Process Equipment Design
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Lecture –22
Design of Condenser-1

Welcome to the second lecture of 5th week of the course Process Equipment Design and this is 22nd lecture of this course and here we are going to start discussion on condenser. So, first of all we will discuss different types of condensers and its uses and then we will start design of condensers. So, this complete topic I will cover in three lectures like lecture 2, lecture 3 and lecture 4 of 5th week.

So, let us start discussion on condenser. So, first of all what is a condenser if I ask you? So, being a chemical engineer, you all know that condenser is a device or an equipment where we convert vapour into liquid and so it transfer its latent heat to another fluid. So, that is basically the condenser.

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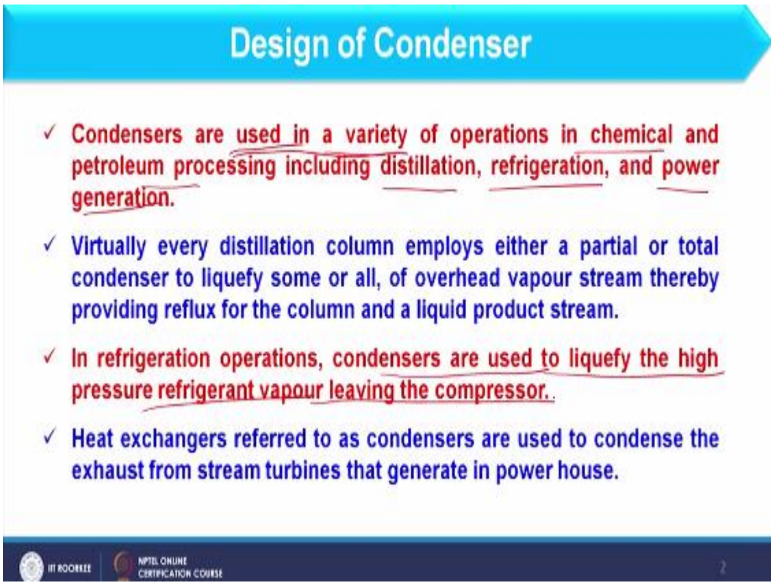

Now, if I ask you what are the utilities or what are the applications of the condenser? So, you can see that condensers are used in variety of operations in chemical and petrochemical processes which includes distillation, refrigeration and power generation. So, I hope you all are aware with the application of condenser in different industries or different processes as we have already discussed.

So as far as distillation is concerned virtually every distillation column employs either a partial or total condenser and in that way it converts vapour into liquid and if you understand the placement of condenser in distillation column it is basically placed at the top of the distillation column where whatever vapour is generated in distillation column it is converted into liquid and what will happen after that?

Some section of that liquid recycles back to the distillation column and which we call as a reflux and at the same time some section of the condenser exits as a product or we can call it as a top product. Now, if I ask you that what is a total condenser and what is a partial condenser? I hope you know that, but let me further explain it to you. So as far as partial and total condenser is concerned it entirely depends on what phase of product you want from distillation column as top product.

So, what will happen when I say that your product should be in vapour form. So, what you can do over here? You can consider whatever vapour is exiting the distillation column that you can consider as a product, but no because what will happen if I ask you that you should consider product in vapour form, but then also you require some liquid because that liquid should return to the distillation column as a reflux because until unless I am not having vapour and liquid phases in distillation column the process cannot be carried out.

So, if I ask you that your top product should be a vapour then only the vapour which is exiting from the distillation column it should enter into the condenser and some section of that vapour should be converted into liquid and that liquid should return back to the distillation column as reflux and in that case vapour you can obtain as product. So, what you have done? You have obtain your product in vapour form, but at the same time you have returned the liquid to distillation column as reflux.

So, whatever feed is entering into the condenser only some section of that vapour is converted into liquid and that will depend on how much reflux you want. So, in that case some of the section of vapour is converted into the liquid and therefore you call that as partial condenser. Now, if I ask you what should be the total condenser? Total condenser basically condense complete vapour which is entering into this.

And in that case reflux as well as top product of the distillation column both should be at liquid phase. So, in that case we consider that as total condenser and if product I want as vapour we consider partial condenser. So, I hope you understand the difference between the two and as we have already discussed that condenser use in refrigeration operation is very important.

So, in refrigeration operation condenser are used to liquefy the high pressure refrigerant vapour leaving the compressor. So, if you recall the refrigeration cycle what will happen initially we have evaporator. In that evaporator, whatever liquid and vapour mixture is entering from throttle wall that liquid is converted into the vapour and complete vapour further enters into the compressor where it is reaching to high pressure and high temperature.

And then it is further entering into the condenser where the vapour gives its heat to the atmosphere and then after that vapour is converted into the liquid and that liquid is further entered into the throttle wall where sudden expansion gives vapour as well as liquid and that vapour liquid mixture is again into the evaporator. So, you see we have evaporator, compressor, condenser and throttle wall.

This is basically the refrigeration cycle and based on that refrigerators which we used in our houses it also works. So, here we use the condenser extensively and after that we can use the condenser in power generation. Now what will happen in power generation or let me ask you what will happen in Rankine cycle because thermal power plant works on Rankine cycle principle.

So, first of all water is basically preheated and then converted into saturated steam in boiler and after that it is converted into super saturated condition and after that it is converted into super saturated form and then it is entered into steam turbine where expansion of vapour takes place due to that expansion in steam turbine shaft moves and we can have electricity, but what will happen with that steam?

Steam is condensed when it come across the turbine, but complete steam is not condensed some vapour will remain there. So, what will happen after that vapour liquid mixture enters into the condenser and whatever vapour is available there that is further converted into liquid and after that whatever liquid is generated it is further entering into the boiler. So what will happen over here?

Here, whatever vapour is available in partial form because some vapour is there, some liquid is there that is converted into complete liquid in condenser. Now, can I directly send this to boiler? The answer is no because what will happen we have vapour and liquid mixture and when we pump it, it will damage the pump or pump will not work when vapour will be there. So, in that case we have to ensure that feed to the pump is complete liquid.

And to ensure that we use condenser where all vapour is converted into the liquid and then it pumps to the boiler. So, in this way we can use condenser in distillation column, in refrigeration cycle and Rankine cycle that is the power generation cycle. So, these are some of the uses of condenser.

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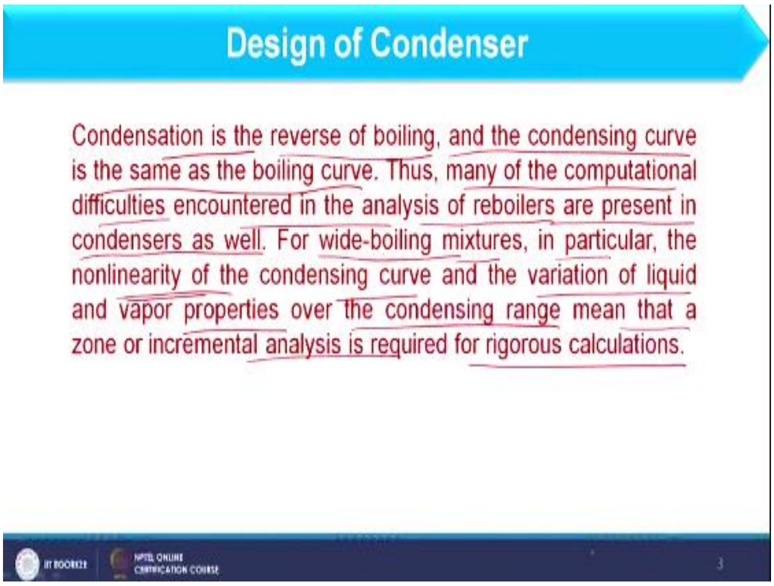

Now, let us further discuss few facts about condenser. So you see condensation is a reverse of boiling, boiling we generate vapour and in condenser we generate liquid and the condensing curve is the same as the boiling curve. Thus, many of the computational difficulties encountered in the analysis of reboilers are present in condenser as well because both activity are just opposite to each other if I consider reboiler and if I consider condenser.

So, for wide boiling mixture in particular the nonlinearity of condensing vapour and the variation of liquid and vapour properties over the condensing range mean that a zone or incremental analysis is required for rigorous calculation. So, you see here we have consider reboiler and condenser just opposite to each other and what difficulty we can obtain because it is not an easy phenomena and some rigorous calculation should be required.

Why we required design of the condenser because its use in chemical industry is extensive which we have already discussed.

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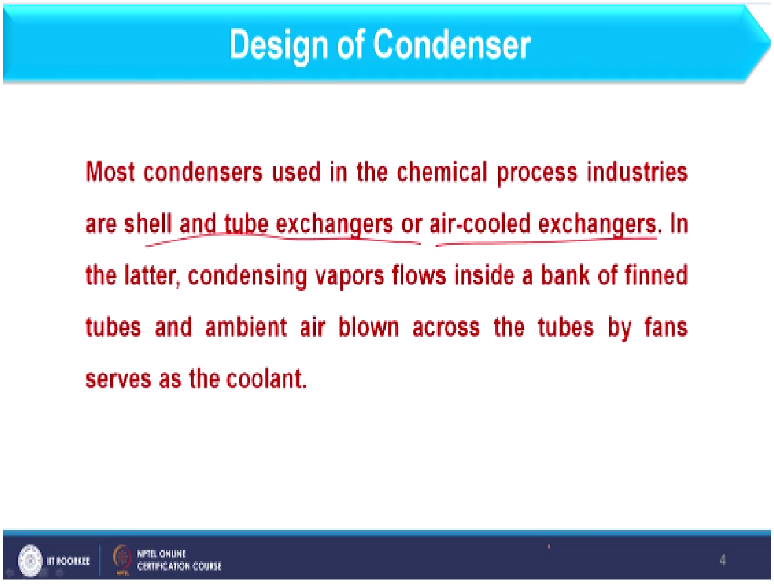

Now most of the condenser which are used in chemical plant are shell and tube type and in some cases we also use air cooled exchangers. So these are specifically shell and tube types as well as air cooled exchanger. Air cooled exchanger we have already discussed in detail when we have discussed classification of exchanger. So, that lecture you can refer to understand air cooled exchangers properly.

Now what will happen with air cooled exchanger? In copper tube we have vapour which is to be condensed and over that in cross manner we inject air. So, instead of some cooling liquid media we use air to condense the vapour. So, you can understand in air cooled heat exchangers we usually use fan in which air is used as a coolant instead of water in shell and tube heat exchanger. So, what we can observe over here that most of the exchangers are shell and tube type.

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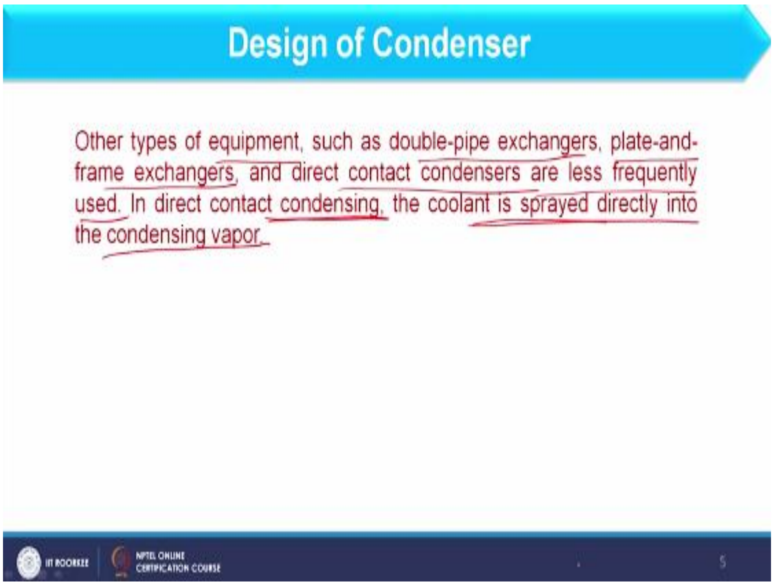

And apart from that other type of exchangers are also used, but it is used as a condenser is not significant. However, other type of equipment such as double pipe heat exchanger, plate and frame exchanger and direct contact condensers are less frequently used. However, it is used, but use is not extensive. In direct contact condensing coolant is sprayed directly into the condensing vapour.

So, you can understand that apart from shell and tube heat exchanger we have other exchangers also which are used as condenser, but not as frequently as shell and tube heat exchanger. So, now discuss the types of shell and tube condenser because we are going to design the shell and tube condensers only.

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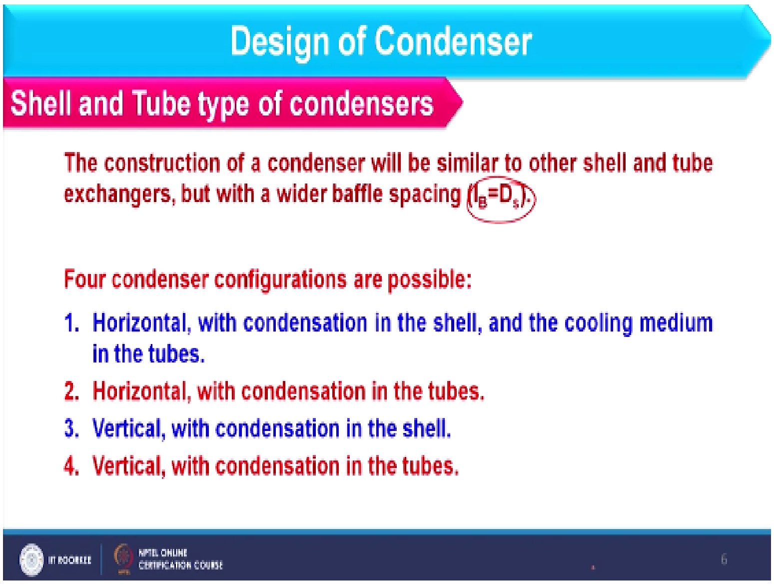

So we will discuss type of these condensers only. So, if you focus on the construction of a condenser it is similar to shell and tube heat exchanger, but with some modifications. What is the modification? Here I am using wider baffle spacing. So, in this case baffle spacing should be equal to D s.

Now here we will not follow the guideline for baffle spacing should be equal to 0.221 into shell dia, here we will consider baffle spacing equal to shell dia. When I am considering condensation in shell side if condensation is in tube side shell side should be designed normally, but here baffle spacing should be wider and the reason is because we are considering vapour and vapour movement is not up and down as usually we have when the liquid stream is used in shell and tube exchanger.

So, in this case vapour move and vapour should require wider space to move and therefore baffle spacing over here is equal to shell dia and that is very wide. I hope you can imagine that. So, now let me classify the condenser and usually we have four types of condenser and these are shell and tube types and as far as classification is concerned this is based on two factor.

Number one based on orientation how it is placed. Second is where condensation is going on. Now, if I ask you where the condensation should be going on in shell and tube condenser? You have only two options either shell side or tube side. Now, if I ask you what is the orientation of condenser? So in that case you again should have two options only one is vertical and second is horizontal.

So only four condenser we can configure depending upon orientation and the side of condensation and these four condensers are horizontal condenser where condensation is in shell side and cooling media is available in tube. Second is horizontal condenser where condensation is in shell side. Second is horizontal condenser where condensation is in tube side.

In the similar line, vertical condenser where condensation is in shell side and vertical condenser where condensation is in tube side. So, we have four configurations as you can observe here. So, now we will see each type of condenser is detail.

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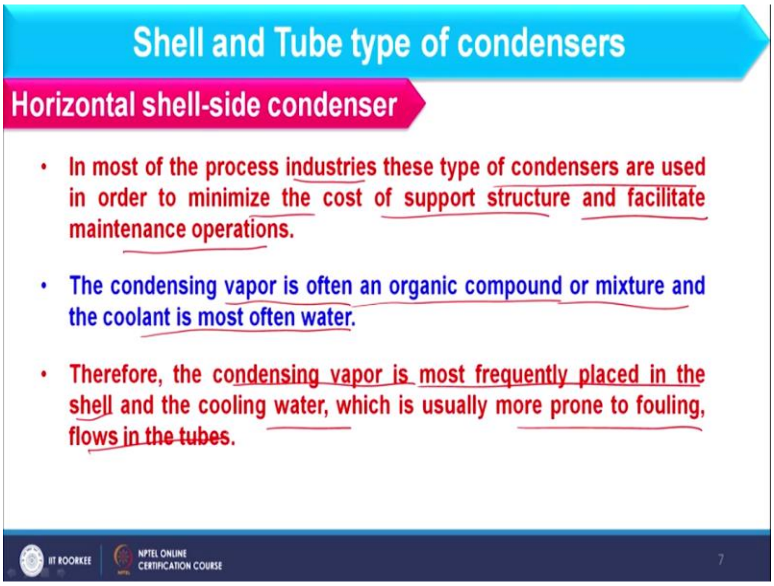

So, let us start with horizontal shell side condenser. So, in most of the process industries these type of condensers are used in order o minimize the cost of support structure and facilitate maintenance operations. So what is the meaning of that? If your condenser has larger duty it is better to place that condenser horizontally because when I am placing the condenser horizontally I can provide better support in comparison to I am providing or I am placing large duty condenser vertically because for vertical equipment support structure is very important and that is not as easy as it is for horizontal condenser.

So, if duty of condenser is larger we should place that condenser horizontally and it will ease the maintenance problem also. How? Because when you have larger condenser and which is placed horizontally you can take the bundle out very easily when it is placed horizontally. However, when it is placed vertically the removal of bundle from shell is very difficult. Though, that can be done, but when we compare the easiness of the maintenance it is more easy in horizontal condenser.

So you should keep in mind how you decide the placement of the condenser it will depend on larger duty. If duty is small, you can place vertically no problem. So, here we have horizontal shell side condenser and if I am saying that shell side condenser it means vapour should enter into shell side and the cooling media should enter into tube side. So, in this case condensing vapour is often and organic compound or a mixture and the coolant is most often as water.

So, condensing vapour is most frequently placed in shell side and cooling media which is the water is usually more prone to fouling and therefore it should be allocated to tube side. So, shell side condensation vapour should enter into shell side.

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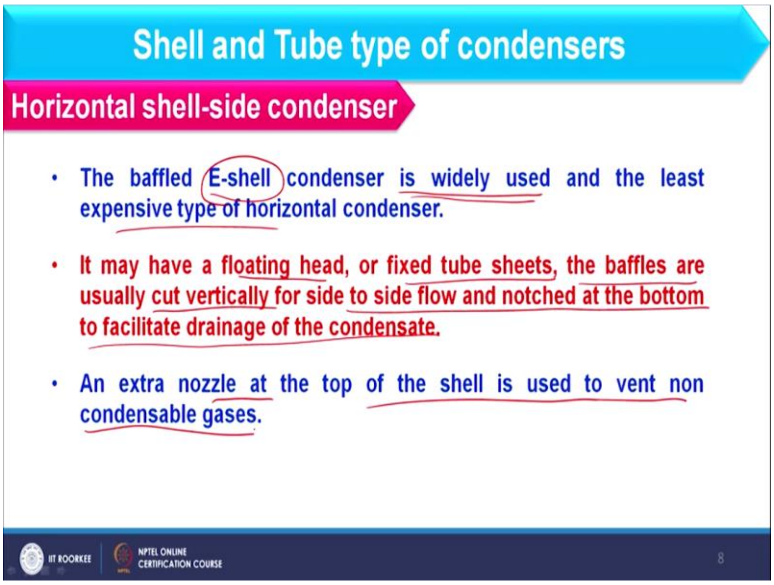

So, now discuss few more points about horizontal shell side condenser and here we usually consider E- shell so TEMA E-shell is considered over here and it is widely used in a condenser and the least expensive type of horizontal condenser so that you can understand because TEMA E is the simplest type of shell so that becomes inexpensive also in comparison to others and therefore it is widely used in condenser.

Next is it may have floating head or fixed tube sheet and baffles are usually cut vertically for side-to-side flow and notched at the bottom to facilitate drainage of the condensate. Now, let us consider this as when I am having a condenser in shell side so what will happen at top of the tube condensate continuously form and moves downwards. So, at the bottom condensate will be collected.

Now in such type of condenser where condensation is taking place in shell side we usually have a vertical cut in baffle. Till now what you have seen as far as baffle is concerned. Usually we have this type of baffles. So, movement of liquid is like this. So we can consider this type of movement in liquid. However, when I am considering vapour, vapour has lesser density in comparison to liquid so it will never come down, it will occupy the space, but it will not come down.

So, in that case instead of horizontal cut we usually consider vertical cut so that vapour can move like this. I hope it is clear to you vapour should move like this not like this as I have just shown. So, in this case usually vertical cut is placed in baffle and it looks like this. Now what will happen because horizontal cut is not there so whatever condensate is collected at the bottom it will remain in the exchanger, it will remain in the condenser.

Now what will happen? When the condensate will be available in shell side what will happen some of the tubes will be merged in that condensate. I hope you understand and when it will be merged in a condensate those tubes will not participate in condensation process anymore until and unless condensate should not be removed. So, how we can remove the condensate when baffles are having vertical cut.

For that, we usually place a v notch at the bottom of the condensate and from this open space condensate is continuously removing. So, we can have removal of the condensate as well as the movement of vapour. So, you should keep in mind horizontal shell side condenser, vertical cut baffle is used with a notch at the bottom for drainage of the condensate and further we can have one extra nozzle at the top of the shell which is used as a vent to remove non condensable gases. So, let me explain this further with the help of schematic.

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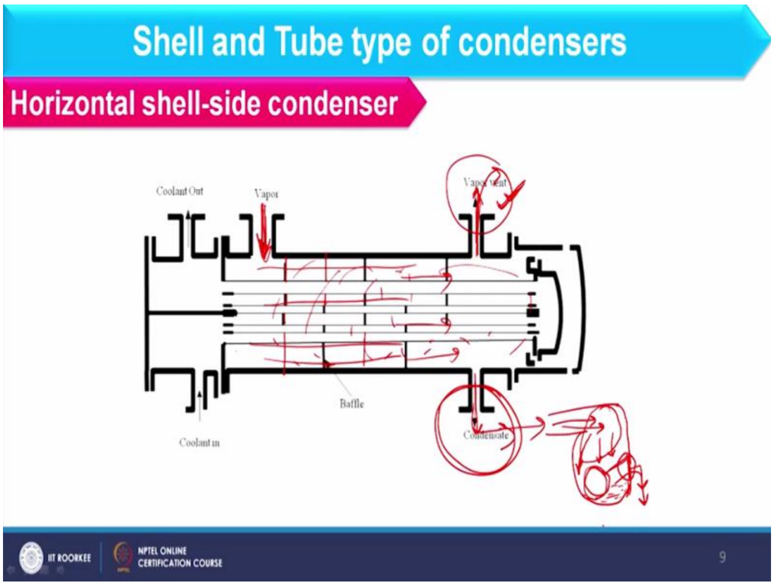

So, here we have the condenser and here vapour is entering into the shell side and if you see in this case baffle should be like this because we have vertical cut in baffles. So, vapour is entering into the shell side and from here at the bottom we have condensate removal continuously. Now, what we have discussed previously that it has one extra nozzle and that we can call as vent so that you can see here I am having a vent which is just at the end of the exchanger.

If vapour is entering from one end at another end vent should be there. So, what is the purpose of this vent? Now, if I ask you that if operation is not going on in a condenser then what will happen? The condenser will remain empty. The answer is no because air must be there and you understand that air is non condensable gas in nature. Now, what will happen when the vapour will enter into the condenser and air will not be removed that air will occupy some of the space in condenser which will reduce the heat transfer area which is available for condensation.

So, when I am using the vapour in such equipment we must have one extra wall and that we call as vent. Now what will happen from this side, when vapour is entering it is continuously moving in this side. So, whatever air is available in this it will move to this direction because from back side vapour is coming. Now as we open this wall at the same time vent wall should also be opened.

So as vapour will keep on entering from this non condensable gases will keep on leaving from vent side. Now, what will happen? When this vapour occupies the whole space it means that non condensable gases have been removed from the system and how we will ensure that when this wall remained opened after sometime whatever vapour is entering it will start moving from this nozzle or from this wall.

So, in this case when vapour starts exiting from the nozzle or from the vent wall we can say that air is completely remove from the system and at that time we close that vent. So, in this way we remove all non condensable gases from the condenser even it is not used only in condenser wherever I am using vapour either it is condenser it is reboiler, it is a boiler wherever I am using vapour or steam in that case we consider vent as well.

And second point is what we do with this condensate because when condensate will exit, when the wall of condensate remained opened and when the operation is going on condensate will keep on exiting from the system and because vapour is also there. So, there are chances that vapour should also exit the system from condensate wall. So, to stop vapour into the system and to let condensate exit the system we use another assembly which we call as steam trap which basically traps the steam or vapour.

So, in that case when I consider let us say condensate is exiting from here along with vapour because we cannot stop vapour to moving out. So, it will enter into this steam trap which is this type of structure and from here we have the exit nozzle for condensate. Now what will happen? Usually this is closed with a wall and that wall is connected with a balloon. This type of balloon is there.

And when I am having vapour and liquid mixture which is entering into this, so we have vapour as well as condensate, so what will happen because of the density difference condensate settles down. So, condensate will start filling this space. So as condensate will start filling this space it will led this balloon to move up because this balloon is very light. So, as this balloon moves up it will open this channel.

And when it will be opened condensate will keep on exiting from here however it will not allow any vapour to exit because vapour is available in this region not in this region because of the density difference. So, in that way steam trap works and we trap the steam or we trap the vapour and let the condensate to exit the system. So, whenever I are using vapour and steam I should use extra assembly in terms of vent nozzle and in terms of steam trap. So I hope you understand the function of vent and steam trap.

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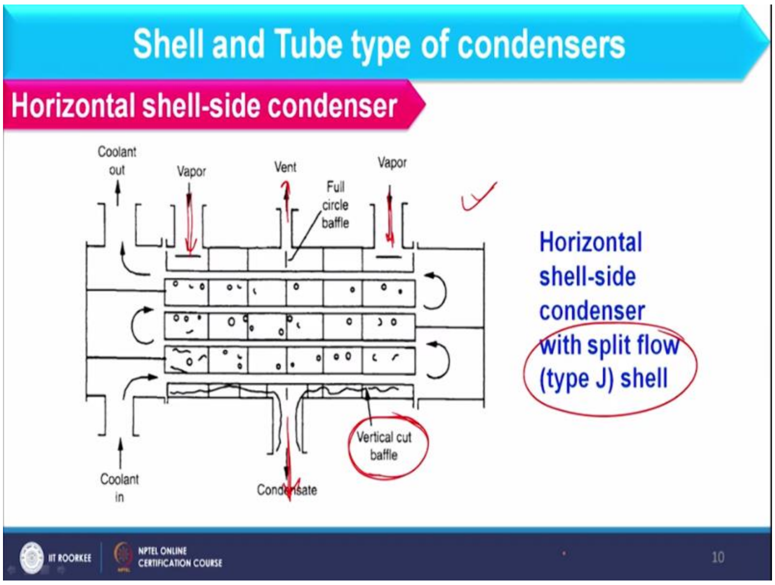

And further we can consider horizontal shell side condenser as it is shown in this schematic where vapour is entering from two sides and though vapour is entering from two side vent is available at the center because vent is must wherever I am having the vapour. So, it is entering into the shell side and baffle are usually having a vertical cut that we have already discussed. So, this type of shell where vapour is entering from two side and condensate is exiting from one side this we call as split flow or J type shell.

So, in horizontal shell side condenser mostly we use TEMA E shell, but sometimes we also use TEMA J shell as it is shown in this image. So, I am stopping this lecture here only and I will continue the types of shell and tube condenser and design in next lectures. So that is all for now. Thank you.