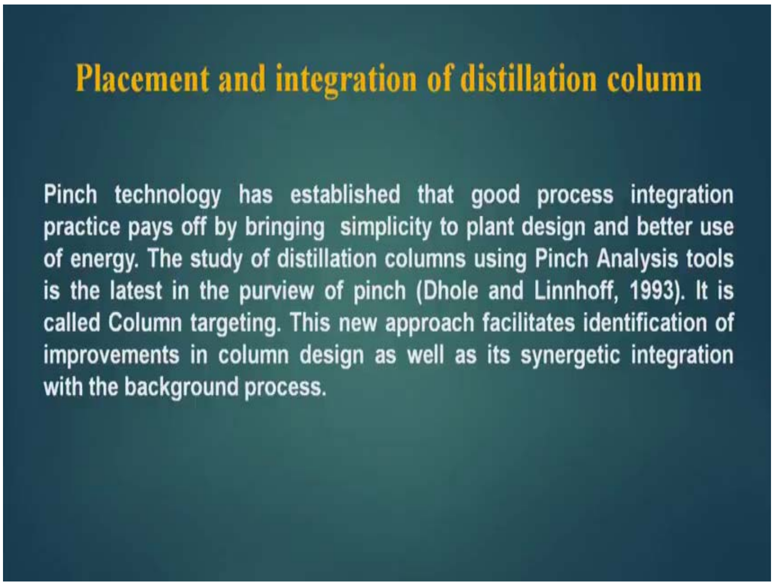
Process Integration
Prof. Bikash Mohanty
Department of Chemical Engineering
Indian Institute of Technology, Roorkee

Module - 6
Integration and placement of equipment
Lecture - 1
Placement and Integration of Distillation Column

Welcome to the lecture series on process integration. This is module six lecture number one. The topic of the lecture is Placement and Integration of Distillation Columns. We will see that, we have talked lot about integration and placement. Why you are doing integration with a heat exchanger network? Once we optimize a heat exchanger network its fixed was cost is almost constant. If we want to decrease its cost further then it is possible through decreasing the utility cost. This integration with different other units gives that opportunity of decreasing the hot utility or cold utility.

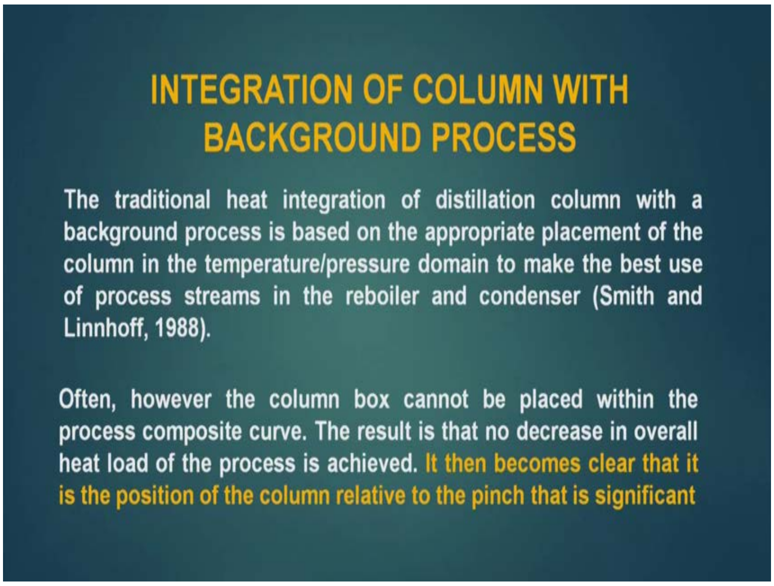
So, we will see in this lecture that, how integration of distillation column with hen or process G C C will either reduce the hot utility consumption of the process or with the same hot utility consumption will make the running of this distillation column free. That means the same hot utility will do the service of the distillation column, in terms of providing the hot utility in the reboiler. And the condenser duty will also be take care of by the process streams.

(Refer Slide Time: 02:57)



So, let see this Placement and integration of distillation column pinch technology has establish that good process integration practice pays off by bringing simplicity to the plant design and better use of energy. We have seen this in several cases the study of distillation column using pinch analysis tools is the latest in the purview of pinch analysis. This is been given by Dhole and Linnhoff in 1993, it is called column targeting. This new approach facilitates identification of improvements in the column design as well as its synergetic integration with the background process. So, with this we will see, now how exactly this is being done.

(Refer Slide Time: 04:06)



Now, let see what is the integration of column with background process? The traditional heat integration of distillation column with a background process, is based on the appropriate placement of the column in the temperature pressure domain, to make the best use of process stream in the reboiler and the condenser. This is been told by the Smith and Linnhoff in 1988. Basically, when we see that distillation column is working under two levels of temperature.

Now, these two levels of temperature may be above the pinch of a process G C C may be below the pinch of a process G C C or may be across the pinch of a process G C C. Depending upon these two temperature levels one level in which the reboiler is working, the other level we have the condenser is working will decide where the placement of this distillation column can be done often. However, the column box cannot the place within the process composite curve.

The result is that no decrease in overall heat load of the process is achieved. It cannot do it place it within the composite curve, then it is not going to do decrease the utilities. It is in becomes clear that it is the position of the column relative to pinch that is significant. This means see that where if I am placing the distillation column above the pinch, it will benefit or below the pinch it will benefit or across the pinch it will benefit. So, we will see thus that where the maximum benefit will take place. Accordingly, we will decide a rule where to place the distillation column with a background column process or integration purpose.

Now, to integrate with the G C C of a process, it is necessary that the distillation column should be expressed in a T H diagram. Why? Because a G C C of a process is expressed in a T H diagram. So, if we want to integrate the distillation column with the G C C of a process then it has to be also expressed in a T H diagram.

(Refer Slide Time: 06:43)

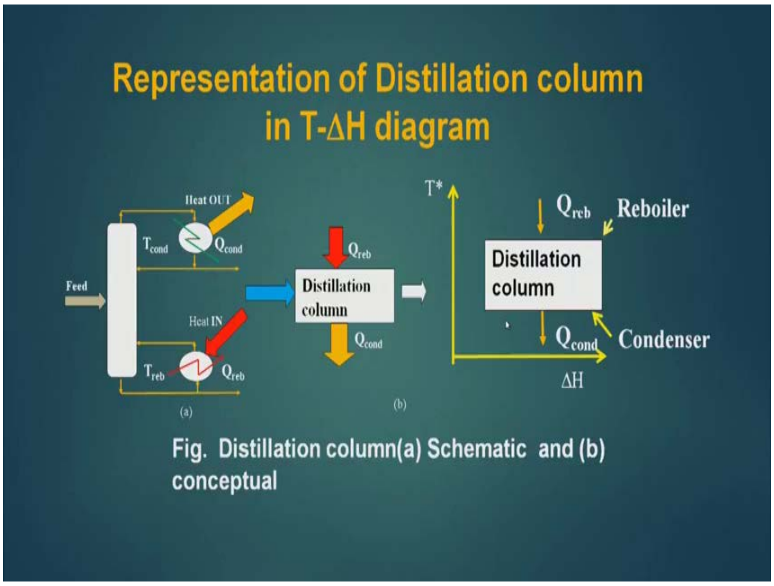


Fig. Distillation column(a) Schematic and (b) conceptual

Now, this shows a schematic distillation column this is the bottom product, because to the reboiler heated by a hot stream. The vapor goes here the feed is added to the distillation column here, then the vapor goes here it gives condensed. Heat is given out here and the condense set is return back to the distillation column as a reflux and some part of it is used as a product. So, we have product one and product two here and this is reboiler, where heat is goes inside it. That means it is the sink and the condenser is a source where heat goes out.

Now, this can be is working under two temperature levels the hot stream temperature in the reboiler and the cold stream temperature here in the condenser. So, we can show a distillation column like this Q reboiler is entering and Q condenser is going out. This can further shown in a T H diagram like this. This is a box distillation column, this is the reboiler temperature and the temperature axis here. This is the temperature of the condenser in the T star axis, this is shifted temperature and Q reboiler enters in to this and Q condenser goes out

(Refer Slide Time: 08:47)

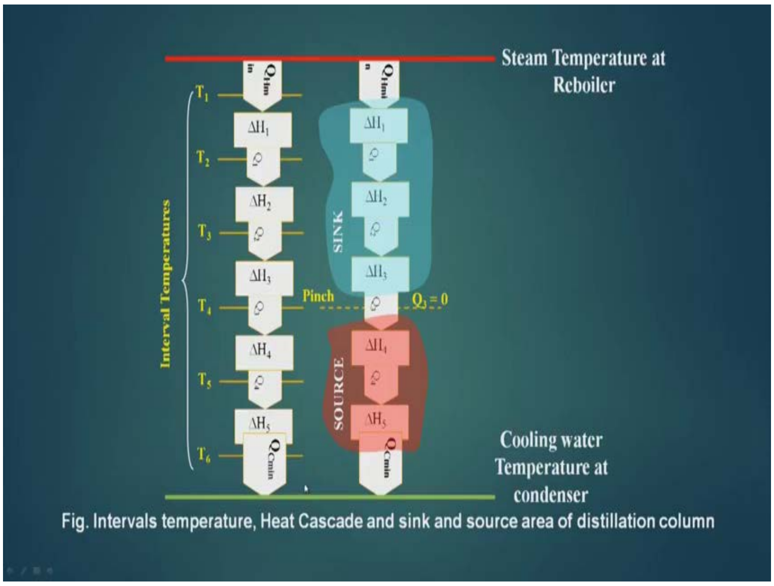
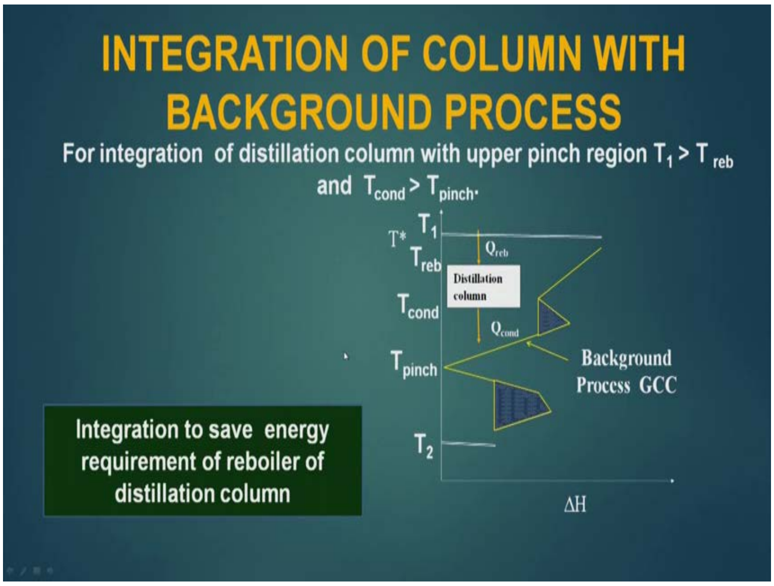


Fig. Intervals temperature, Heat Cascade and sink and source area of distillation column

So, this is the conceptual diagram of a distillation column in a shifted temperature curve and delta H. So, this will be, now used to integrate it with the G C C. Now, if I see a distillation column this may be my top tray with T 1 temperature then the temperature T 2, T 3, T 4, T 5, T 6. If this is the pinch then delta T H is handled by this and Q 1 is passes through T 2, Q 2 passes through T 3. If T 4 is the pinch then Q 3 is 0. Now, if I see this region of the distillation column, so this works as a sink and this region of the distillation column works as a source.

So, this is the stream temperature have the reboiler and this is the cooling water temperature have the condenser. So, within these two temperature levels all the distillation column plates are working. So, these are the temperature intervals, heat cascade and sink and source area of distillation column.

(Refer Slide Time: 10:00)



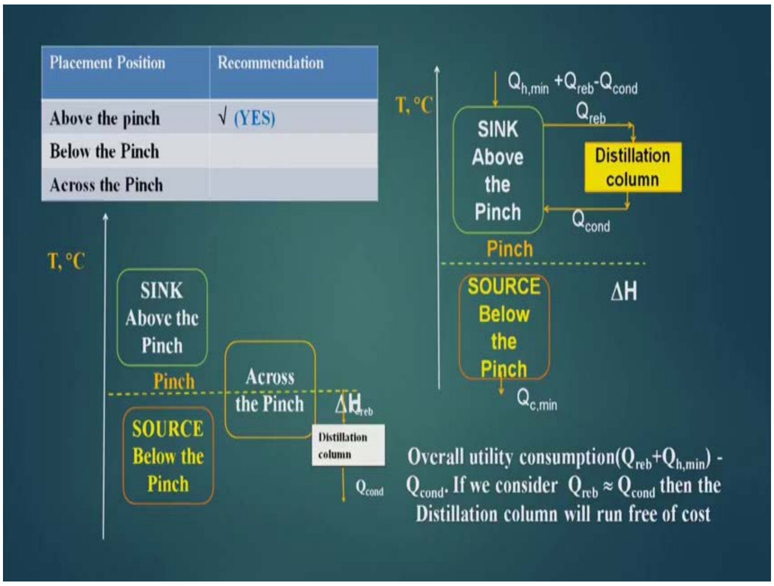
Now, how the integration of a column with background process will take place? Now, this is my background process, this is the G C C of my background process. This G C C clearly tells that you need a hot utility at T 1 temperature and you need a cold utility at T 2 temperature. The hot utility servicing these streams this is heating the stream from this to this. This part is that the process stream is giving heat to the another process stream and from here to here again, heating takes place using the utility, but here we see there is a large delta T available, which decreases then we go to this.

Now, by integrating a distillation column here under this large delta T, I can make the distillation column operation almost free of cost. Already, see how this is under a T a and delta H diagram. So, for integration of distillation column with upper pinch region the condition should be that T 1 should be greater than T reboiler and T condenser should be greater than pinch. So, this is the up region from pinch two T1, so this T reboiler temperature should be less than T 1 and T condenser temperature should be more than pinch. So, this is the T reboiler and T condenser temperature, now this goes and it can be integrated.

Now, what is happening practically? The hot utility is giving heat to the reboiler. Then the condenser is giving heat to this stream switcher available from here to here. So, with this stream this heat this stream available from at this point to this points are getting heated out. So, while this heat is cascading down it grows to the distillation column, now what we are gaining out of it that, now this is this distillation column is running free of cost. Whereas, this background process is also running with the help of the same utility hot utility, so by integrating this distillation column above the pinch I am basically running this distillation column almost free of cost.

So, we can conclude that by integrating a column with the background process either the column will run free of cost or it will be in a position to decrease the amount of hot utility. Now, similarly this part of the column can be integrated below the pinch and in that case T pinch will be greater than T reboiler and T condenser will be greater than T 2, so this can be integrated here also. So, integration to save energy why we are doing integration to integrate some to save energy requirement of reboiler of distillation column and also cooling utility we are also saving.

(Refer Slide Time: 13:56)



Now, the distillation column can be integrated above the pinch or it can be integrated across the pinch. When it is integrated across the pinch it takes Q reboiler from above the pinch area and r jets Q condenser in the below the pinch area when it does. So, we call it that it is been integrated across the pinch or it can be integrated below the pinch. In the below the pinch it is taking Q reboiler from below the pinch and injecting Q condenser below the pinch.

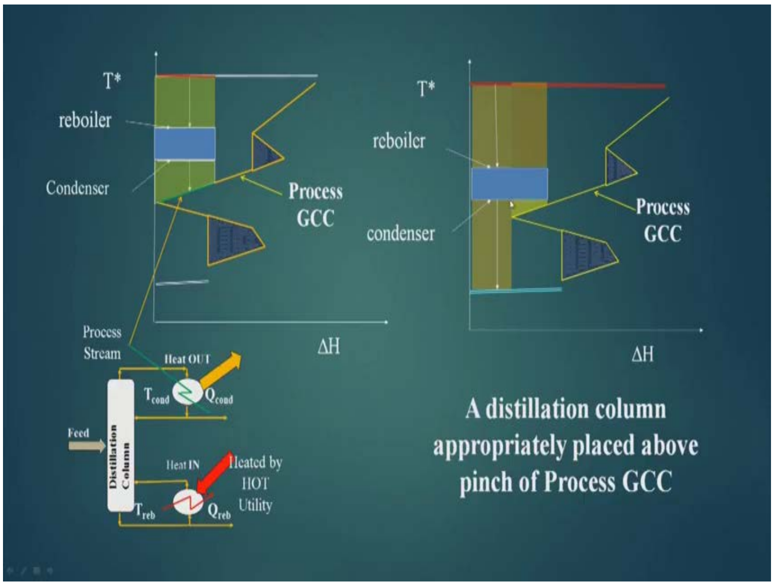
So, let us see that whether these three conditions are favorable to us or not, will analyze one by one. Now, this is a distillation column, which is integrated above the pinch in the above the pinch it is a sink that means it takes heat from outside. Now, I am integrated distillation column here, so it will take heat from here. So, if it takes heat from here it will load the system, because in the sink it comes from outside when it rejects heat to this.

Then it is decreasing the heat load of the sink, so the heat load is now Q h minimum plus Q reboiler, minus Q condenser. Because, Q condenser is giving heat to above the pinch area Q reboiler is taking out that is why it is ring added to this and Q condenser is giving this heat. So, it is deducted from here heat so total heat required to run this distillation column as well as to service the above pinch area is Q h minimum plus Q reboiler minus Q condenser.

Whereas, below the pinch area Q c minimum is rejected to cold water, so it is not changing. When I am integrating this distillation column above the pinch area, this only affecting the hot utility consumption, it is not affecting the cold utility consumption, so let are analyze. So, overall utility consumption is Q reboiler plus Q h minimum minus Q condenser. If we consider Q reboiler is equal to Q condenser then the distillation column will run free of cost.

If Q reboiler is little bit greater than Q condenser, then obviously this distillation column will run with a little addition of hot utility. That means it will load the system, but the load will be very less, because Q reboiler is almost equal to Q condenser in a distillation column. So, what we observed here that if the distillation column is integrated above the pinch then the distillation column runs almost free of cost. So, we are now able to save the hot utility as well as cold utility, which is otherwise you utilized for a distillation column. So, the recommendation will be above the pinch distillation column can be integrated above the pinch and it will going to do the benefit to us.

(Refer Slide Time: 17:50)



Similarly, we see a second case, now let us see the exactly what will happening here this process G C C. I have the integrated this above the pinch from this part of the hot utility heat is coming through the reboiler to this distillation column. This part condenser is rejecting heat to this stream, which are available from this part to this part. Now, how physically this will look like? The streams here, the process streams here will go through the condenser to pick up the heat and the hot utility, which is being used here will be used in the reboiler.

So, hot utility will heat the reboiler and the process stream shall be used in the condenser to cool the condenser. Now, this part of the hot utility is servicing this part and this part of the G C C. This is how it will be integrated physically. Now, this second case is shows that the integration can be like this, but this is not consider to be a very good integration. Because, the hot utility requirement increases the hot utility, which is here to here they goes to the reboiler and then to condenser and condenser sends this heat to the cooling water, which is the cold utility.

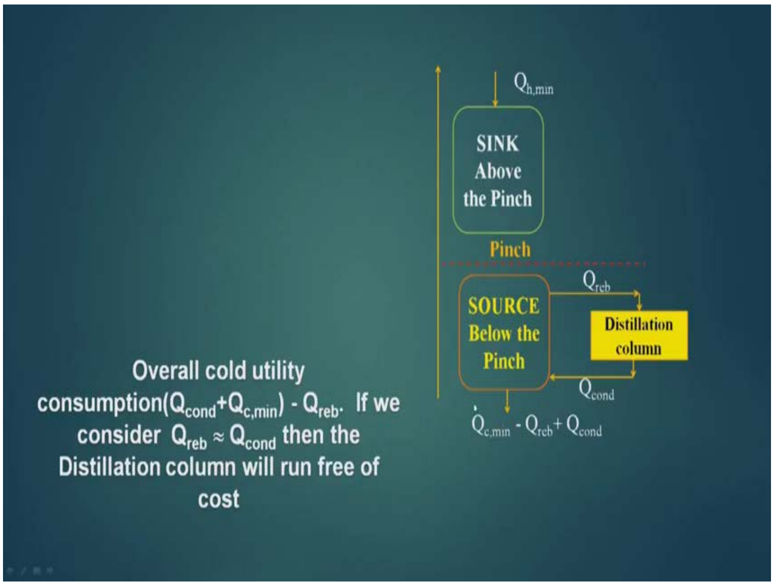
So, the cold utility requirement and hot utility requirement increases, but this is partially serviced by the hot utility here not fully, but partially that means hot utility, which is available here will service this part of the reboiler. The condenser heat of this part will go to the process streams. So, this is how in actual practice this will be integrated with the process G C C. Now, let us take another condition we have discuss that of the distillation column will be integrated above the pinch, then distillation column will run free of cost.

It appears that this is the only one condition that it has to be integrated above the pinch, but there are some other conditions too like when these are the different temperature levels. Say these are temperature level the heat requirement is Q 1 plus Q reboiler minus Q condenser. When I take Q reboiler at this temperature level I deduct Q reboiler here, so this and this cancels out. So, only Q 2 minus Q condenser remains. Now, if the Q condenser is more than Q 2 and at this temperature level this system will not work.

Similarly, here Q three minus Q condenser, so Q condenser should be less than Q 3 and Q condenser should be less than Q 2 for this temperature level is to be feasible here I reject Q condenser here, so this cancels out. So, there is another limit, there is a limit on the heat load that can be borrowed from any process. Sufficient heat flow must remain in the process at all temperatures spend by the column the requirement is that, Q 2 and Q 3 are greater than Q condenser prior to integration of the column. So, this out condition that Q 2 and Q 3 should be more than the Q condenser individually before integration of this column.

Now, if it is not satisfied then this integration cannot take place. If the condenser is only to be integrated as can be seen all heat close above the condenser temperature must be greater than the Q condenser. Now, if it works like this that hot utility is given here as well as here Q reboiler, so hot utility requirement here will be Q h minimum minus Q condenser. Because, Q condenser is rejecting heat inside this above the pinch area, now if it is, so then the heat flow should not be negative. This has to be taken care of then only a integration can take place. This is partially, this column is partially integrated it is not taking Q reboiler from upper pinch area, it is only injecting the Q condenser to the upper pinch area.

(Refer Slide Time: 23:13)

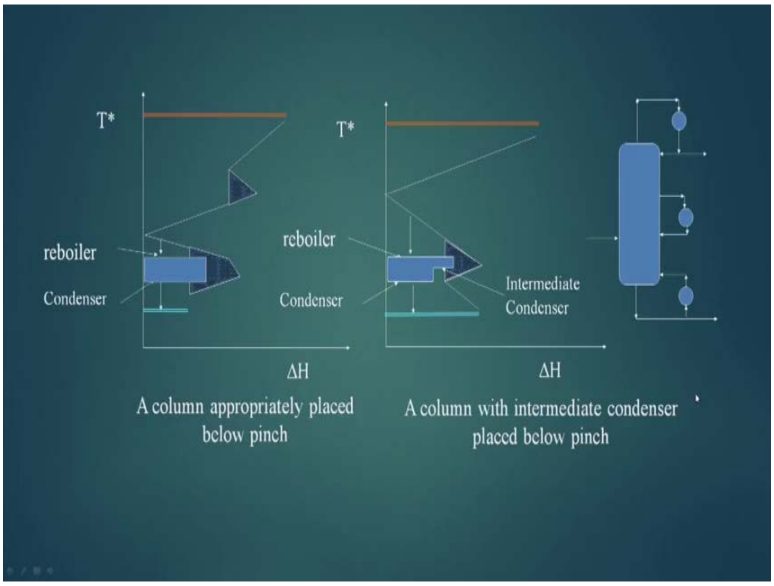


Now, let us see integrate the distillation column below the pinch. Now, when I integrate thus Q reboiler is this heat is taken from the below the pinch area. Now, I can very easily take heat from here, because this is a source now and source has extra heat available with heat. So, I am using that extra heat here then I am also injecting the Q condenser here. So, my cooling requirement will be Q c minimum minus Q reboiler plus Q condenser however at the same time my Q h minimum will remain unalter, because I am not changing the thermal balance here and it is inthermal balance.

So, my cold utility requirement is now this, so the overall cold utility consumption is Q condenser plus Q c minimum minus Q reboiler. Now, if we consider the Q reboiler is equal to Q condenser then the distillation column will run again free of cost. If Q reboiler is little bit more than the Q condenser, then also this will reduce to some extent Q c minimum. So, what we conclude out of it that if the distillation column is operated below the pinch, also in most of the cases either a little bit of less or more utility will be required, but for all practical purposes the distillation column will run free of cost.

So, the conclusion is if the distillation column is placed below the pinch this is yes we can place below the pinch. It is going to benefit at least the distillation column, because the distillation column will now run free of cost note the third part of it that is across the pinch. Let us see what happens, when I place at distillation column across the pinch.

(Refer Slide Time: 25:50)

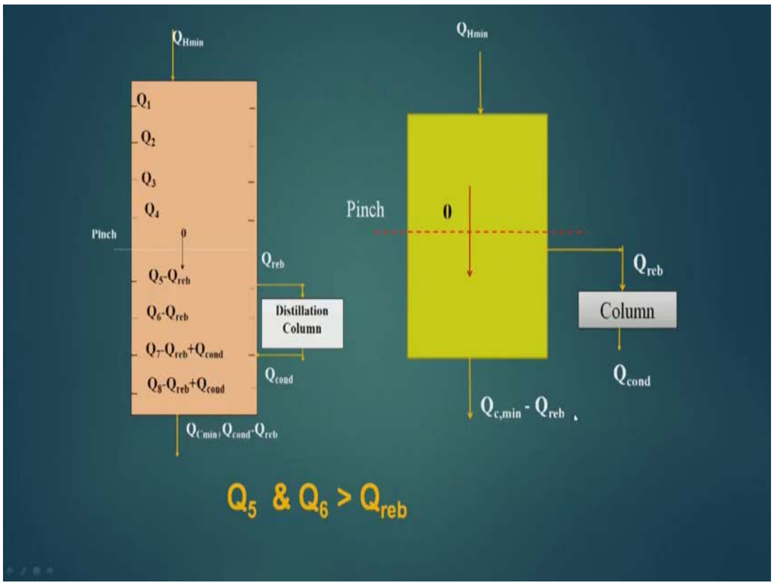


Now, let us see how this will be integrated below the pinch this is physical aspect, let see then will consider the placement across the pinch. So, when I am putting up a distillation column below the pinch it will look like this. So, the heat, which is available from here to here by the process stream will be given to reboiler and the heat, which is available from this to this, is also given to the reboiler.

This part of the process stream is giving heat to this part of the process stream. A portion of this condenser of the distillation column is giving heat to this portion of the stream process stream. This portion of the condenser is pushing heat to the cold water, so it is going to take heat from this portion this part and giving heat to the cold water.

Now, this is another we can also integrate like this here in the distillation column. The intermediate condenser is being used. So, column with intermediate condenser place below the pinch, so heat from this to this is coming to this area. Then this part of this heat goes to this cooling water this part of the heat goes to this cooling water, and for this small part the heat is coming from above this to this and this part of the heat goes to this process stream from here to here. So, this shows a feasible integration of a distillation column below the pinch area.

(Refer Slide Time: 28:07)



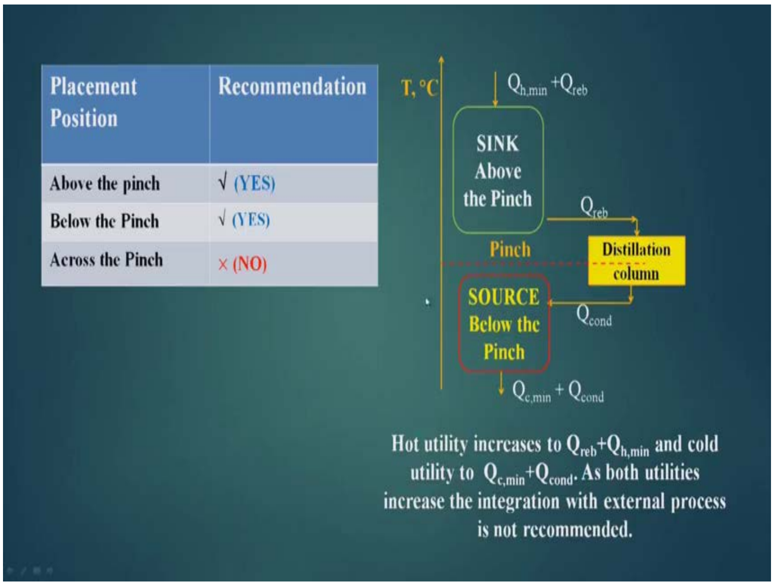
Now, this shows a intermediate condenser, this is a reboiler and a part vapor goes to this condenser. Then it is recycles back to this same column and this is feed and this is the original condenser. Now, if a see here that I am taking heat reboiler heat from here, so this is Q 5 minus reboiler this comes Q 6 minus reboiler these are the temperature levels. Here, Q 7 minus reboiler plus condenser here at this temperature level I am adding condenser heat. Now, for these two conditions this will would be negatives that means Q 5 and Q 6 should be individually greater than reboiler.

So, my condition is this for the integration below the pinch that means the energy flow should not be negative in any case. Similarly, here partially I am doing integration this is taking below the pinch Q reboiler heat, because this is a source if take it from here it will decrease my Q c minimum. It has decrease the Q c minimum by Q reboiler amount. So, my cold utility has decreased, where as my hot utility is remains same and this condenser goes to the cold water again.

So, if I am doing the partial integration it is going to decrease the cold utility of the process. So, while analyzing this we have to see that what is the utility consumption of the process as well as column at the start, when I am operating them without integrating each other then after integration I have to see that, what is the utility consumption of the process as well as the column after integration?

So, if I find some savings then can go for integration integrations can also the complexity. This is has to be kept in mind also while going for integration. Now, here I am integrating the distillation column across the pinch. Now, when I am integrating this I am taking Q rebiler that means the heat required for the reboiler from above the pinch area.

(Refer Slide Time: 30:41)



So, my hot utility consumption increases by reboiler, so Q h minimum plus Q reboiler. Because, this area the system is deficient of heat and that is why I am taking heat from outside. So, if I take heat further from here, so this outside heat has to increase to satisfy this. So, my hot utility requirement has increased from Q H minimum to Q plus reboiler

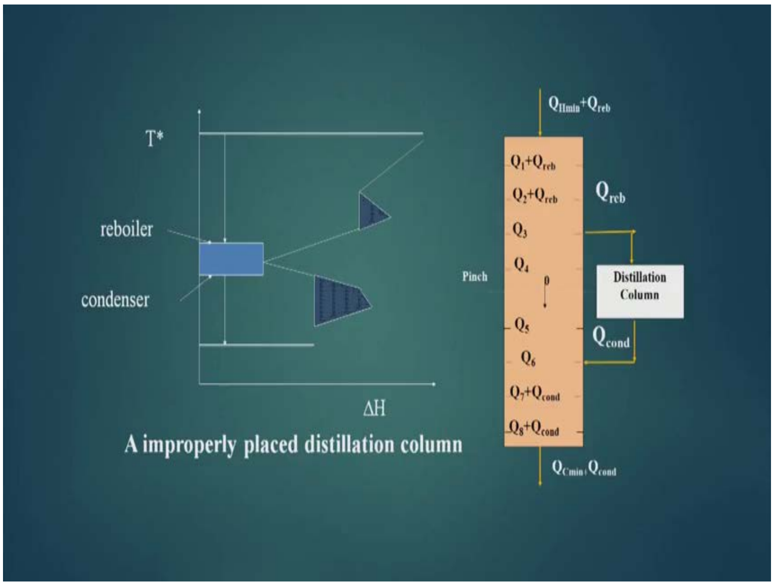
Similarly, I am rejecting a heat to a area, which is the source area that mean it is it has got more than required. So, the cold utility this will obviously, this it will go to the cold utility. That is why the cold utility amount has increase from Q c minimum to Q c minimum plus Q condenser.

Now, if I see separately if I operate the system and distillation column, this is the amount of hot utility and cold utility I will be consume. So, I am not getting any benefit out of it and that is why the third take recommendation is that we should not place a distillation column across the pinch. So, if I conclude the placement positions above the pinch distillation column can be placed it will run almost free of cost below the pinch, yes it will run almost free of cost, but across the pinch no.

So, we will not like to place a heat exchanger across the pinch, but while telling thus that if I tell that it I should not place it this is not solve the problem. Because, if the distillation column temperatures levels are such Q reboiler and Q condenser are such that. It falls across the pinch then we have to place it across the pinch and that scenario what should be done. You will see that we have to increase the pressure of the distillation column to take it to either above the pinch area or to decrease it pressure, to bring it to the below pinch area. When I am increasing the temperature or decreasing the temperature of the distillation column, I am basically affecting the Q reboiler and Q condenser.

If I change the Q reboiler, Q condenser by changing the pressure inside the distillation column such that it either falls above the pinch or falls below the pinch. Then I may solve my problem, which will appears due to the replacement of distillation column across the pinch.

(Refer Slide Time: 33:50)

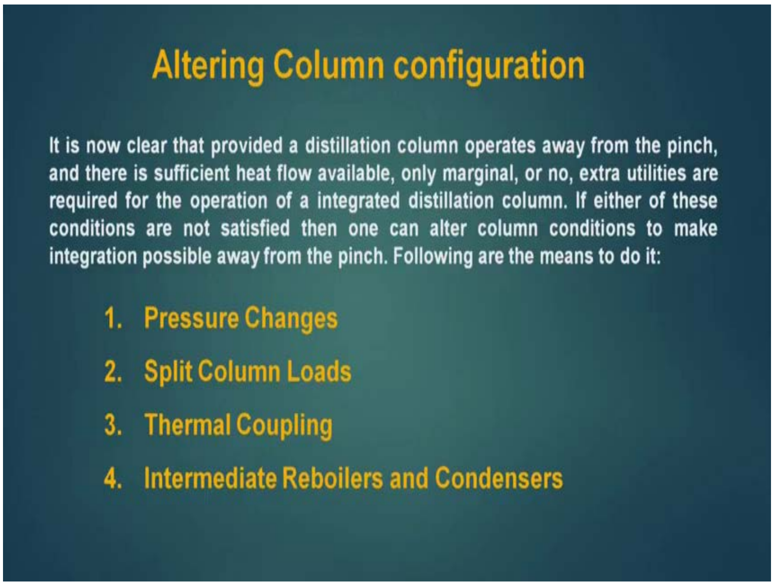


So, we will see that what are the different parameters, which are available in the hand of the designer, so by manipulating those parameters a proper placement can be designed. Now, this show across the pinch, through this is placed across the pinch if you see physically this is the hot utility requirement for the distillation column is goes to the above reboiler. Then the condenser ejects the same heat to the cooling water of the cold utility.

This is the amount of hot utility is required to service the G C C of this process. So, here what we see that, the total hot utility requirement is the hot utility requirement or the distillation column up to this plus for the G C C, which is up to this. Similarly, the cold utility requirement for the column is this, if a project this point here up to this and cold utility requirement for the G C C is from here to here. So, here I am not getting any savings when I place a distillation column across the pinch.

However, if we see here there is no chance of negative flow of heat, because these quantities are positive. So, as where as the distillation column across the pinch is concerned it is not going to make any heat flow negative in any temperature, but a heat exchange, heat a distillation column place across the pinch is a improperly place distillation column.

(Refer Slide Time: 35:46)

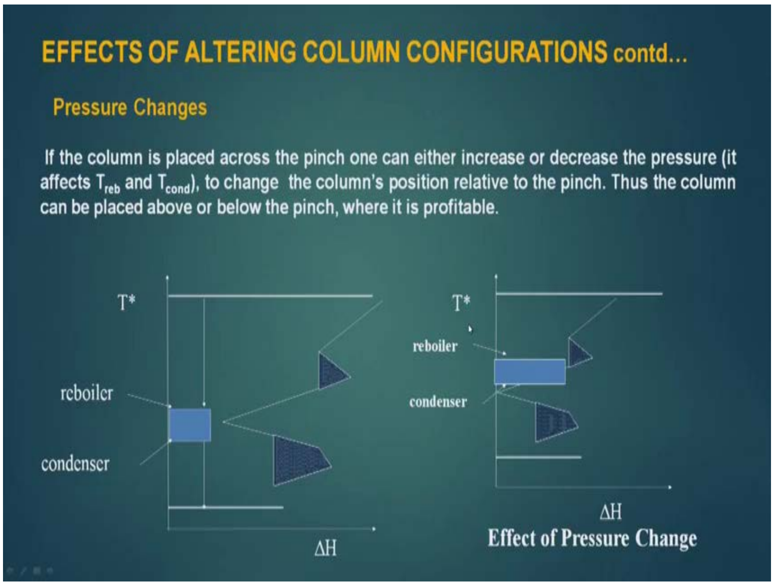


Now, it is now clear that provided a distillation column operates away from the pinch and there is sufficient heat flow available only marginal, or no, extra utilities are required for the operation of a integrated distillation column. This way have seen very clearly that for the upper pinch area if it is integrated it almost runs free of cost or with marginal increase in the utility.

If either of these conditions are not satisfied, then one can alter the column condition to make integration possible away from the pinch. If I am not able to satisfy this condition that is neither it is falling on above the pinch or below the pinch, it is falling across the pinch. Then column conditions has to be chase to make it fall on either side of the pinch

Now, there are many methods to do it and those methods are pressure changes, split column loads, thermal coupling, intermediate reboilers and condensers. So, are intermediate reboilers and condensers by applying this techniques we can properly integrate a distillation column with process G C C. Now, let us see what has the effects of altering column a configuration is required to know that how it is going to affect the distillation column. If I am changing its operating parameters, now if I change the pressure what will happen say this across the pinch? If I increase its pressure the reboiler temperature will go up and condenser temperature will go up, so this will shift to this reason.

(Refer Slide Time: 37:54)

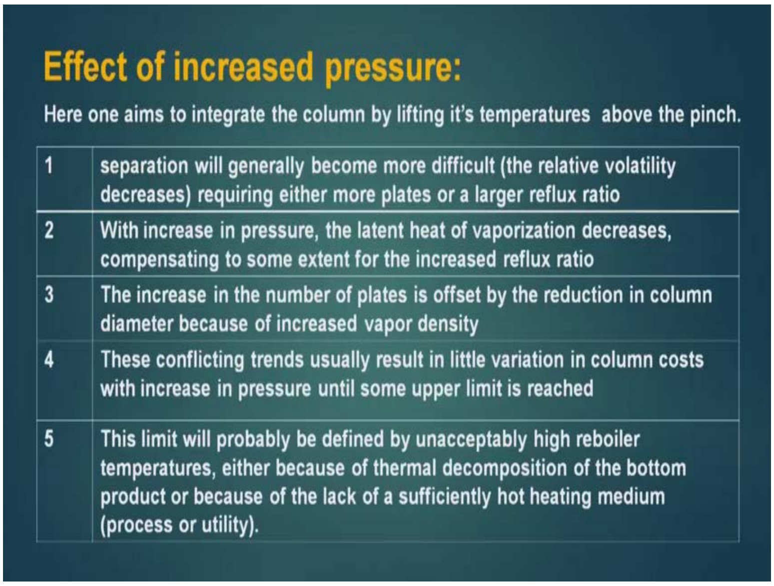


If the column is placed across the pinch one can either increase or decrease, the pressure as it affects the reboiler and T condenser to change the columns position related to the pinch. That means changing this pressure I can either shift it the upper side or decreasing the pressure I can go downside in both of the cases I will be able to integrate it properly. Because, if it is integrated above the pinch it is considered to we go integration and if it is integrated below the pinch it is also a good integration, because above the pinch and below the pinch it will be profitable integration.

Now, let us see with moves up, now it start saving the hot utility in the earlier case it was not able to save the hot utility. It can also be taken down it, now saves the cold utility at this position it is it will run free of cost at this position also it will run free of cost. Now, this was improperly pressed earlier, because it was cutting this line. Now, by increasing the pressure it can go up, now it is beautifully fits in to the G C C. So, by changing the pressure I can teller the position of the distillation column and the G C C or I can move to such a area where it better fits the G C C.

Now, the effect of increased pressure, if I am increasing the pressure of a distillation column it will have its own effect. Now, let us see what happens if basically when I am increasing the pressure the temperature of every tray of the distillation column will increase. Now, if it is, so then what will happen to the separation? The separation, which is being done in the distillation column separation will generally become more difficult.

(Refer Slide Time: 40:30)



Why with higher pressure the relative volatility decrease? If it is, so then it will require either more plates or a large reflux ratio to do the same separation. The second point is with increase in pressure the latent heat of vaporization decreases compensating to some extent the increased reflux ratio. Because, the latent heat of vaporization will decrease with the same amount of Q being transfer to the condenser, more liquid will be formed. Hence, reflux ratio can increase the increasing in number of plates is offset by the reduction in column diameter, because of increased vapor density.

Now, when we increase vapor the pressure the density of the vapor decreases. Due to thus the size of the column, that means the diameter of the column will decrease though the number of plates will increase. That means the height of the column will increase, but due to the reduction in the diameter of the column the fixed cost of the column will be compensated to some extent.

Now, these conflicting trends, which has been discussed in point number one, two and three usually result in little variation in column cost, with increase in pressure until some upper limit is reached. Then we design a column it is designed for a upper limit, so I cannot go beyond that upper limit if I go beyond that the column can burst. So, there is a upper limit to its design.

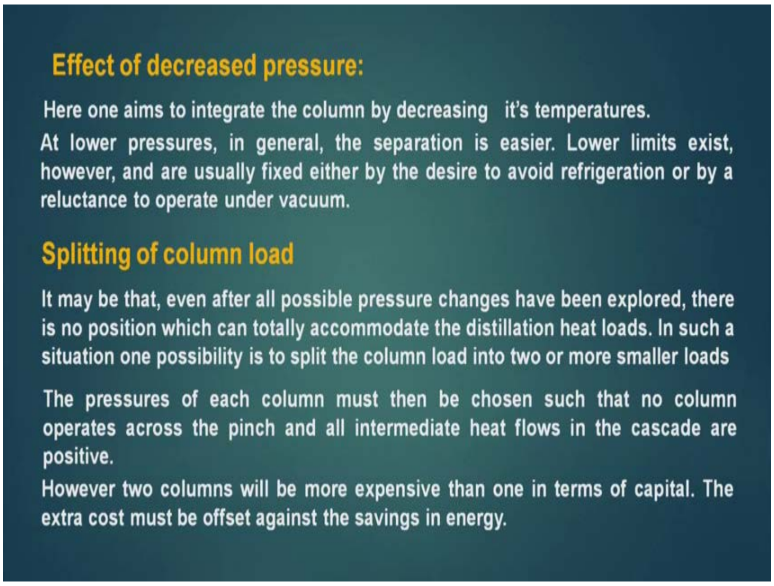
This limit will probably be define by unexpectedly high reboiler temperature either, because of thermal decomposition of the bottom product or because of the lack of the sufficiently hot heating medium required for it. That means there are other constraint also I cannot increase the distillation column’s pressure more than a limit, because the thickness of the distillation column will decide the pressure. The second problem, which will come that it will have a higher reboiler temperature, due to this thermal decomposition can take place in the reboiler, so if it goes for thermal decomposition. So, obviously I cannot operate the reboiler at those temperatures.

The third will be that I may not get a sufficiently hot heating medium to operate the reboiler at such a high temperature. So, these are some constraints, which one will face when it increases the pressure of the distillation column. Now, what will be the effect of decreasing pressure? Here, one aims to integrate the column by decreasing its temperature. If I decrease the temperature the reboiler temperature as well as condenser temperature will fall. So, it will move downward and I may integrate it below the pinch area at low pressure, in general the separation is easier.

Lower limit exist however and are usually fixed either by the desired to avoid refrigeration or by a reluctant to operate under vacuum. If I operate under vacuum the velocity is increase the column diameter will increase the pipe diameter will increase and may be that in the condenser have to use refrigeration. So, these are the different problems, which will face when we decrease the pressure.

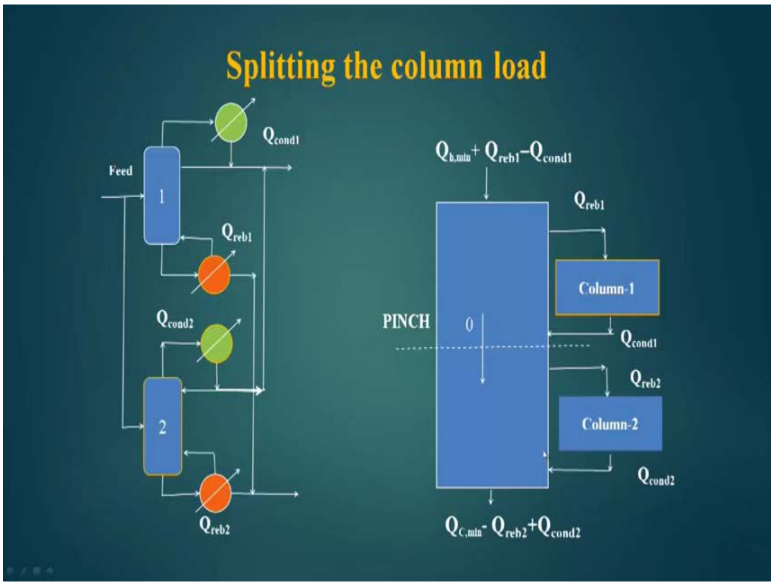
So, the pressure can be manipulated, but too some extent the splitting up column by increasing or the decreasing pressure. If my problem is not solved then, what is the way out the way out is that split the column in to two parts? The place one part above the pinch and the second part below the pinch, so let us see how this is being done it may be that even after all possible pressure changes have been explode. There is no first position, which can totally accommodate the distillation heat load.

(Refer Slide Time: 45:23)



In such a situation, one possibility is to spilt the column load in to one or more smaller loads. The pressure of each column must then be chosen such that no column operate across the pinch. All intermediate heat flows in the cascade are positive these two conditions we have to meet. However, two columns will more expensive than one in terms of the capital the extra cost must be offset against the saving in the energy. So, when I am going for a split column then I am increasing the complexity of the design. Once this complexity increases the capital cost will also increase. So, I have to see a trade off that whether by doing, so my savings are appreciable or not.

(Refer Slide Time: 46:37)



Let us see how physically the splitting will be done. A distillation column is now splitted in to two parts column number one and column number two the feed is also splitted one part is going to column number 1 the other part is going to column number 2. Now, this bottom product from the column one is coming out here the bottom product from column 1 is coming out here it is joined with column 2. I am getting the bottom product here similarly, the top product of the column 2 goes to condenser 2 and top product the column 1 goes to condenser 1. They are joined here and I am getting the top product here.

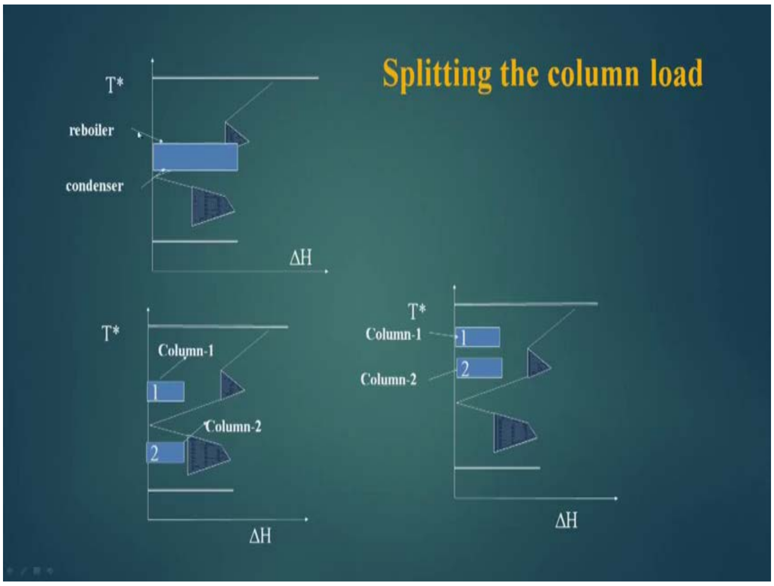
A part of this condense liquid is used as refluxing one a part of condenser two is used as a refluxing in the two. Now, as for as splitting this constraint there are two different distillation columns here and that product are then joined to find out the final product. So, these two columns can be operated at different pressures such that there evaporator, that is reboiler and condenser pressures or temperatures of one falls in the upper pinch area. The second falls in the below pinch area, so here this is the process, which requires Q h minimum and Q c minimum has hot and cold utilities.

When I integrate column one, this part here I take Q reboiler 1 from this and send the Q condenser 1. Similarly, I take Q reboiler 2 and Q condenser 2 to thus. Now, if the flows of heat inside this system or the columns are positive this integration can be done very easily.

Now, if I see here the Q hot requirement is Q h minimum plus Q reboiler minus Q condenser. If Q reboiler 1 is almost equal to Q condenser 1 then they cancel each other. This distillation column one is operating free of cost similarly, if I see the cold utility it comes out to be Q c minimum minus Q reboiler 2 plus Q condenser 2. So, if Q reboiler 2 is equal to Q condenser 2 they cancel out and my Q c minimum remains, which is the cold utility of the process.

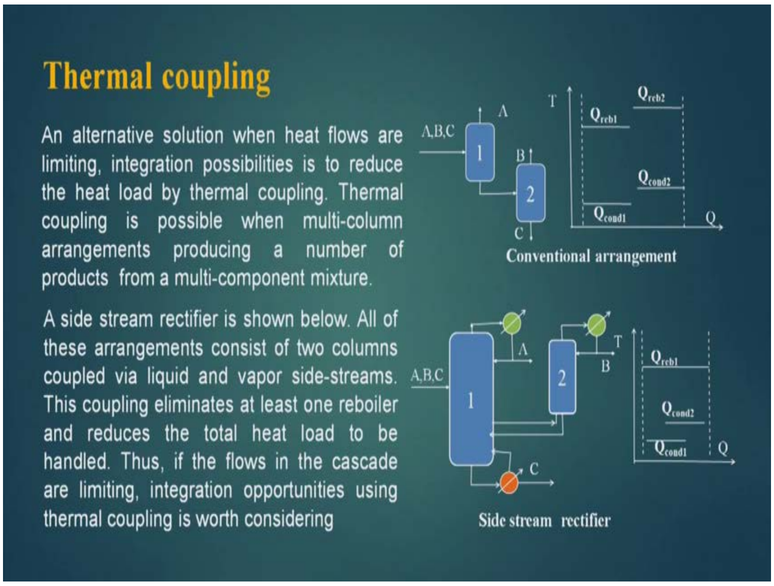
So, this column 2 is also running free of cost, so by splitting a single column in to two columns. Then adjusting these two columns somewhere in the upper reason of the pinch or below reason of the pinch, I can solve the problem of the case, when distillation column falls across the pinch.

(Refer Slide Time: 50:18)



The same is shown here this is the distillation column, this is not fitting in to the G C C I break it in to two columns. Then place one column above the pinch and the second column below the pinch and while doing, so these two columns run almost free of cost. This is the second where both the columns can be put above the pinch, because there is sufficient delta T available here. The both the columns can be put here one above other and utilize the upper pinch area. So, this is how by splitting the columns we can fit those columns in to the G C C and run the columns almost free of cost.

(Refer Slide Time: 51:21)



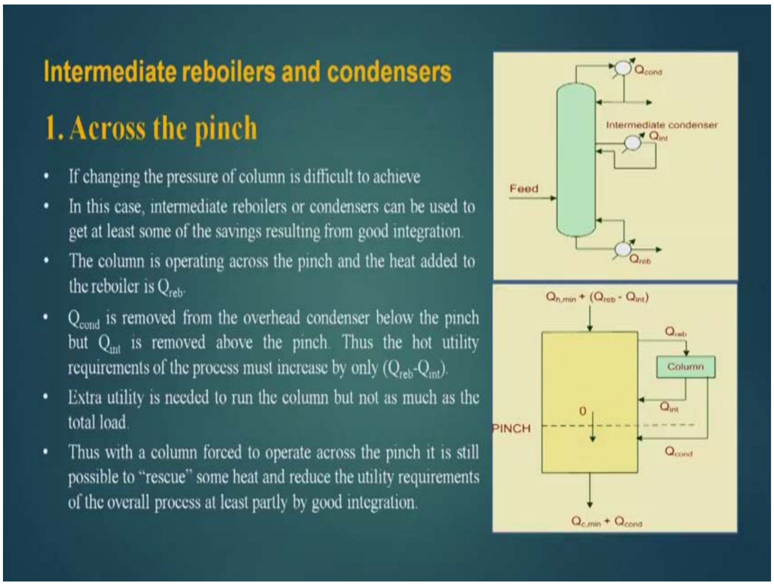
Now, there is another process through, which this can be done is called thermal coupling. A alternative solution when heat flows are limiting integration possibilities is to reduce the heat load by thermal coupling thermal coupling is possible, when multi-column arrangements producing a number of products from a multi-component mixture. Now, this shows a part of it that there are three component in to the fit A, B, C, in the first column I am separating A and B, C. So, B C goes at bottom product and a comes out as top product then this B, C is separated in terms of B and C in the second column.

Now if I see the temperature levels here, so my reboiler 1 has this temperature level reboiler of this and condenser one is this temperature level. For this two the reboiler 2 is this temperature level and condenser 2 is this temperature level. Now, a side stream rectifier is shown below here there is a column where A, B, C goes in to the feed a comes out as a top product then a part of the vapor from a is drawn here. Then goes to a rectification column and it is separates B and a part of it is return here and at the bottom I get C.

So, a side stream rectifier shown here all of these arrangements consist of two columns coupled via liquid and vapor side-streams this coupling eliminates at least one reboiler. So, here if I see this is the reboiler 1 and there are two condensers one and two the condenser number 2 and condenser number 1. So, it eliminates one reboiler and reduces the total heat load to be handled. Thus if the flow in the cascade are limiting integration opportunities using thermal coupling is worth considering. We have seen that it is not that only where the distillation column is placed above or below the pinch or across the pinch.

The heat flows has to be also checked if the heat flows becomes negative, then coupling is not possible. So, here in those cases the thermal come coupling is worth considering. Now, let us see the intermediate reboilers and condensers, now if across the pinch I am placing the reboilers and condensers.

(Refer Slide Time: 54:32)



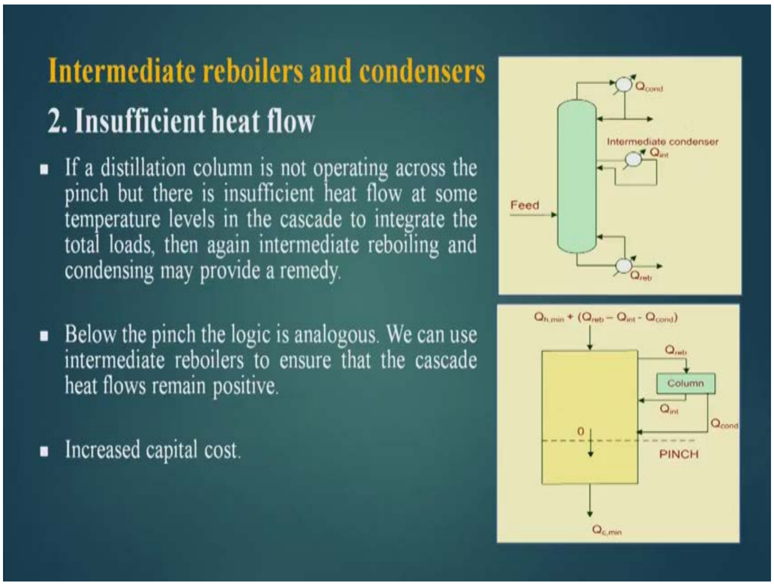
If changing the pressure of the column is difficult to achieve, then what is the way out in this case intermediate reboilers or condensers can be used to get at least some of the savings resulting from good integration? If I not able to find out the complete saving by integration as we have seen in the case of integrating the distillation column above the pinch or below the pinch it. I am not finding the complete integration or complete saving. I should go for partial saving and this partial savings can be done using intermediate reboilers and condensers.

The column is operating across the pinch and heat added to the reboiler is Q reboiler is Q reboiler. Q condenser is removed from the overhead condenser below the pinch, but Q intermediate condenser is removed above the pinch. So, it is taking the heat here from here the Q reboiler and in a intermediate condenser the heat is rejected to the above pinch area through this intermediate condenser.

So, it rejects the heat above the pinch area and rest of the heat is put in to below pinch area. So, if I see the hot utility demand here this is Q H minimum plus Q reboiler minus Q intermediate condenser. So, at least the hot utility demand has decreased by Q intermediate reboiler here. The cold utility demand has been the Q c minimum plus Q condenser otherwise the whole condenser there was Q intermediate condenser plus Q condenser.

So, if I say the hot utility has decreased and the cold utility demand has also increased in comparison to operating the process and distillation columns separately. So, partial saving is done exact utilities needed to run extra utilities needed to run the column, but not so much as the total load this we have seen. Thus, we take column course to operate across the pinch, it is still possible to rescue some heat and reduce the utility requirements of the overall process, at least partly by good integration.

(Refer Slide Time: 58:00)

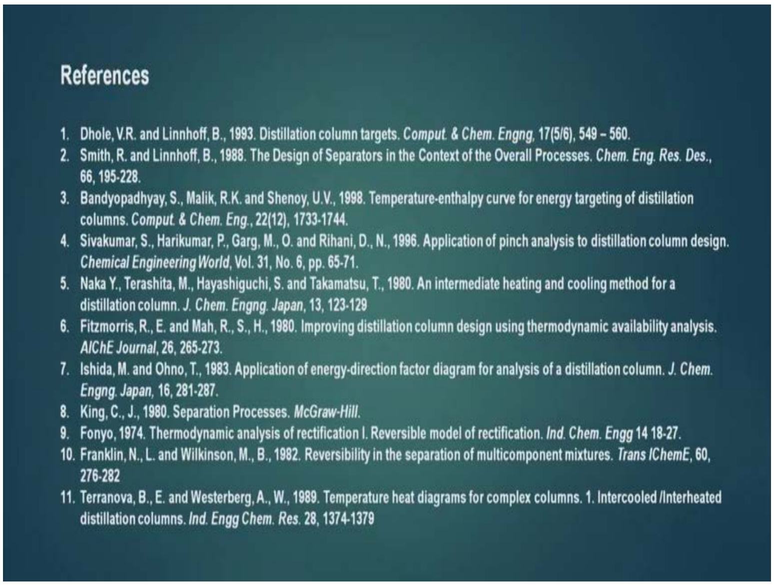


Now, if there is in sufficient heat flow that we have seen that insufficient heat flow like here I will show the picture. Here the condition is that Q 3 should be more than Q condenser. Here the Q 2 should be more than Q condenser here when I am integrating above the pinch.

So, if Q 2 becomes less than Q condenser, then this operation will sees in such cases what will be done if a distillation column is not operating across the pinch, but there is insufficient heat flow at some temperature levels in the cascade to integrate the total loads. Then again intermediate reboiling and condensing may provide a remedy.

Now, here if you see is a intermediate condenser here I am injecting heat in two parts. That means I am not injecting heat at one go like there we have seen that Q 2 minus Q condenser, where Q condenser is the summation of this Q intermediate and Q condenser. So, if I break this load in to two three parts, then again I can guaranty heat flows. So, this what it is shown here if distillation column is not operating across the pinch, but there is in sufficient heat flow at some temperature levels in the cascade to integrate the total load. Then again intermediate reboiling and condensing may prove a remedy.

(Refer Slide Time: 60:48)



Below the pinch the logic is analogous here I have shown you above the pinch. Similarly, below the pinch I can have the same logic we can use intermediate reboiler to ensure that the cascade heat flow remains positive. There we will use a intermediate reboilers in case of intermediate coolers as has been use in the upper part of the pinch, but this will increase the capital cost. This increase in capital cost against the savings, so it trade up between these two has to be found out. If the savings are more than we can go for intermediate reboilers and condensers, so these are the references.

Thank you.