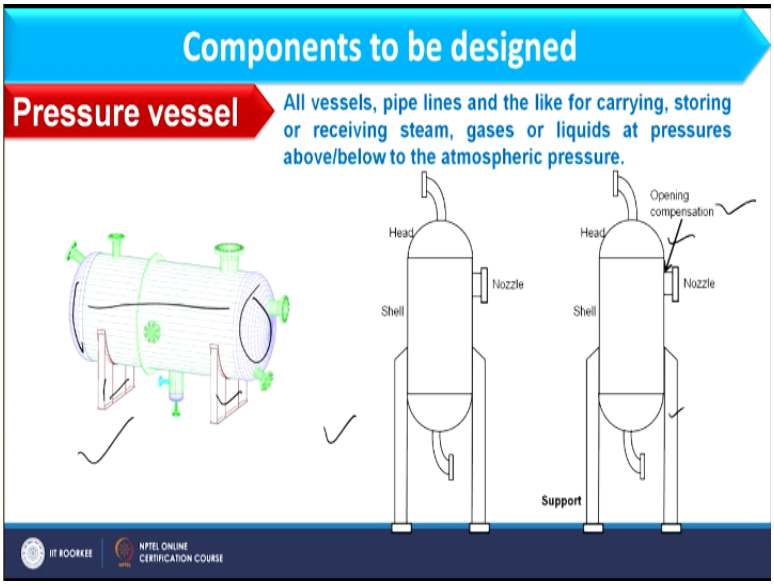

Now we will discuss what components to be designed in pressure vessel okay. So here you see this is the pressure vessel, where this is the shell, here these are basically covers, and here these two are the support. So here this particular vessel is horizontally placed. Now if I am considering the vertical placement of the equipment, here we have different sections. So what component we need to design is, first of all we will start with shell, then we will start designing of heads, then we will proceed for nozzle okay.

And for nozzle we have to discuss the compensation also that will be placed when we make any nozzle or any opening in the shell or head and then finally we will design the support. So in such stages we can design different component and then we join these designs together to make a complete pressure vessel okay. And now are focusing on what is the meaning of design, if I have to design a particular equipment what I mean at that place.

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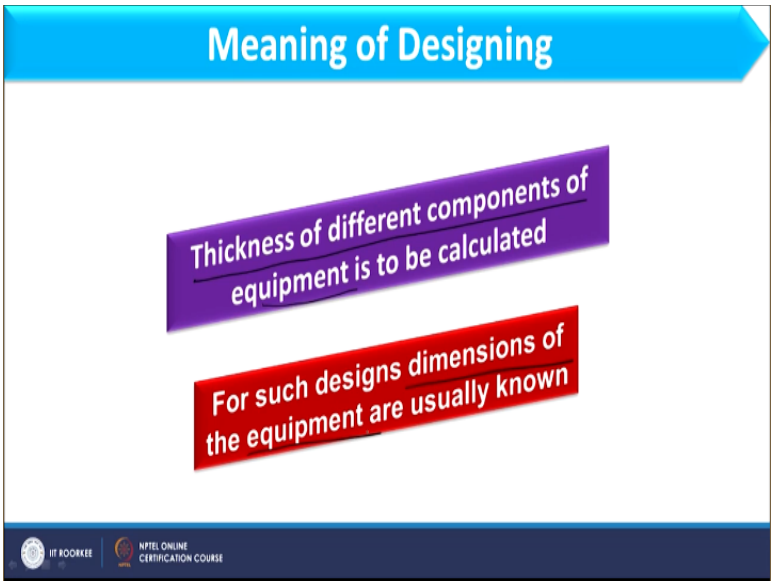

So the meaning of design in this course is to decide the thickness of different components of the equipment, it means to compute the thickness. So for that purpose, as I have discussed earlier, that we need to consider process condition like pressure as well as temperature. So based on that pressure as well as temperature what should be the thickness of the metal sheet we can consider through which that pressure vessel should be formed okay. So for each component we will discuss only the thickness of that particular part or that particular component.

So for such design dimension of the equipment are usually known okay. So once I know the dimension, like height and diameter will be known to us, I will only calculate the thickness of that particular section. So what we will use for design purpose, what are the guidelines and where those guidelines are present. So for that case we will consider design codes okay. Now first of all we will discuss why this design code is required and what is the history of that code.

So what happens in 1905, in Massachusetts there was a boiler explosion okay, and in that explosion 58 persons were killed and 117 were injured.

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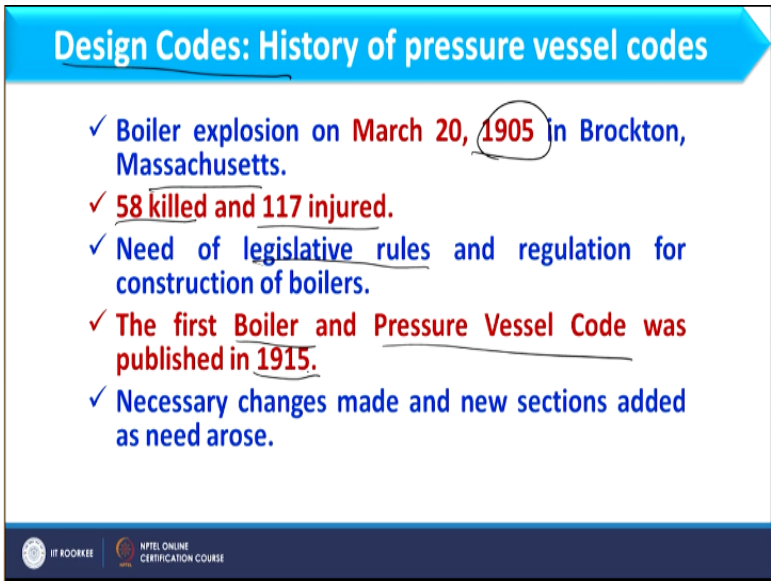

After this huge massive loss, there was a need to have some legislative rules and regulation for construction of boilers okay. So after that incident government has thought to provide some of the guidelines, so that those guidelines can be followed for design of boiler, okay. So first boiler as well as pressure vessel code was published in 1915. So first code was at the year in 1915 and after that as changes arouse and different corrections are made in that code okay.

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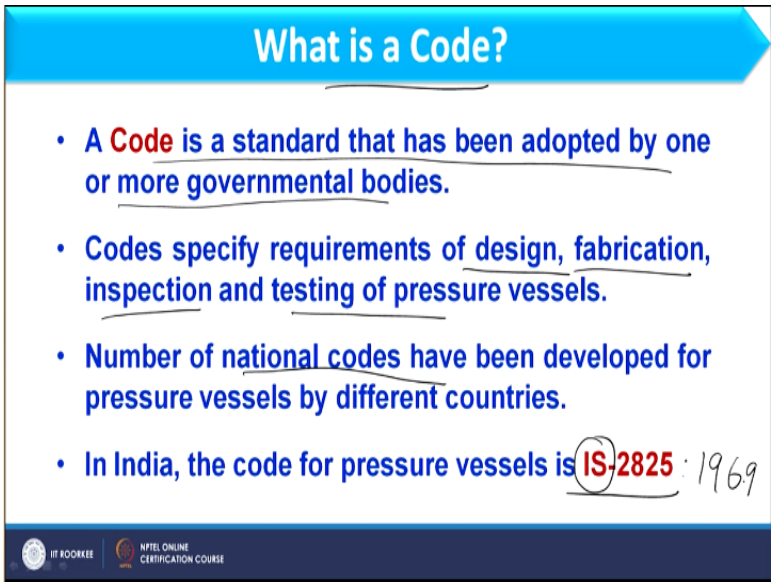

So what is a code. Code is a standard that has been adopted by one or more governmental bodies. So to design a code or to give a code for design purpose we have the governmental bodies and those governmental bodies will provide the guidelines to design a particular

equipment. So code basically consist of design, fabrication, inspection and testing of pressure vessel.

So all these aspects are considered are available in code or I can say guidelines for these aspects are available in code okay. And number of national codes have been developed for pressure vessel by different countries because each country will have different conditions, atmospheric conditions accordingly they provide their own code. So in India the code for pressure vessel is IS2825, is means that is Indian Standard 2825:1969 okay.

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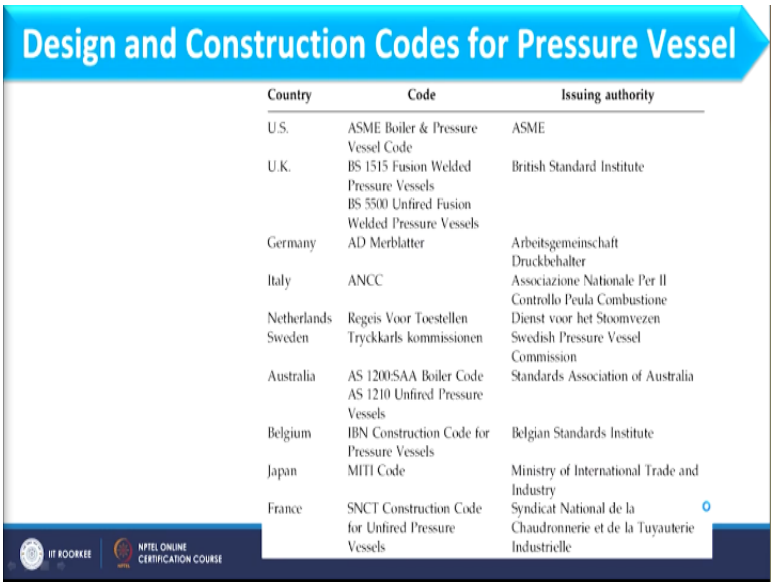

So here we have this code for Indian condition, and if you focus on this particular slide, we have different code for different countries. Like for US, we have ASME code, that is American Society of Mechanical Engineers, for UK we have British Standard codes and similarly we have different codes for different countries.

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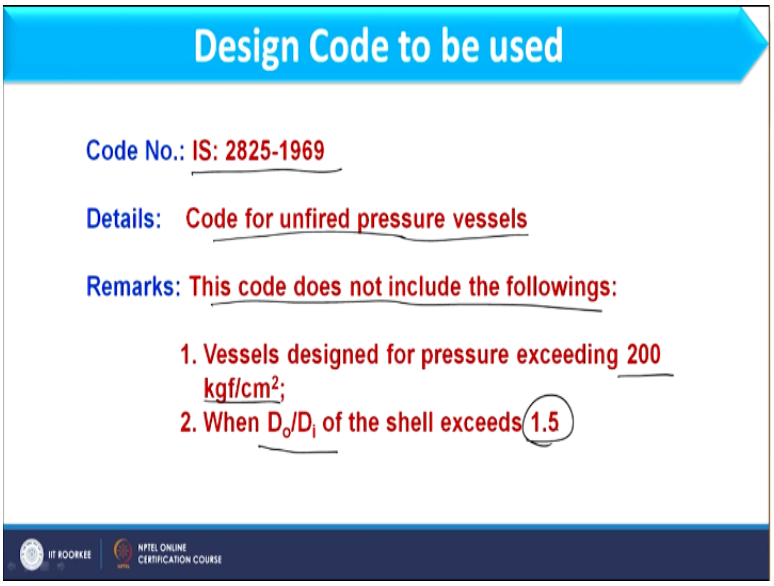

And in this particular course whatever code we are using is IS: 2825-1969. This is specifically for unfired pressure vessel okay. And this particular code has some of the limitation. What is the limitation, that maximum possible pressure to be considered in designing should not exceed 200 kg force per centimeter square, which is equivalent to 200 bar or 20 meganewton per meter square. So beyond that this code will not work. Another limitation is when D O/D I should be less than 1.5 okay. So these are the limitation of this code, beyond these condition we cannot use this code.

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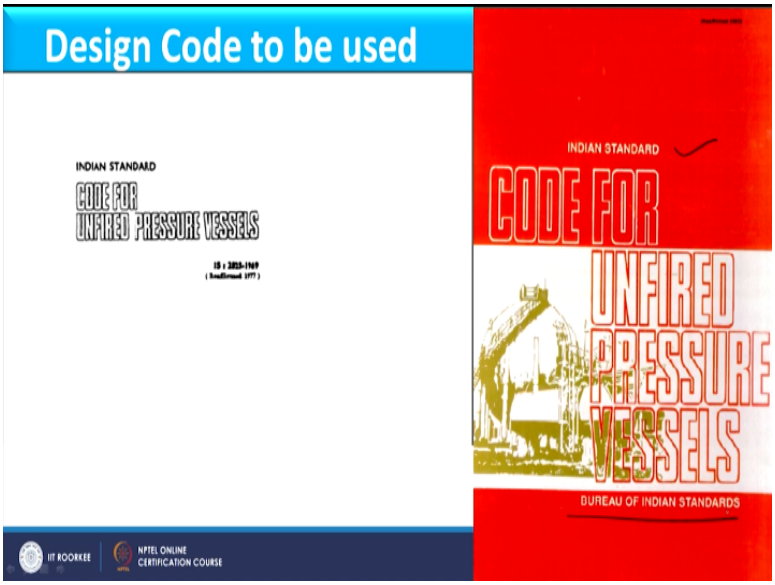

So if you see here I have in this slide I am showing how this code looks like, okay. So this is basically the Indian Standard code given by Bureau of Indian Standards and this is for unfired

pressure vessel. This is the front page and this is the next page where IS: 2825-1969 is printed, so this code we will use in designing.

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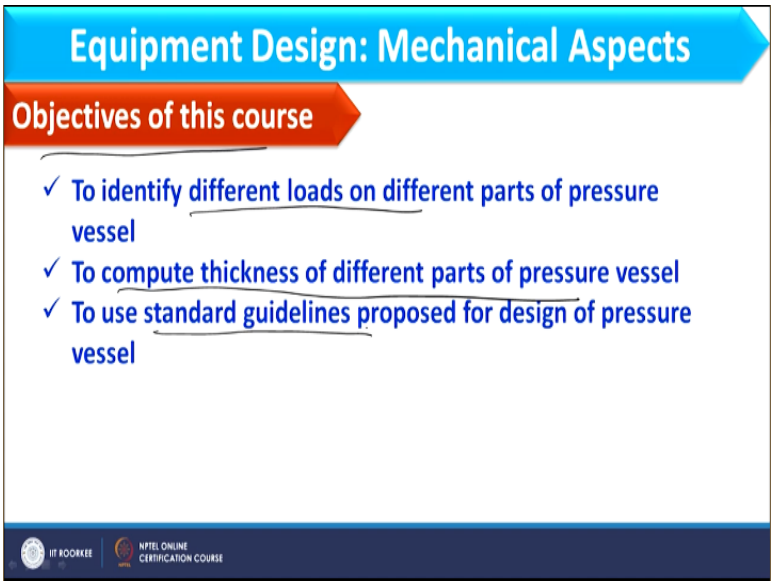

So in this slide we will discuss the objective of this particular course. Objective is to identify different loads on different parts of the pressure vessel because each pressure vessel will have different operating condition, like different pressure and temperature, and these parameter will put some load on the metal wall of the vessel, and those load I need to consider because according to that load we provide the thickness of that particular metal sheet. And then we have to calculate thickness of different part of the pressure vessel and then for that purpose we will use standard guidelines, which are available in code.

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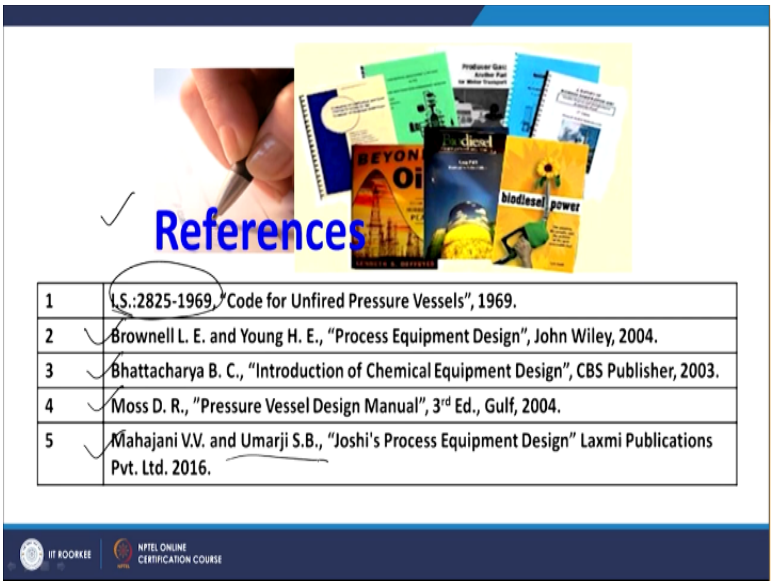

So these three are the objectives of this particular course and here I am having some of the reference books along with this code IS: 2825, I will use Brownell and Young book, I will use Bhattacharya book and then Moss, and then the book given by Mahajani and Umarji. All these books I will consider and these books you can find easily in the market, there is no problem, and this IS: 2825, you may not have access to that, so that I will provide to you so that you can download that and use that okay.

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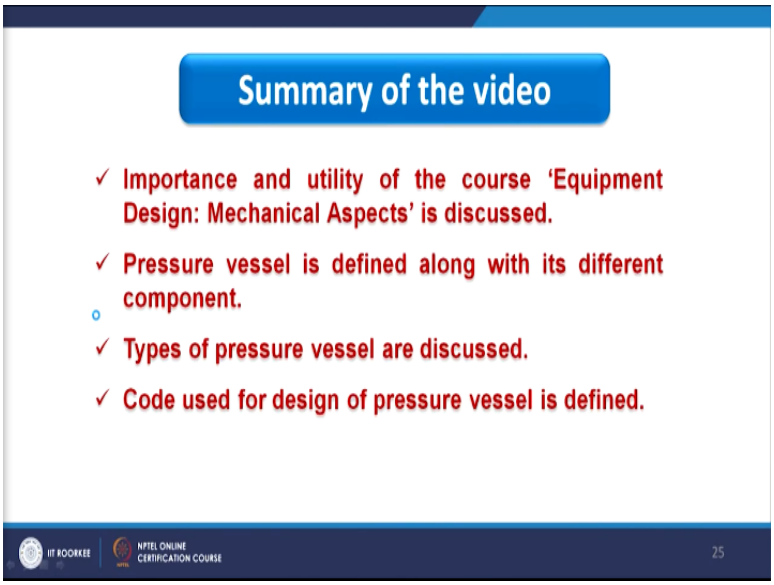

And here I am having summary of this video and in this video importance and utility of the course Equipment Design: Mechanical Aspects is discussed, pressure vessel is defined along

with its different components, types of pressure vessels we have discussed and code used for design of pressure vessel is defined. So that is all for now, thank you.