Equipment Design: Mechanical Aspects
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Lecture 06
Design of Heads

Welcome to the second of week course Equipment Design: Mechanical Aspects. And in this week we will start design of heads and this design of heads we will cover in three different lectures, lecture 1, lecture 2 and lecture 3, where in lecture 1 we will discuss different types of heads and its selection. In lecture 2 we will speak about procedure to design these heads, and in third lecture we will demonstrate a few examples to make you understand how these heads are to be designed okay. So let us start with lecture 1.

So here we are considering heads as well as closure. If we are designing any pressure vessel, okay, its design or its manufacturing cannot be completed until unless I am not covering its openings. For example, if I am considering cylindrical shell that is open from top as well as bottom, so both section I need to cover. So in what way I can cover that, that comes under the category of heads as well as closures.

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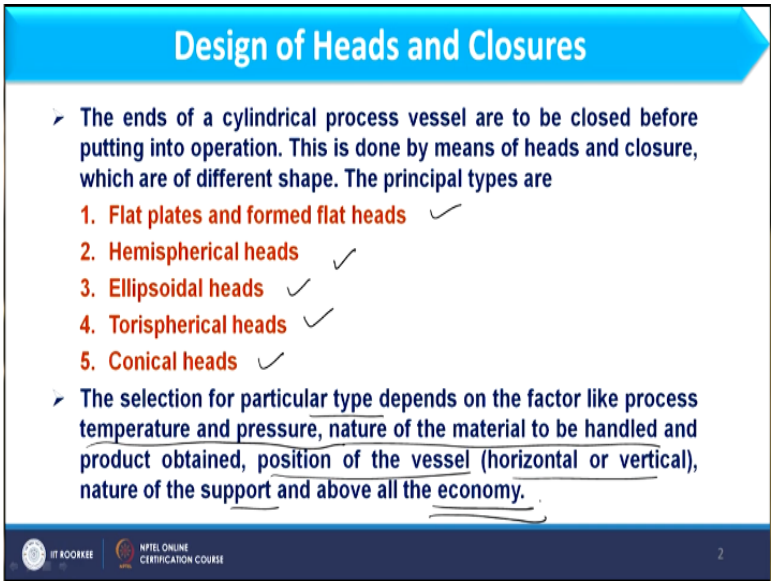

So we have different types of heads such as flat plate and formed flat heads. Second we have is hemispherical heads and then we have ellipsoidal heads, torispherical heads, conical heads. So

these are different types of heads and selection for particular type of head depends on factor like process temperature and pressure, nature of the material to be handled or stored, and position of the vessel whether horizontal or vertical, and nature of support and above all the economy.

So you see for selection economy is the major criteria and along with this we need to see some other factors as just we have discussed, but primarily we need to focus on economy okay. And in subsequent slides I will speak about these heads one by one. So let us start with flat head. So flat head if you consider what can be the flat head. Obviously it is nothing but a flat sheet which is welded over the shell that is simply a flat head or we can call it flat cover.

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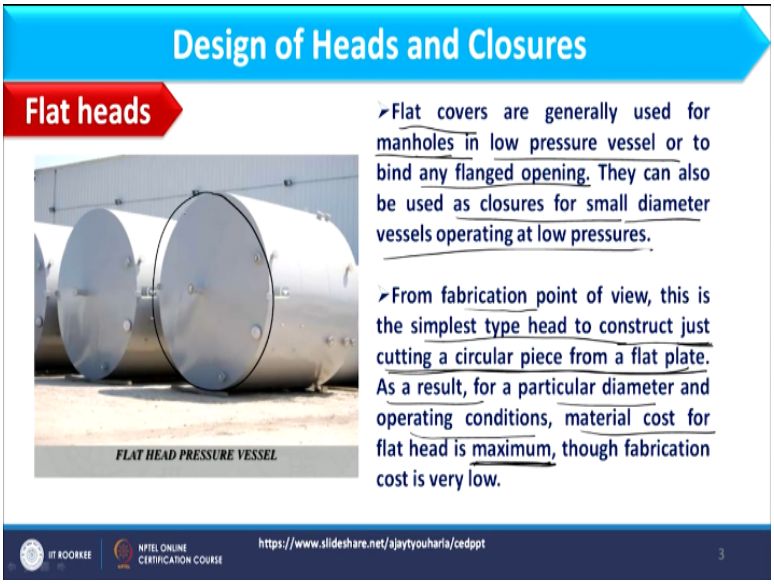

So flat covers are generally used for manholes. What is manholes, when we construct or fabricate any system we provide some windows through this a person can enter in the vessel for repair purpose or for maintenance purpose. So that cover through which that person enters into the vessel that is called as manhole. So that is usually covered by flat plates okay. So flat plates are generally used for manholes in low pressure vessel or to bind any flanged opening.

So what is flanged opening. For example, if I need to cover any nozzle that nozzle should be put with a flat plate, so that flat plate is attached to the nozzle through flange. So what is that flange, that we will discuss in a separate lecture in detail okay. So flat head can also be used as closure for small diameter vessels operating at low pressures okay. Now you must have seen that type of covers or that type of heads in our household things.

For example, if we need to store a wheat flour or rice in large quantity we have very big containers and those containers usually have flat bottom or flat top cover okay. In that case top cover are usually removable, but bottom covers are fixed okay, so that you can image as a flat head. So from fabrication point of view this is the simples head to construct, which is made as just cutting a circular piece from the flat plate. So when I am having a flat plate and when we cut this, this is simply called as flat head okay.

Thus, it is so easy to fabricate or manufacture okay. As a result for particular diameter and operating conditions material cost for head is maximum okay, you should focus on this that material cost for flat head is maximum, however, fabrication cost is minimum okay. Now why this material cost will be maximum okay. Now to understand this you should understand what is flat head and what is formed head.

If I am considering formed head, formed heads means which have slight curvature okay. And if I am considering flat head it is welded over the shell, so wherever it is connected to the shell there we have sharp edge okay. And that sharp edge is not available in formed head and therefore stress distribution is uniform in formed head, however, that is significantly high if I am not having any curved corner, which is the case with flat head okay.

So when I am having formed head though stress is distributed uniformly it can sustain more stress in comparison to flat head. So if we want to operate with the same stress, if you want to design for same stress, I have to give more strong flat head in comparison to formed head because formed head may work with small thickness as it is having the curved section and distribution of stress will be uniform.

That is not available in flat head, and therefore we need to provide more strong head, and therefore we need to provide more thick head. And therefore material requirement for flat head will be significantly high in comparison to formed head; however, its fabrication cost will be very low. So this is the image where you can see the flat head. It is simply the flat sheet which is welded over the shell okay. So that is the simplest type of heads.

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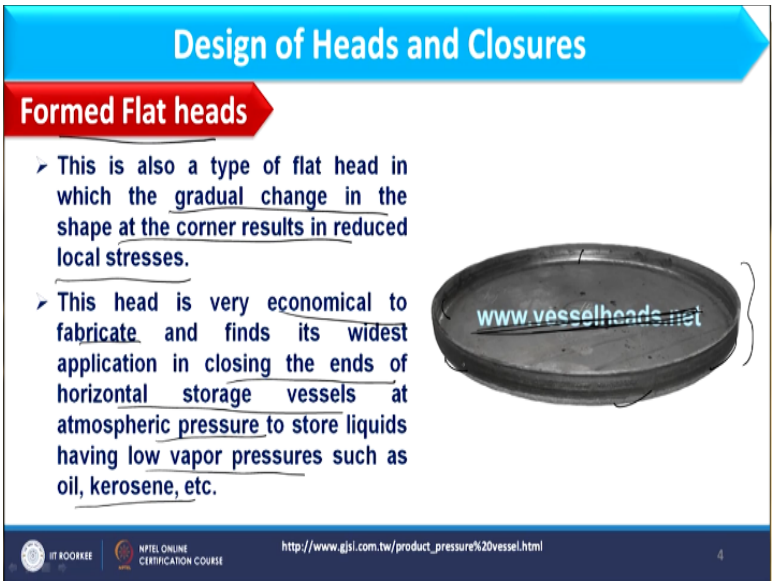

Next we have the formed flat head okay. Formed section we have already discussed okay. So this is also a type of flat head in which gradual change in shape at the corner results in reduced local stresses. It means when I am having the sharp edge, local stresses will be significantly high in comparison to when I am having curved section. So when I have to operate little bit higher or lower pressure than the atmospheric condition we should choose formed head because it has proper distribution of stress and stress is not localized in this as the case is available with flat head okay.

So this head is very economical to fabricate and find its widest application in closing the ends of horizontal storage vessels at atmospheric pressure to store liquids having low pressure such as oil and kerosene, so it is widely used flat head okay. And as far its image is concerned you can see this image, where centre section is flat, however, we have the curved at corners. Corners are not very sharp as the case with flat head okay.

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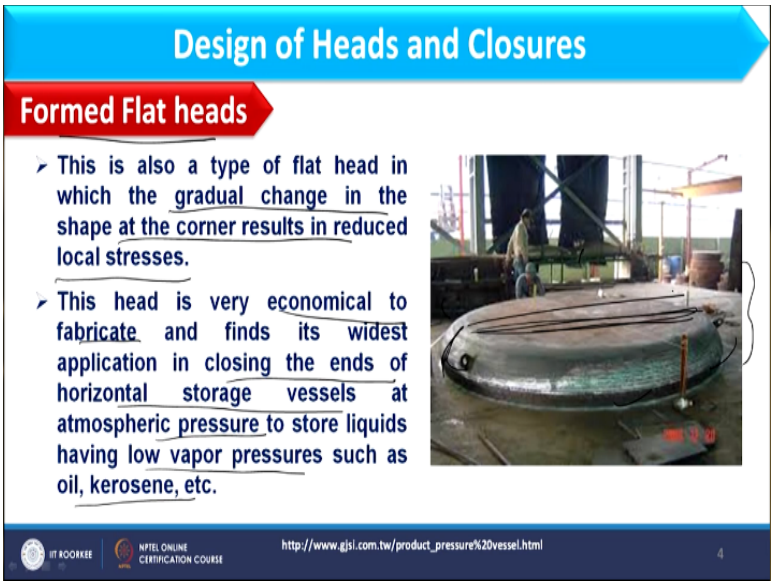

Another image you can visualize over here that here we have curved section and then we have the flat head. So this is basically called formed flat heads.

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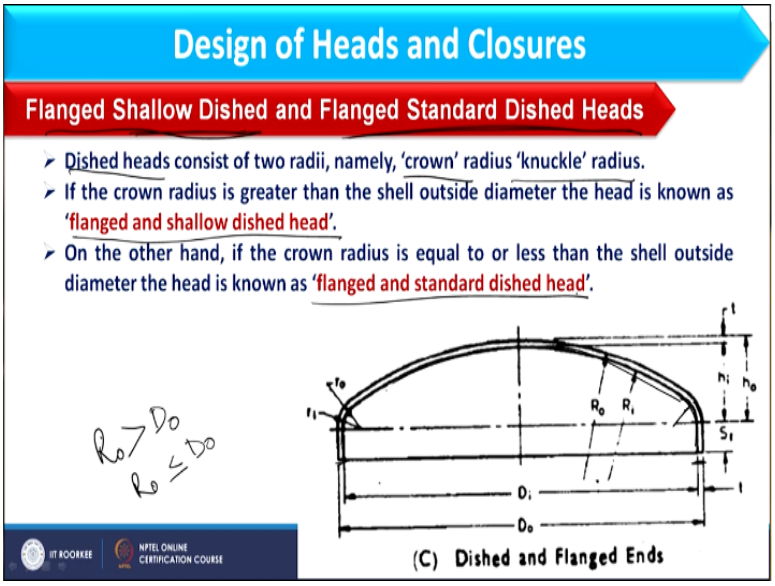

Now next head I am having is more formed than the formed flat head and it comes under the category of flange shallow dished and flange standard dished heads okay. So in this category we have all formed heads or all dished heads apart from formed flat or flat heads okay. Now what is the basic difference between formed head and flat head. In formed head or in dished heads usually we have two radii, first is crown, another is knuckle okay.

So what is crown and what is knuckle that we can understand through this schematic. If you see here I am having this dished head okay. This is the dished section and this is the curve section, and from here it is attached to the shell okay. So this particular section where radius is R O or R I for outer as well as inner okay. So this particular section we can call as crown and R O and R I are denoted as crown radius and second radius I am having is this, knuckle radius, where this corners are available so this radius is basically called as knuckle radius, and this can be represented by r i as well as r o for outer radius okay.

So if crown radius is greater than shell outside diameter what is meaning of that. If crown radius it means if R O is greater than the outer diameter of head okay, usually outer diameter of head as well as shell both are equal, so R O if greater than D O it is known as flange and shallow dished heads okay. And if crown radius that is R O is less than or equal to D O, it is called as flange standard dished heads. So these are two conditions where we have defined standard as well as shallow dished heads okay.

And as far as dished head is concerned, we have two types of heads ellipsoidal as well as torispherical okay. I guess you understand what is torispherical head, torispherical head the curved section or we can say the knuckle radius that is prepared as torus okay. And torus shape I guess you understand that is if you have seen a tire tube that is considered as torus in shape okay. That curve section or knuckle section has torus type of design and therefore it is called torispherical head.

So what is then the ellipsoidal head. Ellipsoidal head has more curved part in comparison to torispherical head because it has specific major and minor axis, which is not available in torispherical heads okay. So therefore considering that major as well as minor axis in a particular ratio ellipsoidal head has more curved part or more formed section in comparison to torispherical heads.

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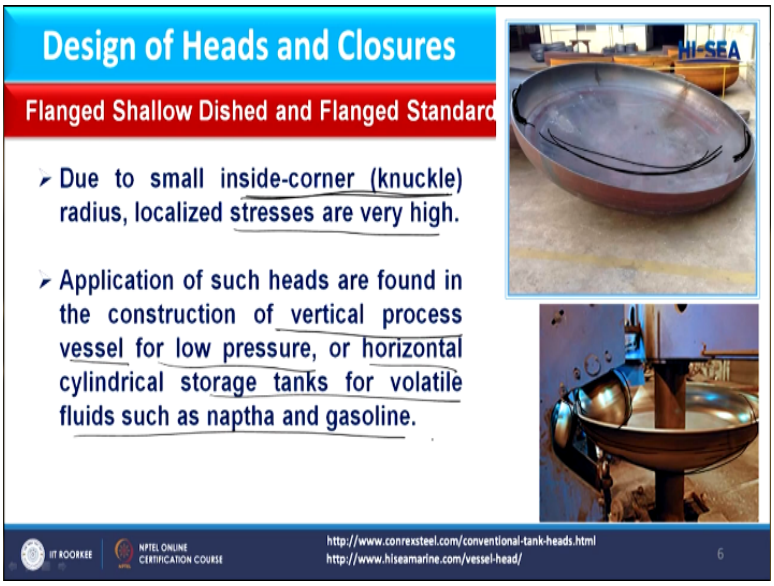

Now what happens in dished head, here we will focus on torispherical head. So due to small inside corner because we are considering small inside corner and therefore that small corner is available in torispherical head, so we are discussing that only. So due to small inside corner knuckle radius localized stresses are very high okay. So because it does not have very uniform or very large corner. Corners are quite small and therefore localized stresses are significantly high in such cases okay.

And if you consider this image, here we have this torispherical shape and if you see this centre point, centre point is like dished type of structure and corners are sharpened than this crown section okay, knuckle are sharpen than this crown section okay. So as this section will be more small, it means if that corner is more sharp localized stress at that particular section will be very high and then that cannot be used to withstand very high pressure.

And here you see here I am having one image where the preparation of torispherical head is shown if you see this is the dished head or crown radius, now what about the knuckle radius. If you see here we have this ball type of structure and here we have another assembly, and while revolving this ball around its periphery, we can prepare this corner as much uniform as possible. Now application for torispherical heads are it can withstand more stress in comparison to form flat, but because corners are not very sharp it cannot be used for very high pressure.

So as far as application is concerned, these are used to construct vertical process vessel for low pressure or horizontal cylindrical storage vessel for volatile fluid such as naphtha or gasoline. So this is basically the application of flange standard and shallow dished heads.

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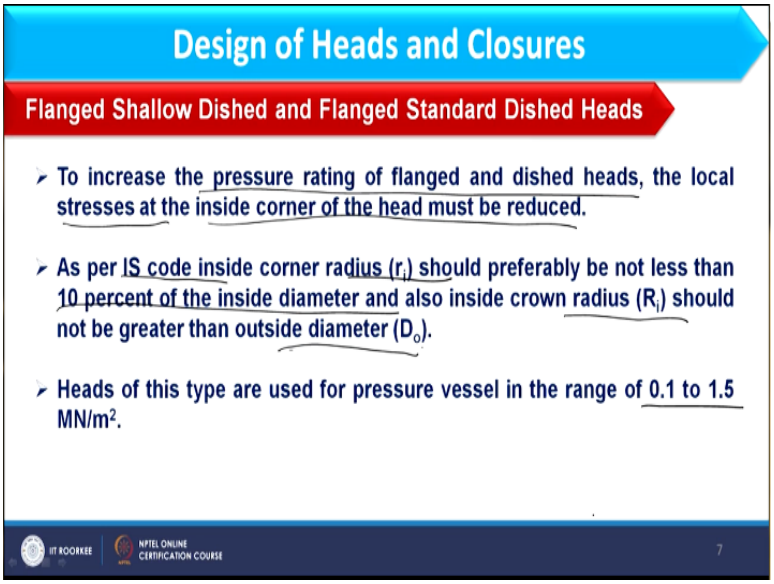

Now to increase the pressure rating of flange and dished heads, local stresses at inside corner of the head must be reduced okay.

So as I have told that when edge of the head is sharp, it means localized stresses are more on that particular section, and therefore it cannot withstand very high pressure. So to allow high pressure it has proper guidelines that what should be the knuckle radius for such heads. So as per IS2825 that is the Indian standard code, inside radius r i should preferably be not less than 10% of inside diameter, and also inside crown radius should not be greater than outside diameter D O.

It means r i should not be less than, so r i should be greater than or equal to 0.1 D i okay. And r i should always be less than or equal to D O. So these conditions are provided as a guideline for such heads. So heads of this type are used for pressure vessel in range 0.1 to 1.5 meganewton per meter square. So as far as limitation of torispherical head is concerned it is basically up to 1.5 meganewton per meter square of 15 bar is the maximum possible range, and beyond that it is observed that it is found that torispherical heads are not as economical as ellipsoidal heads.

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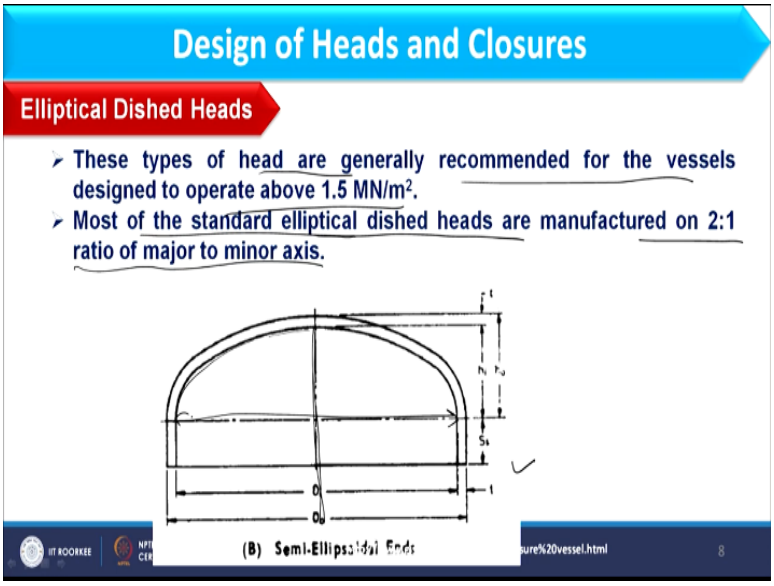

Now we will discuss ellipsoidal or elliptical dished heads okay. So these type of heads are generally recommended for pressure vessel designed to operate 1.5 meganewton per meter square as we have discussed in previous slide, and further most of the standard ellipsoidal or elliptical dished heads are manufactured on 2:1 ratio of major to minor axis. So I hope you are understanding the major and minor axis that we can discuss with this schematic okay.

This is basically the major axis and this is the minor axis. When we transpose this curve section to downward it has the minor axis up to this and here we have the major axis okay. So the ratio of these two should be 2:1. Now if you see this here when we compare this with torispherical head in ellipsoidal head we have more uniform corners in comparison to torispherical heads and because of this it can withstand high pressure in comparison to torispherical heads.

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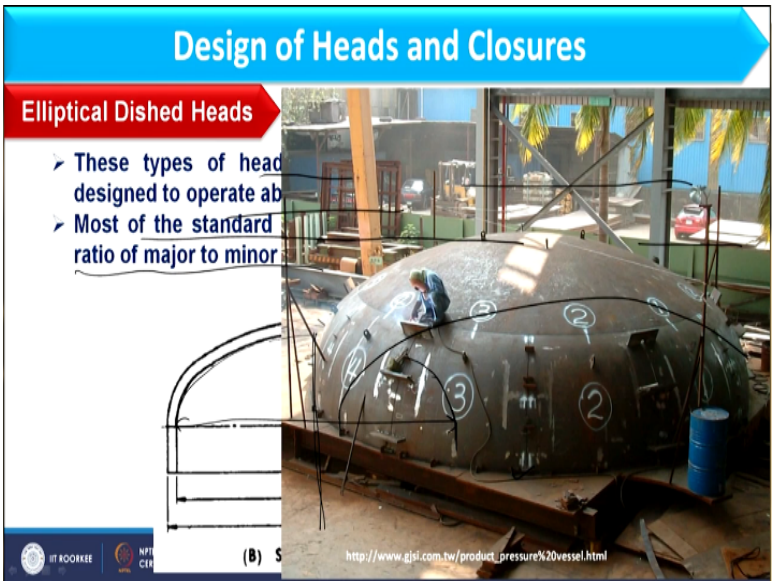

So you can see this image to have an idea that how ellipsoidal heads or elliptical heads looks like, and when we consider torispherical head it has very sharp corner in comparison to this, so it may be like this, corner would be very sharp in that case okay. And now we have the hemispherical heads. Hemispherical heads you can consider it is more uniform or more formed in comparison to ellipsoidal heads.

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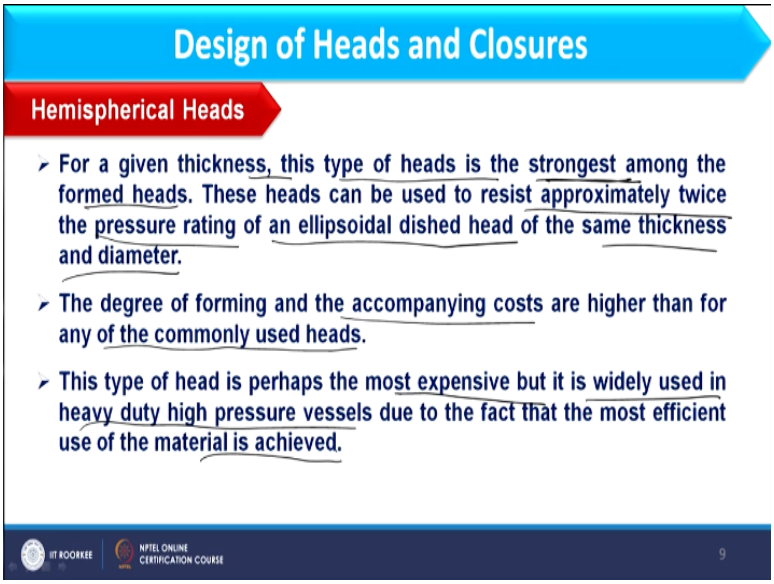

For a given thickness this type of heads is strongest among the formed heads okay. So hemispherical heads are strongest among the formed head, like flat formed, torispherical, ellipsoidal, and whatever we have discussed among this, this is the strongest and why it is strongest because it has maximum formed section okay. So these heads can be used to resist

approximately twice the pressure rating of an ellipsoidal dished head of the same thickness and diameter.

So you can imagine the strength of such heads, it can withstand twice pressure in comparison to ellipsoidal heads okay. The degree of forming and accompanying cost are higher than for any other commonly used heads, okay, that is the drawback of hemispherical head like though it can withstand twice pressure for the same thickness in comparison to ellipsoid, but at the same time this is the costliest head because it has more formed section so manufacturing cost of this head is maximum, okay, but still it is used in many applications.

So this type of head is perhaps the most expensive, but it is widely used in heavy duty high pressure vessels due to the fact that most efficient use of the material is achieved. So these are most expensive but at the same time these are used extensively because it can withstand very high pressure.

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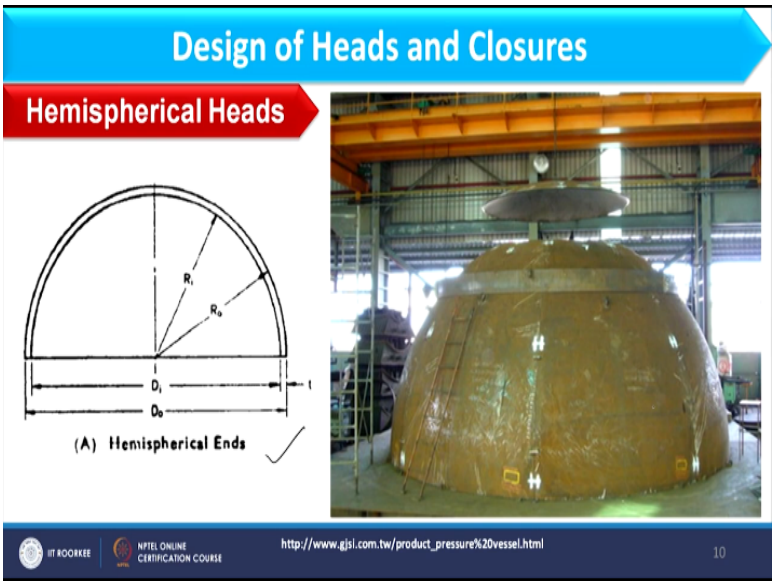

So you see this is the schematic of hemispherical heads where we have only one radius that is R i or R o, you can understand, it does not have crown section or knuckle section like and this is the image of hemispherical head. So when we are preparing such heads its manufacturing cost would be very high.

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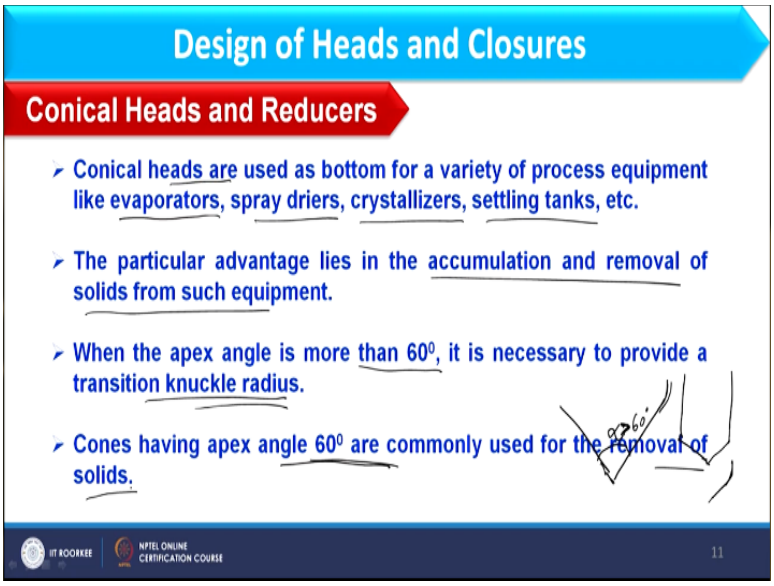

Now we have conical heads as well as reducers. So conical head you understand, it is basically a cone type of structure. So conical heads are used as bottom of variety of process equipment like evaporator, spray drier, crystallizer, settling tank, etcetera. So this conical heads are basically used in different equipment as bottom part okay because what happens, for example if I am having settling tank, settling tank will require continuous removal of solid material which is deposited at the bottom.

So due to having conical structure that solid material is easily directed towards centre and then that can be removed. And similar the case can be observed in crystallizer. So these are mostly used as a bottom head in comparison to top. In some cases we also use top cover, but mostly these are used as bottom heads. The particular advantage lies in the accumulation and removal of solid for such equipment that we have already discussed.

And when the apex angle is more than 60 degrees it is necessary to provide transition knuckle radius. What is the meaning of this okay, what is apex angle. When we are considering conical section, so this particular angle, this angle is basically called as apex angle. As we can see here that this is the conical section and here this angle is basically apex angle okay. When this angle is more than 60 degrees, it means it has knuckle radius, knuckle radius means when it is attached to the shell okay, so this section will not be very sharp.

Otherwise, for example, if this is the shell here we can simply attach the conical head. So here these corners are very sharp. However, if that corner will not be very sharp, this will be like this okay. So here we have the formation of curved section or we can call that as knuckle, so that is used when the apex angle is more than 60 degrees. And cones having apex angle 60 degrees are commonly used for removal of solids okay. So in this way we use the conical heads.

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Like you see in this image, here we have this conical section where this edge is quite uniform, it is not very sharp, and therefore it is called as knuckle part of the conical section and this will be used when we have this angle more than 60 degrees. So when it is used at the bottom, it is also called as reducer along with conical heads. And here you can see this vessel where the bottom section is conical, so conical head we are using over here okay.

So we have discussed different types of heads and the condition. Now we will summarize that condition to have an idea that in which condition which head should be used okay. So let us discuss that.

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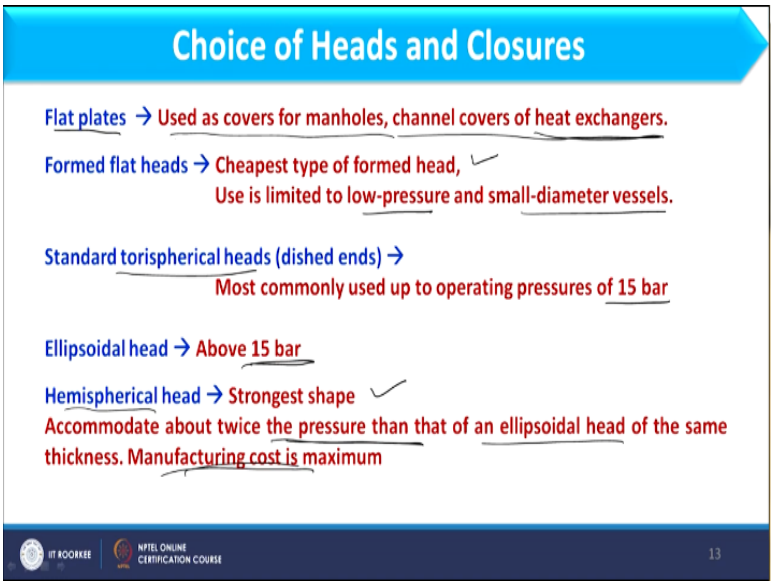

If I am having flat head, it is used as covers for manholes, channel cover of heat exchanger. So in this application flat heads are usually used. Formed flat head these are cheapest type of formed head and use is limited to low pressure and small diameter vessel. So when we have this condition, we can use flat formed heads.

So next head I am having is standard torispherical heads or dished head and these are mostly used up to operating pressure of 15 bar or 1.5 meganewton per meter square. And next head I am having is the ellipsoidal head, which is used beyond 15 bar. So beyond 15 bar we can also use torispherical heads, but that will not be as much economical as ellipsoidal heads. So beyond 15 bar we usually use ellipsoidal heads.

And finally we have the hemispherical head, this is the strongest shape accommodate about twice the pressure than that of an ellipsoidal head of same thickness. It has maximum manufacturing cost. So in this way we can use different types of heads in different condition. And here I am stopping lecture 1 of week 2 and we will continue design of heads in lecture 2 as well as in lecture 3 of this week. And that is all for now, thank you.