Process Integration
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Module - 3
Building Blocks of Pinch Technology
Lecture - 1
Data Extraction

Welcome to the lecture series on Process Integration. In this part of the lecture, we will talk about data extraction. This is module number one and lecture number three. In pinch technology, which is used for process integration, first, the problem is identified.

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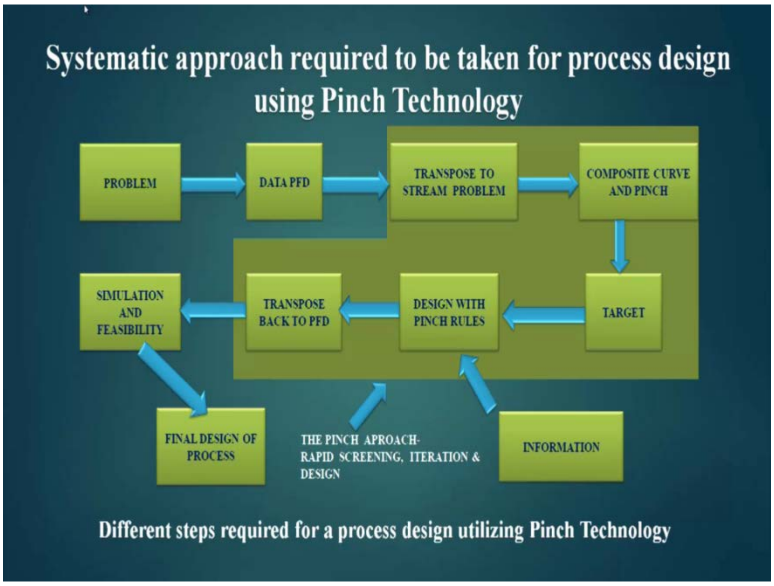

That means in the plant in which area you are going to apply the pinch technology. Then process flow diagram of that area is taken, and data is extracted from the process flow diagram which is called PFD, then this data are converted into streamed problems and then with the help of stream problem or the stream data table the composite curves are created. After the composite curves targets are specified in the targets we go for energy targets, units target, area target, cost target. And once targets are available, we go for design with pinch rules, and then we create a new PFD that PFD has got benefit over the older PFD, and this new PFD is simulated to test its feasibility, and once we find that this new PFD is good, accurate, robust then the final design is accepted.

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There are a few key steps in the pinch technology. There are four key steps of pinch analysis in the design of heat recovery systems for both new and existing processes. The first one is data extraction; this involves collecting data for the process and the utility system. Then comes targeting, this establishes targets for design in terms of energy, number of units, area, cost etcetera for the best performance. Then comes design, it establishes an initial heat exchanger network. And then comes optimization, wherein the initial design is simplified and be improved economically.

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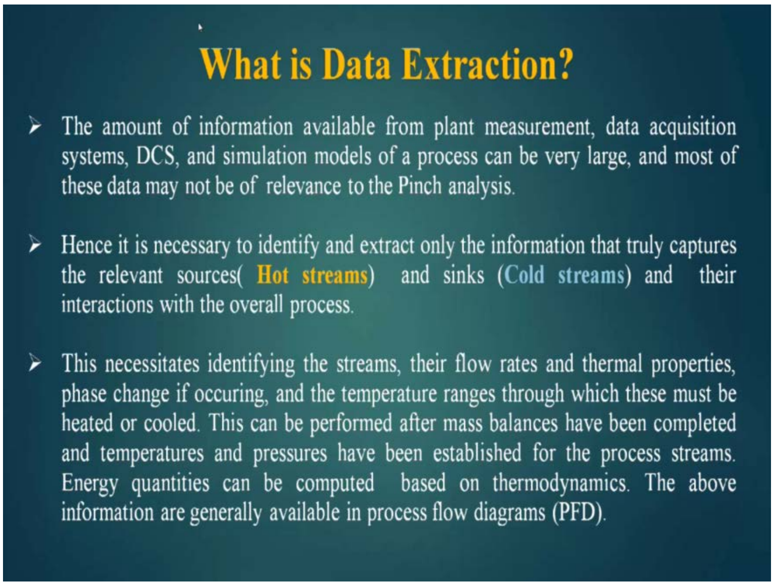

Now, what is the data extraction? The amount of information available from the plant measurement, form data acquisition systems etcetera or from models are very large, and most of this data are not required or not relevant for the pinch analysis. So, what is to be done is that we have to identify and extract only the information that truly captures the relevant sources that is hot streams and the sinks which are called cold streams and their interaction with the overall process. This data part of data is necessary for pinch analysis. This necessitates identification of streams, their flow rates and their thermal properties phase changes if occurring, and the temperature ranges through which this must be heated or cooled.

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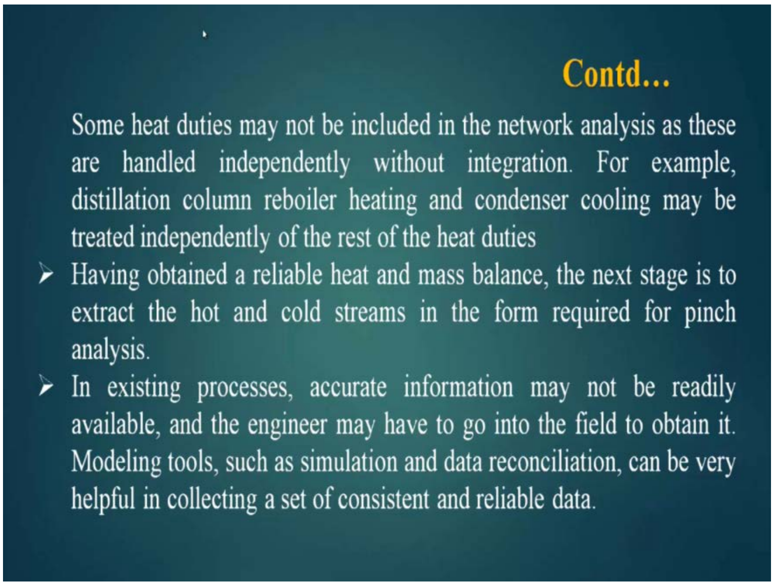

Having obtained a reliable heat and mass balance, the next is to extract the hot and cold streams in the form required for pinch analysis. In existing processes, accurate information may not be really available. We have our experience when we use plant data in many a times, the plant data do not conform to the heat and energy balance. Hence the engineer may have to go to the field to obtain it. Modeling tools, such as simulation and data reconciliation, can be very helpful can be very helpful in collecting a set of consistent and reliable data.

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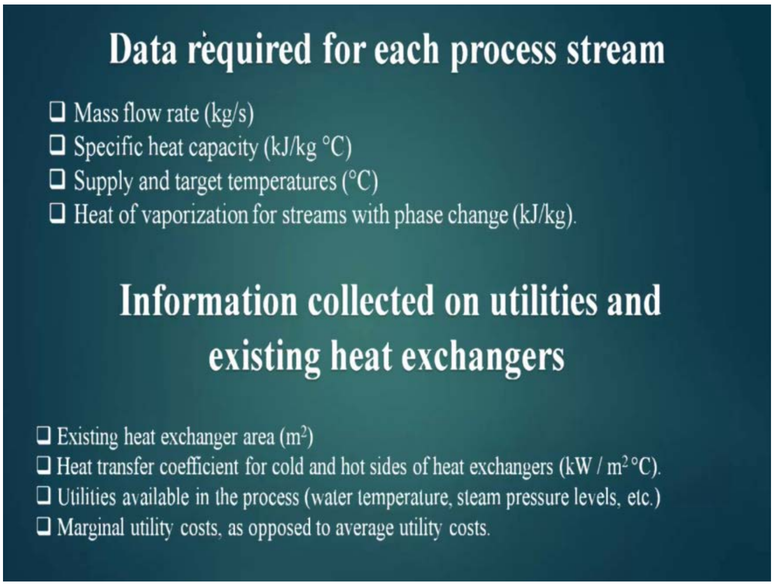

Now, data required for each process streams consists of mass flow rate, the unit may be kg per second. Specific heat capacity is kilo joule per kg per degree centigrade; supply and target temperatures in degree centigrade. Heat of vaporization of streams with phase changes if any in kilo joule per kg. Information collected on utilities and existing heat exchanges may include, existing heat exchanger area, heat transfer co-efficient for cold and hot sides of the heat exchanger, this information is necessary for area targeting utilities available in the process that is water temperature, stream pressure levels etcetera and marginal utility cost as opposed to average utility cost.

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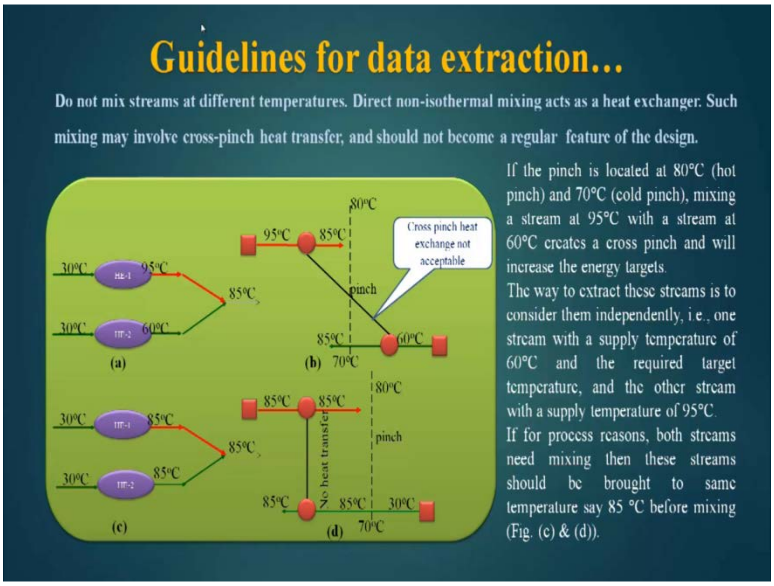

Now, there are some guidelines based on which the data should be extracted. The first type is that do not mix streams at different temperatures. Direct non-isothermal mixing acts as a heat exchanger. Such mixing may involve cross-pinch heat transfer, and should not become a regular feature of the design. If you see in this diagram, the stream is heated from 30 degree to 95 degree using heat exchanger one, and stream is heated from to 30 degree centigrade to 60 degree centigrade and then both are mixed here to get a 85 degree centigrade stream. Now if this pinch lies at 80 degree centigrade and 70 degree centigrade means, 80 degree centigrade hot pinch and 70 degree centigrade cold pinch, while delta t minimum is 10 degree centigrade.

Then this heat exchanger it will appear as if it is in a heat exchanger, and this heat exchanger will be a cross-pinch heat exchanger. And if we put a cross-pinch heat exchanger then utility requirement will always increase. Now if streams are to be mixed then we have to create isothermal streams like from 30 degree to 85 degree centigrade, we should heat it from 30 degree to 85 degrees centigrade then we can mix them together to form a 85 degree centigrade stream. And obviously, the heat exchanger which will do this or the virtual heat exchanger which will do this will have no heat transfer.

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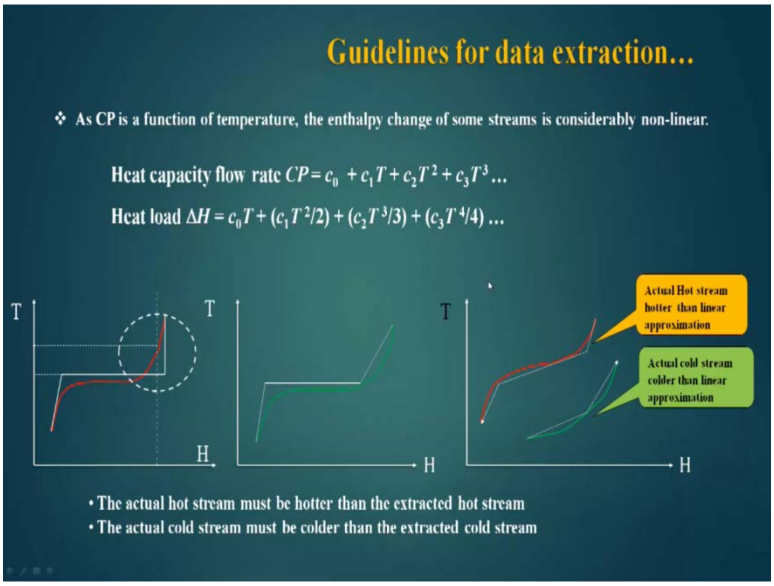

There are some other guidelines for data extraction as well. While we take hot streams or cold streams, temperature changes. As CP which is heat capacity flow rate is a function of temperature, the CP value also changes. Now if we consider this part then we find that the enthalpy-temperature diagram of such streams are considerably non-linear in nature. The figure shows a non-linear stream which is shown by the red line here, and this non-linear stream can be approximated by linear streams. Now, here if we see here, this part of the stream is approximated by this part and this part, now here the stream is at this temperature whereas the approximation which we have drawn. So, the temperature is this that means a considerably lower temperature or a false lower temperature is shown by the approximated stream. Now suppose, there is a cold stream which temperature falls here; now hot stream can very well transfer the heat from this temperature to this temperature; whereas approximated temperature which is at this temperature will not be able to force it to the cold stream. So, such types of errors will be created if the approximation of the stream are not proper in nature.

Now this was another approximation. Now, the rule for approximating a non-linear stream to a linear stream is that the actual hot stream should be hotter than linear approximation, and the actual cold stream should be colder than linear approximation. Now this part is shown here. Now we see that this hot stream actual hot stream is hotter than the approximation, and this actual cold stream should cooler than the approximation. So, the rule of thumb is the actual hot stream must be hotter than the extracted hot stream, and the second rule is the actual cold stream must be colder than the extracted cold stream.

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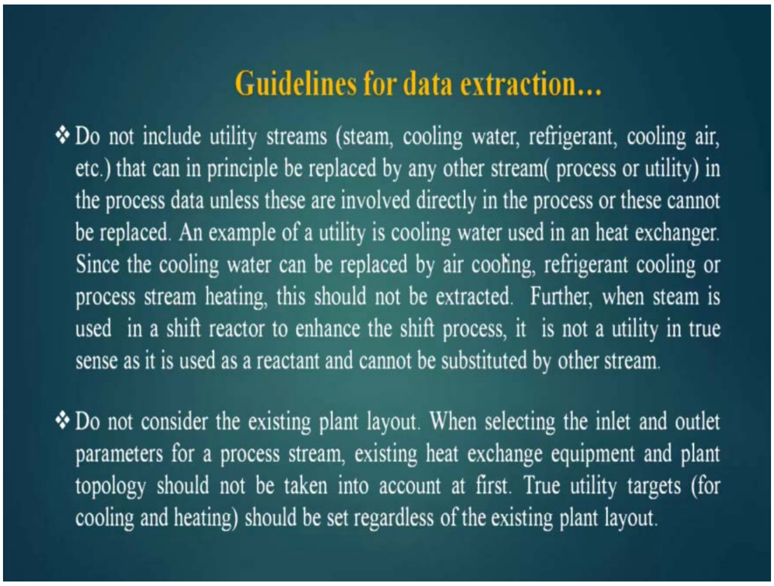

Now, the other data extraction guidelines are do not include utility streams, while extracting data. The utility streams are steam, cooling water, refrigerant, cooling air etcetera. Why we do not include the streams, because while doing pinch analysis, we have to find the quantity of utility streams, or we have to find out how much hot utility and how much cold utility is required. If we include these streams in with the process streams, we will not be able to find out the requirement of hot utility and cold utility. So, do not include utility streams that can in principle be replaced by any other stream that is process or utility streams in the process data unless these are directly involved in the processes or these cannot be replaced.

If these utility streams are directly involved in the process like you are using air and this air is being used for hitting purposes by burning f well then it is directly used in the process. Another example of utility cooling water used in a heat exchanger, since the cooling water can be replaced air-cooling refrigerant cooling or processed in heating, this will not be extracted. Further, when the stream is used in a shift reactor, if the stream is used in a shift reactor to enhance the shift process, it is not a utility then because it is a part and it is used as a reactant. So, we cannot eliminate these streams, we have to use this as a process stream. Now the other guideline is that do not consider the other existing plant layout, while extracting the data. When selecting the inlet and outlet parameters for a processed stream, existing heat exchanger equipment and plant topology should not be taken into account first. True utility targets should be set regardless of the existing plant layout. After we do this in the stage of optimization, we can use this plant layout.

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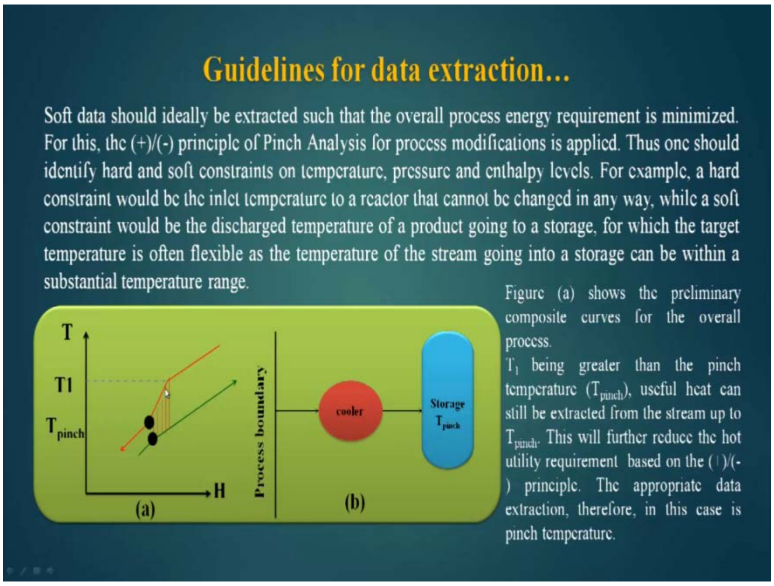

Now there are concept of soft data. Soft data are those data which can be changed considerably. Soft data should be ideally extracted such that the overall process energy requirement is minimized and to do this plus minus principle of pinch analysis for process modification is applied. We can give an example on this. Like suppose, this is a hot stream and this is a cold stream, and this is a pinch temperature. Now up to this pinch temperature, the hot stream can give heat to the cold stream. Now here we have a cooler and a storage tank. This is the T 1 temperature and this is the T pinch temperature. So, the cooler should cool form the T 1 temperature to the T pinch temperature, and we should do this storage at T pinch temperature. Now suppose that earlier we are storing at a 50 degree centigrade, which is above the T pinch temperature then we should try to cool it down to that pinch temperature and should store it at T pinch temperature. If we do this, then our hot utility requirement will decrease.

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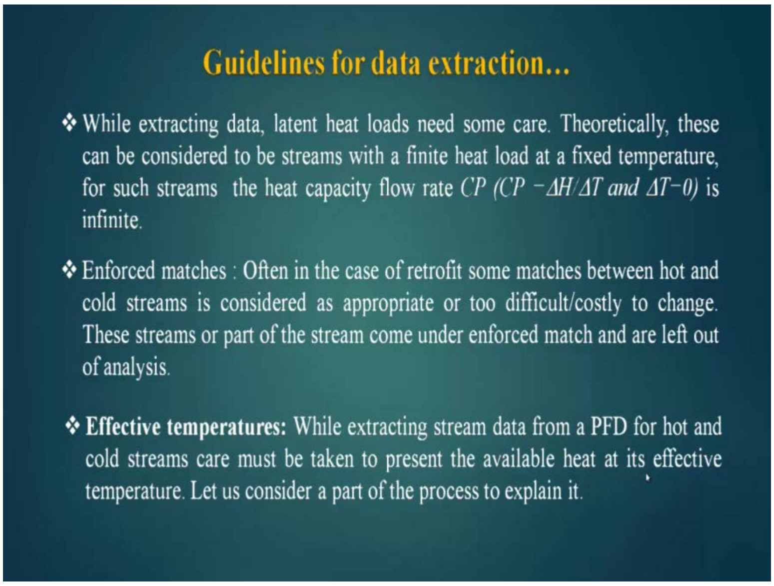

Now, there are other guidelines, while extracting data, latent heat loads needs some care. Theoretically, this can be considered to be streams with finite heat load at a fixed temperature, for such streams the heat capacity flow rate received becomes infinite. Because a boiling or condensing steam will give heat at delta T equal to zero; that means, its temperature does not change while giving heat. Now if this is cause then when we calculate the value of CP using q is equal to CP dt and dt becomes zero then CP becomes infinite. Now to handle such cases, we consider that the condensing or boiling stream temperature is decreased by a degree centigrade or so and while assuming this we get a high CP value, but not infinite.

But if you see the actual process, this also happens. Take a case of a condenser; say steam condenser, the steam enters at one end flows to the other end of the condenser. So, there must be a pressure difference for this flow, and if there is a pressure difference, there will be a temperature difference. So, taking a temperature difference of one degree centigrade in this case, and calculating the CP, a virtual CP which will be very high does not affect the calculation and hence it is permitted. There are some matches which are called enforced matches. Often in the case of retrofit some matches between hot and cold stream is considered as appropriate or too difficult or costly to change. These streams are part of the steams come under enforced matches and are left out of analysis. There is something called effective temperatures, while extracting stream data from a PFD of hot and cold streams care must be taken to preserve the available heat at its effective temperature. Let us consider an example to explain this.

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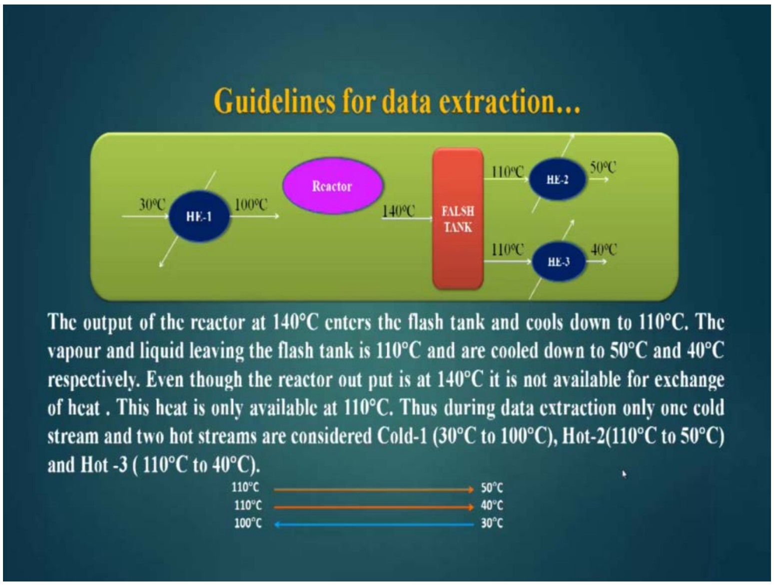

Now, suppose at 30 degree centigrade a steam enters, it goes through heat exchanger number one. It is heated to 100 degree centigrade, it goes through a reactor. From the reactor, it comes out to a 140 degree centigrade, it goes through a flash tank. And the flash from the flash tank there are two streams coming out one the vapor stream which is at 110 degree centigrade goes through a heat exchanger two, and comes out at 50 degree centigrade and a liquid stream which comes out at 110 degree centigrade goes through heat exchanger three and then comes out at 40 degree centigrade.

Now while doing data extraction from this PFD, the hot streams will start form 110 degree centigrade to 50 degree centigrade, and other hot streams 110 degree centigrade to 40 degree centigrade and the cold stream will start from 30 degree centigrade to 100 degree centigrade. We will not consider this 140 degree centigrade at the starting point, because the effective temperature for heat transfer is 110 centigrade and not 140 centigrade.

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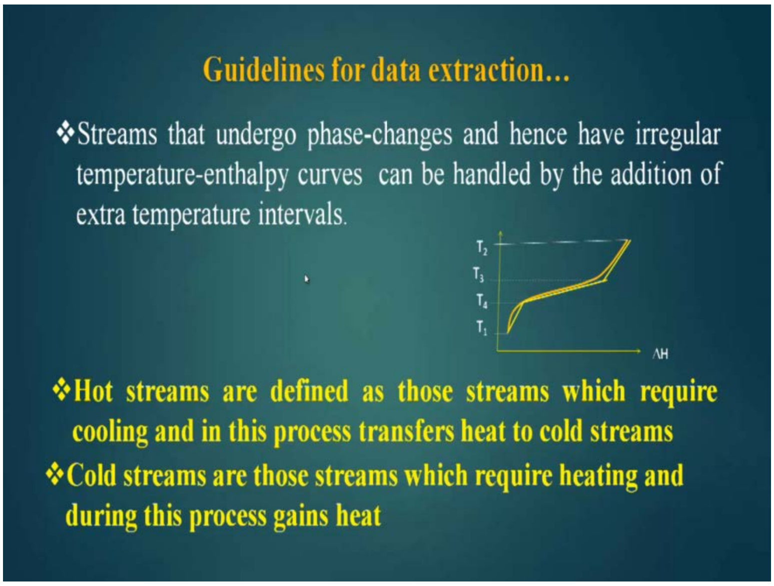

Streams that undergo phase-changes and hence have irregular temperature-enthalpy curves can be handled by the addition of extra temperature intervals. Like, the example is that this is a hot stream which is non-linear in nature. It goes from temperature T 1 to temperature T 2. Now if I want to linearize it, it can be linearized using three linear temperature intervals; that means, T 1 to T 4 and then T 4 to T 3 and then T 3 to T 3. So to do this, we are introducing two more temperature levels that is T 4 and T 3 in this case. Now hot streams are defined as those streams, which require cooling and in this process transfers it to cold streams. So, we will always define these hot streams are those streams which give hit to the cold streams. And cold streams are those streams which require heating and during this process gains heat.

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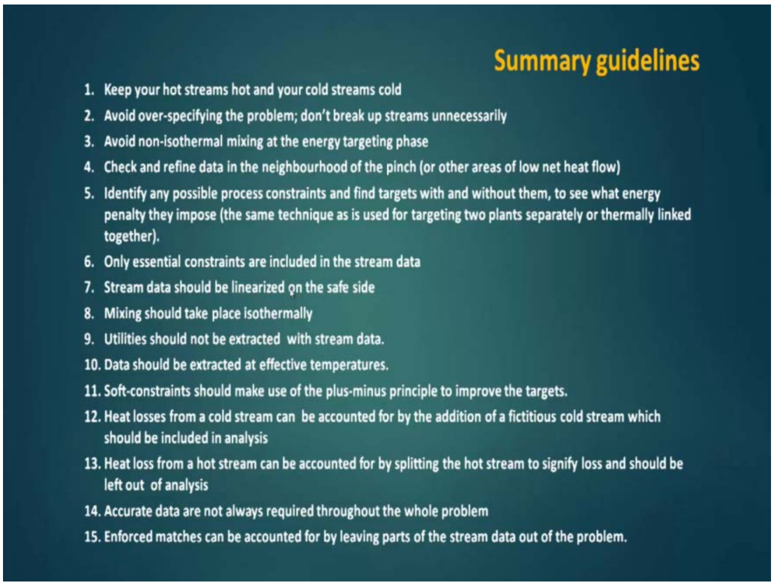

Now, there are some summary guidelines whatever we have talked in detail. They are converted into summary, and there are fifteen points in the summary for data extraction purposes. The first one is keep your hot stream hot and cold streams cold; that means, do not mix them. The second number is avoid over specifying the problem; do not breakup streams unnecessarily. Third is avoid non-isothermal mixing at the energy targeting phase. Fourth one is check and refine data in the neighborhood of the pinch, and this is very necessary because here the heat flow is low, so a little change in temperature difference will effect a lot, because it affects the area of heat exchanger. So, the data in the neighborhood of the pinch should be very very accurate.

Identify any possible process constraints and find targets with and without them, to see what energy penalty they impose - the same technique as is used for targeting two plants separately or thermally linked together. The sixth point is only essential constraints are included in the stream data. Seventh point is stream data should be linearized on the safe side. We have already told about this when you are linearizing the data, the linearized data should have a low temperature than a hot stream, and the linearized cold stream data should be hot in temperature then the cold stream. Mixing should take place isothermally. Utility should not be extracted with stream data this is very very important we will see in an example that we should not include utilities with this stream data.

Data should be extracted at effective temperature this I had already explained to you. Soft-constraints should make use of the plus minus principle to improve the targets this also we have discussed. Heat losses form a cold stream can be accounted for by the addition of a fictitious cold stream which should be included in the analysis, this is very important. Almost industries we incur heat losses from the hot streams, so how to account these streams or these heat loss in data extraction phase. So, the tips is that the heat losses from a cold stream can be accounted by the addition of fictitious cold stream which should be included in the analysis, this is important.

The fictitious cold stream should be included into the analysis, while the heat loss form a hot stream can be accounted by splitting the hot stream to signify loss and should be left out of the analysis. It should be left out of the analysis, the heat loss from the hot stream and for the cold stream it should be included in the analysis. Accurate data are not always required throughout the whole problem. It is seen that with the approximate data, we can do the analysis - pinch analysis, but near the pinch point data should be as accurate as possible. Enforced matches can be accounted for by leaving part of stream data out of the problem.

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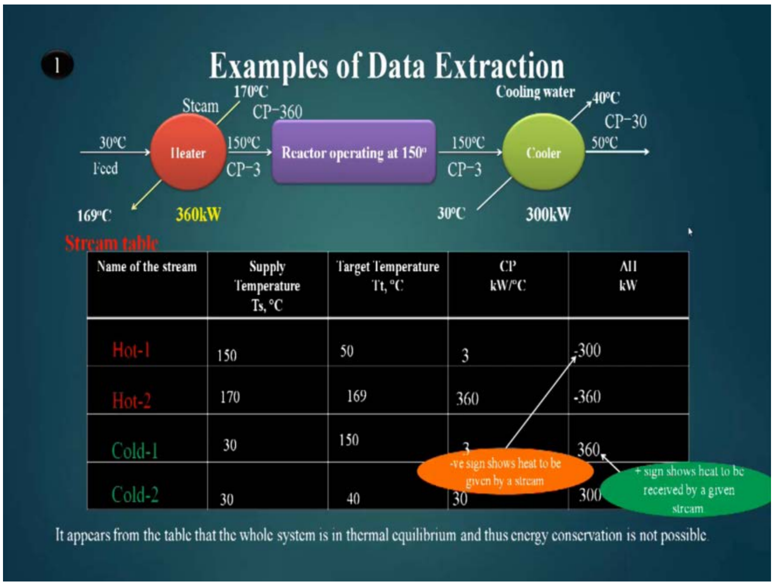

Now, let us take some example, which demonstrates how the data extraction should be done. We take the example one, where the feed is at 30 degree centigrade using a heater it is heated to 150 centigrade, its CP is 3, and it goes to a reactor operating at 150 centigrade; form the reactor the stream comes out at 150 degree centigrade; obviously, CP is 3. Then it goes to a cooler where, its temperature drops down to 50 degree centigrade. Now, here you will see that in this heater I am using a stream, which enters at a 170 degree centigrade and comes out at 169 degree centigrade. This I have explained why I have taken one degree drop in the steam. Moreover most of the books you learn that the steam heating is a isothermal heating; that means, that the temperature remains constant. But practically if you see the steam is flowing there is a pressure drop and due to this pressure drop there will be a temperature drop.

Now the capacity of the heater is 360 kilowatt; similarly, in the cooler the cooling water enters at 30 degree centigrade comes out at 40 degree centigrade, and the capacity of the cooler is 300 kilowatt. Now if I do this data extraction of this PFD then the hot is starting for 150 centigrade to 50 degree centigrade, CP-3, and heat exchange is 300 the hot-2 is 170 to 169; CP is 360, and heat exchanger is 360. And then the cold stream is 30 to 150 having a CP of three heat exchanger is 360, and cold-2 30 to 40 CP is 30 and heat exchanger is 300.

Now, we will see that here 300 units is given here 300 units heat is taken, here 360 units is given and 360 units of heat is taken by cold 1. So, what we observe, here the negative sign is so the heat to be given by a stream, and the positive sign shows heat to be received by a given stream. If you overall analyze that it appears from the table that whole system is in thermal equilibrium and thus energy conservation is not possible, but this statement is not true. And the second part of this analysis we see that we can conserve energy, we can decrease the heater capacity form 360 to 60, and we can eliminate this cooler. Why this has happened here, because I have conceded the utility streams as process streams in the steam table, so utility streams would not be considered while extracting the data.

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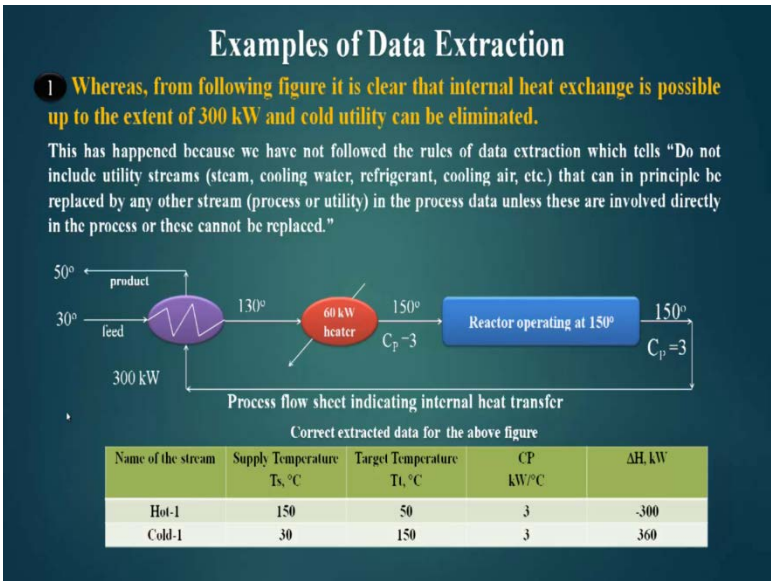

Whereas form the following figure, it is clear that internal heat exchanger is possible up to the extent of up to 300 kilowatt, and cold utility can be eliminated. Now form this figure we see that this feed goes from 30 degree centigrade to this point, and then I have to use a 60 kilowatt heater only then it goes to 150 degree centigrade and comes out 150 degree centigrade, this can be recycled back to this heater. And this product goes at 50 degree centigrade which is the required temperature.

So, you see in this figure, I have replaced a 360 kilowatt heater by a 60 kilowatt heater, and cooler has been eliminated. Why this has happened, this has happened because we have not followed the rule s of data extraction, which tells do not include utility steam, cooling water, refrigerants cooling air etcetera that can in principle be replaced by any other stream in the process data, unless these are involved directly in the process this cannot be replaced.

So, in the previous example, we have done a wrong thing; that means, we have included the utility streams and that is why we are not able to save energy. When we eliminate those utility streams, we find that the hot utility and cold utility can be saved as it is shown in this diagram. So, my correct data extraction will be hot from 150 to 50, CP-3, delta H minus 300; and cold 30 to 150, CP is 3, this is 360. So obviously, the amount of heat required by the cold stream is 60 units more than the available heat of 300, and hence I have to put a heater of 60 kilowatt to satisfy the process.

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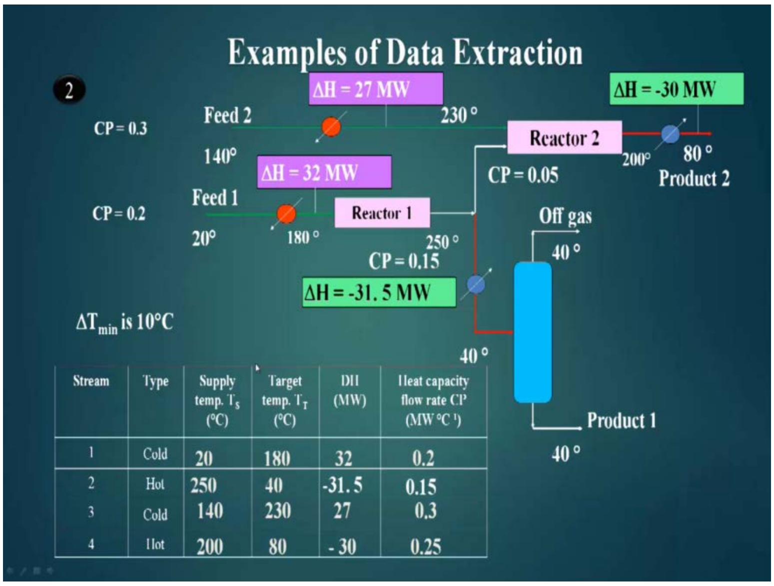

Let us take another example. Here there are two feed streams one feed stream going to the reactor, and whatever comes out partly goes to the reactor two and partly goes to this system which may be a expander. Or this is a flash tank and feed 2 goes to the reactor two and whatever product comes is cooled down and we are getting product two here and here we are getting product one. If we see the temperature levels, feed 2 is at 140 degree centigrade it is heated by a heater here, and we are providing 27 megawatts for this purposes, and it is heated up to 230 degree centigrade; that means, as the stream is receiving heat this is a cold stream as per the definition.

Similarly here the feed 1, enters 20 degree centigrade this is heated up to 180 degree centigrade the delta H is 32 megawatt that means it takes 32 megawatt to heat it form 20 degree centigrade to 180 degree centigrade. So, as this stream is getting heat from outside, this is a cold stream; its CP is 3.3, and its CP is 0.2. Then the hot stream which comes out at two 150 degree centigrade splitted in two parts; this parts goes to the reactor 2, having c p equal to 0.05; this part goes to a cooler where this is cooled down from 250 degree centigrade to 40 degree centigrade. As it is giving heat, so it becomes hot stream shown to you by red line.

Then off gasses is coming out at 40 degree centigrade and the liquid is coming out at 40 degree centigrade which becomes product 1. Then form the reactor 2, the reactants or the product comes out at 200 degree centigrade, the product comes out at 200 degree centigrade it is cooled down to 80 degree centigrade. And as this stream is cooling down and giving heat it is a hot stream, and it is giving heat 30 megawatt.

Now our job is to extract data from this process flow diagram and create a stream table. Now let us see the delta T minimum we have considered to 10 degree centigrade for this case. Now this cold stream which is called cold 1 is form 20 degree centigrade to 180 degree centigrade; this delta H is 32, and this heat capacity rate is 0.2. The hot 2, this is 250 degree centigrade to 40 degree centigrade; the delta H is minus 31.5, and CP is 0.15. And for cold 2, this is the data; and for hot 4, this is the data. So, we have extracted data from this PFD, and this is our stream data table and this is the starting point for the further analysis of the system using pinch analysis.

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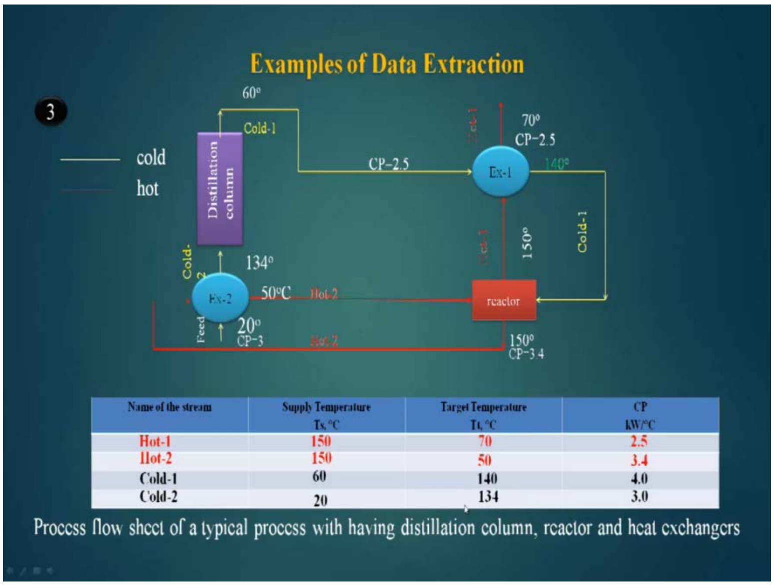

Let us take another example example number three. Now here the feed enters at 20 degree centigrade, CP is three, it is heated by this hot comes to 134 degree centigrade goes through a distillation column. And stream is coming out is 60 degree centigrade, it goes to exchanger number one comes at 140 degree centigrade, it goes to the reactor and this recycles back to the reactor. And the product one is going this way, another is going to this way to heat exchanger number one and comes out at 70 degrees centigrade.

Now we can extract heat from here and make a stream table. This is hot 1, hot 1 starts from 150 degree centigrade hot 1 it is taking, and it cools down to 70 degree centigrade, and CP is 2.5 - the CP is 2.5 here. The hot 2 is this, it goes form 150 degree centigrade to

50 degree centigrade, and CP is 3.4. And similarly cold 1, which starts at 60 degree centigrade goes to heat exchanger and got heated up to 140 degree centigrade, and the CP is 2.5, this would be 2.5, it is not four - it is to 2.5. And the cold 2, cold 2 is this; it starts from 20 degree centigrade goes to 134 degree centigrade and CP is 3. So, this shows data extraction of this PFD.

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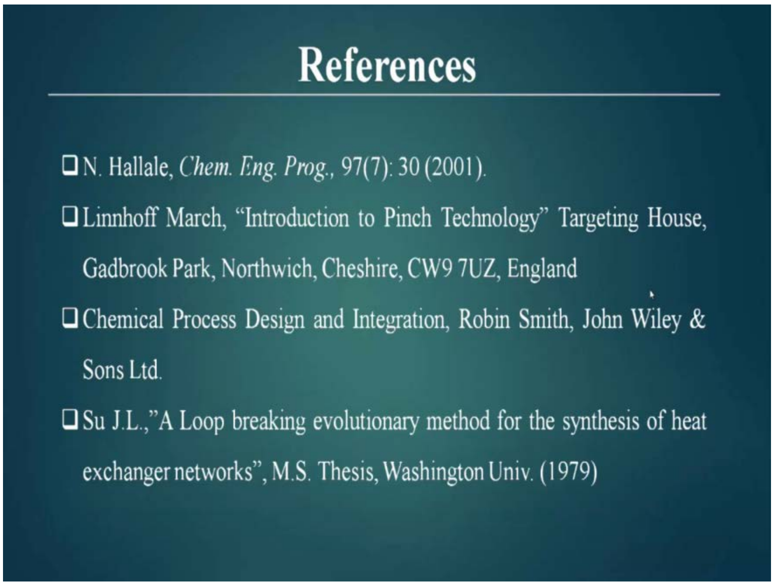

This is our references and thank you.