Process Integration
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Module - 4
Targeting
Lecture - 5
Number of units Target

Welcome to the lecture series on Process Integration. Today, we will see how the number of units target is created. So, the topic of this lecture is number of unit target, it is module number four lecture number five. We have already seen how to do targeting of hot utility and cold utility in the unit, this is the second lecture on targeting. Here we will target the number of units in the heat exchanger network.

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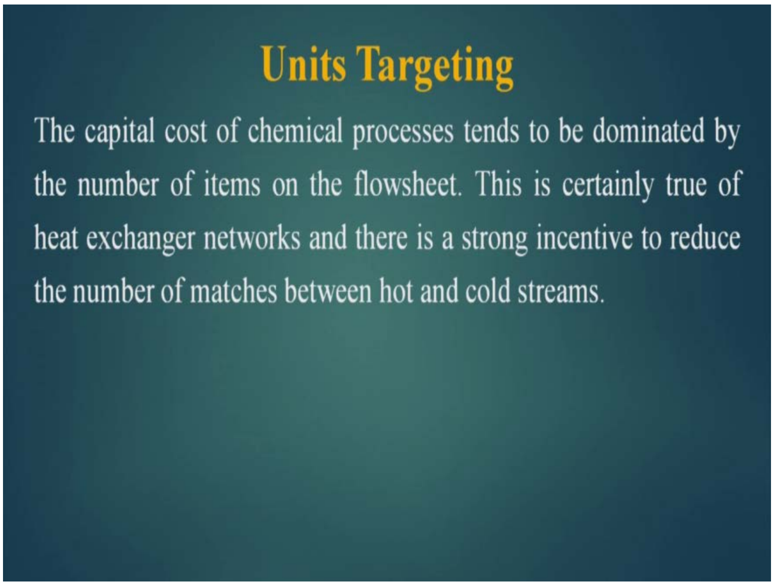

This is a known fact that the capital cost of chemical processes is dominated by the number of items on the flow sheet, and hence that is a strong incentive to decrease the number of items on the flow sheet. This logic is also true for heat exchanger networks, that is a strong incentive to reduce the number of matches between hot and cold streams. This unit targeting gives prior to the design, the minimum number of units in the heat exchanger network. Suppose I have designed two heat exchanger networks HEN 1 and HEN 2, if HEN 1 has got ten number of units and HEN 2 has fifteen number units, obviously I should go for HEN 1, because the cost of HEN 1 will be less than the HEN 2.

And this logic is based on the fact that one big exchanger cost less than the two small exchangers which has equal area of that big heat exchanger.

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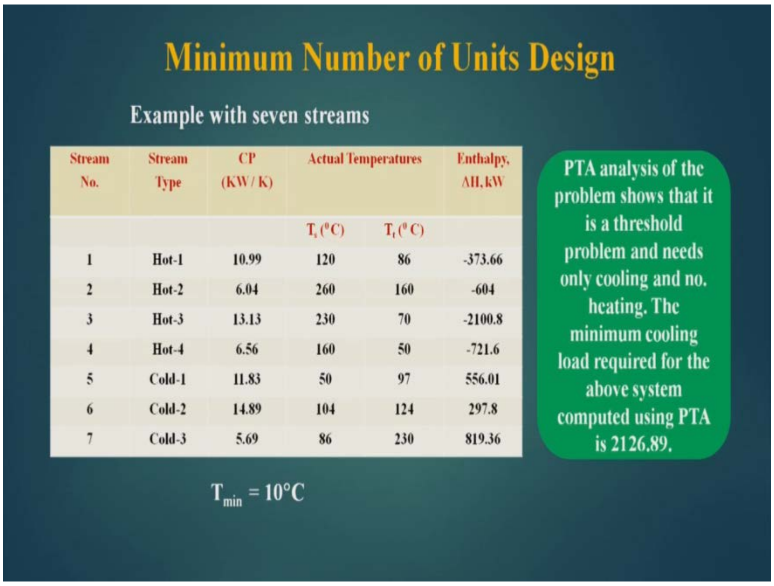

Stream No.	Stream Type	CP (KW / K)	Actual Temperatures		Enthalpy, ΔH, kW
			T_s (°C)	T_t (°C)	
1	Hot-1	10.99	120	86	-373.66
2	Hot-2	6.04	260	160	-604
3	Hot-3	13.13	230	70	-2100.8
4	Hot-4	6.56	160	50	-721.6
5	Cold-1	11.83	50	97	556.01
6	Cold-2	14.89	104	124	297.8
7	Cold-3	5.69	86	230	819.36

Now, let us demonstrate this numbers of unit targeting with an example. See a stream table, which has seven streams - four hot streams and three cold streams having delta T minimum is equal to 10 degree centigrade. The PTA analysis of this problem shows that it is a threshold problem and needs only cooling and no heating; that means, hot utility stream is not present, and only cold utility stream is present. So, if you count number of streams including the utility streams it will be seven process streams and one cold utility streams making total number of stream count to be eight. The minimum cooling load required for the above system is computed using PTA as 2126.89 units.

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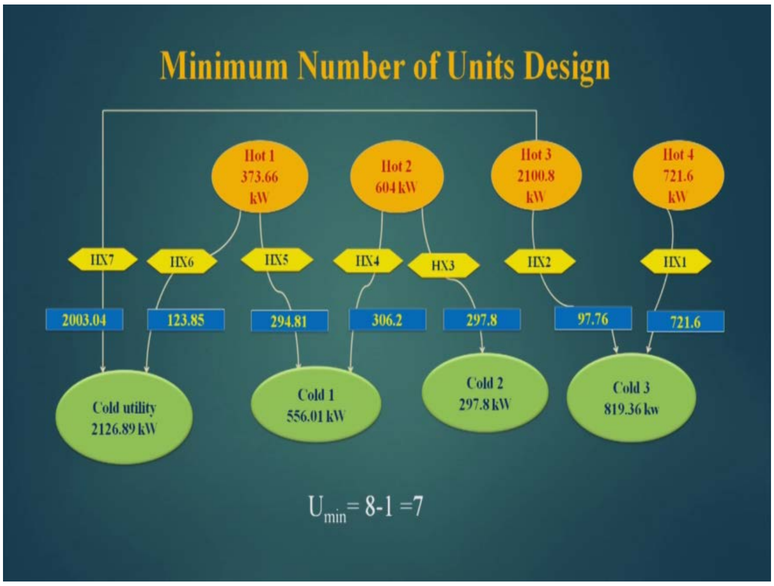

Now, if I translate that stream table into a picture like this, we have four hot streams; hot 1 is 373.66 kilowatt; hot 2 is 604 kilowatt; hot 3 is 2100.8 kilowatt and hot 4 is 721.6 kilowatt. Cold 3 is 819.36 kilowatt; cold 2 is 297.8 kilowatt; cold 1 is 556.01 kilowatt, and cold utility requirement using the PTA is 2126.89 kilowatt. Let us remember again that this problem does not need a hot utility, and that is why hot utility stream is not present here. Now our aim is to design a heat exchanger network, which will satisfy the need of cold utilities, cold streams from the heat of the hot streams and excess heat which is available with the hot stream will be push to the cold utility. So, total number of streams including the cold utilities stream is eight in this case.

So, we start designing from the right to left. So, the cold three stream requires 819.36 kilowatt. Now I can push the total heat available with the hot 4 stream that is 721.6 kilowatt at once to the cold stream. I can also push by dividing this heat into two three parts, but if I do so, the number of heat exchanger will increase. Now in a units target, we always take off the streams to bring down the number of heat exchanger to a bare minimum. So, 721.6 kilowatt heat of hot stream number 4 is pushed to the cold stream number 3, after pushing this it the cold stream number 3 requires 97.76 kilowatt of heat to satisfy it. This heat comes from hot stream number 3 to cold stream number 3, and hence now the cold stream number 3 is satisfied, but there is some heat available with hot 3.

Similarly, we see that cold stream number 2 requires 297.8 kilowatt heat and hot 2 has 604 kilowatt of heat. So, it can directly satisfy the cold 2 by giving its heat. So, it pushes 297.8 kilowatt of heat directly to the cold stream number two and picks it up; that means, this amount of heat satisfy the cold stream. The remaining heat with the hot 2, which is 306.2 is now pushed to cold stream number 1, which needs 556.01 kilowatt. Hence it partially satisfy the cold 1, and another 294.81 kilowatt is required by the cold stream to the completely satisfied. This heat comes from hot 1, who has which has got a value of 373.66 kilowatt with it. So, the remaining 123.85 kilowatt with hot 1 will now be pushed to the cold utility, because it is the extra heat which is available with hot 1.

Now, we see that some heat is available with hot 3 which is 2003.04 kilowatt extra, and some extra it is available with hot 1. These two extra heats are now pushed to the cold utility which is 2126.89 kilowatt and which satisfies the cold utility. So, what we see now the all the heat which is available with the hot streams are pushed to the cold streams as well as cold utility. So, the whole system is in thermal balance. Now to do so we see that we are using seven number of heat exchangers HX 1, HX 2, HX 3, HX 4, 5, 6 and 7. So, can we develop a method to calculate that how much number of heat exchangers will be required if number of streams including hot utility and cold utility are known to us. So, we see that 8 minus 1 is seven - that means, we have eight number of streams minus one gives as the number of heat exchangers require for this design.

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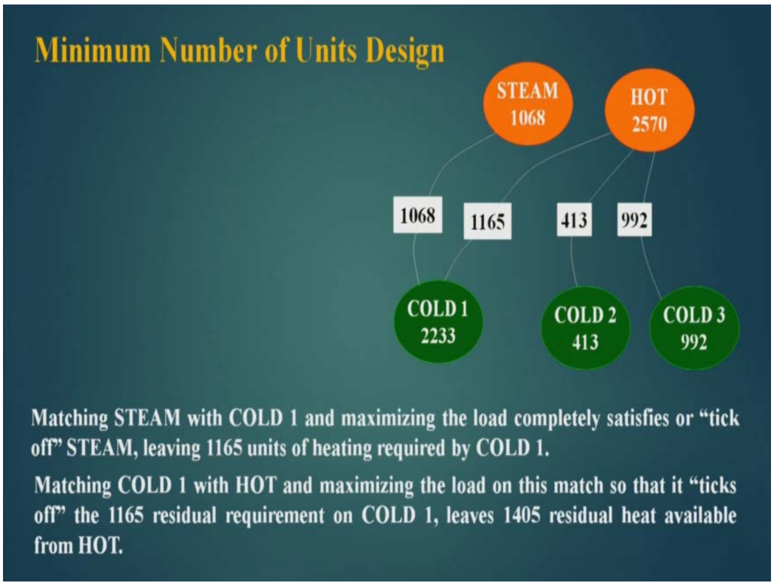

Let us take another example. In this process, only hot utility required, but no cold utility is required. So, hot utility as steam is available with 1068 units of heat, one hot stream is available as 2570 units of heat. There are three cold streams; cold stream number 1 requires 2233 units of heat; cold stream number 2 requires 413 units of heat, and cold 3 requires 992 units of heat. Now, we have to develop a heat exchanger network for this, so that the heat available with steam as well as hot stream number one is pass to this cold streams numbering three. So, the total amount of heat available with steam which is 1068 is now push to cold 1 which required 2233 units of heat, so obviously, the steam with its 1068 units of heat is not able to satisfy completely the cold 1. So, some heat from the hot stream number one has to go to the cold stream number one to satisfy it completely.

So, we pass on now, the remaining 1165 units of heat from hot stream to satisfy the cold stream. Now the remaining two cold streams are then completely satisfied by transferring heat from the hot stream, which are to satisfy cold two we are transferring 413 units of heat, and to satisfy cold three we are transferring 992 units of heat. Now, this way all the heats available with the hot steam and the steam is not pushed to cold 1, 2, 3 streams, and they are in thermal balance. Now the heat exchanger which are required for this purpose is four - that means, four number of heat exchangers are required its capacities are 992, 413, 1165 and 1068.

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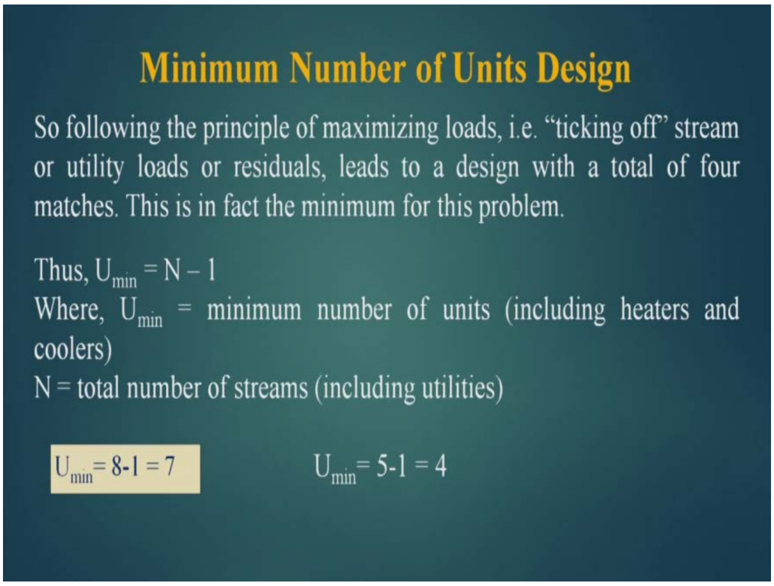

Now, the for the earlier problem, the number of heat exchangers were given by 8 minus 1 is equal to 7, where eight is the number of streams available. In this case the number of streams available were 5, so 5 minus 1 is 4 is the number of heat exchangers for this HEN - last HEN. So, following the principle of maximizing the load which is called taking of streams or utility loads or residuals leads to a design with a total number of four matches. Why we have done so, because if you do not do the maximization of load by taking of stream or utility loads or residuals, we cannot reach to a minimum number of units and our aim is to calculate the minimum number of heat exchangers in the network, which will satisfy the design or the requirement.

So, a small correlation or formula can be generated which says that U minimum that is the minimum number of units is equal to n minus one, where U minimum is the minimum number of units including heaters and coolers, and n is equal to total number of streams including utilities. So, if I developed this equation and apply to the earlier two problems, I see that they predict the number of heat exchangers accurately. Now the question is whether this equation is pool proof will see that in some of the cases, it fails and hence this equation has to be modified or enlarged.

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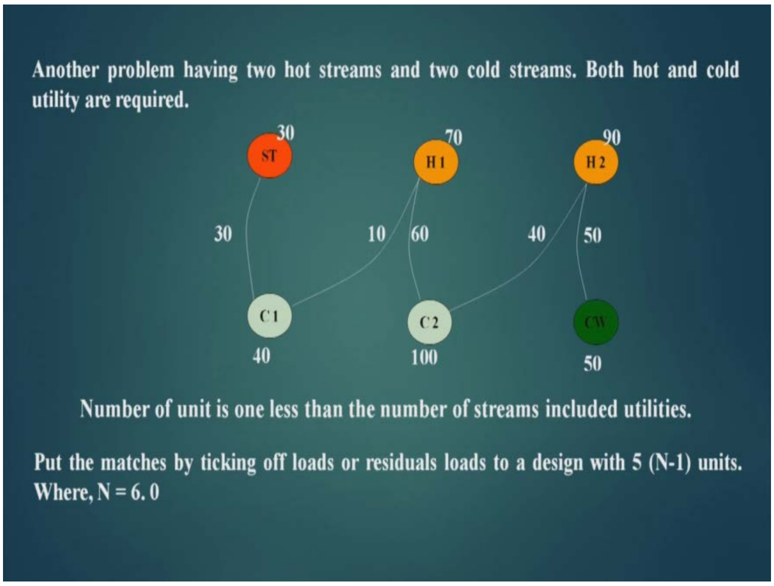

Now, let us see a problem with 2 hot streams, two cold streams a hot utility and a cold utility. Hot utility is give by ST, which is a steam; and cold utility CW - cold water. And hot streams are H 1, H 2; cold streams C 1 and C 2. The steam which is given by ST as

30 units of heating, H 1 steam hot steam has 70 units of heating; H 2 90 unit of heating. Cold water that is CW is 50 units, it can take heat; C 2 can take 100 units of heat C 1 take can take 40 units of heat. These can be satisfy with these arrangement - that means, H 2 can pass on 50 units of heat to CW and take it off the remaining 40 can be pass on to the C 2, but it will not satisfy the C 2. So, the remaining 60 units to satisfy C 2 will come from H 1. So, this way H 2 and H 1 will satisfy C 2 by giving them giving it 100 units of heat, the remaining 10 units of it with H 1 will now pass on to C 1, and the reaming 30 units of heat which is required by C 1 will pass from ST that is steam.

Now we see here, all the heat available with the hot streams and hot utility are able to satisfy the cold utility and cold streams. So, they are in thermal balance. And we are using five heat exchangers in this case; having capacities 50, 40, 60, 10 and 30 units, and the number of streams with us including the hot utility and cold utility is 6. So, if I apply this equation it satisfies N minus 1, because N minus 1 is five, while n is 6 and here we have five heat exchangers.

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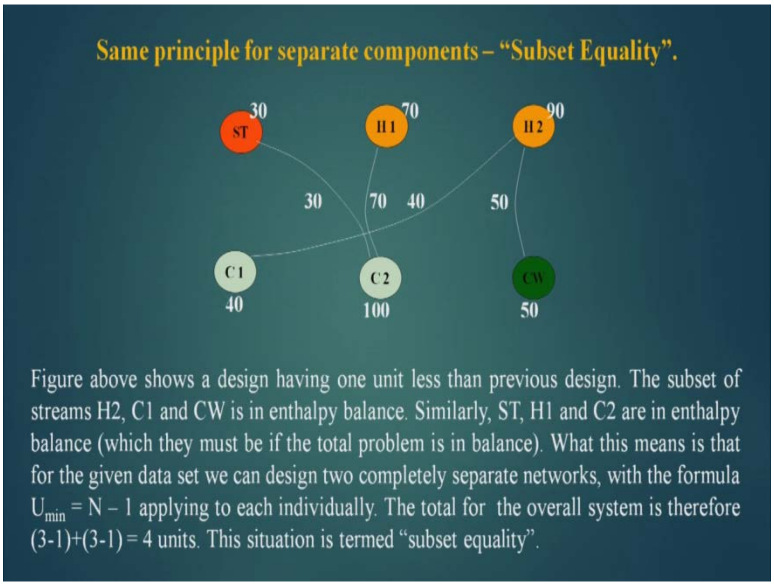

Now, the same can be done in this way - that means, H 2 gives 50 units of heat to cold water, and remaining 40 of units of heat is passed to C 1 then H 1 gives 70 units of heat to C 2 and remaining 30 to passed on by the steam to C 2. If I arrange this way, the heat exchangers I find that I am using one less heat exchangers that is 5 minus 1 equal to 4, and with four heat exchangers I am able to solve the problem. A special case we see that

H 2 satisfy C 1 and CW, whereas, ST and H 1 satisfy C 2. So, there are two subset inside it, if there is a single subset; obviously, that will be a second subset. So, we here we see that two subset are available one subset is C 1, CW, H 2, and other subset is ST, H 1 and C 2.

So, it appears as if it is a two problems, because two separate components are available which are thermally satisfying each other or which are thermally satisfied internally. So, if I apply my rule to both the subset then three minus one for subset ST, H 1 and C 2 is two; and for second H 2, C 1 and CW three minus one is two, so two plus two is four. So, this way we can predict the number of heat exchanger in this arrangement. So, we see that the subset equality also plays a role in the determination of number of heat exchangers. So, in a heat exchanger network, we should always search for subset equality and we by chance if we get subset equalities then we will be able to decrease the number of heat exchangers.

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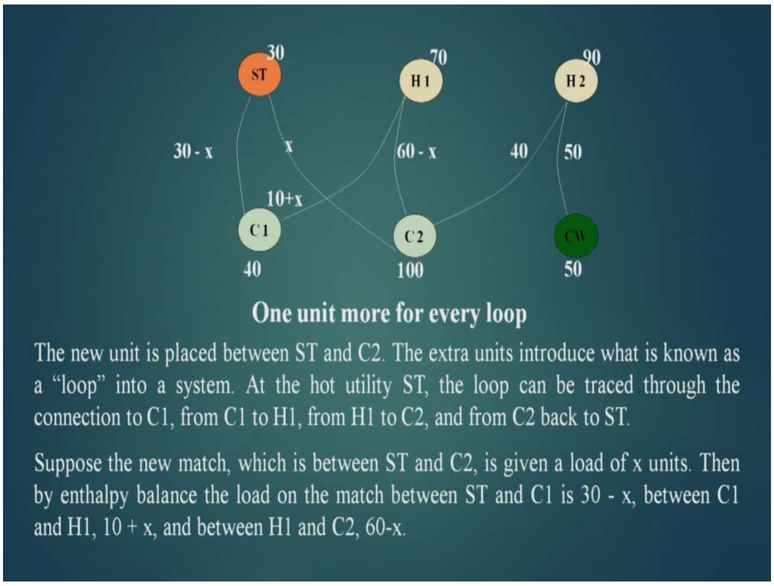

Now we see a second case, here I put a extra line between steam to C 2 which transfers x amount of heat. If it transfers x amount of heat to C 2, then 30 minus x amount of heat will be transfer to C 1, and 10 plus x amount of heat from H 1 will be transfer to C 1, and when we add 30 minus x plus 10 plus x it is 40, so it is C 1 is satisfied. Similarly 60 minus x will be transfer to C 2, and 40 units of heat come from H 2 to C 2, and 50 units of heat goes to CW. So, this is also a arrangement which satisfies the need, but requires six heat exchangers.

Now, let us analyze why it requires six heat exchangers. We see that ST, C 1, C 2 and H 1 forms a loop. In many times, loops are necessary, because in a loop the heat can be transferred from one unit to another unit, and the heat loads becomes flexible, but for that flexibility we have to pay one extra unit. So, we see that if there is a loop in the heat exchanger network, it will increase the number of heat exchangers. So, for each loop, one heat exchanger will be added; as in this arrangement, there is only a single loop we are paying one more heat exchanger for this loop.

So, though a loop gives flexibility in operation, but we have to give a tax in terms of a additional heat exchanger per loop. So, breaking will decrease the number of heat exchangers in a heat exchanger network. This we will see when we will develop non-MER designs. And in a MER design will find that always loops will exist, and if you want to decrease the number of heat exchanger in n then this loops have to be broken. So, loop also contribute to the number of heat exchangers and hence our equation should contain this.

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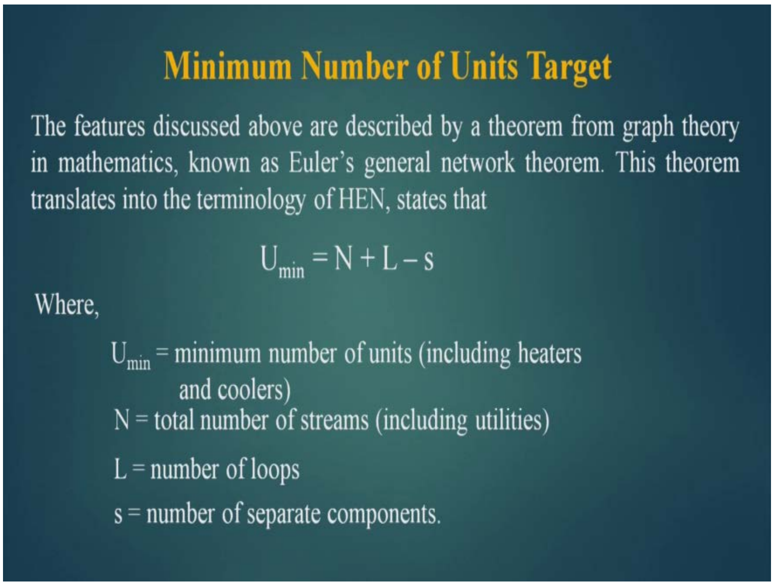

So, we saw that number of separate components contributes, number of loops contribute, and number of streams including the hot utility and cold utility also contributes. So, U minimum is equal to N plus L minus S, where U minimum is the number of units including heaters and coolers. N is the total number of streams including utilities that is hot utility and cold utility. L is the number of loops present in the HEN, and S is the number of separate components present in the HEN. This equation is basically from graph theory in mathematics known as Euler's general network theorem. This theorem translate into the terminology of HEN and states that U minimum is equal to N plus L minus S. So, this is the full fledge equation and will always use use this equation to target number of units in a HEN.

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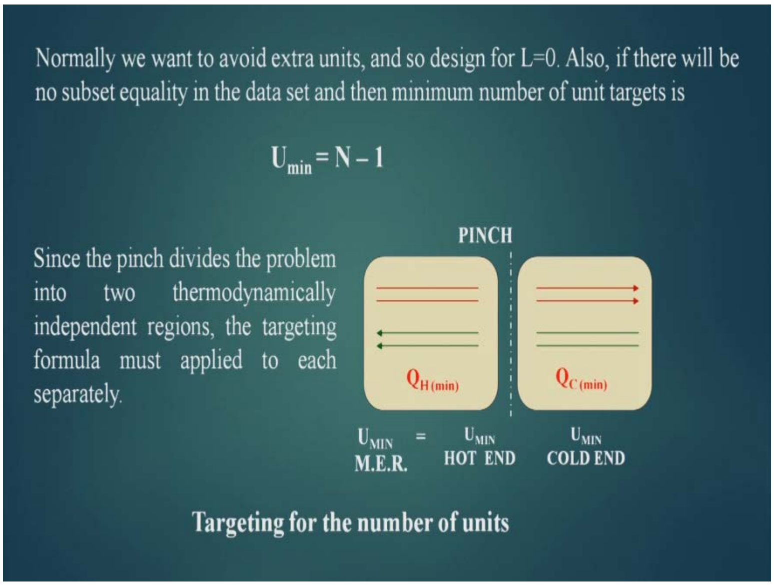

Normally, we will like to avoid extra units, and hence we will design for L is equal to zero; that means, we will break the loop, if there is a loop present in the hen and will decrease the number of units. And hence, our aim will be to design hence for L equal to zero. And if we are lucky enough then that will be subset equality otherwise there will be no subset equality, and hence the S value will be equal to one. If I keep these values then the U minimum becomes N minus 1. Since the pinch divides the problem into two thermodynamically independent regions, the targeting formula must be applied to each separately. When I am using pinch analysis for the design of heat exchanger network then it breaks the problem into two thermodynamically independent regions as through the pinch no heat transfer takes place.

So, as far as thermal independency is concern, they are independent from each other, but physically they loop as if one unit, one heat exchanger network; but thermodynamically they are divided into two heat exchanger network. And hence I should apply this equation in the upper part of the pinch as well as to the lower part of the pinch, and then the regions should be added to find out what should be the minimum number of units in a design which uses the pinch analysis. So, the U minimum MER - that is maximum energy recovery design is equal to U minimum of the hot end which is the upper part of the pinch plus the U minimum of the cold end which is the lower part of the pinch.

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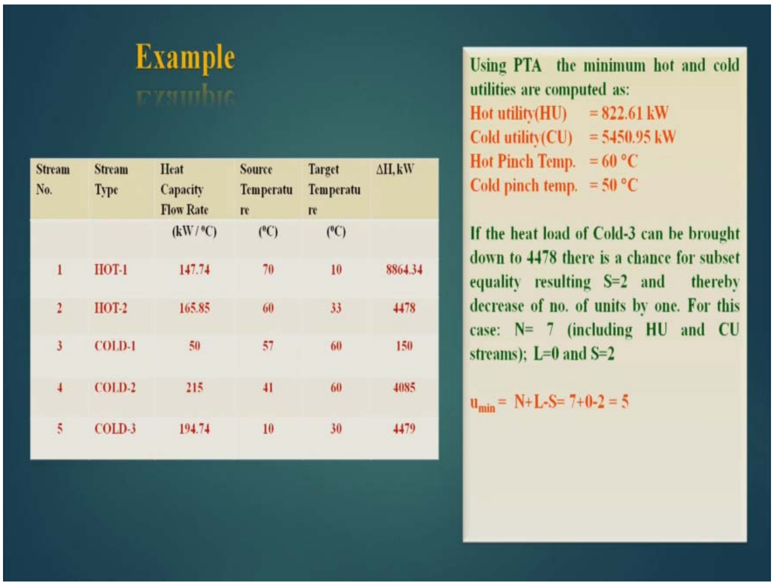

Let us take an example of a five-stream problem. When we use PTA, we find that the hot utility requirement is 822.61 kilowatt, cold utility requirement is 5450.95 kilowatt, hot pinch is 60, cold pinch is 50, because delta T minimum is 10. Now here we see that if the heat load of the cold stream 3, which is 4479 can be brought to 4478; there is chance for subset equality and S will have a value of 2 and thereby decrease of number of units will be 1. For this case, n is equal to seven including HU and CU that is hot utility and cold utility, L is equal to zero, and S equal to two. So, N plus L minus S is equal to five. So, if somehow a unit is cut down from the load of cold 3 – 4479, and make it 4478, we can drastically cut down the number of units by one. So, in this case process modification we should go for process modification and should try to bring down the cold 3 stream to 4 for seven-eight units. If subset equality is not created then N is equal to 7, L is equal to zero, and S equal to 1 then the number of units minimum number of units is 6.

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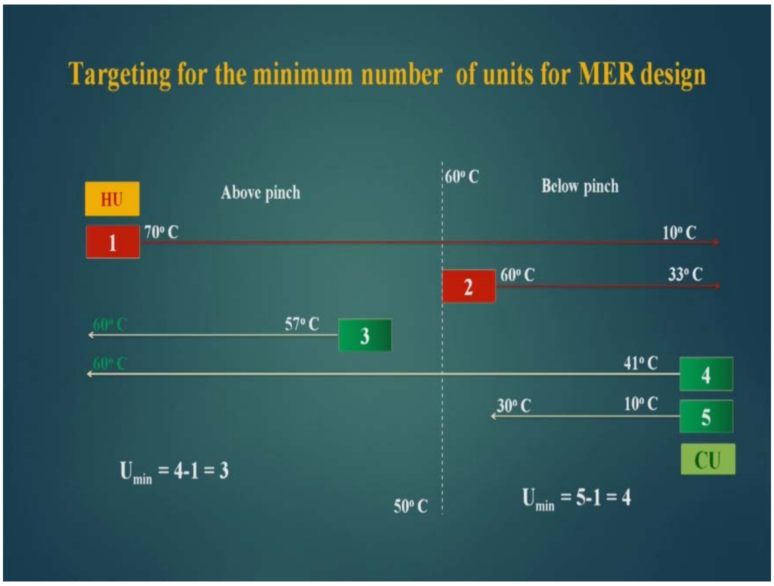

Now, we apply as formula for the hot end as well as cold end then above the pinch this is hot end, the number of streams are four including hot utility, and S is equal to 1, so 4 minus 1 is equal to 3. And for the below pinch, this is 5 minus 1 is equal to 4, so overall u minimum for the m e r design is 3 plus 4 equal to 7.

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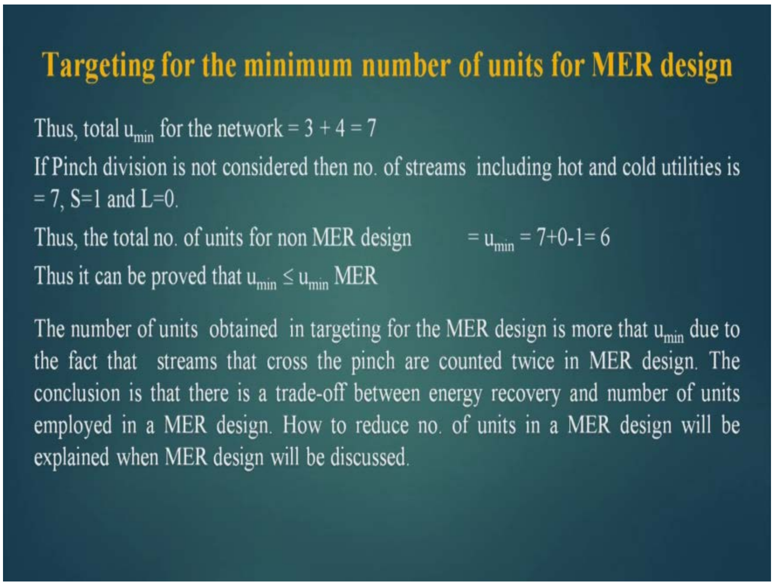

So, what we conclude out of this. If you do the targeting for the minimum number of units for the MER design, and what we find that U minimum for the network is 3 plus 4 is equal to 7 units. If pinch division is not considered then number of streams including hot and cold utilities is 7, S is equal 1, L equal to zero. So, if pinch division is not considered then we call it an non-MER design, and in a non-MER design U minimum is equal to 6; that means, a non-MER design gives less number of heat exchangers than a MER design. So, this conclusion, we can find out here that U minimum MER is always greater than the U minimum non-MER design. The number of units obtain in targeting of a MER design is more than the U minimum due to the fact that streams that cross the pinch are counted twice in a MER design. This conclusion is that there is a trade-off between the energy recovery and number of units employed in a MER design.

What does it mean, if I am going for a MER design then I am recovering maximum energy, but I am and my hot utility and cold utilities are minimum, but I am paying in terms of more number of units. Now, if I go for a non-MER design, my hot utility requirement and cold utility requirement will increase, but I will able to decrease the number of units. So, decision is very simple, if gain is there in a non-MER design then I should prefer a non-MER design. If there are losses in the non-MER design, I should not prefer a non-MER design, I should go for a MER design. And this decision will be clear when I do the cost targeting of a MER design or I do the costing, I find out the tack total annual cost of a MER design, and the total annual cost of a non-MER design. So, this I should remember, there is always a trade-off between energy recovery and number of units.

Thank you.