Process Design Decisions and Project Economics

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Module - 5
Energy (or Heat) Integration of the Process
Lecture - 25
Identification of Area and Cost Targets

Welcome we are now, in the 3rd lecture of the module 5 that is Heat Integration of Process. In the previous 2 lectures we learnt some basic principles of heat integration of the process, how the hot streams in the process can be coupled in the co stream, so as to minimize the load on hot and cold utilities. And then we saw some important parameters of this coupling, one of the important parameter was the delta t minimum the minimum is the difference between, the two streams at any end of the heat exchanger which is coupled in the stream.

And then we saw how the capital cost as well as the operating cost varies the in the important parameter delta t minimum. We also saw the construction of composite curves the relative positioning of the curve's and then we saw how the grand composite curve can help us identify the utility selection. Now, in this lecture we take ahead this theme and then try to learn the wage of estimation of the capital and the total cost targets.

Now, in addition to prediction of the energy cost of the heat exchanger network it would be useful, if we can also consider, if we can also calculate or at least estimate to some extent in some accuracy the capital cost of the network. The principle components that contribute to the capital cost are ((Refer Time: 02:09)) first the number of units or the number of heat exchangers that make match between, hot and cool stream, then the area of these heat exchangers, then the number of shells in this exchangers.

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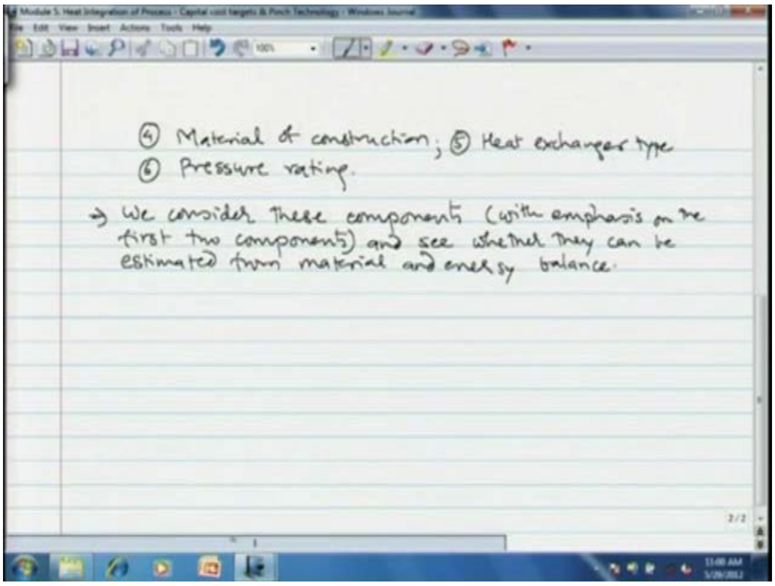

Then the material of construction, then the heat exchanger type whether we have the floating head or the fixed tube heat exchanger, plate heat exchanger so on and so forth; and then the pressure rating of this exchangers. Now, some of these aspects you are going to learn in other course of NPTEL, for example there is the special course of NPTEL on design of heat transfer equipment that is also the course on heat transfer. So, in these courses you will learn some of these aspects, for example like material of construction, heat exchange type, pressure rating type etcetera.

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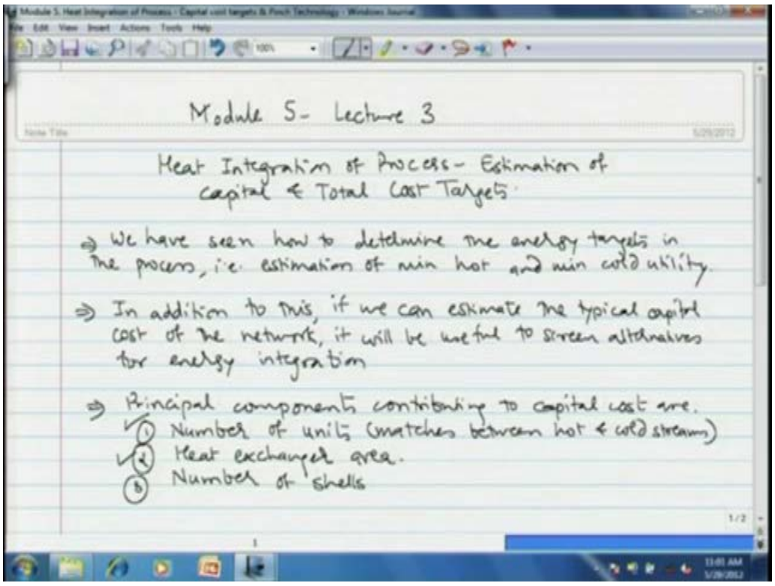

So, what we do is that we mainly make emphasis on the first two aspects that is the number of units, the number of exchangers that we are going to use for particular heat transport process and the area of these heat exchangers.

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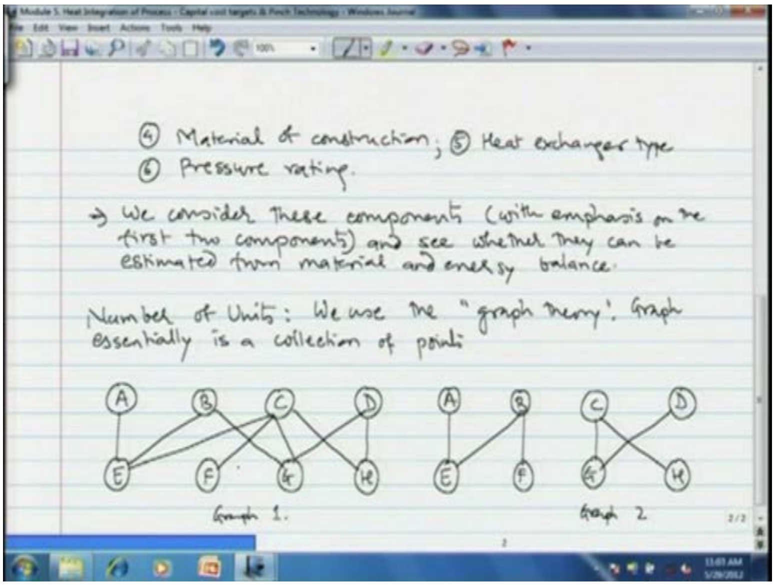

Now, to estimate the number of units we use of the graph theory. Now, how graph theory helps us in estimation of the number of units let us see. Now, graph essentially is the collection of points, now I am showing you 2 types of graphs each of which has 8 points A, B, C, D, E, F, G, H and these points are connected by lines. So, the lines which are been shown some of them is crossed, but basically, they are not crossing, but we have to read the diagram in 3 d.

So, this is say graph 1 and graph 2 same points are there same 8 points, but these are connected in different way as I am showing the points corresponds to process units stream and the line to the heat exchange matches between, the heat source and the heat streams.

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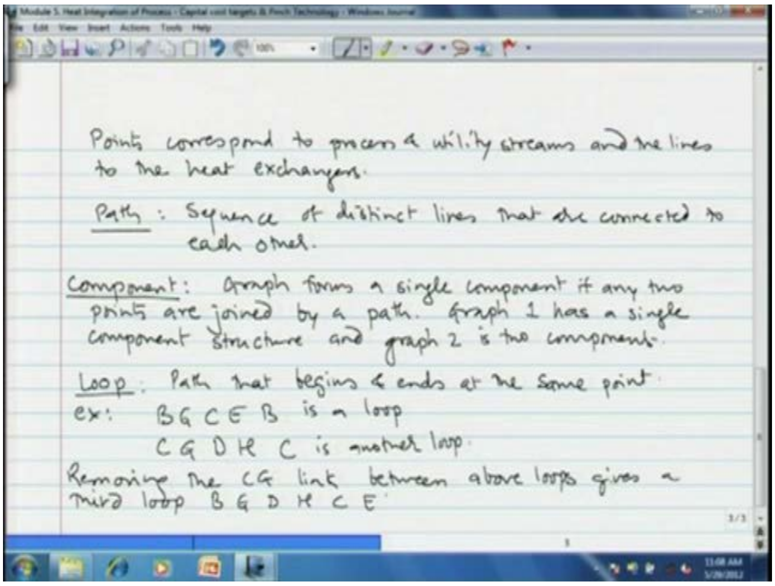

Now, which I define certain terms this are the points corresponds to process stream and the utility streams and the lines to the heat exchange matches. Now, let us define the first term that is path, path is the sequence of distinct lines that are connected to each other. For example, in this diagram the A, E, C, G and D this is the path the graphs forms the single component, if any two points are joined by the path. So, that graph forms the single component if any two points are joined by the path.

Now, if you try to identify the components in the 2 graphs that you have seen. We can say that in graph 1, that is single component because each of the 2 points is join by any point in this graph each joined to another point and there is the single component, so any 2 points are joined by the path. However, in graph 2 there is the distinct separation for example, there is no connection between B C and F G or B G and F C.

And therefore, the graph 2 has the two components, graph 1 has the single component structure, and graph 2 has the two component structure. Then we define a term called loop, loop is the path that begins and ends at the same point. For example, in graph 1 B, G, C, E and B is a loop. Similarly, C, G, D, H, C is another loop so that point loop at some pulse of loop B, G, C, E, B is a loop, then C, G, D, H, C is another loop.

And then if you compare this loops then you will find that there is the link C, G link, so if you remove that link then B, G, D, H, E, C, B is a complete loop. Removing the C, G link between loops there is the third loops that is B, G, D, H, C, E, B. From the graph theory the main result that is needed in the present context, where we are trying to find out the number of exchangers required can be formed.

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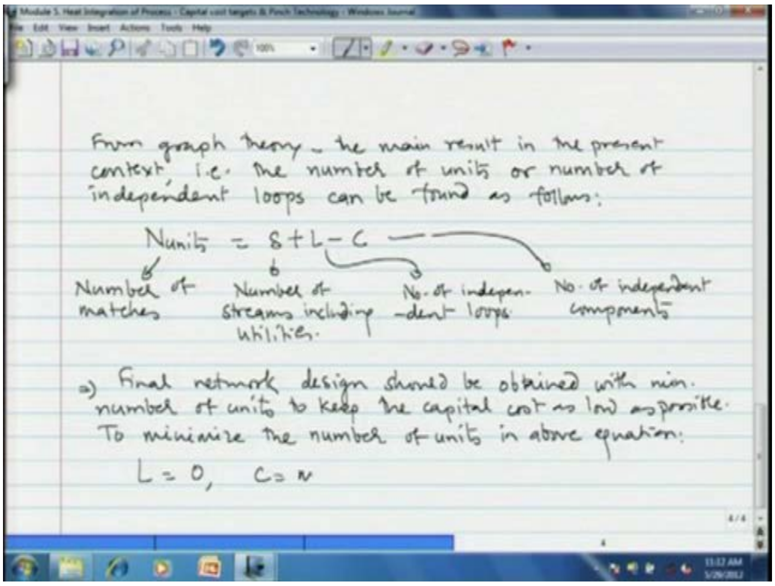

So, from the graph theory the main result in the present context that is the number of units can be found as follows or number of independent loops and number of units is equal to s plus l minus c where n units are the number of matches between, streams s is the number of streams including utilities then l is the number of independent loops and the c are the number of independent components.

Now, the final network design should be achieved with minimum number of units that is quite obvious to keep the capital cost loop on that point we note final network design should be obtained with minimum number of loops to keep the capital cost low and to minimize the number of loops in the above equation l has to be 0 and c has to be maximum. Because, the number of streams that are s is the quantity which is given to us, it is not in the hands of the designer it will be decided to actual process.

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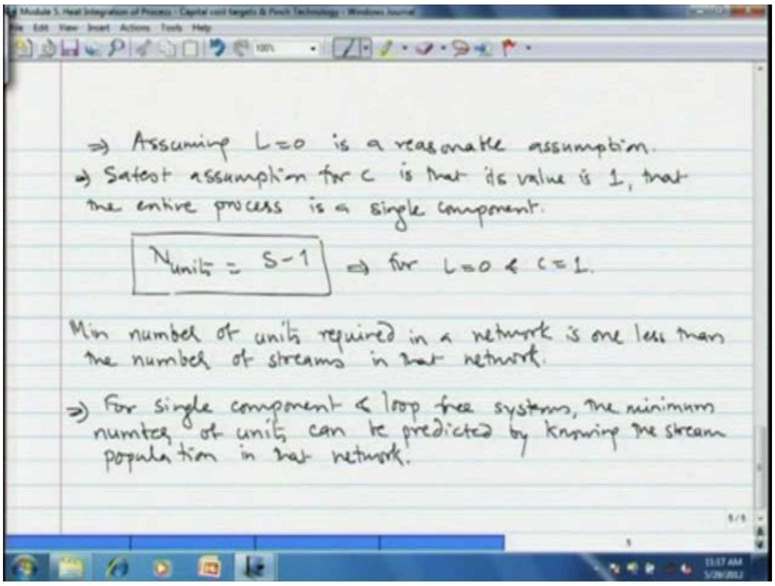

Assuming L to be 0 is the reasonable assumption because; in a process all of the points will be connected by one or the other way. So, the number of independent loops will be 0 as we saw in case of graph two as in case of loop components and the number of loops were. So, in process having many, many streams that coupled to each other assuming L equal to 0 is a reasonable assumption.

However, if the network has two components than the heat duties for streams A and B must exactly balance the duties for streams E and F and the same holds per streams C D and G and H ((Refer Time: 15:27)).

So, this are un natural if you see the second graph now, A and B are hot spins A and B are cools stills, but there are 2 components. So, B and C and F and G are not connected. So, there is the separate component of A B E F and separate component of C D G H in such cases A plus B excess should be equal to E plus F it deficit. And same things hold for C D and G H but this is usually not possible.

So, first assumption for C the number of component is just 1 component exist in the process safest assumption for C is that it is value is 1 that the entire process is a single component number of units become equal to S minus 1 for l equal to 0 and C equal to 1. So, the minimum number of units required in the heat exchanger network is 1 less than the number of streams in the particular network. Therefore, for the single component and loop free network the minimum numbers of unit can be predicted by, simply knowing the stream populations.

That important factor we have answered for single component and loop free systems, the minimum numbers of units can be predicted by knowing the stream populations in that network. Now, as we saw in the previous lectures the process is divided at pinch and therefore, we have two reasons like one above peach and one below peach and then we also saw previous lectures as how heat transfer across pinch causes excessive load on the utilities.

So, it is an inappropriate heat transfer you cannot transfer heat or you are not suppose to transfer heat that cross the pinch and therefore, if the network does not have pinch than that formula directly applies and unit equal to S minus 1.

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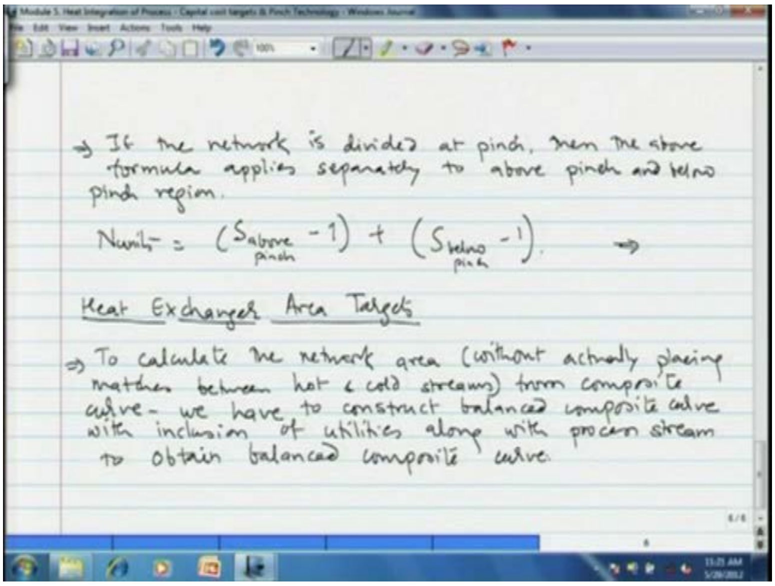

if the network is divided at pinch, than we have to apply that formula separately for above pinch and below pinch region if network is divided at pinch than above formula applies separately to above pinch and below pinch region. So, number of units is equal to S number of streams above pinch minus 1 plus S below pinch minus 1. So, we have answered the first questions that we started.

That we have to determine the numbers of unit matches between, the hot and cold stream. Because, they contribute they are one of the principle components that contribute to the capital cost.

Now, the next task before us is to calculate the heat exchanger area target. Now, we have an made the actually matches between, the spin we had we have only identify the pinch and we have the composite curves. Now, in such cases how can we identify or how can we determine the exact heat exchanger area target. The composite curves themselves contain the necessary information to predict the network heat transfer area.

To calculate the network area from composite curbs the utilities streams must be included with process streams in the composite curb to obtain the completely balanced composite curb. Basically, the same procedure as we have seen before, but with inclusion of the utilities streams. So, that point the note, that we have to do we have to calculate the heat exchanger network area calculate the network area without actually placing matches between the streams that is very important without actually placing matches between, hot and cold streams, but with using composite curbs.

So, to calculate heat than network area from composite curves. We have to construct balanced composite curves with inclusion of utilities along with the process stream to obtain the balanced composite curves.

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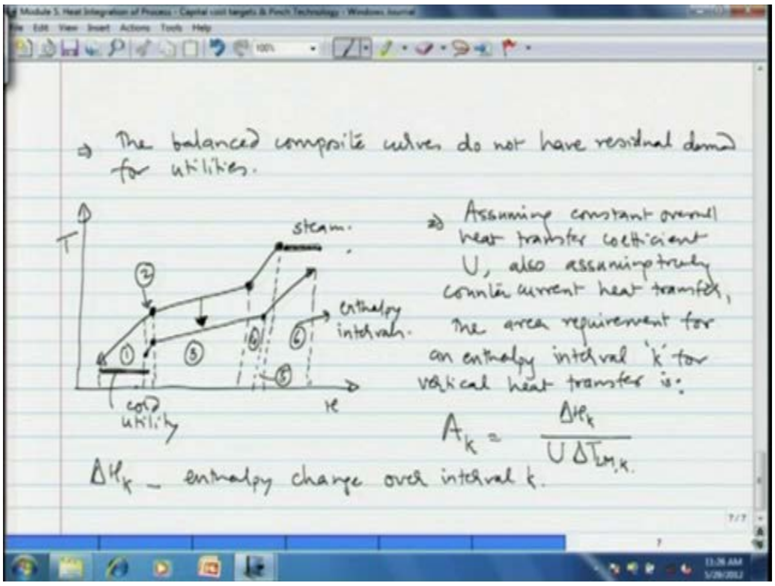

Now, the balance composite curve do not have the residual demands for utilities. Now, I am showing you here a typical example, let us say we have 2 balance 2 composite curve as follows which are not of course balanced. So, this much is the hot utility requirement stream and this much is the cold utility requirement and then we can identify here the enthalpies intervals. Whenever, the curve changes loop we have addition or deletion of the streams.

And then for every change point for the, which the slope at for every point wherever the curve changes loop moves to the down and then identify certain enthalpy interval. So, this are all enthalpy intervals, right now we have 1 2 3 4 5 and 6 enthalpy intervals. we can make the reasonable assumptions that over heat transfer coefficient is constant throughout the process. And then assuming a 2 counter current heat transfer the area requirement for any enthalpy interval k for the vertical heat transfer; that means, direct transfer from hot stream to cold streams.

We can calculate the area of the network. So, that point note assuming constant u constant over all heat transfer coefficient and also assuming through the counter current transfer the area requirement for an enthalpy interval k for vertical heat transfer means A k is equal to delta H k divide by U into delta T l m for that particular interval. Delta H k is nothing, but the enthalpy H changed over the interval k.

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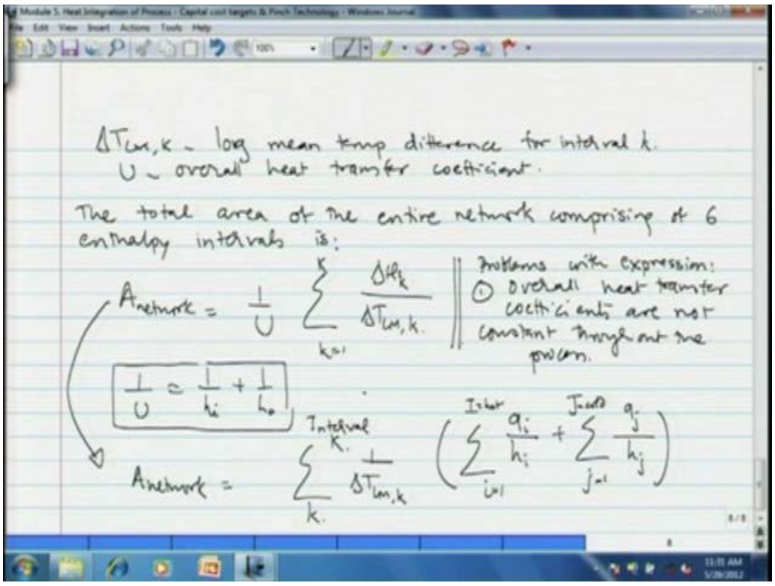

And then delta T L m k is the log min temperatures difference for that interval and U is the overall heat transfer coefficient. Now, the total area of the entire network comprising of 6 enthalpy intervals as shown ((Refer Time: 28:40)) 1, 2, 3, 4, 5, 6, six and intervals.

Total area of the entire network comprising of 6 enthalpy intervals is A network is equal to 1 by U. We assume it transfer to the coefficient to be constant. So, that comes out of the solution sign k comes from 1 to capital K, let us say capital K is the total number of enthalpy intervals delta H k divided by delta T l m k. Now although this expression is straight forward they are formed the individual enthalpy intervals, there are certain problems.

Problem with this expression are let first of all the over heat transfer coefficient are not constant throughout the process. And then we need to make changes to this, now we know the basic relation in heat transfer is that 1 by U is equal to 1 by inside heat transfer coefficient plus 1 by outside heat transfer coefficient plus the direct factor and the conductivity but for time being we ignore that we assume only the basic equation.

And then we can now divide this particular expression we compose this expression into expression that takes into account the derivation in U but it takes into account the number of hot stream and cold stream. So, in any interval there is a delta T log min and then what we do is that we calculate heat duty on hot stream and divide by the fill co efficient for hot stream. So, let us hot streams number of hot streams are capital I, so I running from 1 to capital I q i by h I, were hi is hot stream.

So, q i by h i is the area contribution from hot stream plus summation j running from 1 capital J which are the number of cold stream and then q j by h j. So, this is how we decompose, the simple expression into slightly vigorous expression that takes into account the variation in film co efficient. But, still there is the problem of determining the film co efficient.

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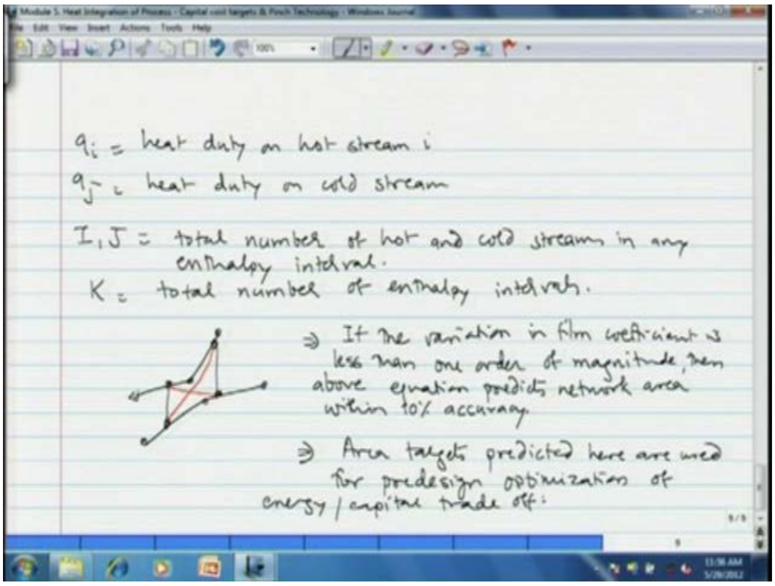

First of all I will give you the notation, so that you can use this formula because we shall use this formula in our tutorials. So, q i is the stream heat duty or heat duty on hot stream i, q j is the heat duty on cold stream then capital I, capital J are the total number of hot and cold streams in an any enthalpy interval. And capital K is the total number of enthalpy interval ((Refer Time: 33:45)).

The formula that we just saw allow the calculation of network area based on vertical heat exchange model, if the filled transfer co efficient vary for large variation in filled transfer co efficient the above equation gives problems. In this case the non vertical matching may be required to achieve the minimum area; that means, let us say.

That we have in the exchanger let us say, we have enthalpy intervals like this and we are making matches directly vertical matches, but if film co efficient of the streams very largely, then this kind of the match may not give us the minimum area. So, we may have to go for a cross match like this, may give us the minimum area. So, those point we need to keep in mind while making the matches. Now, if the fill co efficient very largely then the expression we have seen does not give the minimum network area.

In this case the prediction of true minimum area should be placed on linear programming; however, this equation is still useful basis for calculation of the network area. Because, if the variation in filled co efficient is less than 1 order of magnititude. Then the above equation predicts network area within 10 percent of the actual minimum.

if the variation in filled co efficient h i and h j is less than one order of magnititude which is called large margin then above equation predicts network area within 10 percent accuracy.

Now, the network design usually do not approach the minimum as the true minimum designs are too complex. And then signification reduction in complexity requires small penalty in the area, the area targets being predicted here are used for 3 design optimization of capital and energy trade of evaluation of alternative blue shirts, thus the area prediction that is used here, along with the capital cost data for exchangers have considered degree by uncertainty.

More over the capital cost prediction obtain from our equation are likely to be more reliable than the capital cost prediction for major equipment items. So, that point we note here, that area target predicted are only for pre design optimization.

Area target predicted because we are not making one to one match, we are just finding out the area in particular enthalpy interval where there are many streams, many streams hot and cold streams. Predicted here, are used for pre design optimization of energy or capital trade off.

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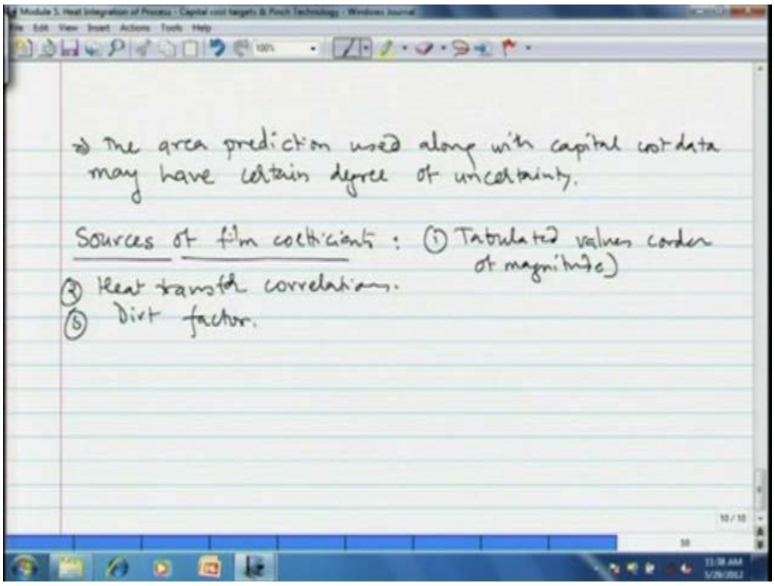

Then the capital cost data the area prediction used here along with capital cost data may have certain degree of uncertainty. Now, the only issue we are left with are the sources of film co efficient h i and h j, now there are many sources here one can use the tabulated experienced values order of magnitude coefficient which are listed in the standard books of such as various standard engineering hand book tabulated values which are may be order of magnitude accuracy.

Then the second is heat transfer coordination which are also given in different hand books and then we have also to account some dirt factor, that is also based on experiences. So, now, we have seen as how we can calculate the minimum number of minutes, and then relatively the approximately area target from which we can estimate the capital cost of heat exchanger network. Now, with this we move head to the pinch technology of heat exchanger network design.

Now, we shall go to one to one match after streams and then how we can have minimum number of minute above and below pinch minute.

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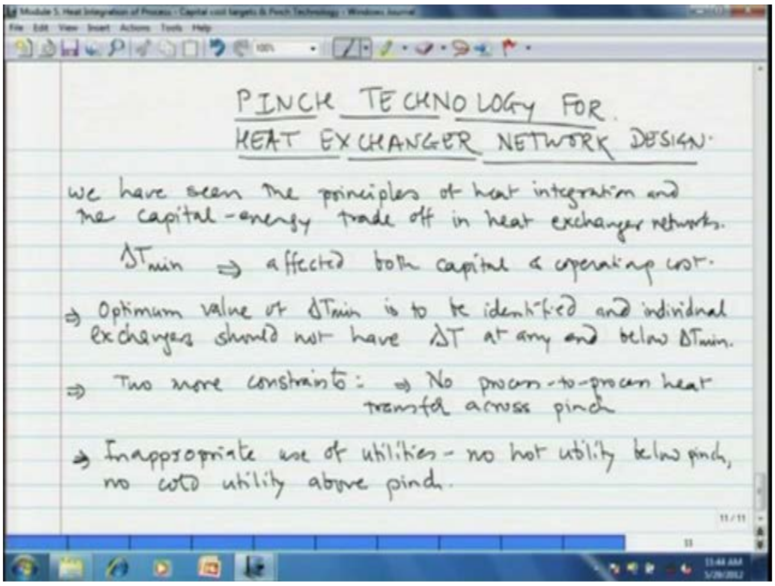

So, the pinch technology for heat exchanger network design. We have seen before the principal of energy integration of the system and then the capital energy trade off in the heat exchanger network.

The major factor in the entire design was delta T min which affected both the capital and operating cost increase in delta T min reduces the capital cost, but increases the operating cost in vise versa. Now, to start with actual design of the heat exchange network by placing matches, that is left out and that we will do? Now, the two cost that are combined the capital and operating cost, to obtain the total cost the optimum point the capital trade off is to be identified and correspondence to the optimum value of delta T min. Optimum value of delta T min is to be identified.

And individual exchangers should not have delta T min less than that particular set value should not have delta T at any end below delta T min. This is the constant that we put, more over we also have seen that there should not be, two more constant that there should not be process to process heat transfer across pinch and then in appropriate use of heat or cold finch that no cold utility is used above pinch and no hot utility is to be used below pinch.

Now, these rules are necessary for design to achieve the targets and then assuming that no efficient there delta T min less than given said value. Now, before we can have some more criteria which help us in identify the overall exchangers network design and that we shall see now.

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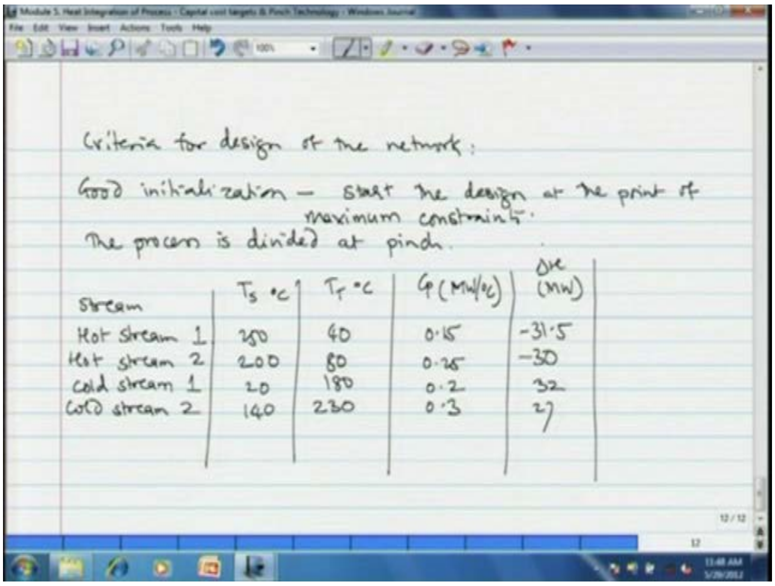

When we start making the design when we start placing matches between the streams. We should have good initialization, which means we should start the design at a point which has maximum constraints. The process is divided at pinch we shall demonstrate the strategy for this particular pinch technology or the algorithm of the pinch technology with an example, we take the same example as in the previous lectures the 4 stream data which I am writing for you, now.

Hot stream 1 supply temperature T s 250 degree centigrade the target temperature 40 degrees centigrade heat capacity flow rate of point 0.15, and then hot stream 2 supply temperature 200 target temperature 80 c 2 value 0.25 cold stream 1 supply temperature 20 target temperature 180 heat capacity flow rate 0.2 and then cold stream 2 supply temperature 140 target temperature 230 heat capacity flow rate 0.3.

So, with this you can calculate the delta H are the heat content or the heat deficit of this streams as point minus 31.5 then minus 30 then 32 and 27. So, with this example we shall explain or we shall learn the technique of pinch design for heat exchanger network, but that we shall see in the next lecture.