Process Integration
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Module - 6
Integration and placement of equipment
Lecture - 4
Placement of Heat Engine, Heat pump and Reactors

Welcome to the lecture series on Processes Integration. This is module-six, lecture-four. The topic of this lecture is placement of heat engine, heat pump and reactors. We have seen that proper placement of heat engine or proper placement of any equipment with respect to pinch of a process GCC is important. We have seen the placement of distillation column; similarly, you may see here, how the placement of a heat engine, heat pump and reactors, and what placement will help us to reduce the heat load on GCC or will make the equipment running free of cost.

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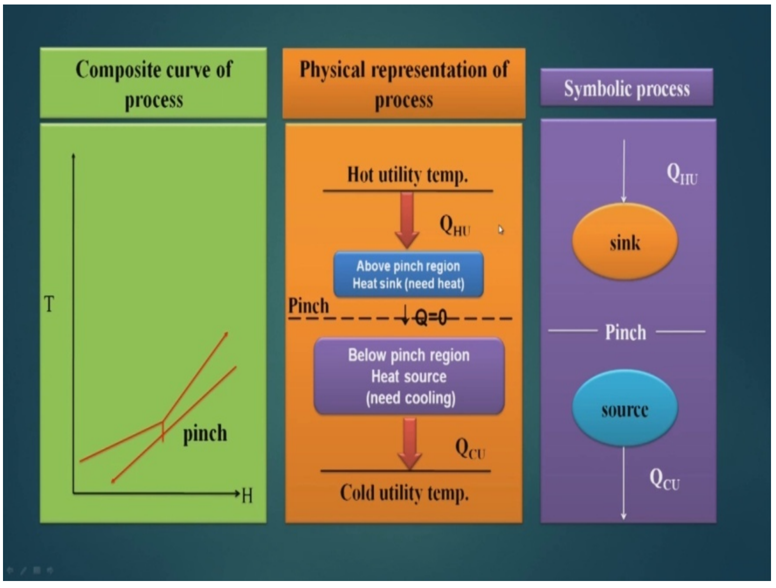

Now a composite curve is show like. This is a T H diagram, and this is the pinch. Now the physical representation of process, here the hot utility temperature is there, this is the above pinch region, which is a heat sink because it needs heat from outside. And the below pinch region is a heat source, it needs cooling for its reject heat into the cooling. And the Q is equal to zero at this level, which is called pinch. So, heat Q HU which is the hot utility comes to above pinch area, here zero heat passes through this pinch, and below the pinch this cold utility to the cold utility it goes Q CU minimum cold utility, and this is minimum hot utility. So, whole process works under two temperature levels that is hot utility temperature and cold utility temperature. And this is the above pinch region and this is the below pinch region. So, this is the physical representation of the process. And see up symbolic representation is this. This is pinch, this is sink, this is source, this Q HU, and Q CU. And once we know this representation will use this for our integration purpose.

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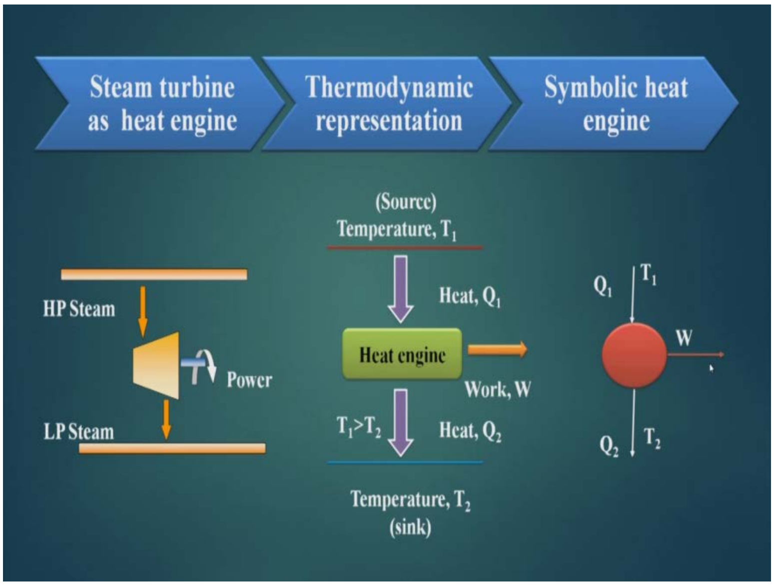

Unless take a steam turbine as heat engine, so here from the HP steam, the steam comes HP steam from this pipeline, and here we generate power and the LP steam goes. So, it is pressure reduction takes place from HP steam to LP stream, and due to the pressure reduction, this steam turbine which is the heat engine gives us power. Now, the thermodynamic representation is like this. There are two temperature levels T 1, which is the source with temperature level up this here; Q 1 amount of heat flows to the engine, and Q 2 amount of heat is rejected by the engine to the temperature level T 2, which is this temperature level. Where T 1 is greater than T 2, and in this process we get a work-W. And the symbolic heat engine will look like this T 1, Q 1, T 2, Q 2 and W.

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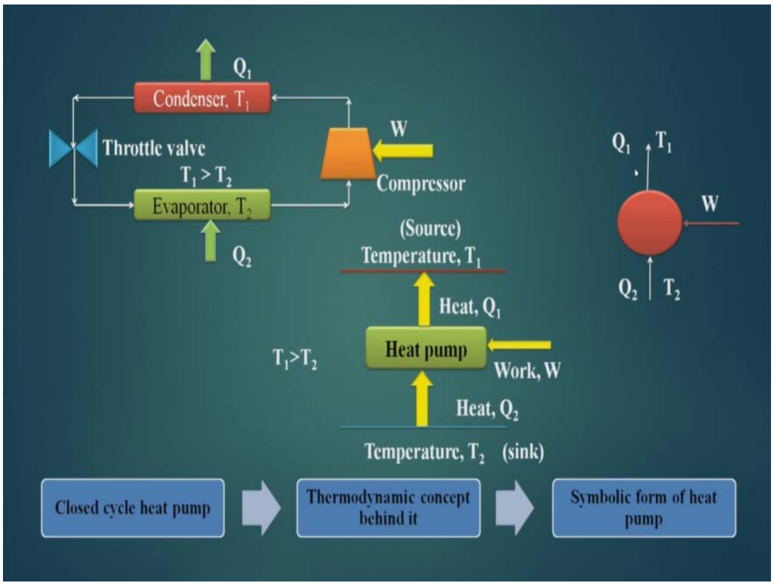

Now, this shows the diagram of a closed cycle heat pump. This is the evaporator, where heat is picked up, and the amount of heat, which is picked up is Q 2. And during this evaporator, in this evaporator air refrigerant evaporators and we get refrigerant vapor here, this is compressed. And for compression, we have to give some energy W, and then compressor vapor, which is at higher temperature goes to condenser, where it rejects Q 1 heat. And the condenser is at T 1 temperature, and the evaporator is a T 2 temperature then the vapor which is at higher pressure condensers, becomes a liquid. Then it is throttle through a valve, where it undergoes pressure change, and then here we get mixture of vapor and liquid at a lower temperature that goes to the evaporator. And the liquid part of the refrigerant evaporates by taking the heat, and again this cycle moves on. So, this is a closed cycle heat pump. Here T 1 is greater than T 2 - that means we are taking heat form a lower temperature and rejecting it at a high temperature.

This is against the natural flow of heat, which moves form a higher temperature to a lower temperature. And hence for this reverse flow of heat, we have to spend energy for this purpose. Thermodynamic concept is this, this is a heat pump picks the heat form a lower temperature level, rejects heat at a higher temperature level. This is Q 2 is sucked, Q 1 is rejected, and for that we give work W, where T 1 is greater than T 2. And the symbolic is this; W goes in to the system, it takes up heat from T 2, Q 2 goes to the system and Q 1 is rejected at T 1.

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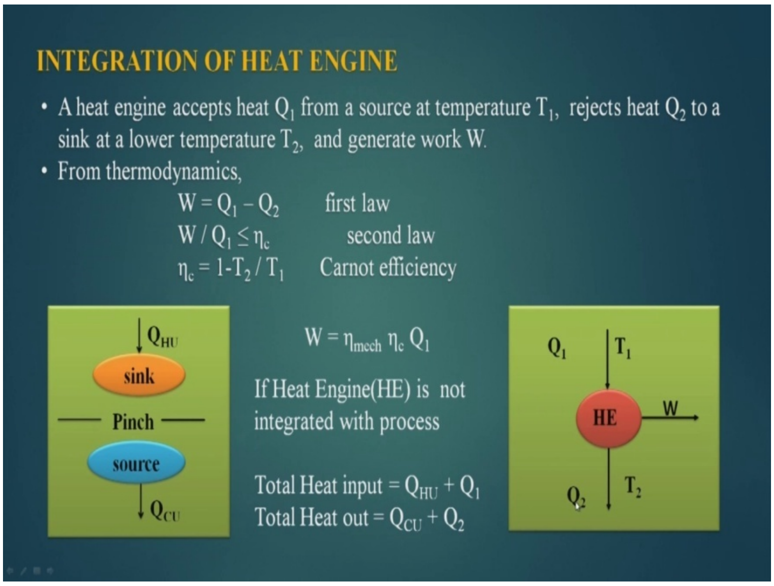

So, we start, first we see the integration of heat engine. A heat engine accepts Q 1 heat from a source at temperature T 1, rejects heat Q 2 to a sink at a lower temperature T 2, and generates work while doing so. So from thermodynamics W is equal to Q 1 minus Q 2 - first law. This W by Q 1 is less than or equal to n c, this second law, where n c is 1 minus T 2 by T 1, this Carnot efficiency. So, if heat engine is not integrated with the process, then what we are consuming, total heat input is Q HU plus Q 1 and total heat out is Q CU plus Q 2. So, in the process Q HU is taken out in the sink, and rejection is Q CU. Similarly, the heat engine takes Q 1 and rejects Q 2, so this is the conjunction of utility when I take the process and heat engine simultaneously. Now, if I integrate this then my this total heat input and total heat output should decrease then only I get some profit out of it here. So, let us see. Now this is my heat engine and this is my process. So, the heat input is Q HU plus Q 1, this plus this, and output is this plus this.

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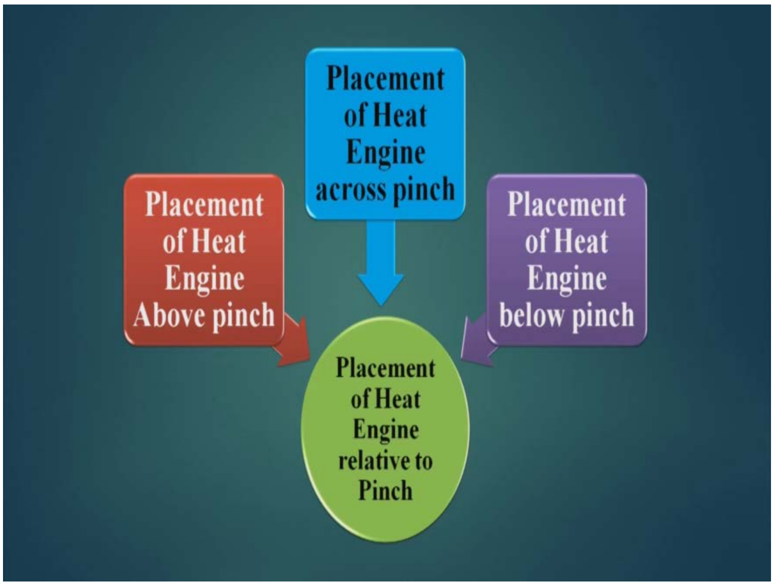

Now, when you talk a placement of heat engine, so obviously placement can be done in three places of a GCC, above the pinch, below the pinch and across the pinch. There is only three possible placements, and all these three possible placements we will see and check where it is profitable to place the heat engine.

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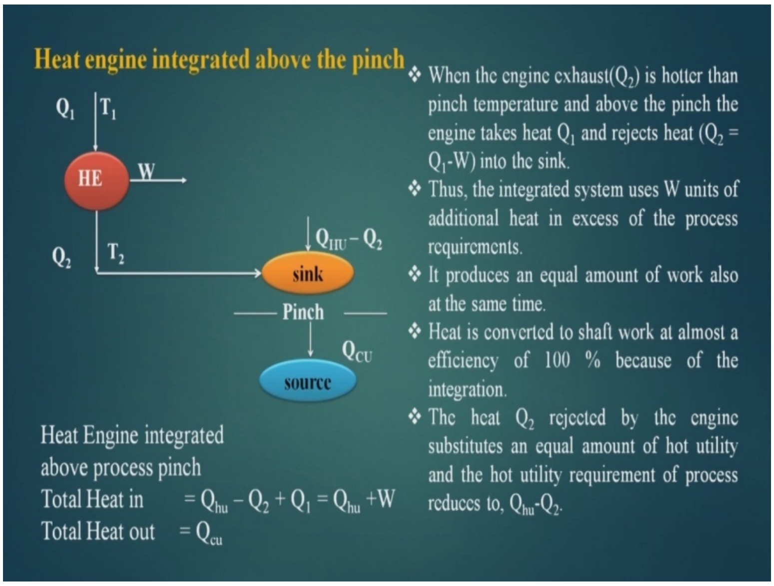

Now this is a process, this is the heat engine. Now if I am placing like this, I am taking Q 1 and rejecting Q 2 to this. If I do so, my hot utility decreases by Q HU minus Q 2. So, heat engine integrated with the above pinch, my total heat in is Q HU minus Q 2 plus Q

1 and which is nothing but Q HU plus W, because Q 1 minus Q 2 is W, and total heat out is Q CU. When the engine exhaust Q 2 is hotter than the pinch temperature and above the pinch the engine takes Q 1 and rejects Q 2, which is equal to Q 1 minus W into the sink. Thus, the integrated system uses W units of additional heat in excess of the process requirements. It produces an equal amount of work also at the same time. So, heat is converted to shaft work at almost a efficiency of 100 percent because of the integration. The heat Q 2 rejected by the engine substitutes an equal amount of hot utility and the hot utility requirement of the process reduces to, Q HU minus Q 2.

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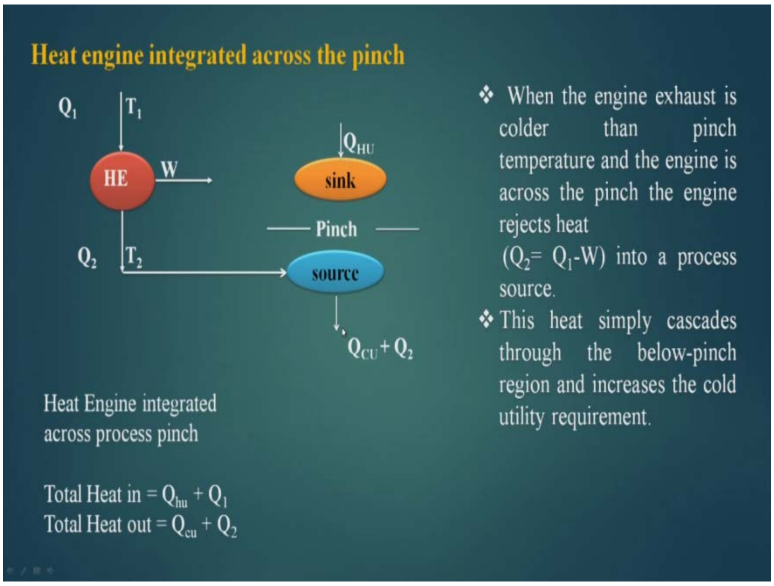

Now we see across the pinch. Heat engine integrated across the pinch. When the engine exhaust is colder than the pinch temperature and the engine is across the pinch the engine rejects Q 2 amount of it into the process source. So, it is rejecting Q 2 amount of heat into this process source which is below pinch. This heat simply cascades through the below-pinch region and increases the cold utility requirement, so it has increases the cold utility requirement.

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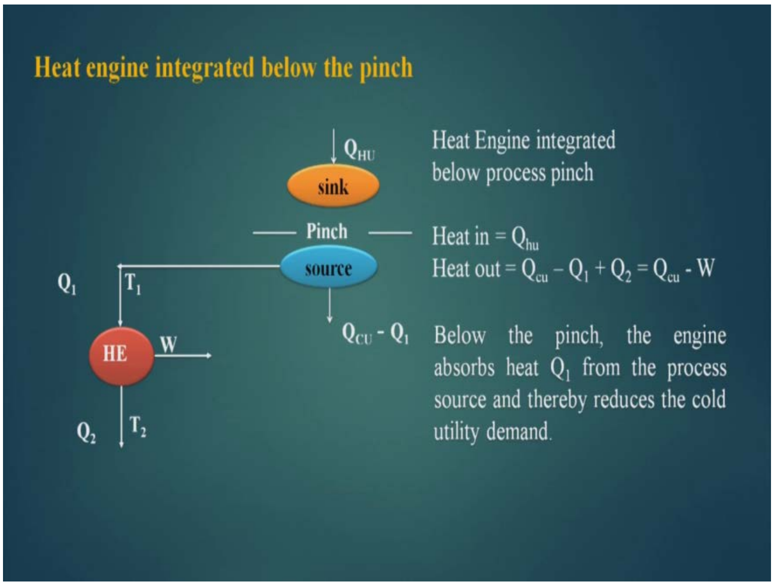

Now if I am integrating it below the pinch, the heat engine integrated below the pinch, I am taking Q 1 heat from below the pinch and rejecting it into the cold water. So, the demand of the cold utility for the process is Q CU minus Q 1, so this is Q CU minus W. Below the pinch the engine absorbs Q 1 from the process source and thereby reduces the cold utility demand.

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Conclusion of heat engine integration with process

	Total Hot Utility	Total Cold utility	Recommendations
Without Integration	$Q_{hu} + Q_1$	$Q_{cu} + Q_2$	
Above process pinch	$Q_{hu} - Q_2 + Q_1 = Q_{hu} + W$	Q_{cu}	PROPER PLACEMENT
Across process pinch	$Q_{hu} + Q_1$	$Q_{cu} + Q_2$	IMPROPER PLACEMENT
Below process pinch	Q_{hu}	$Q_{cu} - Q_1 + Q_2 = Q_{cu} - W$	PROPER PLACEMENT

So, after seeing this, let us see what is happening. Without integration, my total hot utility was Q HU plus Q 1, total cold utility was Q CU plus Q 2. Now above the pinch when I am integrating it, it becomes Q HU minus Q 2 plus Q 1 is equal Q HU W, and the cold utility remains same. When across the pinch I operate, this becomes Q HU plus Q 1 Q CU plus Q 2 - the same as without integration. And when the below pinch I am doing, the Q HU remains same, but your cold utility becomes Q CU minus W.

So, now the final conclusion is that if I am putting of a above the pinch it is a proper placement, though it is not benefiting me very much. But it is decreasing the amount, because Q 1 will be more than W. The below pinch it is proper placement, because it decreasing the cold utility by W amount, but if I am putting it across the pinch, this is a improper placement. So, whenever I will try to put integrate my heat engine with a process, it will be either above the pinch or below the pinch, and it will neighbor be across the pinch. This conclusion we draw by integration.

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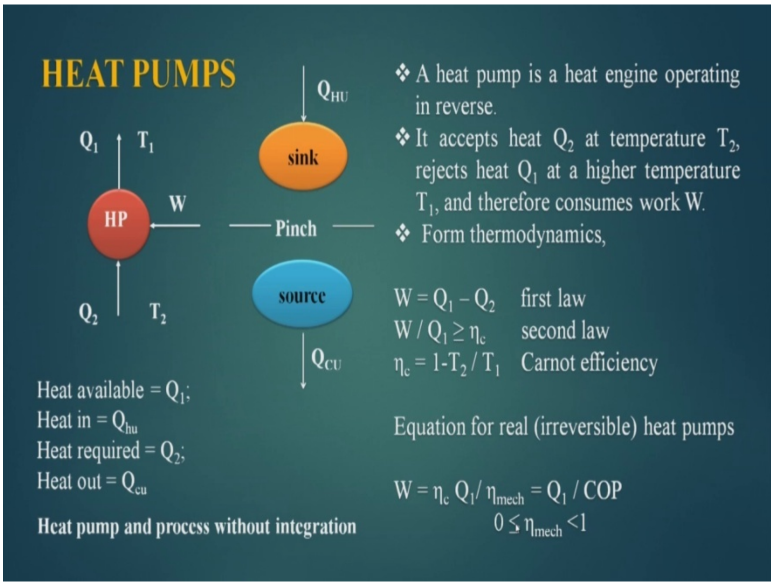

Now, let us see the heat pumps. After finishing the integration part of the heat engines with process GCC, let us take the case of heat pumps and its appropriate placement. So, symbolically the heat pump is shown like this, and the process is also shown the right hand side. So, heat available is Q 1, heat in is Q HU, heat required is Q 2, and heat out is Q CU. So, here heat is pumped, Q 2 amount of heat is pumped by using W amount work and it converts in to Q 1. So, this heat is available and this needs to be pump from a lower temperature level.

Now a heat pump is a heat engine operating in reverse, this we know. It accepts Q 2 heat at temperature T 2 at a lower temperature, which is rejects Q 1 at a higher temperature T 1, and therefore, consumes work, which is equal to W, because it is against the natural flow of heat. From thermodynamics, W is equal to Q 1 minus Q 2 - first law; second law W by Q 1 is greater or equal to n c; n c is this 1 minus T 2 by T 1. And the equation for real irreversible heat pumps is this, where n mechanical efficiency is this heat 0 to 1, there is a concept of COP here.

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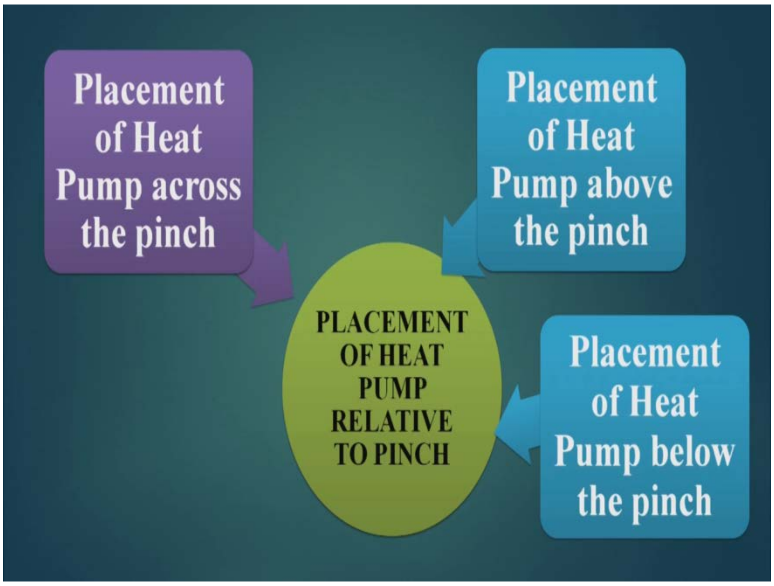

Now let us take the placement of heat pump across the pinch. So, when I talk about the placement of the heat pump, we saw this pinch then it can be above the pinch, it can the below the pinch or it can be across the pinch. So, there are three places for placement, and we have to check all these three places, and see where the placement is beneficial and where should not place the heat pump.

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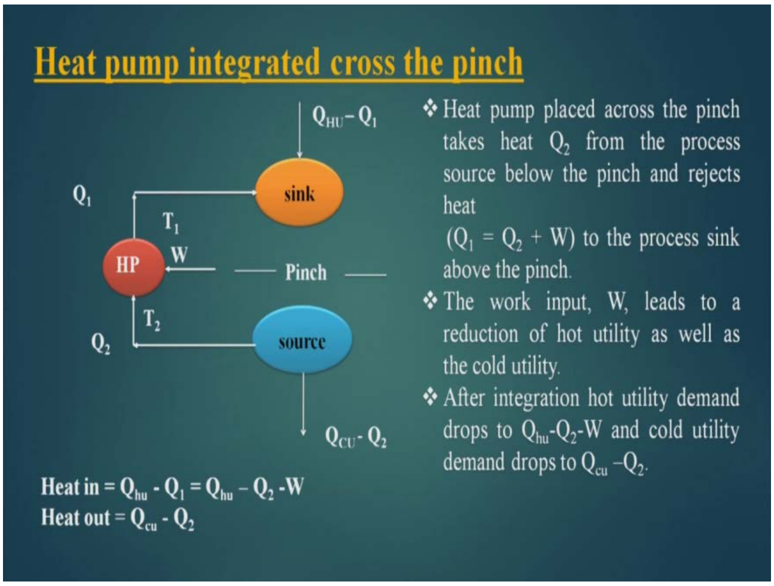

Now, we see the heat pump integrated across the pinch. So, what we are doing here, I am injecting heat Q 1 to this sink, and taking Q 2 heat form here, injecting Q 1 heat to the sink, and to transfer the heat I am working giving work equal to W. So, when I do so, the hot utility requirement reduces from Q HU to Q HU minus Q 1, and the cold utility requirement also reduces said Q CU minus Q 2, and this is expected, because at this source heat is available extra, it is available which will otherwise go to the cold utility. So, if I take up some heat form here, so conjunction of cold utility will decrease. Similarly, sink needs heat if I supply from outside, it will decrease the hot utility requirement and this is what we see here. So, heat in is Q HU minus Q 1 is equal to Q HU minus Q 2 minus W, and heat out is Q CU minus Q 2.

The heat pump placed across the pinch takes heat Q 2 from the process source below the pinch and rejects heat Q 1 to the process sink above the pinch. The work input, W, leads to a reduction of hot utility as well as the cold utility. So, we are spending W amount of work, but while doing so, we are reducing the hot utility and cold utility requirement. After integration hot utility demand drops to Q HU minus Q 2 minus W, and cold utility demand drops to Q CU minus Q 2.

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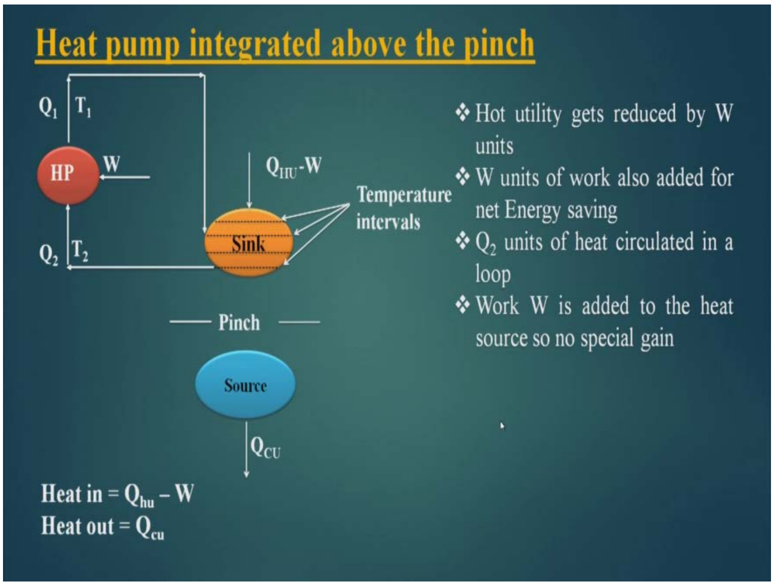

Now, heat pumped integrated above the pinch. So, if I integrated above the pinch, so at a particular temperature level, I pick up the heat, reject the heat at this temperature level. At the bottom temperature level I pick up the heat Q 2 at a T 2 temperature level and reject it at a T 1 temperature level, where T 1 is greater than T 2, and these are the temperature level. So, while doing so, my hot utility requirement is Q HU minus W, and Q CU remain same. Heat in in is Q HU minus W, and heat out is Q CU.

So, hot utility gets reduced by W units. W units of work also added for net energy saving. So, I am utilizing W amount of work, and I am getting the reduction in Q HU, the same amount. Q 2 units of heat circulated in the loop from this to this area Q 2 amount of heat being circulated. Work W is added to the heat source so no special gain. So, whatever I am investing, the same I am getting so no special gain.

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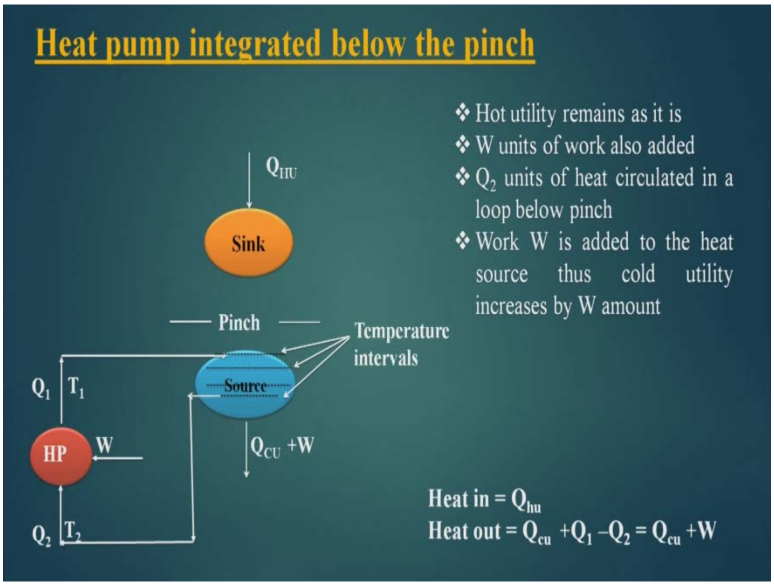

If I heat pump is integrated below the pinch, so here at a lower temperature level, I am picking up Q 2 amount of heat and then pumping heat at a higher temperature level T 1 and spending W amount of work. So, heat in is Q HU, this is remains unchanged; heat out is Q CU plus Q 1 minus Q 2 is equal to Q CU plus W. So, hot utility remains as it is. W units of work also added. Q 2 units of heat circulated in the loop below pinch. And Work W is added to the heat source thus cold utility increase by W amount.

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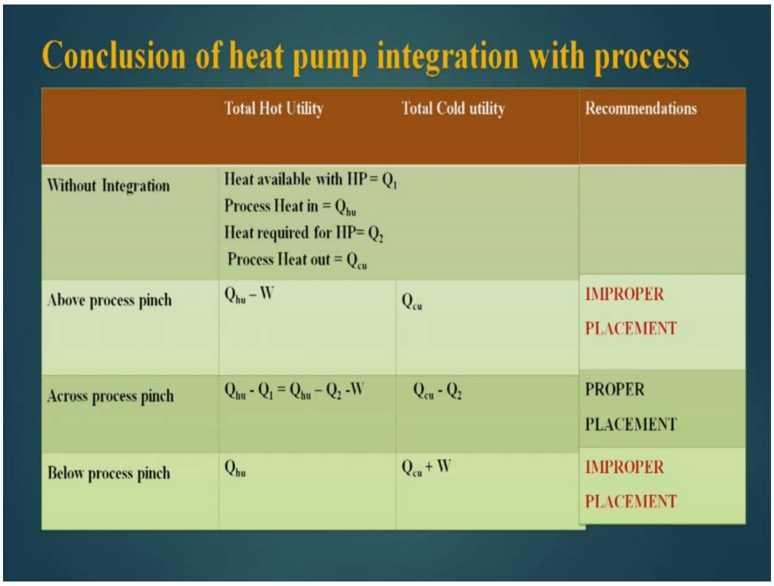

Let us now see the conclusion part of the heat pump integration with the process. Now, without integration, the heat available with the heat pump is Q 1 that means, it is able to push Q 1 heat to the surrounding, and heat required for the heat pump is Q 2 that means, it picks up Q 2 heat and sends Q 1 heat to the surrounding. And if you see the process, hot utility requirement for the process is Q HU, and the cold utility requirement is Q CU. So, when we integrate the heat pump above the pinch, the hot utility requirement becomes Q HU minus W, and the cold utility requirement remains unchanged, this Q CU. However, we are utilizing W power to pump the heat Q 2 form a lower temperature, and rejecting it with Q 1 at a higher temperature.

So, practically no gain, because we are investing W work, and we are reducing the heat by W, so no gain. But if you see for the across the pinch, when we integrate heat pump across the pinch, then my hot utility requirement comes down, and this is now Q HU minus Q 2 minus W, substantial reduction in hot utility. And then, Q CU also reduces that is cold utility requirement and it becomes Q CU minus Q 2.

So, here we get a gain that means, hot utility reduction is there, and cold utility reduction is there. Below the pinch, if we see this scenario, the hot utility remains the same, but the cold utility increases by W amount. So, here also below the pinch, we are a loser and we not a gainer. And hence the final conclusion will be that above the pinch - improper placement; that means, do not place heat pumps above the pinch. Across the pinch - proper placement, because it reduces hot utility and cold utility. And below the pinch again improper placement that means, do not place heat pump below the pinch. So, the only place, where heat pump will profitably work is across the pinch.

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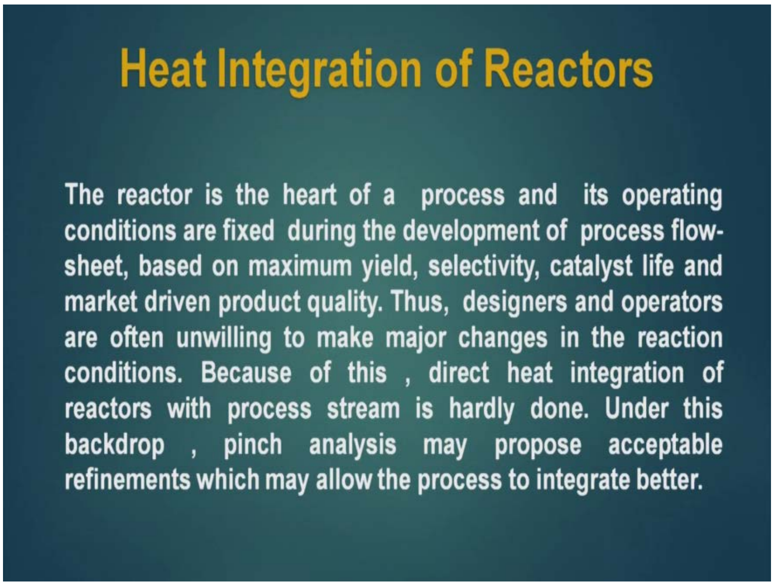

Now let us take the reactor, the placement of the reactor. The reactor is the heart of a process and its operating conditions are fixed during the development of process flow sheet, based on maximum yield, selectivity, catalyst life and market driven product quality. Thus, designers and operators are often unwilling to make major changes in the reaction conditions. Because of this, direct heat integration of reactors with process stream is hardly done. Under this backdrop, pinch analysis may propose acceptable refinements, which may allow the process to integrate better.

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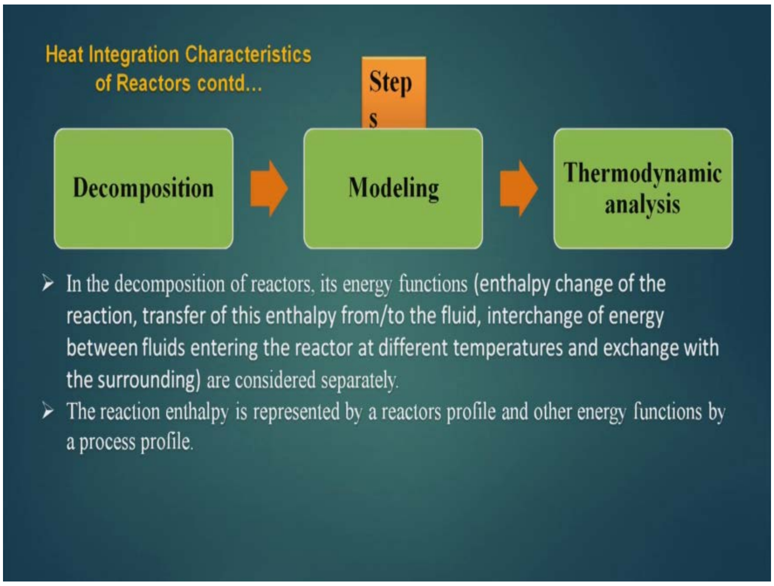

Now, the heat integration characteristics of rectors can be divided in to three parts – decomposition, modeling and thermodynamic analysis. In the decomposition of reactors, it is energy functions that is enthalpy change of the reaction, transfer of this enthalpy from to the fluid, interchange of energy between fluids entering the reactor at different temperatures and exchange with the surrounding are considered separately. The reaction enthalpy is represented at a reactor profile and other energy functions are a process profile.

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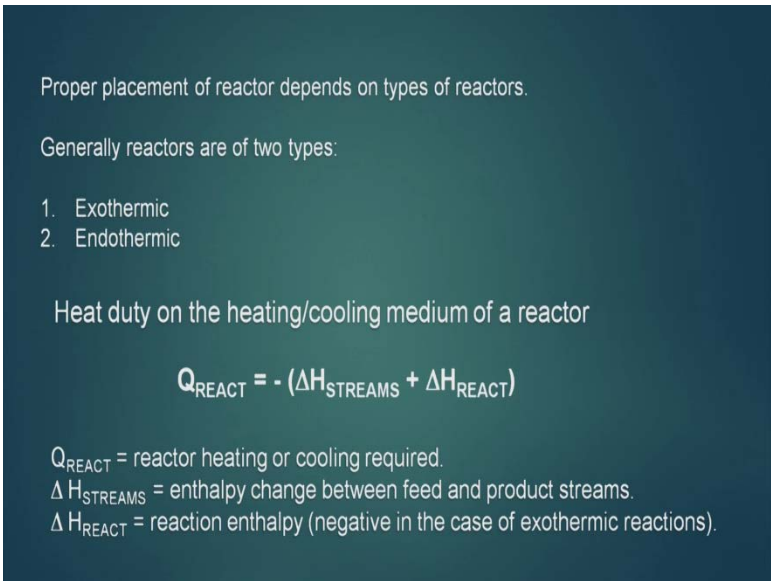

Now the proper placement of reactor depends upon type of reactors. Generally reactor are of two types – exothermic, endothermic. Heat duty on the heating cooling medium of a reactor can be retain like this Q reactor is equal to minus delta H streams plus delta H reactants. And Q react is there reactor heating or cooling requirement, delta H streams is enthalpy change between the feed and product streams, and delta H react is reaction enthalpy negative in the case of exothermic reactions.

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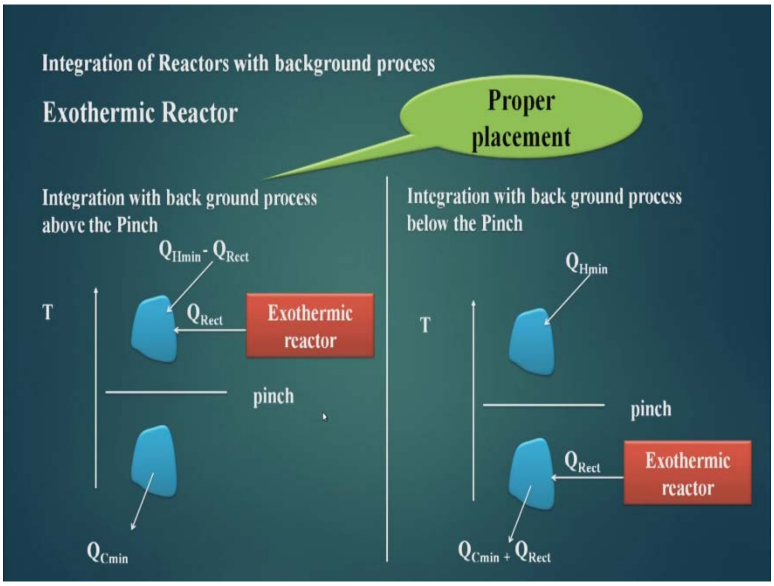

Now, integration of rectors with background process, if I have a exothermic rector then integration if I do above the pinch then it is beneficial, because exothermic reactor has got large amount energy available with it and needs cooling. So, back it can be put into this to decrease the hot utility demand above the pinch. Now if I put this below the pinch then the cold utility demand increases which is not acceptable fact. So, the proper placement is above the pinch, if it is a exothermic reactor.

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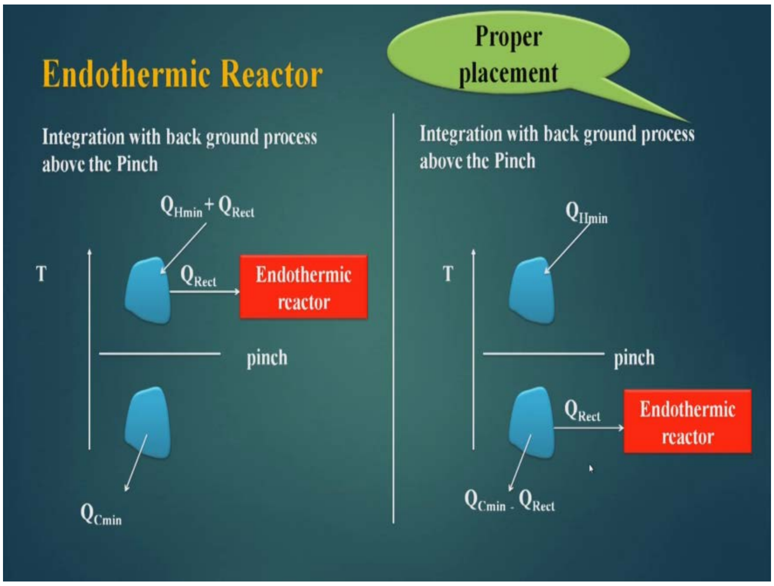

For endothermic reactors, it will be reverse. If I pick up it, if I integrated above the pinch then it will take heat from here, and this is heat deficient. So, my hot utility requirement will increase, which is not acceptable. And if is integrate it below the pinch, here extra heat is available which can go to endothermic reactor, so it will reduce the cold utility react amount of the process. So, this is acceptable fact. So, proper placement is this. If it is an endothermic reactor, below the pinch; if it is a exothermic reactor, above the pinch.

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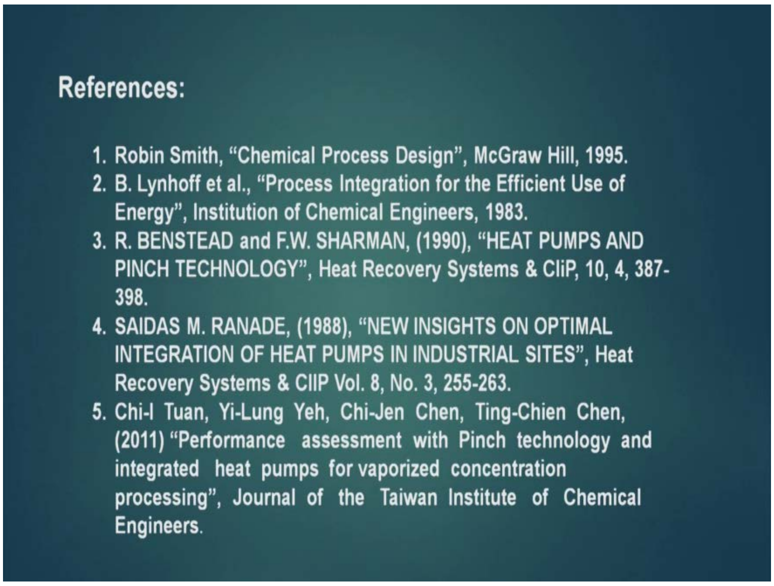

So, these are the references.

Thank you.