Process Design Decision and Project Economics

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Module - 5
Energy (or Heat) Integration of the Process
Lecture - 24
Concepts and Basic Principles of Heat Integration – Part 2
(Problem Table Algorithm and Identification of Energy Targets)

Welcome. We are in the second lecture of the 5th module that is Heat Integration Design of the process. In the previous lectures, we saw some basic concepts and principles of heat recovery and heat integration of the process. We saw as how the how different process streams in the process can be represented on a h t diagram, and then we can identify the maximum heat recovery between these streams. And then we also saw how we can identify the minimum hot and cold utility requirement, the measure variable in the heat integration of the process was delta T min, the minimum temperature difference that could exist at any one end of the heat exchangers that are in the process.

So, we saw as how the value of delta T min can be decided. And how does this value change the entire feature of the process; increasing delta T min, reduces the areas of heat exchangers that reducing the capital cost. But at the same time, they increase the load on minimum hot and cold utility requirement thus increasing the operation cost. So, then there has to we economic trade off. We first saw this concept for single- streams, then we extended that to multiple streams. Then we also saw this special case of threshold problems.

And now in this lecture we continue the same theme for determining the Q H min and Q C min without plating graphs to the measure of plating graphs is easy. But in when you have very large number streams, then it becomes combustion. Because slopes of the graph changes has the c p value change with different temperature interval. And then it becomes difficult to determine Q H min and Q C min accurately.

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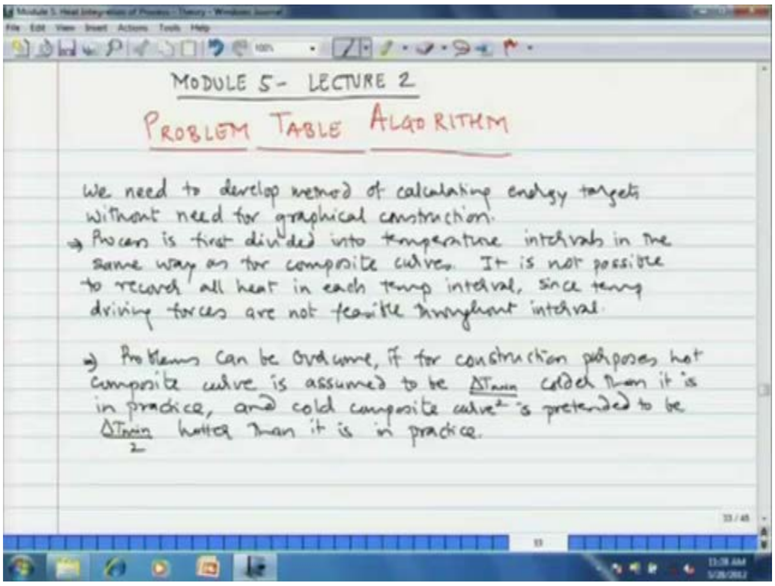

So, we shall now see an alternate algorithm for determination of minimum hot and cold utility of the process that is known as problem table algorithm. We need to develop method for calculate the energy targets without need for graphical construction. The process is first divided into the temperature intervals in the same way as for the complete curves, it is not possible to recover all heat in each temperature interval.

Since, the temperature driving forces are not feasible thought the interval the problem can be overcome if for construction purposes. The hot complete curve is assume to be delta T min by 2 colder means, the temperatures are reduced by quantity delta T min by 2. And, then it is in practice and the cold complete curve is pretended to be delta T min by 2 hotter. This, increase a temperature exact steam quantity has you have reduced the temperatures of for hot streams. Then it is in practice the shifted complete curves touch each other at pinch.

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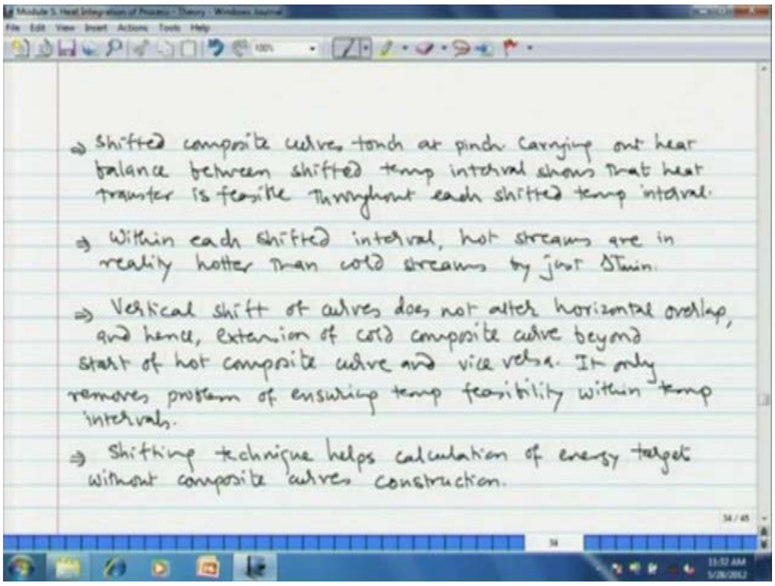

In the previous we saw how we can shift the complete curves horizontally and set the minimum temperature difference between the streams. But when you reduced temperatures of hot streams but delta T min by 2. And, increase the temperature of the cold streams by delta at the same quantity. Then they difference between the 2 streams reduces to 0. And, shifted complete curves touch each other at the pinch carrying out heat balance between the shifted temp interval shows that it transfer is feasible throughout each shifted temperature interval. Within each shifted temperature interval the hot streams are in reality hotter than the cold streams by just delta T min that is what it is means in reality.

The difference exits by delta T min. The vertical shift of the curves does not alter the horizontal overlap. And, hence; the extension of the cold complete curves beyond the start up hot complete curves and vice versa. So, the Q H min and Q C min does not change, it only removes the problem of ensuring the temperature feasibility within the given temperature interval. Shifting techniques also helps in calculation of the energy target without actually graphical clotting of the complete curves.

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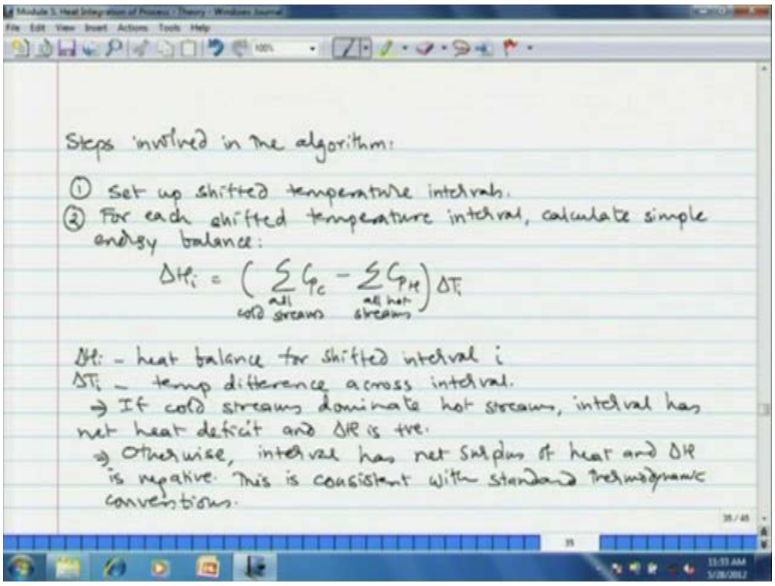

Now, let us see how? The steps involved in this algorithm first setup the shifted temperature interval. Then for each shifted temperature interval calculate the simple energy balance delta H i is equal to summation C Pc for all cold streams minus summation C P H for all hot streams into delta T i the temperature difference of that interval. So, delta H i is the heat balance for shifted interval i. Delta T i is a temperature difference across interval. If the cold steam dominates hot streams the interval has net heat deficit and delta H is positive ok. Otherwise, the interval has net surplus of heat and delta H is negative.

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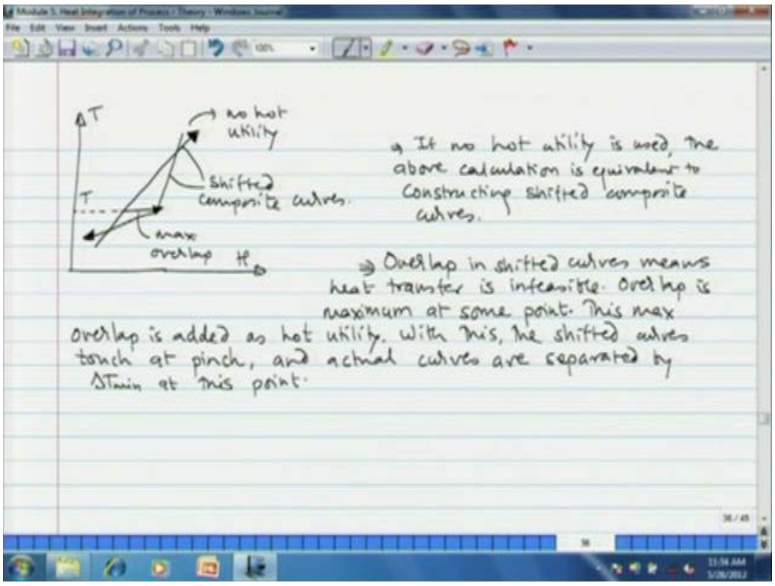

And, this is consistence with standard thermodynamic conventions, what you see is the shifted complete curve. If no hot utility is used the above calculation is equivalent to constructing shifted complete curve. The overlap in the shifted curves means, it transfer is infeasible, that is; what is been shown here. If the hot complete curves goes below the cold complete curve at any point. Then here that delta T becomes negative. And, there is no heat transfer feasible overlap is maximum at some point. This maximum overlap is added as hot utility.

So, this is the maximum overlap which is added as hot utility here, this. So, that when these curves shift horizontally; then they touch each other at this point. So, this becomes like the whole situation become like this, that the construct each other. So, this is parallel line this and this another parallel. So, this is the pinch when you add in the hot utility. The overlapping shift in shifted curves means, the heat transfer infeasible overlap is maximum at some point. This maximum overlap is added as hot utility with this shifted curves touch at the pinch. And, actual curves are separated by delta T min.

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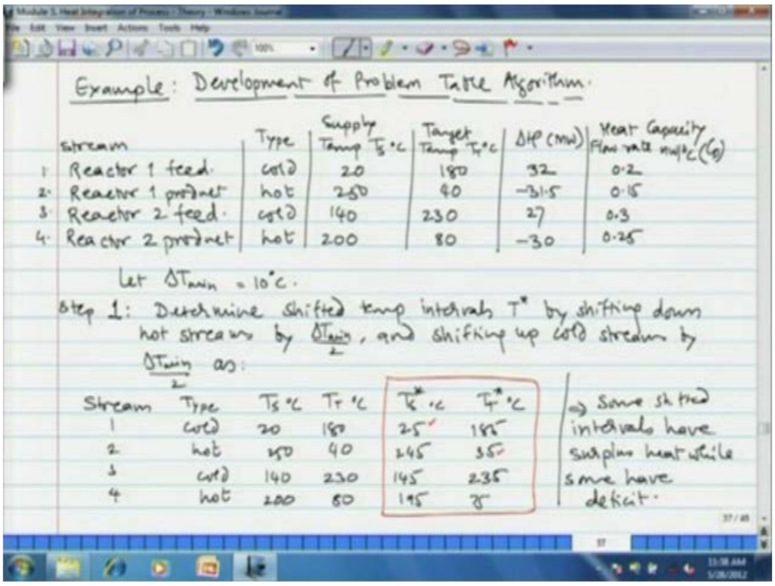

We shall see insect, in the same problem as in the previous lecture the reactor, 2 reactors different fields and products. And, then we shall determine the minimum hot utility and minimum cold utility using problem table algorithm. So, I have given here, the data again the steam data. Reactor 1 field is a cold steam with supply temperature of 20 degrees, target temperature of 180 degrees. Reactor 1 product is hot streams with supply temperature of 250; target temperature of 40 reactor steams is cold, with supply temperature 140, target temperature 230. And, reactor 2 product is again hot steam with supply of 200, targets of 80 degrees ok.

So, together we have 61.5 these 2 minus T 61.5 mega watt of XC and heat requirement is 59 mega watts of the 2cold streams. Now, we assume delta T min to be 10 degree centigrade as in the previous case. Though; so the step one according to the algorithm is to determine the shifted temperature interval that, we denote by T star by shifting down the hot steam temperature by delta T min. And, shifting of the cold steam temperatures by delta T min, to the steam 1 which was cold the supply temperature as 20. We now, increase it by delta T min by2 that is; 5 degrees. And, make it 25. Similarly, the target temperature is increased from 180 to 185. The steam 2 which was hot steam reactor 1 product the supply temperature as 250 which is reduce to 245 the target temperature as 40 which is reduced to 35.

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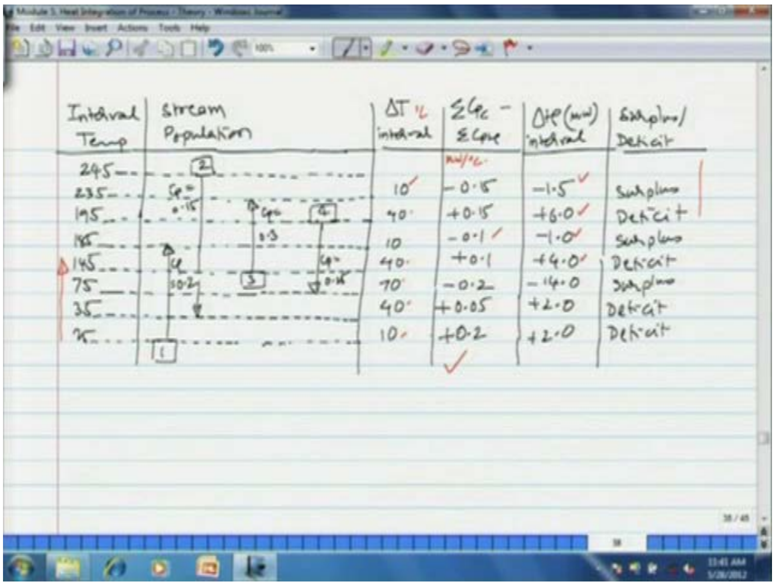

And, therefore, we have here the table of shifted temperature interval ok. Some shifted intervals have surplus heat, while some have heat to deficit we shall plat these streams in a steam population diagram what you have done here. Now, the diagram that appears on your screen we have listed here. All temperatures that are in the process in the ascending order. So, the least temperature was 20 degrees which is like cold streams which is shifted by 5 degrees. So, it becomes 25; then 35 that temperature was 40 you can see here. The least temperature, shifted temperature interval means, look at the box that is; marked in red. The least temperature is 25, thereafter 35, thereafter 75 like that.

And, then we have arranged all these temperatures in ascending order. And, then we have also marked the streams in these intervals like, steam 1 goes from 20 to 180. So, a shifted temperature interval 25 to 185. Then steam 2 goes from 250 to 40. So, is shifted temperature interval 245 to 35. And, I have also written here the cp values against these arrows ok. So, the arrows show the range of the streams in temperature interval. And, cp values that are written against the arrows are the heat capacity fluorides. And, then the 3rd column is delta T of that interval ok. The first interval is from 240 to 245 to 235. So, 10 degrees; then 235 to 195; then 40 degrees like that.

So, 10, 40, 70, 40, 10; so these are the temperature intervals in degree centigrade. And, the next step is to calculate the summation C P c by summation C P H here. The unit is mega watt 12 degree centigrade; the difference in heat capacities ok. So, in the first temperature interval where the only there is no code steam here. In the first temperature interval 245 to 235 though hot steam yields the only hot steam is steam 2 which cp equal to 0.15. So, that becomes minus 0.15.

In the next interval however; we have 1 cold and 1 hot steam. The cold steam is steam 3 which cp equal 0.3; the clod steam is steam 2 which cp equal to 0.15. So, 0.3 minus 0.15 is plus 0.15. And, then similarly, we go ahead the 3rd interval 185 to 195 we have 2 hot streams second and 4th and 1 cold steam. So, 0.15 plus 0.25, that is; 0.4 minus 0.3 sorry, 2 hot streams 0.3 minus 0.4. So, minus 0.1 and so and so forth. So, we have now listed the summation C P c minus summation C P H values. Now, the delta H in that interval the heat surplus or deficit that can be obtained by multiplication of the 3rd and 4th column ok. Delta T interval into summation C P c manner summation C P H.

So, in the first temperature interval we have minus 0.15 sorry, minus 0.1 into10 that is; minus 0.15 mega watt of surplus heat. Then in the next interval we have C P c is point oven 5 into40 that delta T temperature. So, 6 mega watts of heat deficit and then so on so forth. So, next interval we have minus 1 mega watt of surplus heat, next interval plus 4 mega watt of heat deficit and this thing.

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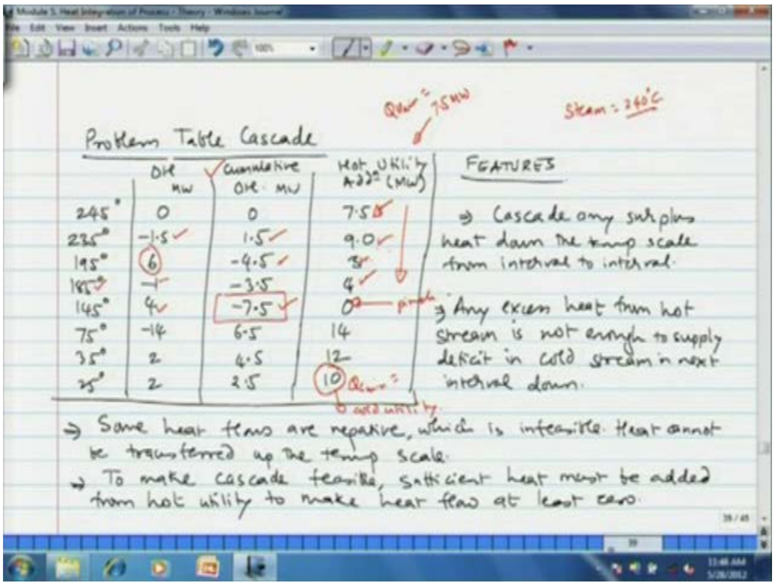

So, we have now completed the algorithm. So, the next step is to how do we now transfer heat? You can keep on transferring heat from higher temperature to lower temperature. So, that we shall do now, we shall now add the cumulative heat values ok. So, let us say that at 245 degrees we start so that is; 0. So, between 245 to 235 we have 0.15 mega watt of heat. Now, this heat could be utilized to satisfy the heat deficit of the next temperature interval that is; between 235 and 195. Here we have 6 mega watt of deficit out of which 0.5 mega watts would be taken care by the surplus heat available in the previous higher temperature interval.

So, that leaves us with a deficit of minus 4.5 ok 6 minus 0.15 minus 4.5. In the next temperature interval we have minus1 mega watt of excess heat. So, that can satisfy what you said that the heat deficit in the previous interval; so minus 3.5 and so on so forth. So, you can see here, the cumulative delta H vales. And, then let us see where is the maximum deficit in this whole thing, that is; in the temperature interval of 185 to145 that is; minus 0.7 mega watt. So, this particular deficit has to be this is the maximum. So, going back to this diagram where we had seen that where is the maximum overlap. Overlap is shifted curve is the heat transfer is infeasible, overlap maximum at some point and this maximum overlap is added as hot utility.

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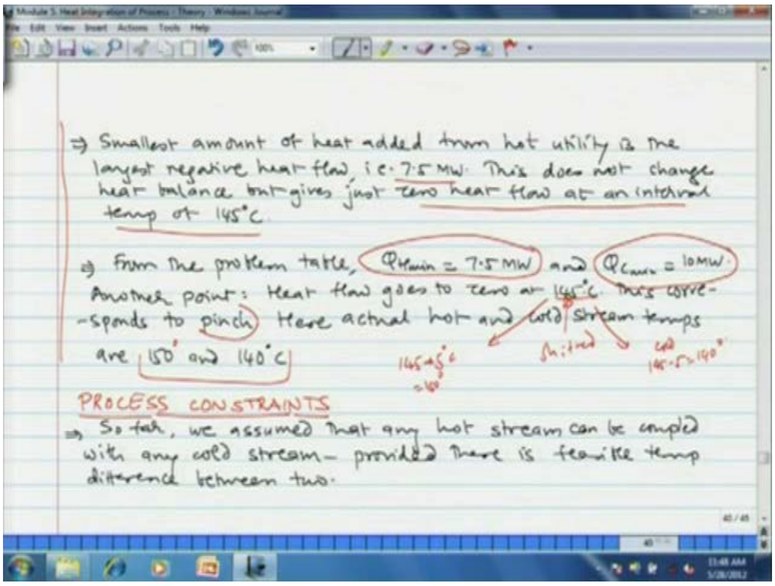

So, essentially what we have done is that, we have identified the maximum overlap that the maximum overlap between the shifted temperature components curves. And, that is 0.7 mega watt. Now, this much of heat needs to be added from hot utility and then it will satisfy the entire process. So, now we had 7.5 mega watt of hot utility from let us say some source is steam. So, that 7.5, that is; at we start is 7.5 mega watt of heat. So, add to 245 we have 7.5 mega watt of heat let us, we have seen which is available at 240 degrees But this is remember this is a shifted this actual temperature interval. So, we have to consider 245 degree. And, that is 7.5 mega watts to 245 degrees.

So, we start with 7.5 mega watt of hot utility that next interval to this 7.5. The 1.5 mega watt of the surplus heat between 245 and 235 degree centigrade add. So, together in the next at 235 degrees we have 9 mega watt of surplus heat. That can take care of the 6 mega watt deficit in the next temperature interval 195 to 235. So, we are left with 3 mega watt and so on so forth you just keep on going downward by subtracting these values 9. Now, 3 mega watt in the 195 temperature interval to that minus 1 mega watt of 185 degree this surplus minus 1 mega watt. So, that adds so 3 minus 1 become 4. Now, this 4 mega watt of heat available at 185 degrees can take care of 4 mega watt heat at 145. So, here the net heat flow becomes 0. So this is the pinch temperature, net heat flow becomes 0 here.

And, there after we have 14 mega watts of surplus heat which can take care of the 4 mega watt of heat available heat requirement. In the next 2 temperature interval 2 plus 2 total 4 mega watt of heat. And, finally, we are left with 10 mega watts of surplus heat which needs to be rejected to the cold utility. So, thus; the problem table algorithm has given is the answer is that we are seeking for. We have to add 7.5 mega watt of Q H minimum. And, we are finally, left with 10 mega watt to be rejected to cold utility, that is; Q C minimum plus ok.

The smallest amount of heat added from utility is the largest negative heat flow, that is; 7.5 mega watt this does not change the heat balance. But gives just the 0 heat flow at the interval of and interval temperature of 145 degrees. And, then finally, we arrive at the answer that we are looking for. That, from the problem table algorithm we have found the minimum hot utility as 7.5 mega watt and minimum cold utility as 10 mega watt. Now, another which I already mentioned, but I repeat because it is important the heat flow goes to 0 at 145 centigrade this corresponds to the pinch. But remember 145 degree is a shifted temperature interval.

So, for this particular temperature the hot streams are 145 plus 5 degrees hot, that is; 150 centigrade. And, cold streams are 145 minus 5, that is; 140 degree centigrade. So, the actual hot and cold steam temperatures are 150 and 140 degree centigrade. So, that is we have answers to all the questions that we are looking for without clotting a graph. We have determine the minimum hot and cold utility requirement. And, we have also determine the pinch temperatures that temperatures of hot and cold complete streams at which the pinch occurs ok.

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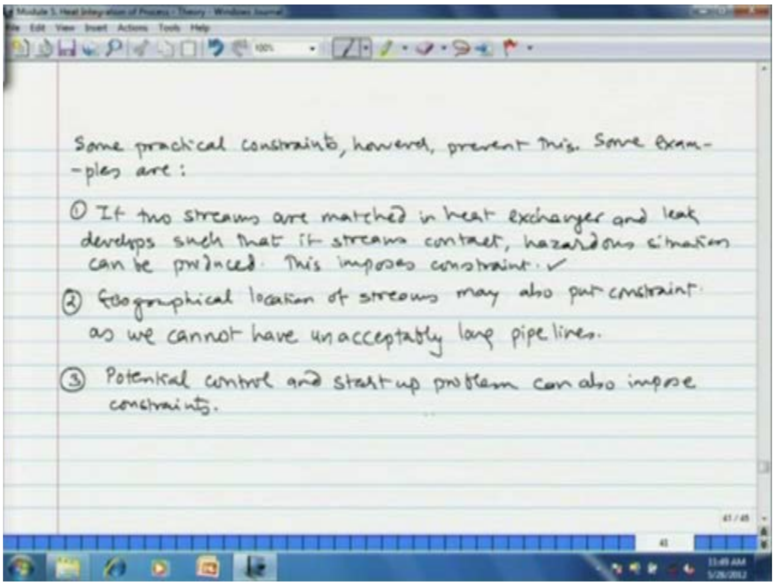

Now, there are certain process constraints ok. So far, we have assumed that any hot steam can mixed with any cold steam are can be coupled not mixed. It be coupled can be coupled with any cold steam provided there is no feasible temperature difference between the 2. But some practical constraints are available or possible; some practical constraints can prevent this particular coupling.

Some examples, of these are if the 2 streams are matched in heat exchanger and leak develops practical constraints such that if streams contact. Then hazardous situation can be produced this imposes the constraint. We usually 1 steam usually the fesses of the 2 streams have to be same if they are vapor phase, gas phase. There is any phase change then sudden pressure drop can occur. So, there are certain constraints which can prevent coupling of the streams. So, geographical location of the streams may also put constraints as we cannot have an acceptably long pipe lines. And, potential control and startup of the problem can also impose constraint.

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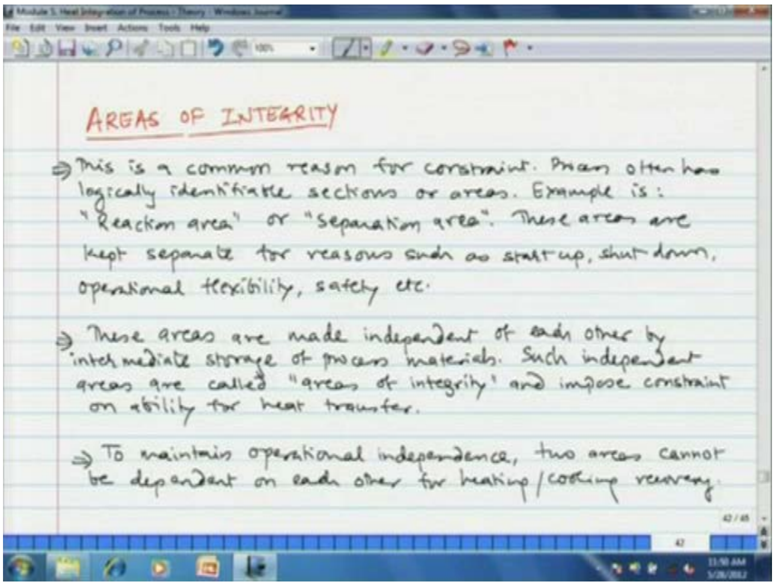

Let us see one such constraint like that areas of integrity, this is a common reason for constraint. The process often has logically identical sections or areas the entire plant. For example, 1 area of the plant is the reaction area; then another area is suppression area. And, these areas are kept separate for reason such as; startup, shutdown, operational flexibility or safety etc ok. These areas are made independent of each other by intermediate storage of the process materials. Such, independent areas are called areas of integrity. And, impose constraint on ability for heat transfer to maintain the operational independence the 2 areas cannot be dependent on each other for hitting and cooling recovery.

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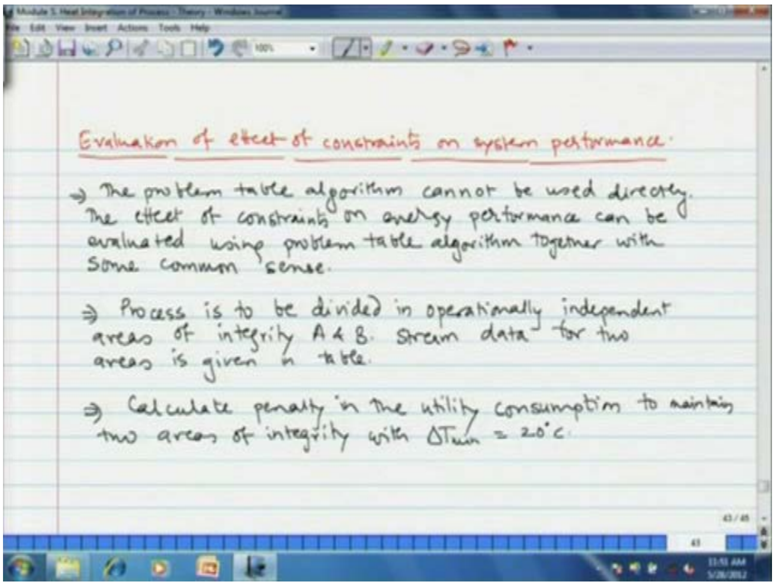

So, let us evaluate the effect of constraint on insisting performance. Suppose, there is a constraint then how it affects the insisting performance? How it affects the minimum hot utility requirement, minimum cold utility requirement? So, we see now an example, the problem table algorithm cannot use directly in such cases. The effect of constraints on energy performance can be evaluated using problem table algorithm, together with some common sense. The process is to be divided in operational independent areas of integrity A and B the steam data for areas is to be listed. Now, we shall see an example. And, then we have to calculate the penalty utility consumption to maintain the 2 areas of integrity with certain delta T min.

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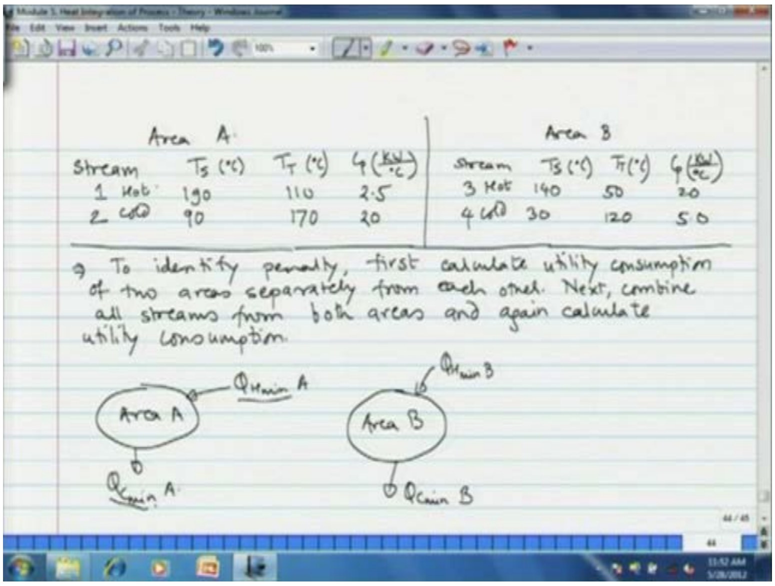

Now, let us assume the value of 20 degree. I have given here an example, suppose; we have 2 areas in the plant 1 area A and another area B. And, there are 2 streams in each of these areas steam 1 area A has steam 1, supply temperature 190, target temperature 100 and 10 that is the hot steam. And, then the 2 steam which is cold steam the supply temperature 90, target temperatures 170. Similarly, area B has 1 hot steam supply temperature 140, target temperature 50. And, another cold steam supply temperature 30 target temperature 120.

The C P values are also listed. The heat capacity fluorite values in kilo watt per degree centigrade by multiplying the delta T which C P you will get the heat that is available with hot steam. And, that is heat required for cold steam. To, identified penalty first calculate the utility consumption of 2 areas separately from each other. And, next combines all streams from both areas and again calculate the utility consumption. For each area we have Q H min Q C min. So, area A Q H min, A Q C min A, for area B Q H min, B Q C min B, and then the combine area.

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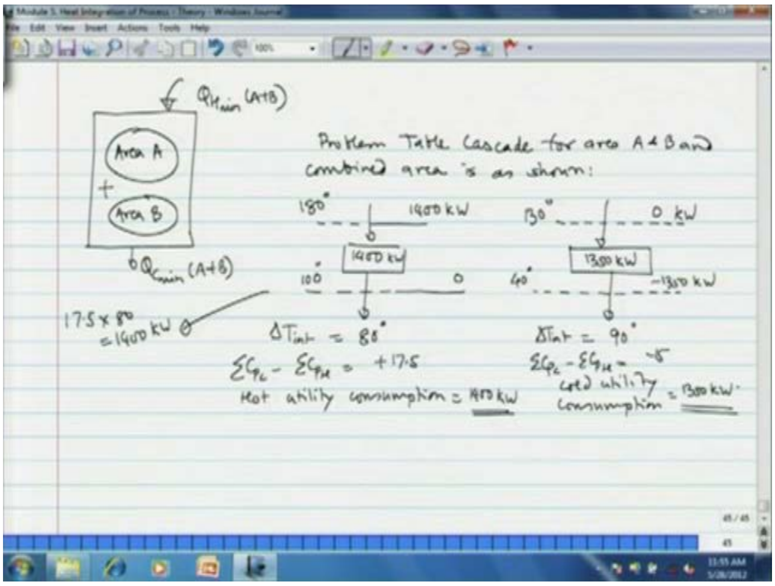

Now, let us try to do this; with the area A with only 2 streams; here, we have delta T min is this 20 degrees. So, we have 2 shift temperatures by 10 degrees. So, here that the hot steam is the shifted temperature is 11800; so 11800. And, then the delta C P value is 2 .5. So, we have 2.5 into 80; so delta T interval 80. And, then we have another steam of another cold steam that is available at 90 degrees and it has to be heated to 170 degrees. So, the shifted temperatures are 100 and 180 ok. So, that requires 80 into 20, that is; 1600 kilo watt of energy the 1 that will be supplied through the hot steam is 200. 2.5. So, here; I will write the balances for you summation C P c minus summation C P H 17.5 into 80. So, that is 1400 kilo watts of heat that is required.

Similarly, in this case, in the second case if you see summation C P c summation C PH summation. That, summation is minus 50 summation C P c minus summation C P H into 90. So, that gives 1350 kilo watt of heat. So, the cold utility consumption in this case is 1350 kilo watt. And, hot utility consumption in case of area A is 1400 kilo watt. Now, if these areas are kept independent of each other.

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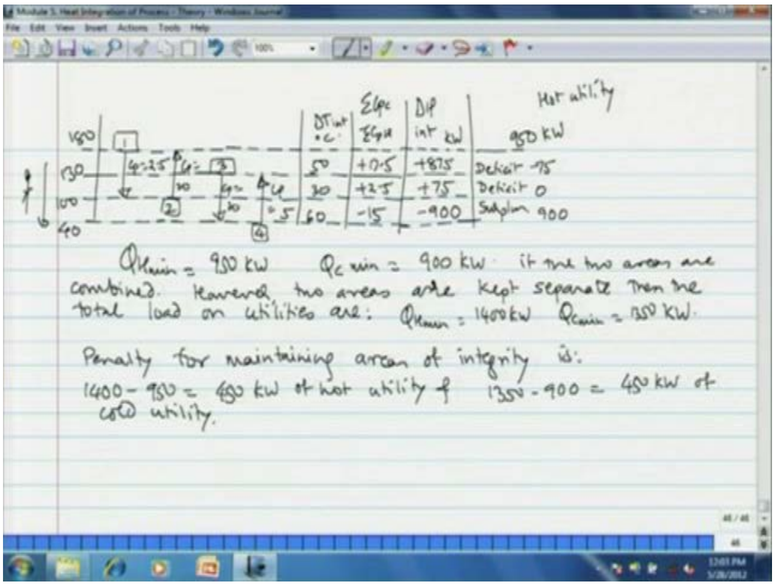

Now, if you combine the 2 areas then we have the same problem table algorithm. As, before; we have to list all the temperatures in descending order, all the shifted temperature intervals. And, then we have to mark this streams between these temperatures steam 1 goes from 180 to 100 C P value is 2.58. Then steam 2 goes from 100 to 180 with C P value of 20. Steam 3 goes from 130 to 40 with C P value of 20. And, steam 4 goes from 40 to 130 with C P value of 5. Then the delta T interval is in the first case 50 degrees 180 to 130 then 30 and then 60 degrees.

Then, summation C P c minus C P H, this is; plus 17.5 in this case. Because there is 1 hot in between 180 to 130. We have 1 hot steam with C P 20; 1 cold steam is C P 20; 1 hot steam is C P 2.5. So, it becomes plus 17.5 in a next interval we have all 4 streams. So, 2 hot streams with total C P of 22.5. And, 2 cold streams with total C P of 25. So, 25 minus 22.5 becomes plus 2.5. And, then in the next interval between 100 and 40 we have 1cold steam with 5 C P. And, 1 hot steam with C P equal to 20. So, 5 minus 20 is minus 50 with delta H interval. This you have to multiply C P summation C P c minus summation P H with delta T. So, plus 875; so this is not mega watt. But kilo watt this plus 875 plus 75 minus 900. So, we have 2 intervals of deficit followed by last interval of surplus.

Now, we cannot transfer heat at 40 degrees whose satisfy required at 100 degrees, reverse is not possible, this is; possible but this is not possible. Therefore, we have to now; here add 875 to satisfy the deficits in the first 2 temperature intervals. We have to add total 875 plus 75 that 950 kilo watts of hot utility heat from hot utility. And, then it will make the heat balance 0 at100 degrees centigrade. And, then we have left with 900 kilo watts of heat in the next interval last interval to be rejected to cold utility. So, the Q H min is 950 kilo watt Q C min is 900 kilo watts. If the 2 areas are combined ok.

However, if the areas are kept separate. Because of the constrains that, I mention before if the areas are physically quite far apart; then we have to transport a lot of material through pipes which is not only past intensive. Because we have to use form circumferences. But it can also cause significant temperature drop during transportation. And, the temperature that is actually achieved at the place of exchanger may not be same as at the source which is you are for calculation. So, because of these constraints we cannot couple all streams with any steam.

So, we have to keep the areas separate. So, however; 2 areas are kept separate then the total node on utilities hot utility 1400 kilo watt cold utility 1350 kilo watt Q H min 1400 kilo watt Q C min 1350. So, the penalty for maintaining areas of integrity is 1400 minus 950 kilo watt of hot utility. So, 450 kilo watt of hot utility and 1350 minus 900, that is; another 450 kilo watt of cold utility. The penalty as a result of constraint enables the judgment as whether; it is acceptable or too expensive.

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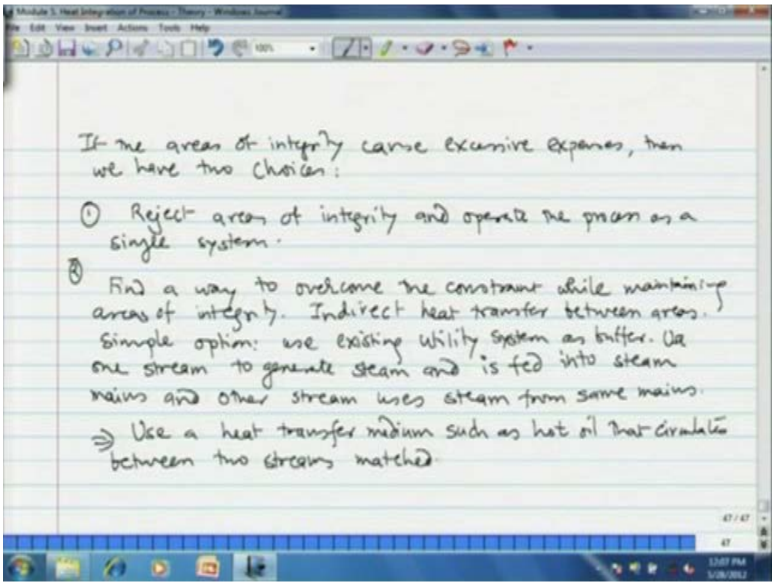

If it is too expensive; then we have 2 choices that want to know the areas of integrity cause excessive expense. Then we have 2 choices first choice is that reject areas of integrity and operate the process as a single system, that is; 1 option. And, second option is to find a way to overcome the constraint while maintaining the areas of integrity. And, how this could be achieved? A simple option is to use an existing utility system adds buffer using 1 steam to generate steam to be fed into a steam means. And, another steam to use that steam from the same means.

So, that point you know the option of indirectly transfer between areas. And, the simple option in this case, is at use existing utility system as buffer use 1 steam to generate steam. And, is fed into steam means or steam source, central source of steam. And, other option is that use heat transfer medium such as, oil that circulates between streams matched. Use a heat transfer medium such as, hot oil that circulates between the 2 streams matched; so these are the options.

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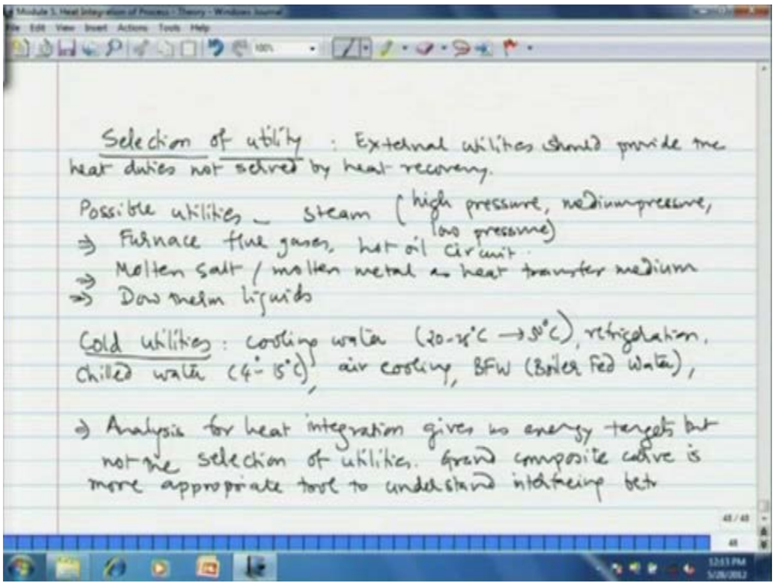

And, then we are left with 1 final point to close this lecture, that is; the selection of utility. Now, after maximizing the heat recovery in the network the heating and cooling duties must be served by the heating and cooling duties that are not serving must be provided by external utilities. External utilities should provide the heat duties not served by heat recovery. Now, what are the possible utilities are most common hot utility steam, which is a different level high presser steam, medium presser steam, low presser steam, depending on the temperature levels? Then high temperature duties require furnace glucoses or hot oil circuit furnace flue gases.

Then, hot oil circuit in some cases molten salt or even molten metal is used as a heat transfer medium for very high temperature processes Dow Therm liquid are also quite common. As far as possible the idea is to avoid face change in the heat exchanger. So, that the pressure interrupt across the heat exchanger immunes constant. So, in such cases the Dow Therm liquids are molten salts are quite frequently used. The cold utilities that are used in the process or the cooling water the most common the typical range of temperature range is. Let us say 20 to 25 degrees to above 50 degrees depending on location immunity etc. You have already dealt with this cooling tower in the mass transfer course. So, that is already known to you cooling water.

Then, if the vapors contents at temperature lesser than 30 degrees the room temperature then you have to go for refrigeration. Shield water is also is an option, shield water which is supplied at 4 degrees. And, comes out at above 10 to 15 degrees that is an option. Then air cooling, then in some cases B F W that boiler fed water is used as heat transfer medium this water absorbs the heat by face change. And, steam is generated this is for highly exothermic reactions like for example, polymerization reactions are Fischer trop synthesis; where, the boiler fed water is used for steam generation.

Now, the composite curves can be used to set the energy targets. But not for the selection of utilities. So, the analysis that we have seen in this lecture; as well as, in previous lecture analysis for heat integration gives us energy targets but not the selection of utility. So, the grand composite curve is a means, for this movement composite curve is more appropriate tool for understanding interfacing between process and utility system.

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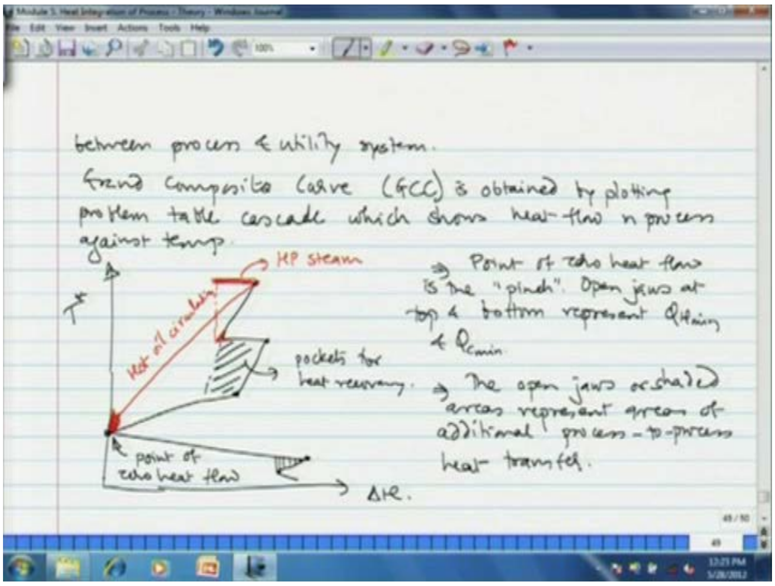

Now, the grand composite curve which is often abbreviated as GCC can be obtained by plating the problem table cascade. And, this shows the heat flue through the process against temperature. Whatever, data that we had if we plate T star versus delta H that we have obtained you may get curves something like this. The pockets of heat recovery this means the H value delta is changes and at pinch delta H goes 0. And, then again this stage. So, the open jaws in this curve are the packets of heat differ the point of 0 heat flow is a pinch point.

And, the open jaws at the top and bottom very present Q H min and Q C min at the heat sink above pinch and heat source below pinch can be identified with this. That point value T open jaws at top and bottom represent Q H min and Q C min. The open jaws or the shaded areas represent the areas of additional processed process heat transfer a. The profile of current composite curve represents the residual heating and cooling demand after recovery. The heat within shifted temperature interval in the problem table algorithm. So, in the pockets that are shown the local surplus of heat in the process is used at temperature differences in excess of delta T min to satisfy the local deficit.

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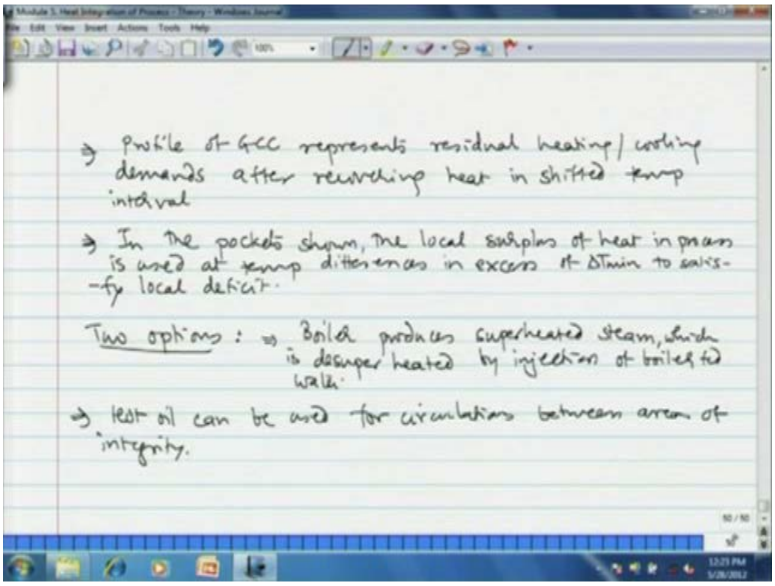

So, these points are I am noting for you profile of GCC represents residual heating. And, cooling demands after recovering heat within shifted temperature interval in the problem table algorithm. And, the local surplus of heat in the pockets shown. The local surplus of heat in process is used at temperature differences in excess of delta T min satisfy local deficit. There are 2 options we like grand composite curve how it can be used? Now, 2 levels of saturated steam can be produced has add hot utility. And, then the low pressure steam being desperate by injection of boiler fed water after the pressure reduction to maintain such saturated conditions.

So, let is how what we do is that, the boiler produces separated steam which is desperate by injection of boiler fed water. And, in some cases if a hot oil can be used for circulation between the areas of integrity. Now, let us see we can represent these 2 options on a GCC ok. So, the first option, that is; steam generation the high pressure steam could be made saturated in this temperature zone. That grand composite curve with 2 levels of saturated steam as hot utility. The low pressure steam, high pressure steam being these separated by injection of boiler fed water after pressure reduction to maintain saturated condition.

So, this is a region of H P steam generation the open jaws that have heat pockets for heat recovery. So, this is probable area for generation of high pressure steam otherwise you can also have a hot oil circulation that can directly go in this is which can provide heat form the source to the sink, this is; hot oil circulation. So, the 2 options of additional heat recovery are selection of utility can be identified with the grand composite curve that completes several discussions on principles of heat integration.