Process Integration
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Module - 6
Integration and placement of equipment
Lecture - 2
Heat Integration of evaporators

Welcome to the lecture series on process integration, this is module 6 lecture number 2. And the topic of the lecture is heat integration of evaporator.

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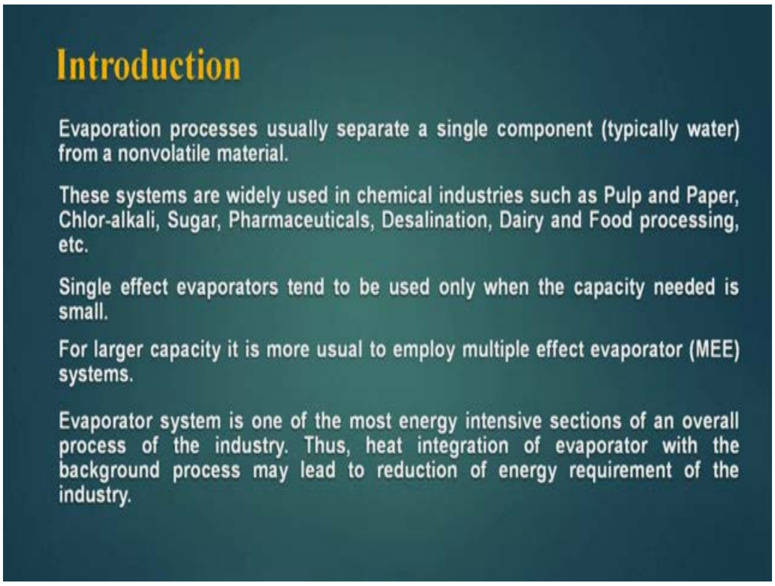

Evaporation process usually separates a single component typically water from a nonvolatile material. These systems are widely used in chemical industries, such as pulp and paper, chlor-alkali, sugar, pharmaceuticals, desalination, dairy and food processing industries. Single effect evaporators tend to be used, only when the capacity needed is small. And for larger capacities, it is more usually to employ multiple effect evaporation system because this steam economy in a multiple effect evaporation system is quite high.

Evaporators system is one of the most energy intensive section of an overall process of the industry. Thus heat integration to evaporator with the background process, may lead to reduction of energy requirement of the industry. And that is why if somehow the evaporators and the background process can be integrated, a large savings is expected out of it.

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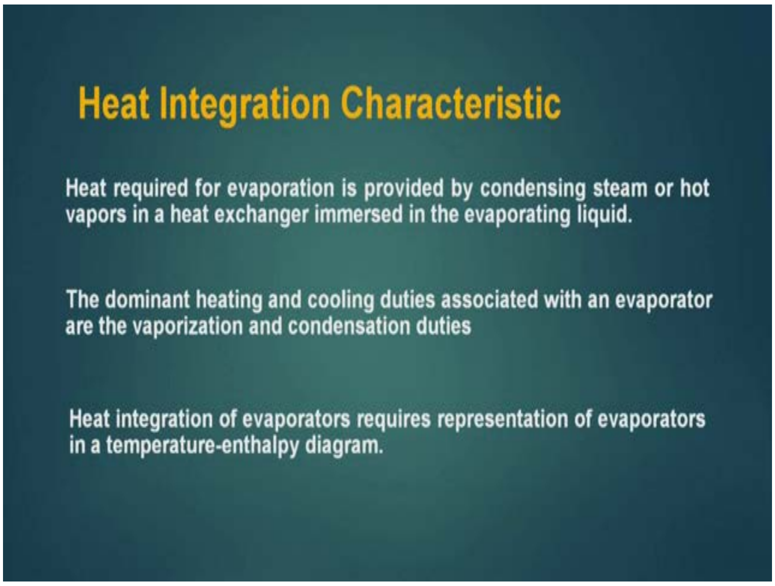

Heat required for evaporation is provided by condensing steam, or hot vapor in a heat exchanger immersed in the evaporating liquid. The dominant heating and cooling duties associated with an evaporator are the vaporization and condensation duties. Heat integration of evaporators requires representation of evaporators in a temperature-enthalpy diagram. This I have also told in several lectures, that if we want to integrate a evaporator with a G C C then the evaporator has to be represented in the T H delta H diagram because the G C C plant composite curve is also represented in the T delta H diagram. So, first we see how a evaporator can be represented in a T H diagram.

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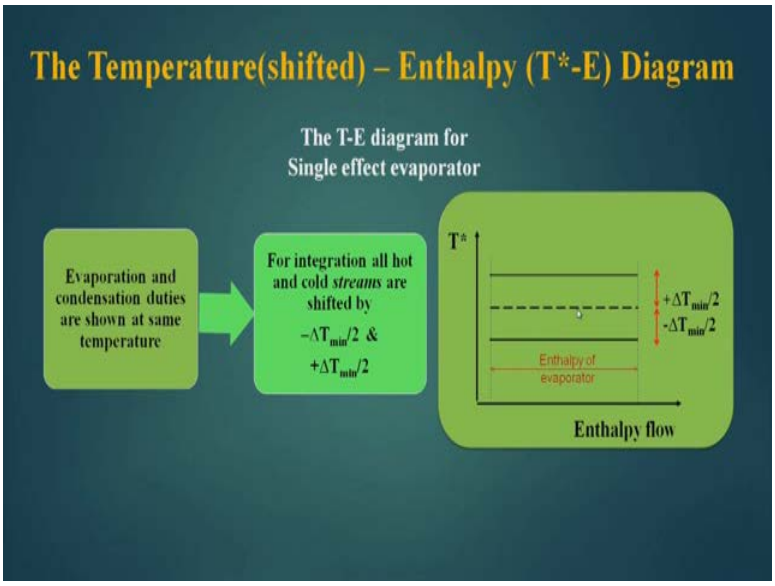

Evaporation and condensation duties are solved at the same temperature, if you see a evaporator the evaporations takes place of the liquid. And the evaporation or the steam which is being or the vapor, which is being generated due to this evaporation works as a heating medium to the second evaporator. And thus the evaporator liquid or the boiling liquid and the vapor, which is created out of heat are at the same temperature. For integration all hot and cold streams are shifted by minus delta T minimum by 2 and plus delta T minimum by 2. We know that the hot streams temperature has to be decrease by delta t minimum by 2 and code stream temperature has to be increase by delta T minimum by 2. When we convert them into a T H diagram, where the temperature is shifted and enthalpy is represented by H or E.

So, this is the line which if shown in a actual temperature they will consider the temperature of the boiling liquid and the vapor which being created due to this boiling liquid will have the same temperature. So, this is the same line, but if I consider the boiling liquid to be a cold stream and the condensing vapor is a hot stream, then they have to be shifted by delta T minimum by 2, either way. And this link of this line shows the enthalpy of the evaporator which a particular evaporator is handling.

Now, when I convert this into T star which is a shifted temperature that code stream has to be shifted by plus delta T minimum by 2. And hot stream will be shifted by minus delta T minimum by 2, if I do now the both streams are separated by a delta T minimum and this square, now represents the evaporator in a shifted temperature enthalpy diagram.

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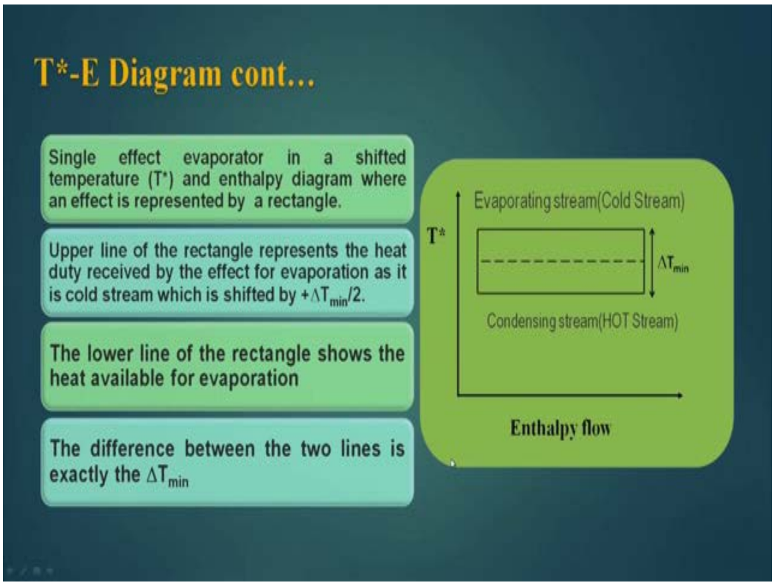

So, here this stream is evaporating stream which is called cold stream and this is the condensing stream, which is hot stream. And this gap is only due to that I have converted the temperature to a shifted temperature, otherwise the actual temperature is the same. So, this is the representation of a single effect evaporator system in a T H diagram where T is shifted temperature. This is evaporating stream is a cold stream and the upper line of the rectangle represents, the heat duty received by the effect of evaporation as it is cold stream, which is shifted by this. And the lower part shows a hot stream heat available for evaporation. The difference between this 2 streams are delta T minimum in a shifted T H diagram.

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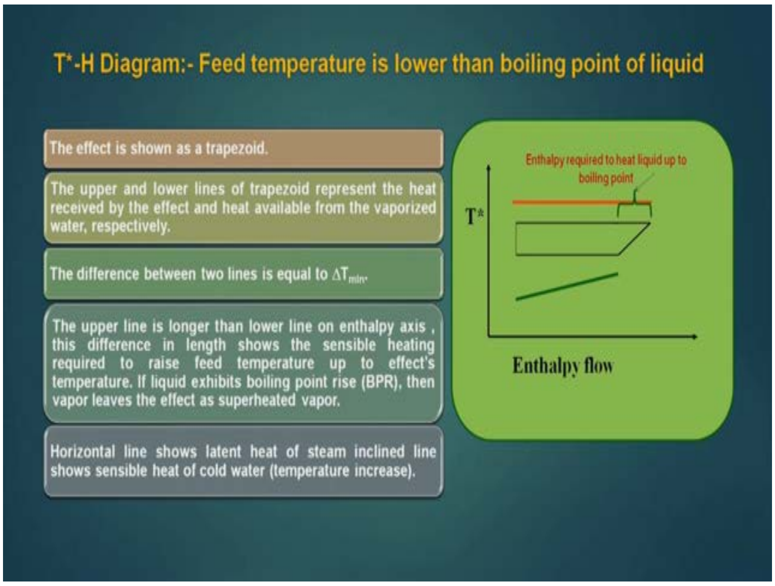

Now, this is a ideal state which we have seen, but ideal states are not always found in a evaporator. Now, suppose the feed temperature is lower than the boiling point of the liquid, the feed which is entering into a evaporator if it is lower than the boiling point temperature, then how the T H enthalpy diagram will look like. Now, this will be shown like trapezoidal and the liquid which is has a lower temperature here will be heated up to this, which is a boiling point here. And this part of the heat is the enthalpy required to heat liquid up to the boiling point. So, the upper and lower lines of the trapezoid represent the heat received by the effect and heat available for vaporize water. So, this part has got more enthalpy, but this is going to only generate this much of enthalpy as saturated vapor, which will come out due to the boiling of the liquid.

So, the difference between the two lines is again equal to delta T minimum, we can observe that the upper line is longer than the lower line on enthalpy axis. This difference in length shows the sensible heating required to raise the feed temperature up to the effects temperature. When I say effects temperature the effects boiling temperature basically, if the liquid exhibits boiling point raise then the vapor leaves the effect as a superheated vapor. So, if it includes the boiling point rise, the diagram will be also somewhat like this. A horizontal line show the latent heat of steam inclined line show the sensible heat of the cold water.

Now, this is the, this evaporator is in within 2 lines one is the steam line that is live steam and this is the cooling water, because the first effect will be failed by the live steam. So, live steam temperature is the maximum temperature of the evaporator network and the last effect evaporator has to be last effect evaporators vapor generation or whatever vapor comes out from the last effect of the evaporator, has to be cool down by cooling water. So, cooling water shows you the lowest temperature level in a evaporation system, whether it is a single effective operator this basically shows a single effective operator where feed temperature is lower than the boiling point, it will work under this temperature levels.

So, I can cram more number of evaporators within this temperature levels or I can operate a single evaporator, if I cram more number of evaporators within this temperature levels. Then each evaporator will work under a certain delta T minimum because this is the maximum delta T which is available, but while doing so my steam economy will increase, and that is why multi effect evaporation system is utilized.

Now, we take the reverse case when the feed temperature which is entering into the evaporator is more than the boiling point, and what will happen? If it is more than the boiling point once it enters the evaporator, it will flash and the vapor will be generated. So, the amount of vapor generated will be more than what it would have been done if the feed temperature is equal to the boiling point of the liquid.

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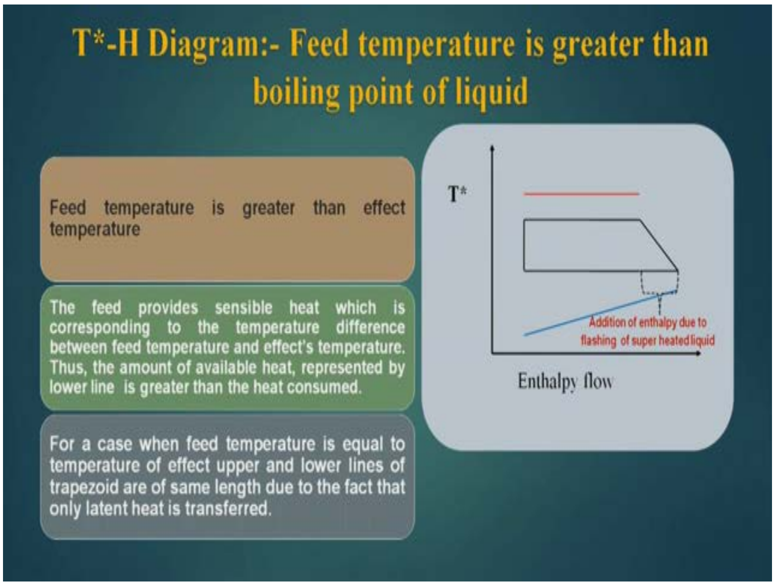

So, here the bottom line will be longer and this part of enthalpy, this additional enthalpy is due to the flashing of super heated liquid because when we say the feed temperature is greater than the boiling point, the liquid is super heated. And to keep this super heating it has to be at a higher pressure. So, when it enters into a lower pressure zone then it flashes.

So, the feed temperature is greater than the effect temperature here in this case. This is also working under two temperature levels one fixed by the live steam, and the other fixed by the cold water. The feed provides sensible heat which is corresponding to the temperature difference between the feed temperature and the effect temperature, when I say effect temperature basically this is the boiling point of the liquid inside the effect. I am not considering BPR, thus the amount of available heat represented by the lower line is greater than the heat consumed.

For a case when feed temperature is equal to the temperature of the effect upper and lower lines of the trapezoid are of same length, due to the fact that only latent heat is transferred. Now, if this feed temperature is equal to the boiling temperature it will convert into a rectangle, this part will go away and this will convert into a rectangle as the latent heat transfer will be only this much.

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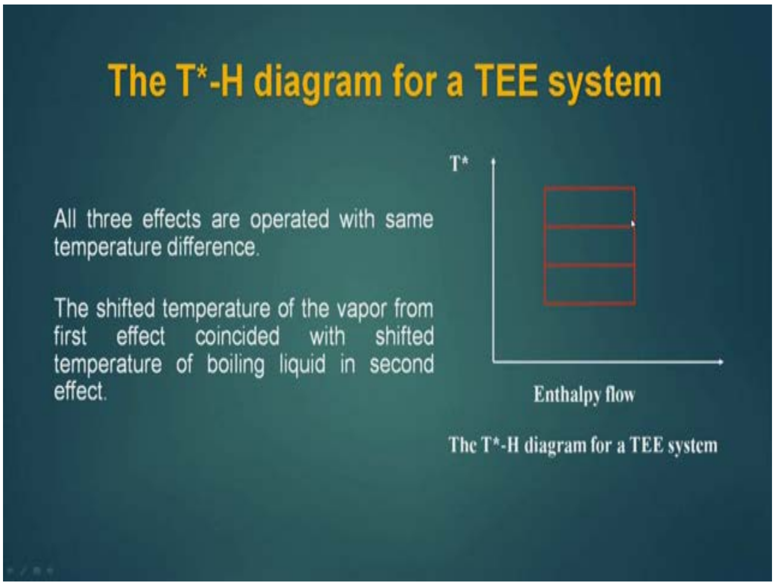

Now, let us draw the T H diagram for a triple effect evaporator system. Now if we see the boiling point and vapor generation temperatures, there will be 3 such temperatures here. When I draw it in a natural T versus enthalpy diagram so all 3 effects are operated with same temperature difference, then if I convert it into T star then this becomes this becomes this and this becomes this. So, when I converted into shifted temperature levels the T H diagram becomes like this, the shifted temperature of the vapor from the first effect coincided with the shifted temperature of the boiling liquid in the second effect, and so on so forth. And that is why we get a T H diagram of a triple effect evaporator system like this.

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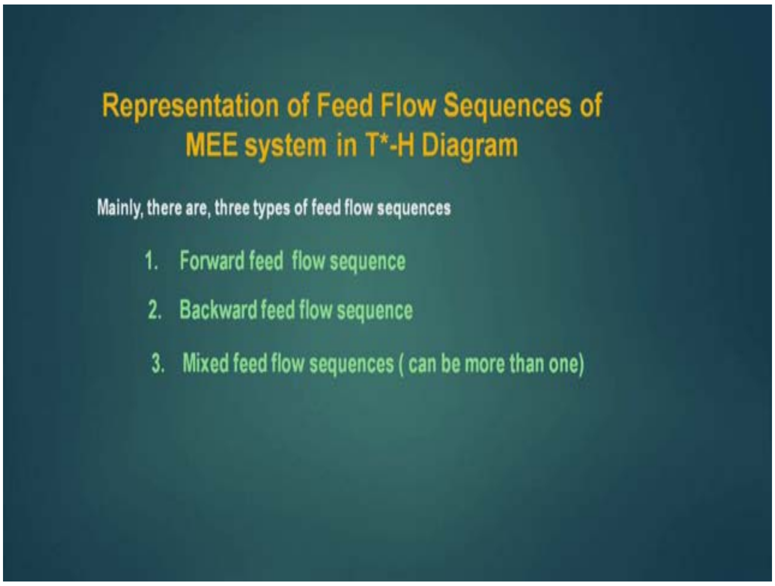

Now, let us see how a T H diagram of a multiple evaporation system will look like, when it goes through different feed flow sequences. I should explain this that a evaporator can be run with different feed flow sequences, and what are those feed flow sequences? Now, forward feed flow sequence backward feed flow sequence and mixed feed flow sequence. And when I say mixed feed flow sequences that can be more than one such sequences.

Now, the evaporators are run under this flow sequences based on different operating conditions. Depending upon what material it is processing, what is the condition of the following condition of the material, what type of fluid sequences are necessary for bleeding of the vapor, all these will decide that what type of flow sequences one should take. And the energy consumption for evaporating a kilo of liquid or a K G liquid will be different for this different flow sequences. That means the I should say that the steam economy of this feed flow sequences will be different. Now, let us check the feed flow sequences, so we go for the forward feed flow sequence.

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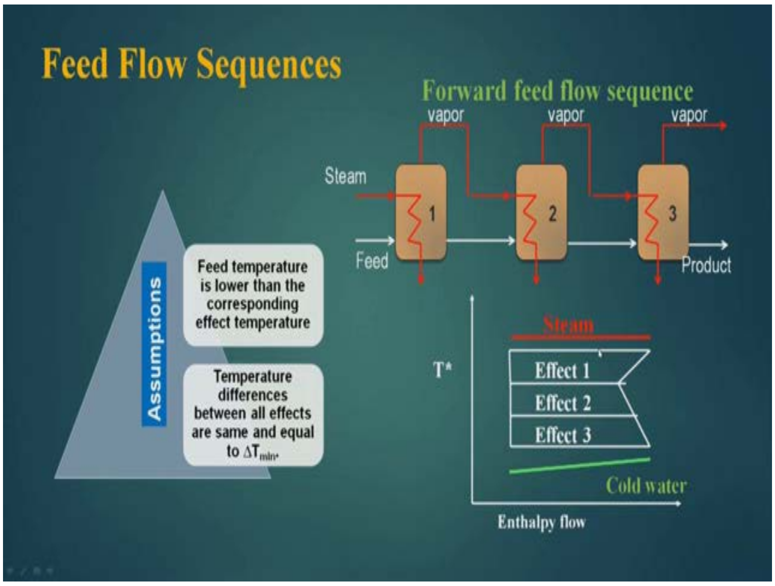

When the forward feed flow sequence, this is the live steam which is injected into the effect number one, and this comes as condensate from the steam, feed is injected into the first evaporator the vapor from the first evaporator goes to the second evaporator for heating and comes out at condensate. Then vapor from the second evaporator goes to the third evaporator for heating comes out at condensate, and the vapor from the third evaporator is cooled by the cold utility or cooling water. Now, the feed goes to the first from first to the second and then second to the third and then comes out as a product.

So, here we see that steam and feed are both are in the same direction, the vapor and the movement of liquid is in the same direction, and this is called forward feed flow sequence. So, feed temperature is lower than the corresponding effect temperature, temperature difference between all effects are the same and equal to delta T minimum this is the condition. Now, this is the at the highest pressure and this is at the lowest pressure, so the boiling temperature of liquid here is higher. When it goes to here where the pressure is low here the boiling temperature is low, so this liquid is superheated in comparison to the boiling temperature here.

Similarly, this also happens this liquid is superheated in comparison to the boiling temperature here. And that is why they will start flashing, when it enters into it there will be flashing and it enters into this there will be flashing. So, this is a case, where the feed temperature is more than the boiling point temperature, if it is so then how it will look like in a T H diagram, this will look like this.

And if I consider this feed temperature is less than the boiling temperature of one, then it will consume more energy and this will be the sensible heating part. But for effect number 2 and 3 this feed temperatures are super heated and that is why this part will be longer than this part. So, this part will be longer than this part, so it will take a shape like this. So, for a forward feed flow sequence for a triple effect evaporators is come my enthalpy and T N enthalpy diagram will look something like this.

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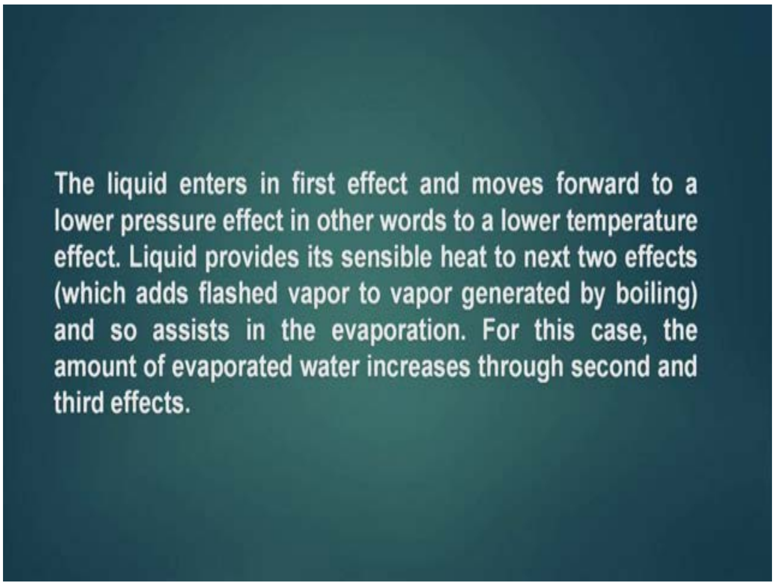

So, it is again within the steam and cold water temperature levels, this falls within this temperature levels. The liquid enters in the first effect and moves forward to a lower pressure effect. In other words to a lower temperature effect, liquid provides its sensible heat to the next two effects, which adds flashed vapor to vapor generated by boiling, and so assist in the evaporation. For this case the amount of evaporated water increases through second and third effects.

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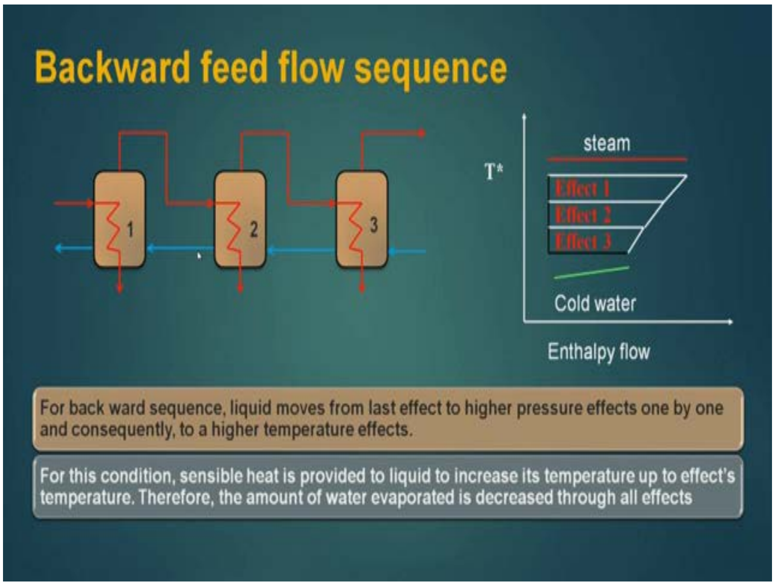

Now, let us see the backward feed this looks like a backward feed, here the live steam enters. The live steam enters and the flow of the vapor is in this direction, but the feed enters into the third effect. So, this is the lowest pressure effect and this is the highest pressure effect. So, when it goes from third to second it is of cooled, in comparison to second and this is sub cooled in comparison to the temperature of one. So, the upper line will be always longer because it is handling sub cooled liquid.

So, in this case also in this case also, this part is longer than this part, and this part is longer than this part. And the whole triple effect system falls under the two temperature levels that the live steam and the cold water. For the backward sequence, liquid moves from first effect to the higher pressure effect one by one and consequently to a higher temperature effect. For this condition sensible heat is provided to liquid to increase its temperature up to effects temperature. Therefore, the amount of water evaporated is decreased through all effects.

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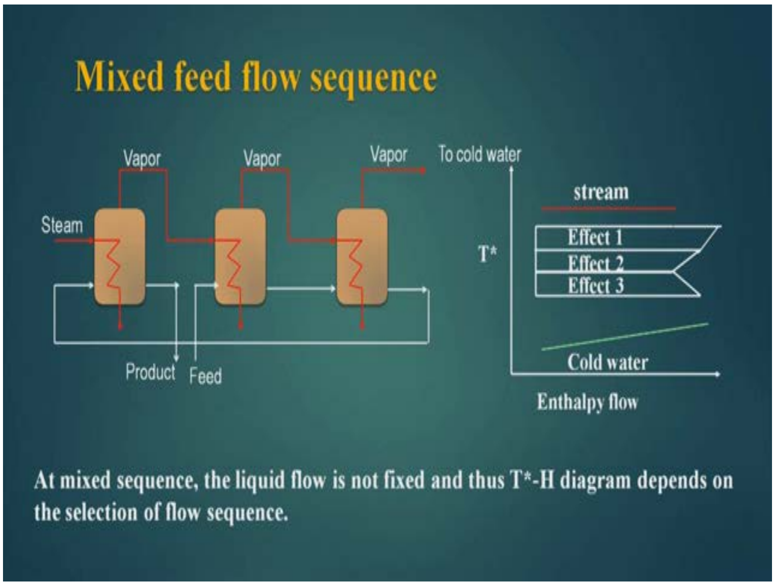

Now, is a mix flow sequence of a triple effect evaporator, now if you see this triple effect evaporator you say simple triple effect evaporator, when feed temperature is equal to the boiling point temperature of the effect, and if it is not so then its shape will change. Now, we are considering a mixed flow sequence and for a mixed flow sequences are can be many sequences not one. As for the forward feed, there is only one sequence backward feed only one sequence, for mixed flow there can be many sequences. Here the feed is entering into the column number, evaporator number 2 then it is going to the evaporator number 3. Then from the 3 again it is entering into evaporator number one and then from evaporator number one we are getting product.

However, the vapor flows in the earlier direction that means steam goes to the first effect condensate comes out whatever vapor is generated into the first effect, it goes to the second effect comes out as condensate then the vapor goes to the third effect, comes out at condensate and the vapor goes to the cold water for condensation. This pressure is minimum and this pressure is maximum and this is running at a intermediate pressure.

So, when the feed is entering into this, this is a sub cooled liquid that means temperature is less than the boiling point of this effect, and that is why this distance is more and this distance is less. But for this case this side is at a higher temperature, so this is a super heated liquid which enters into the third effect so it will flash. So, we see that this flashes in the third it flashes. So, this length is more and this length is less, and then from the third it goes to the first where it is again a sub cooled liquid and it needs sensible heating. So, this length is more and this length is less.

Now, this is a sequence and for this particular feed sequence this will be the diagram, if I change the feed sequence that means I feed heat from 3, and then take to one then 1 to 2. And then I take out the product then this may change so what conclusion we made that depending upon the feed flow sequences, and other operating parameters the T H diagram of a multiple effect evaporator will be different. It is also operating at under two temperature levels, the height temperature level is steam the lowest temperature level is cold water. A mixed at mix sequence the liquid flow is not fixed and thus the T H diagram depends on the selection of the flow sequence.

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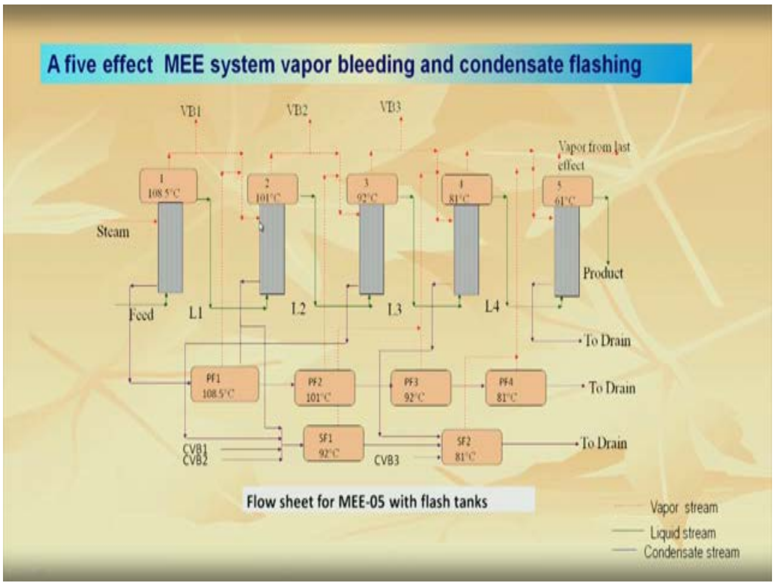

Now, let us take see two more things in multiple effect evaporator, one is called vapor bleeding and another is called condensate flashing, what does it mean? Now see this is a five effective evaporator system with vapor bleeding as well as condensate flashing. Now, this here I mean the first effect I am feeding steam and the condensate of the first effect goes to a flasher, here its pressure is decreased and flash steam is generated and that is flash steam joins the vapor to the second effect.

Now, by doing this flashing basically I am increasing the amount of vapor which is injected to the subsequent stage of the evaporator. And thus my steam economy will improve, that means the amount of heat which is going out as condensate, out of his some heat I am extracting due to flashing and then reusing it. This type of concept is effectively used in a multi effect evaporation system to improve its efficiency.

There is another thing which is being used also whatever vapor is generated here, I am taking a part of vapor called VB 1 from this first effect and again utilize this vapor for heating in some other equipment if I do so, I do not have to create a boiler to generate steam this is the advantage. But this decreases the steam economy of the evaporator network.

So, two things we observed here VB 2 here I am bleeding vapor form this effect VB 3 I am bleeding effect vapor from this effect like this. So, there are two new terms which is coming which is called vapor bleeding and condensate flashing. Let us see what is the effect of this vapor bleeding? And condensate flashing in a T H diagram of a multiple effect evaporation system.

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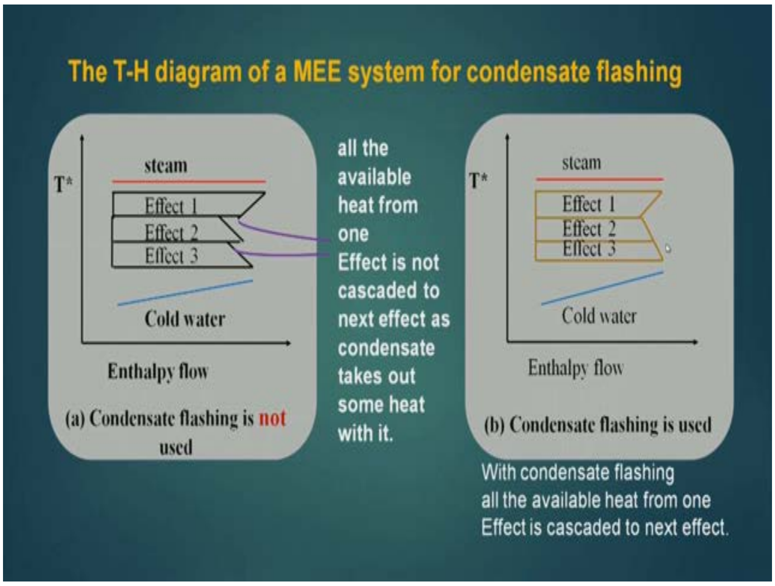

Now, this shows the condensate flashing is not used, if I am not using the condensate flashing this may look likes something like this because this much of heat, goes away with the condensate. So, my a MEE diagram will look something like this, but if I am using condensate flashing, this will look like this because I am to some extent regaining that heat which is being lost.

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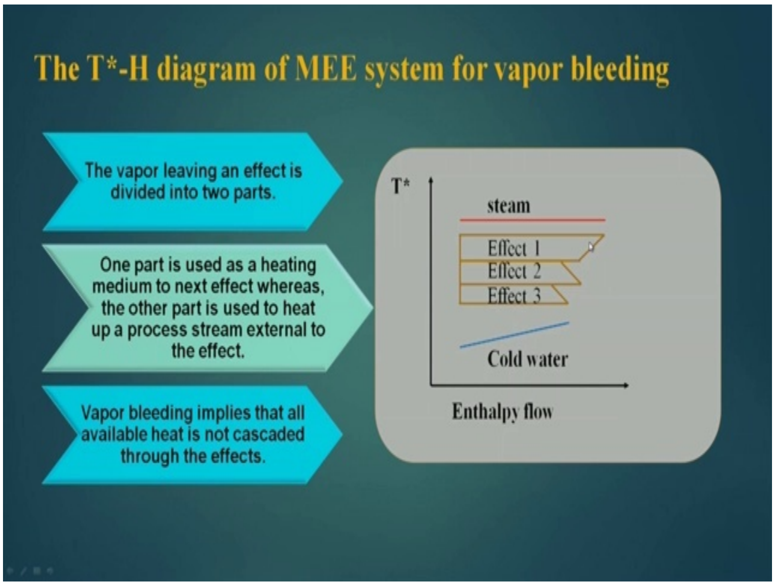

Now, if it is a vapor bleeding then it will look like this because some of the heat, which is available here a part of it which starts form here to here is be taken as bleeding stream. So we complete enthalpy is not pass from 1 to 2 and 2 to 3 because I am drawing some vapor from one as well as 2. So, the vapor leaving an effect is divided into 2 parts, one part is used as a heating medium to the next effect. Whereas, the other part is used to heat up a process stream external to the effect, if I am doing so then my T H diagram will look like this because this part of enthalpy is taken out as vapor bleeding.

The vapor bleeding implies that all available heat is not cascaded through the effects. Obviously if I take some heat out from the effect one the complete enthalpy will not be transmit to the effect 2, and the same thing happens from effect 2 to effect 3. This is also operating on the same temperature levels of steam and within the temperature level of steam and cold water. Now, if I am using vapor recompression.

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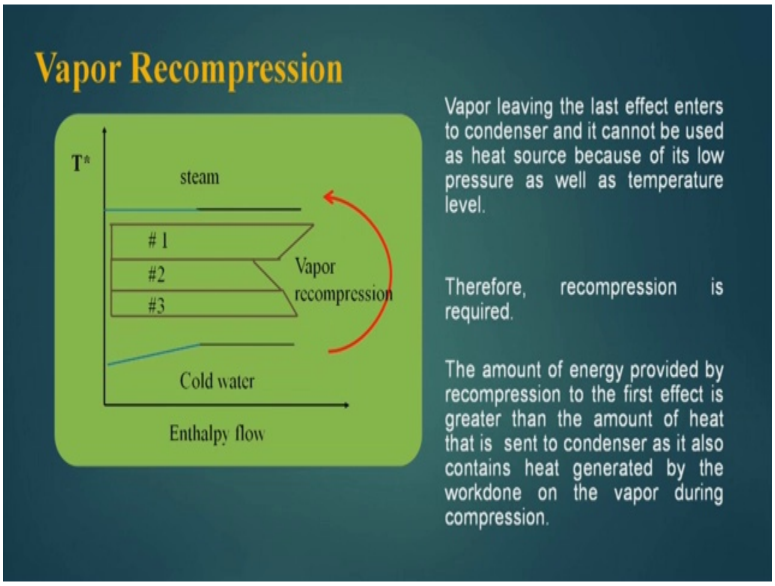

The vapor leaving the last effect enters to the condenser and it cannot be used as heat source because of its low pressure, as well as low temperature. So, the vapor which is coming out from the third effect cannot in fact be used in first or second effect because its temperature is low. But it has some heat with it, now the question is whether that heat can be used as it is? The answer is yes by using vapor recompression method, so what is being done to utilize what is heat is available here in this level, this vapor is taken and it is compressed by a compressor using some work and its pressure is raised. So, its temperature also raises and then this raise temperature is used here.

So, by the compressing the vapor I can use it at the first effect, but for doing so I have to utilize electrical energy in the compressor. So, whatever heat I pickup from here, the amount of heat which will reach to this level will be more, because the work done on this vapor will convert into heat. So, heat available here you will be more than whatever heat is available here. The amount of energy provided by compression to the first effect is greater than the amount of heat that is sent to condenser, as it also contains heat generated by the work done on the vapor during the compression.

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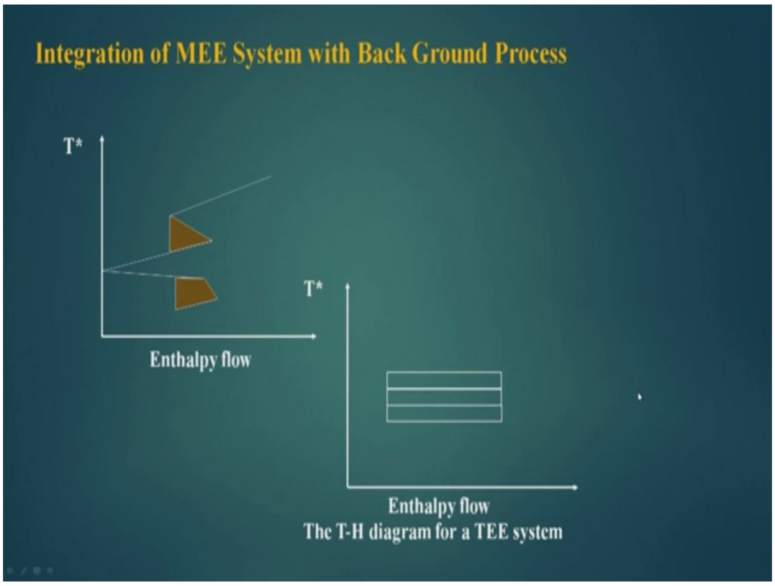

Now, let us talk about the integration of MEE system with back ground process. Up till now we have learnt how the a multiple effect evaporator will look like at different operating conditions. So, we know the shape of it, now it can be integrated into a background process, when I say background process, I always talk about the G C C of the background process. Now, this shows a G C C it is under T star enthalpy flow that is shifted temperatures and enthalpy this is also a shifted temperature enthalpy. So, both are within the same accesses. So, it can be integrated let us see how to integrate it.

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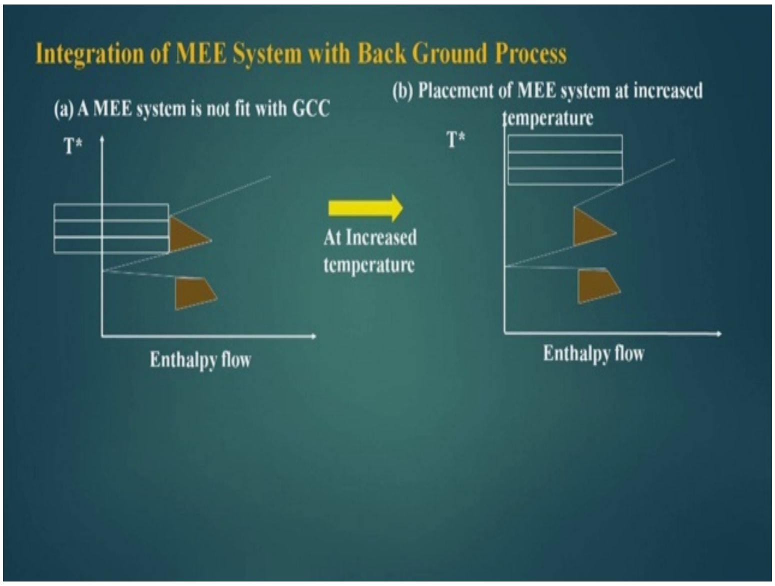

Now, when I am integrating this it is not fitting properly, so this is not a good integration that to do this what I can do, I can increase the temperature of the evaporator. And once I increase the temperature that means pressure of the evaporators all the effects of the evaporator it will rise up, because the temperature levels here, here, here and here will rise once it rises it goes to this place and now its fits. So, by increasing the temperature I can lift this to a proper place so this gives me a manipulation a tool to manipulate the evaporator systems.

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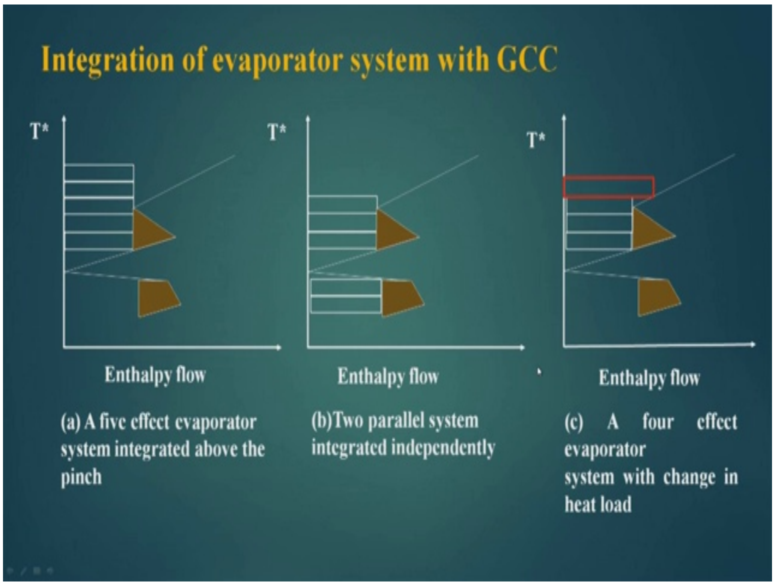

Now, the second way of manipulating it this that I can raise it to this level or I can break this into smaller, smaller evaporator system multiply evaporator system. And then I can fit it like this a five effect evaporator system integrated above the pinch. Or what I can do I can break this five effect evaporator system into a 3 effect and a 2 effect, I can place it above the pinch this 3 effects and this 2 effects below the pinch because we have seen that a evaporator system can be feed, above the pinch or below the pinch. Or what I can do I can this five effect evaporator system or make 3 effects of the same size and the forth effect a bigger effect.

So, a 4 effect evaporator system with change in heat load by doing so also I can integrate with this G C C. So, these are some methods which can be employed to feed the evaporator system with G C C of the process because G C C process cannot be changed. So, I can change my evaporator systems in such a way that it feeds to the G C C system, and what benefit I get out of it? If I do so my evaporator system will run free of cost and I will not required a condenser, which runs cooling water because the heat will be given to the process stream. And from the hot utility I will directly get the heat for my first effect, now let us taken example of the heat integration of system.

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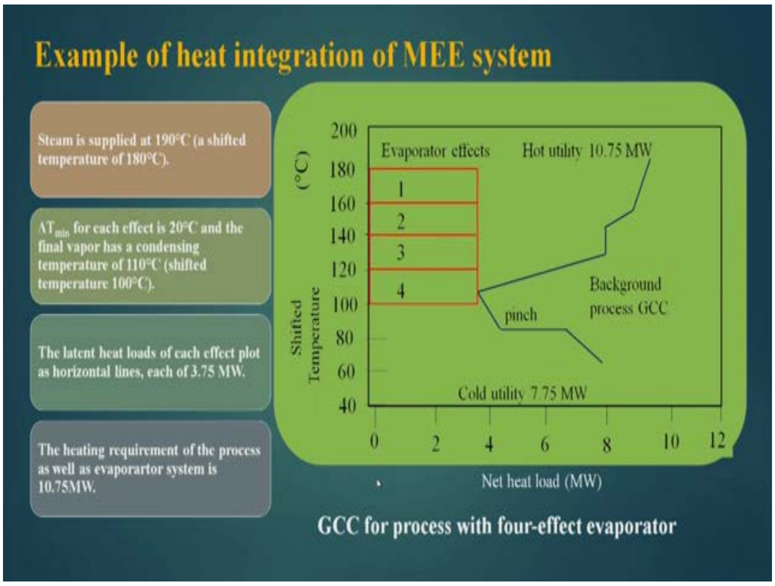

So, the first my G C C this is my background process or G C C this is the pinch. Now, I have a 4 effect evaporation system, now the hot utility requirement of the G C C is 10.75 megawatt. And what here I see the this sort of integration is not helping me much, this steam is supplied at 190 degree centigrade, this shifted temperature is 180. Delta T minimum for each effect is 20 degree centigrade, and the final vapor has a condensing temperature of 110 degree centigrade shifted is 100 degree centigrade. And the latent heat of load for each effect is around 3.75 megawatt, this is 3.75 megawatt.

The heating requirement of the process, as well as the evaporator system is 10.75 megawatt. Now, if I am able to decrease the 10.75 megawatt, then I will achieve some profit let us see how this can be done. Now, what I have done, I have converted this 4 effect evaporator system into a 3 effect evaporate system.

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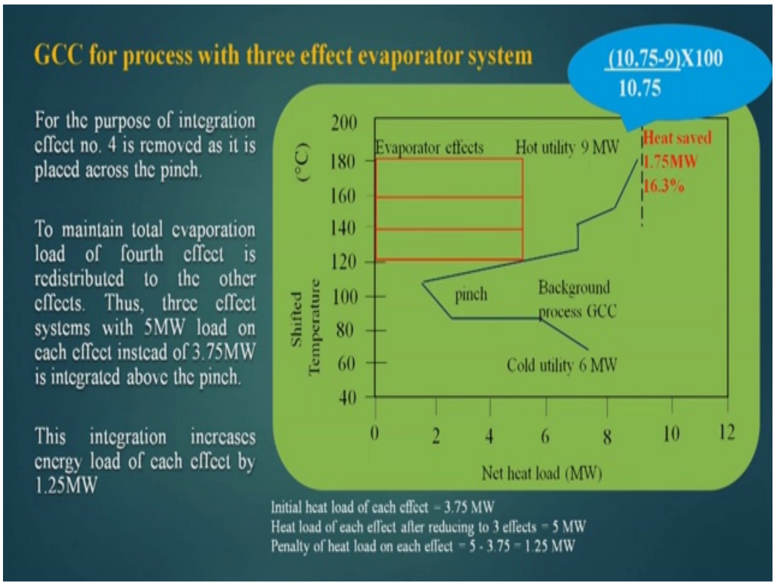

But I have increased the load of each evaporator, so this can be shifted invert. So, the lower from 3.75 megawatt I have increase it to 5 megawatt so 3.75 into 4 and 5 into 3 are same. Now, the hot utility requirement is 9 megawatt. So decrease in hot utility requirement is now 16.3 so by converting a 4 effect evaporator to a 3 effect evaporator. And while doing so increasing the head load of each evaporator to 5 megawatt, will do a saving of about 16.3 percent.

For the purpose of integration effect number 4 is removed as it is placed across the pinch, to maintain total evaporation load of 4th effect is redistributed to the other effects. Thus 3 effect system with 5 megawatt load on each effect instead of 3.75 megawatt is integrated above the pinch. This integration increases the energy load of each effect by 1.25 megawatt, but heat saved is 1.75 megawatt, which is 16.3 percent.

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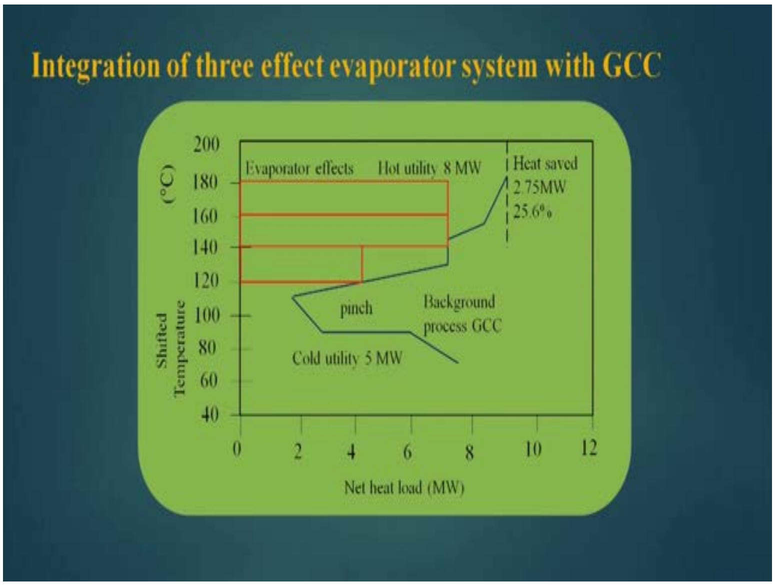

Let us see whether more saving can be done with it or not. Now, we have 3 evaporator systems, 3 effect evaporator systems. Now, if I change this 3 effect evaporator system to a 2 effect evaporator system and integrate it may be that I can do further saving. So, out of this 3 effect I am making 2 effects bigger effects and one smaller effects, and keeping the evaporation capacity same. If I do this then hot utility requirement is now 8 megawatt and saving is of the 25.6 megawatt. So, what conclusion we draw?

Rather than going for a 4 effect evaporator a by considering the G C C of the system or for the process, if I can design 3 effect evaporator having 2 bigger effects and one smaller effects, having the same load or same evaporation capacity. And integrate this evaporator system whit the G C C of the back ground process, then I will be in a position to save 25.6 percent energy which is a quite big amount.

So, if I have a evaporator system and I have a G C C, I should design the evaporator system in such a way that it can be properly integrated with G C C. That means integration of a evaporator house with the G C C of the process will decrease the total heat requirement of the process, as well as evaporator systems.

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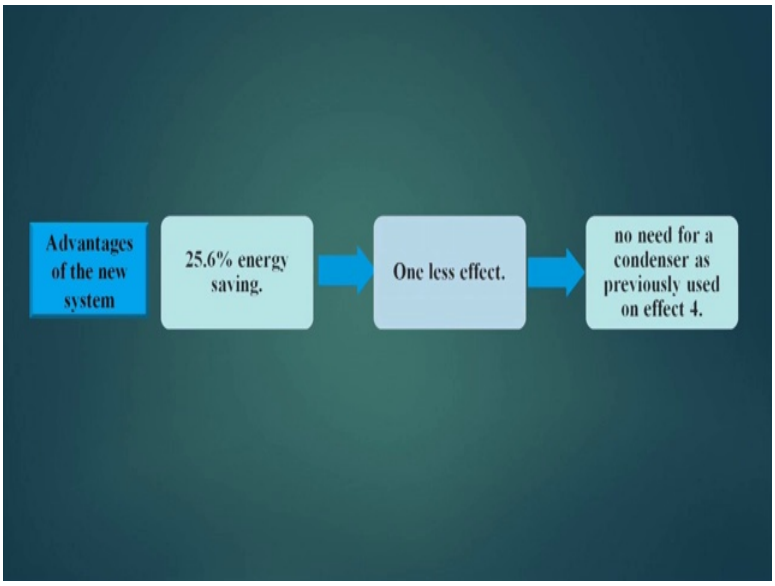

So, our conclusion is the advantage of new system is 25.6 percent energy saving and one less effect. No need of condenser as previously used on effect number 4. So, these are the savings we achieved by integrating a evaporator system with the G C C of a back ground process. So, what we learnt that if we have to design a new evaporator system will first study the G C C of the process. And based on the G C C evaporation system will be designed and they will be integrated with the G C C. So that the larger savings can be achieved, so one more conclusion that integration saves energy, this we have seen for the dispersion column, we have seen for the evaporators and in seen for the other systems also these are the references.

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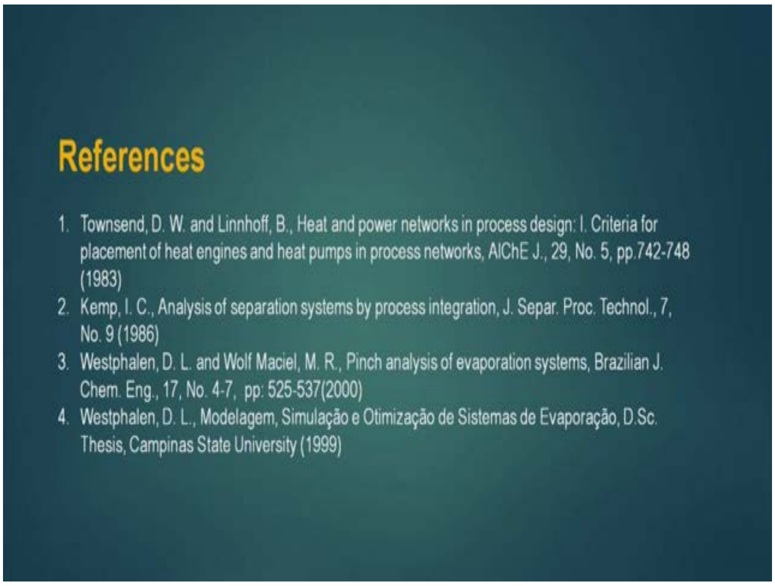

Thank you.