Process Integration
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Module - 05
Pinch Design Method for HEN synthesis
Lecture -13
Integration of Gas turbine with process- 2nd Part

Welcome to the lecture series, on process integration. The topic of the lecture is integration of gas turbine and this is the part 2 of a 2 lecture series on integration of gas turbine. As we know that when we design a hen or a heat exchanger network, it needs hot utility as well as cold utility. In general the hot utility is purchased and thus we spent a lot of money on these two utilities, in most of the industries we also use gas turbine for the production of electricity.

Now, the exit hot gas the exit hot gas of the gas turbine, if it is used as a hot utility in the heat exchanger network. Obviously the total cost of operation of the gas turbine, as well as heat exchanger network will come down. So, it is a win-win situation, so when see now that how the exhaust gas which comes out of the gas turbine can be used as hot utility, in the heat exchanger network. And in this process we are integrating, the gas turbine with a heat exchanger network. In the lecture number 1 of the part 1 of this series of lectures on gas turbine, we have learnt about the gas turbines and their types. We have analyze the gas turbine we have seen the process GCC and possibility of matching the gas turbine exhaust with process GCC…

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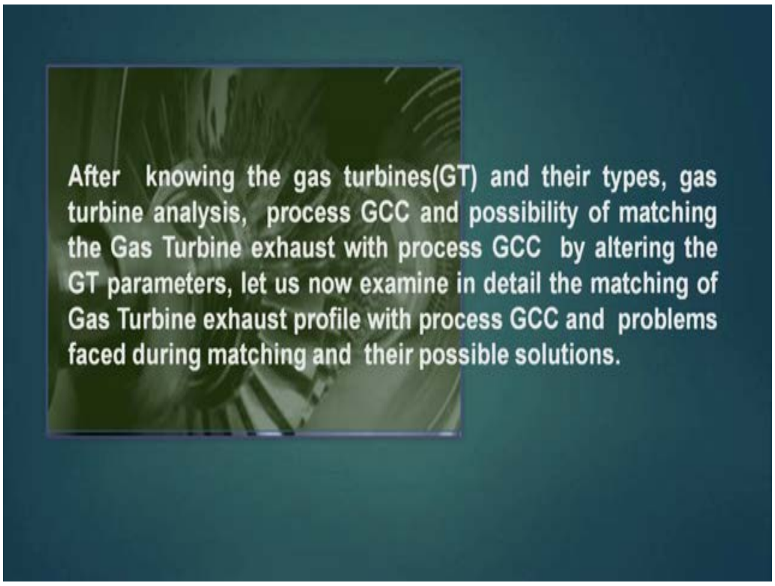

By altering the G T parameters that means the matching is not very accurate, then we have some parameter in our hand using which we can adjust our gas turbine, exhaust gas temperature to suit the G C C. Now, we will examine in detail the matching of gas turbine exhaust profile with the process G C C, and problems face during matching and their possible solutions. The matching of exhaust profile of gas turbine to the G C C of a process events examinant in detail.

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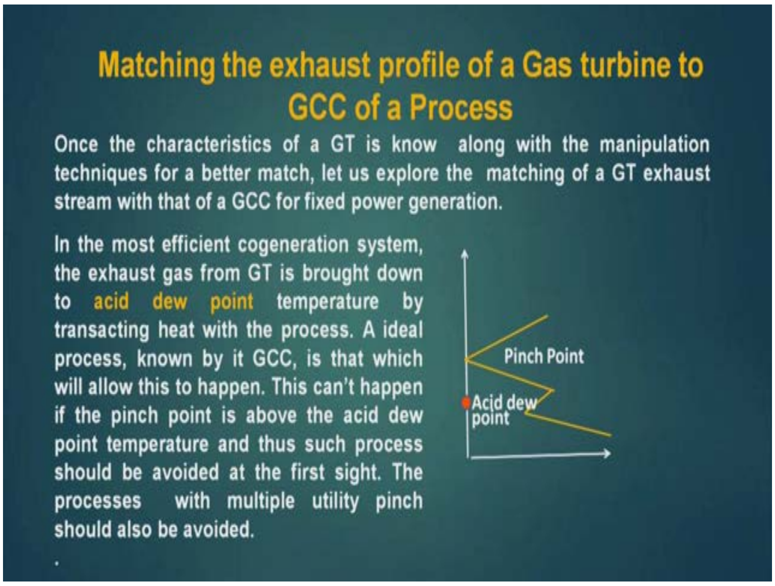

Once the characteristic of G T is known along with the manipulation techniques which we have seen using of after burners a better match can be done. So, let us explore the matching of G T exhaust stream with that of G C C for a fixed power generation. Now, let us see, when a cogeneration system in which we are producing power, and the hot gas form the gas turbine is also used as a hot utility. In such a cogeneration system how the hot gas from the G T can be used optimally.

In most of the cases a efficient cogeneration system, the exhaust gas from G T is brought down to the acid dew point temperature by transacting heat with the process, because we cannot go below the acid dew point temperature. Otherwise condensation of acid will take place in the gas price and that will erode the equipment handling the gas. So, the minimum temperature up to which we can go is acid dew point temperature, in fact we keep our temperature little bit higher than the acid dew point temperature in a design. For in a ideal design you can say that you can go up to the acid dew point.

A ideal process known by G C C is that which will allow this to happen, we will see that it is always possible to happen and if it is not happening, then what are the ways to make it happen. Now, this cannot happen if the pinch point is above the acid dew point temperature here in this plot, we see that acid dew point is below the pinch point. So, if it is so then the G T exhaust gas profile cannot touch dew point, it has to be above the pinch point. In such a process will be avoided at the first sight if such happens, then we should try to avoid such type of processes. So, we will try to avoid this process. A second thing is that if the process is with the multiple utility pinch, we should also try to avoid it.

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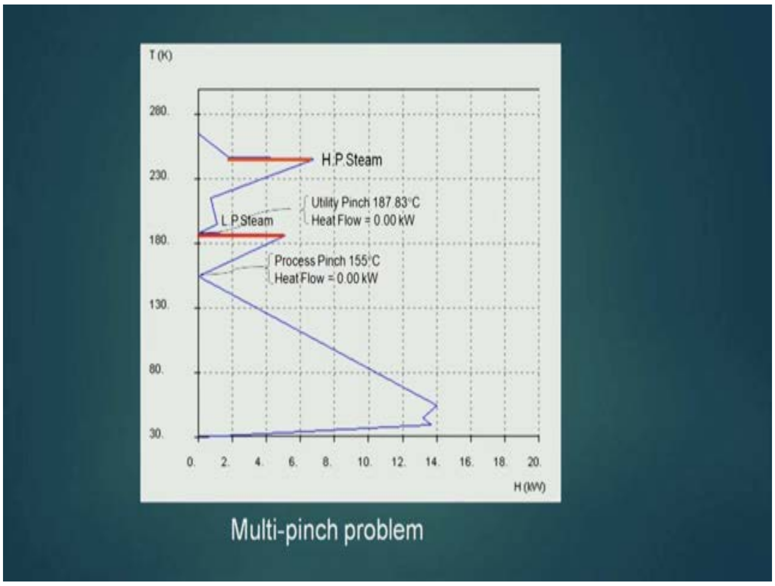

Now this is a G C C of a process, which has got multiple pinch this one is the utility pinch the heat flow is 0, here this is the process pinch the heat flow is 0. So, it has got multiple pinches you can have more than one utility pinches also, if we face such a problem then will try to avoid it for integration.

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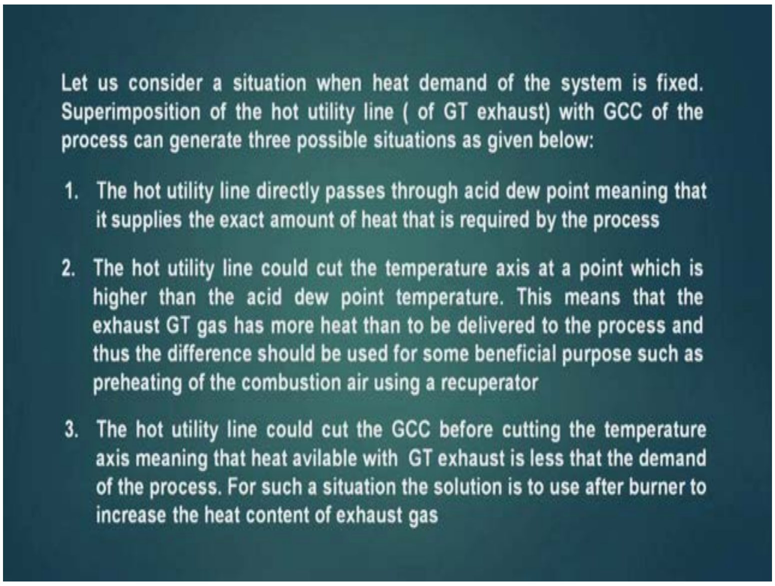

Let us consider a situation when heat demand of the system is fixed. Superimposition of the hot utility line that is G T exhaust with G C C of the process can generate, three possible situations as given below. The first situation is the hot utility line directly passes through the acid dew point meaning that it supplies the exact amount of heat, that is required by the process. This is very ideal situation and we will always welcome this.

There can be a second situation also that hot utility line could cut the temperature axis at a point, which is higher than the acid dew point temperature. And if the hot utility line is doing so, that means it is not giving its full heat to the system. This means that the exhaust gas has more heat than to be delivered to the process, and thus the different should be used for some beneficial purpose, what will be that beneficial purpose? It can be preheating of combustion air using a recuperator, a more heat is available with the G T exhaust. Then it should use it for a fulfill purpose and that purpose will be a recuperate or in which the incoming gas will be heated up for the incoming air will be heated up.

Now that can be third possibility the hot utility line could cut the G C C before cutting the temperature axis. Meaning that heat available G T exhaust is less than the demand of the process. For such a situation the solution is to use after burner to increase the heat content of exhaust gas. Basically this after burner and recuperator using this two techniques we are manipulating the G T gas profile to match properly with the process G C C. So, design can be from two angle you can see the design a gas turbine is use is available we are matching the hot gas profile of the gas turbine with G C C, or G C C is available and we are designing a gas turbine to match the demand of the G C C.

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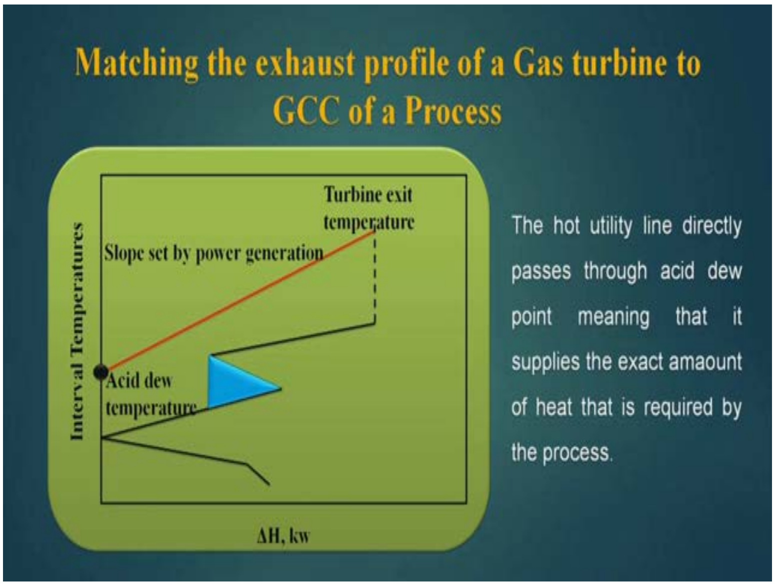

Now, the first possibility where the turbine exist temperature is this, this is a G T gas profile heat crosses the acid dew point temperature. This is a very ideal situation if it is so then we do not have to bother much. The hot utility line directly passes through the acid dew point meaning that it supplies the exact amount of heat, that is required by the process now the second possibility is that.

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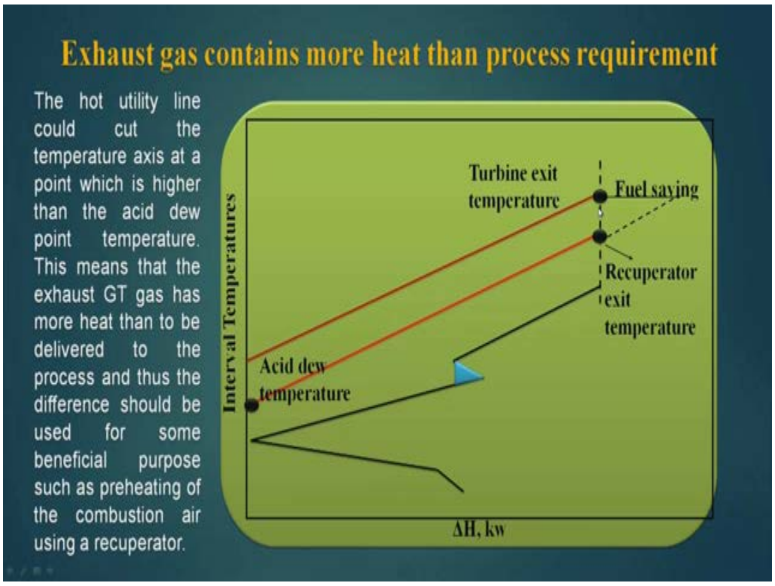

Now, this turbine exhaust is add this temperature, it is cutting the temperature axis above the acid dew point. That means it has got more energy than required, hence I should shift this temperature to this temperature, so that it passes through the acid dew point temperature. Now how to do this? That means I will take up some energy from this turbine exit gas and that energy will be given to the recuperator. So, this recuperator will heat the incoming air and will bring down the turbine exist gas temperature. So, there will be a fuel saving of this amount because this is delta h axis. So, the fuel were saving will be worth this much of delta h.

The hot utility line could cut the temperature axis at a point, which is higher than the acid dew point temperature which we see in the picture. This means that the exhaust gas has more heat than to be deliver to the process, and thus the difference should be used for some beneficial purpose. Such as preheating of the combustion air using the recuperator, basically we using the recuperator, where resizing it and we are making the matching better by now using the recuperator.

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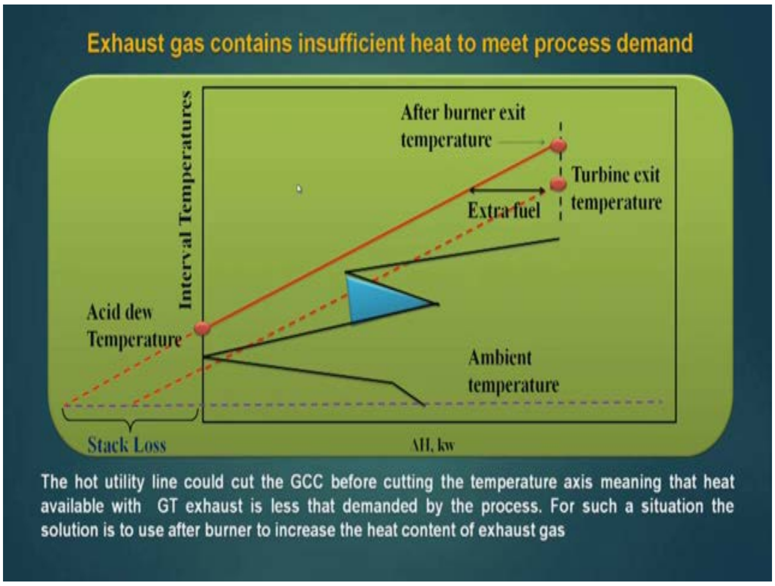

Now, the third situation is then when the turbine exist temperature is this, this is the G T exit gas profile it cuts the G C C see that it cuts the G C C here, here, here. Now, this part of the G C C will not be served by the hot gas and this part of the G C C will not served by the hot gas. So, it is not fulfilling its requirement, basically the G C C heat will be used to heat the stream from this temperature to this temperature, from this temperature to this temperature. Now, it is not doing because this part of the stream will not be heated by this gas. So, it is not satisfying.

Now, if it is so then we will use the after burner to increase it heat, so we use after burner to increase the exit temperature of the gas. And now it moves away and now it is able to give heat to all part of this G C C, which are above the pinch and passes through the acid dew point. That means if it is not passing through the acid dew point it is below than the acid dew point, we can heat it up using a after burner so that it passes through the dew point. So, we have to use here extra fuel of this much of amount to bring this temperature from here to this point, and the other thing is that when doing this the losses are also increasing, this stack loss is also increasing a part of this fuel will go for this stack loss which has increase from this point to this point.

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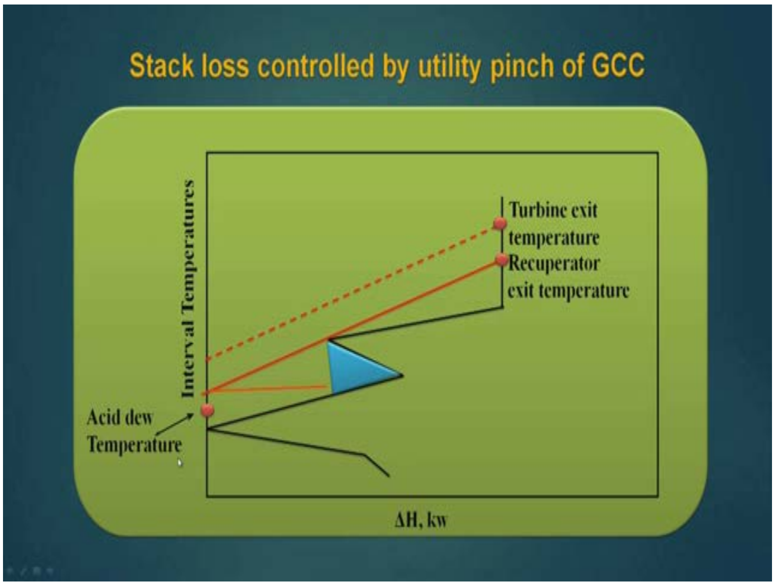

Now, there is utility pinch here what we see that this area where there is a utility pinch controls that the temperature, this is acid dew point and I should come to this acid dew point. That means, the this line should cross this, if it cross then the real job has been done otherwise there is a loss, I am not able to sue this much of heat and why this is not able to cross this acid dew point because there is a utility pinch here. So, as the maximum heat has to be tangent to this point.

So, if the turbine exit temperature is here which is much above the acid dew point, I can bring it down by using a recuparetor to a temperature, when this line is tangent to this point I cannot go below. If I go below to reach this point then a part of G C C will not be serviced by this hot G T gas, this is a exhaust gas of the G T. So, the utility pinch will control this stack loss because when it is reaching up to this point, I have larger stack loss here. And if it will go through this I will have smaller stack loss here.

So, in many times we will see that the stack loss is controlled by the utility pinch and the early part of this lecture, we have seen that that if there are lot of utilities pinches are available in the G C C. Then we will try to avoid that problem because it will not allow the full heat of the G T exhaust to be utilize for the heating purpose. Now, let us see after seeing all these things, about learning about the gas turbine outs temperature can be manipulated using recuperator and after burner. What is a G C C of a process, how to match the G T exhaust gas profile with the G T, G C C. Let us formulate a algorithm for integration of gas turbine exhaust with process.

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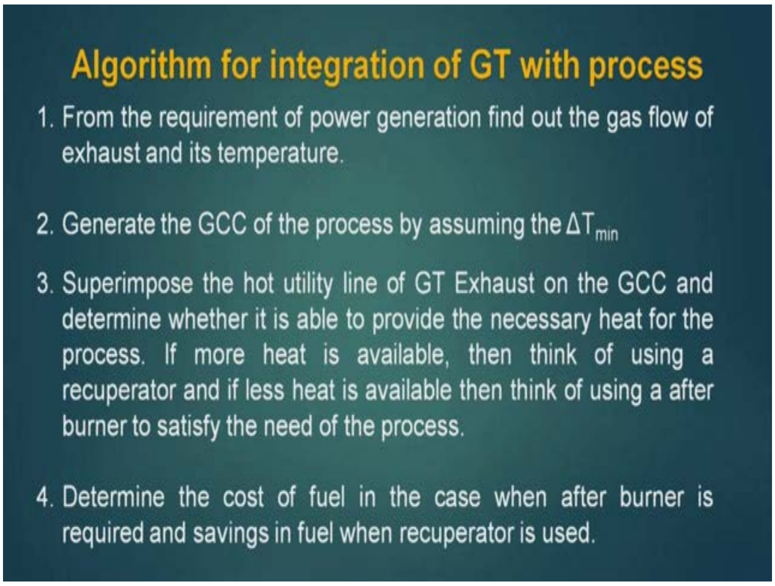

The number one point of this is from the requirement of power generation, find out the gas flow of exhaust and its temperature. Second generate the G C C of the process by assuming the delta T minimum value. Now, this delta T minimum value here is adoc value, which can further be optimized through economic analysis. Number 3 superimpose the hot utility line of G T exhaust on the G C C, and determine whether it is able to provide the necessary heat for the process. If more heat is available then think of using a recuperator, and if less heat is available then think of using a after burner to satisfy the need of the process.

Forth point determine the cost of fuel in the case when after burner is required, and savings in fuel when recuperator is used. Basically all our decision will be based on an economical analysis, when will use the stack total annual cost of the integrated system. And based on the performance of the system, based on the analysis of stack means select the system which keeps us the best profit.

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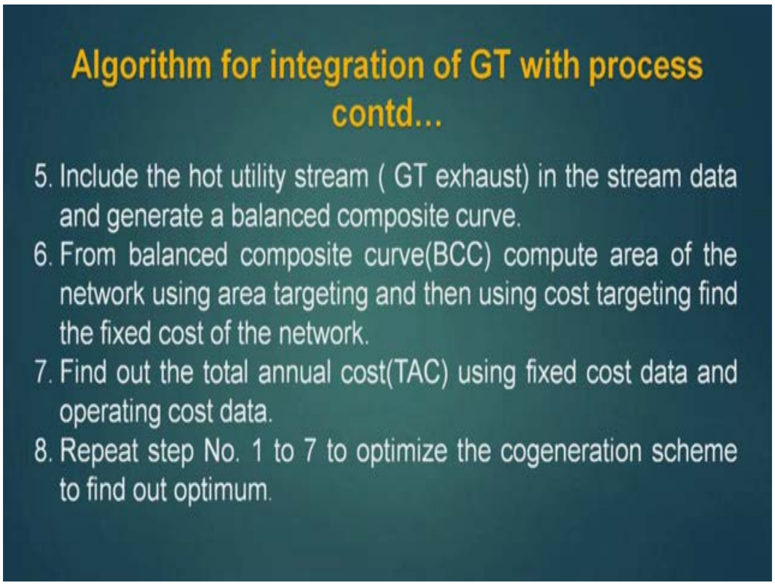

The fifth number is include, the hot utility stream G T exhaust in the stream data and generate a balanced composite curve. We have already learnt in this lecture series how to create a balanced composite curve, why we create a balanced composite curve? Because if you want area targeting then balanced composite curve is required, because once we take the balanced composite curve the area involved for heaters and area involved for coolers can be computed.

From the balanced composite curve, compute area of the network using area targeting. And then using cost targeting find the fixed cost of the network. So, we have gone to the area targeting to compute the fixed cost of the network, find out the total annual cost using fixed cost data and operating cost data. Operating cost will be obviously the cost of the hot utility and cold utility and also we can use the pressure drop data. Repeat step number one to seven to optimize the cogeneration scheme to find out optimum, we can have different cogeneration streams. We can have different temperature of the exit gas, we can use different techniques to adjust it and for all those techniques, we have to find out the stack value to find out the optimum.

The optimum power generation, let's see that what is a optimum power generation when we can we are going for the integration of a heat exchanger network and a gas turbine. Now, there can be tools cool of thoughts, we can design a G T for a given G C C or we can, think of a G T which is already available and we are trying to matching its temperature profile of the exit gas temperature profile with the existing G C C. And best matching we want to find out. So, we will let us see this tools cool of thoughts rather than fixing the power generation at a constant value the problem can be modified to examine, how much power can be economically generated for a given process heat demands.

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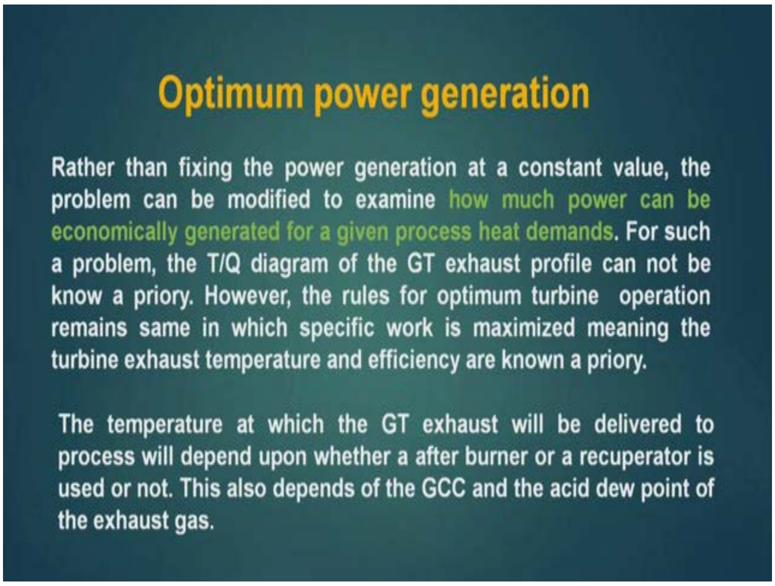

So, processes with us and process G C C will tell us that what is the process heat demand. So, we will see that if the G C C is available, how much power can be economically generated for that G C C of the process. For such a problem the T Q or T H diagram of the G T exhaust profile cannot be know a priory. However, the rules for optimum turbine operation remains same in which specific work is maximized meaning the turbine exhaust temperature and efficiency are known a priory.

So, the fundamentals of G T is known and how to maximize the G T for a power application and in that case, we have seen that we have to maximize the specific work and the compression ratio. The temperature at which the G T exhaust will be delivered to the process will depend upon whether a after burner or a recuperator is used or not. Obviously we have seen that the G T temperature or the exhaust temperature of the G T exhaust can be manipulated using the after burner and recuperator. And this is important we have seen this because by doing so, we can pass the G T line or the temperature profile line, through the acid due point or you can go close to the acid dew point. This also depends on the G C C and the acid dew point of the exhaust gas.

So, the fitting of the G T exhaust gas profile depends upon the G C C of the process. The G C C of the process will dictate and the dew point position will dictate, what should be the profile what should be the mass flow rate of the gas because the mass flow rate of the gas or N C P will decide the slope of the G T exhaust line. So, all these parameters are G C C and dew point dependent.

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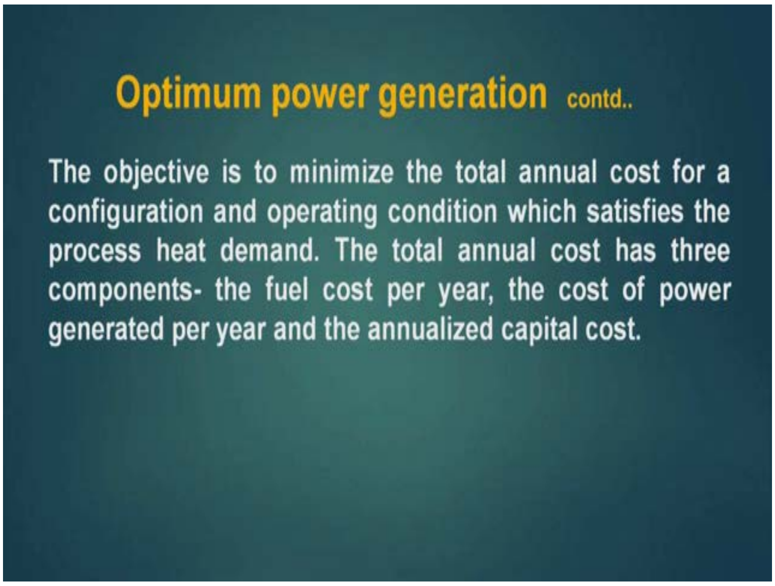

The objective is to maximize the total annual cost for a configuration, sorry the objective is to minimize the total annual cost for a configuration and operating condition, which satisfies the process heat demand. So, for a given processes demand, which is given by the G C C of the process, we have to minimize the total annual cost by changing the operating conditions. The operating conditions should satisfy the processing demand, yet should give us the minimum total annual cost. So, this is how the problem is formulated. The total annual cost has three components, the fuel cost per year, the cost of power generated per year. And the annualized capital cost, now let us see how this cost are calculated.

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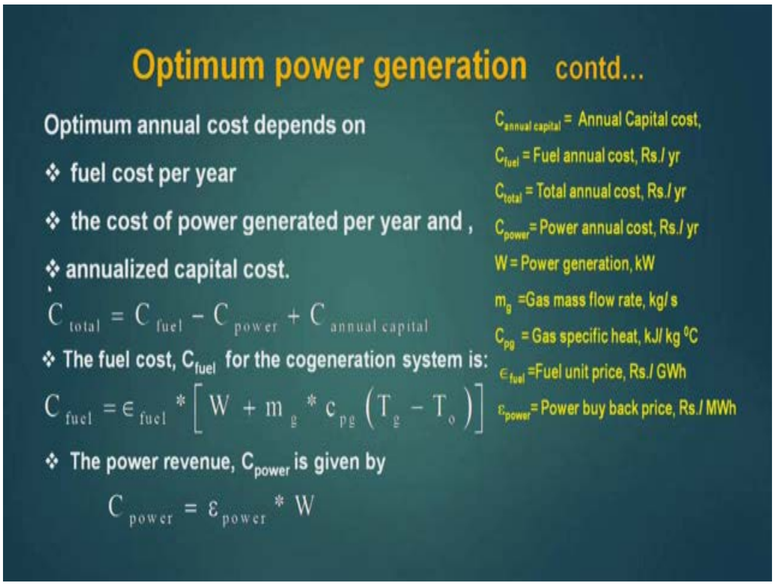

So, the optimum annual cost depends on fuel cost per year, the cost of power generated per year and the annualized capital cost. The C total is equal to C fuel minus power plus annual capital because the power we can sell in the market. So, it will decrease our stack value. So, here we have given that c annual capital the annual capital cost equal fuel cost annual fuel cost C total annual total annual cost, C power annual cost, W power generation m g gas mass flow rate C p g, the gas specific heat and the epsilon fuel is the fuel unit price and these things.

So, C fuel is equal to epsilon fuel into W plus m g plus C p g, T g minus T o so T g minus T o is this is the heat available with the gas in reference to the T 0 temperature. And this is what is being converted into work so for this work also we are spending fuel and this also we are spending fuel. So, these are been added up and we are multiplying with a fuel price to get the cost of the fuel, and cost of the power will be obviously unit cost of the power into W.

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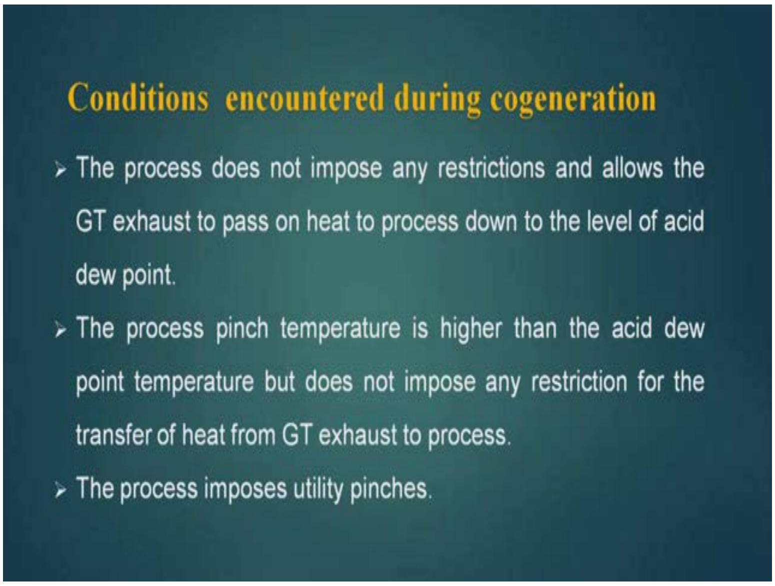

So by calculating this expressions, we can find out this C total cost and this will be automatically annualized cost or the stack. Now, the conditions encountered during cogeneration let us analyze this. The first point is the process does not impose any restriction and allow the G T exhaust to pass on heat to process down to the level of acid dew point. If it is not imposing any restriction this is say free problem and easier to tackle.

The second point may be or the second situation may be the process pinch temperature is higher than the acid dew point temperature, but does not impose any restriction for the transfer of heat from G T exhaust to process. This way we have seen that how to tackle this we can use the recuperator to bring it down so it process the acid dew point. The third is the process imposes utility pinches, if the utility pinches are there then reaching to the acid dew point becomes difficult. So, design becomes complicated and there is a large loss from the system.

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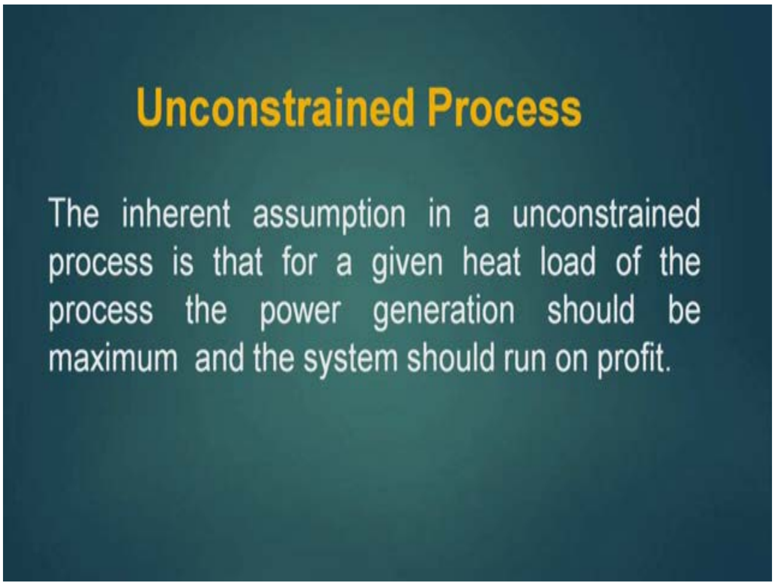

Now, the first one is called a unconstrained process, the inherent assumption in a unconstrained process is that, for a given heat load of the process the power generation should be maximum and the system should run on profit. So, we have a G C C which consumes a certain amount of heat load, and we have to find out what will be the maximum power generation for that given heat load. That means, we have to find out what should be the my G T temperature profile, means what should be the outlet temperature or exit temperature of the G T gas.

What should be the mass of the gas turbine that is flow gas, all these parameters or I should say that the running parameters what should be the compression ratio. So, all these running parameters or the operational parameters of the gas turbine will be fixed in such a way that, it is services the given heat load of the G C C. Yet the power generation is maximized, why? Because we will maximize the power generation so that this system should run on profit, if it is not running on profit nobody will try to use it.

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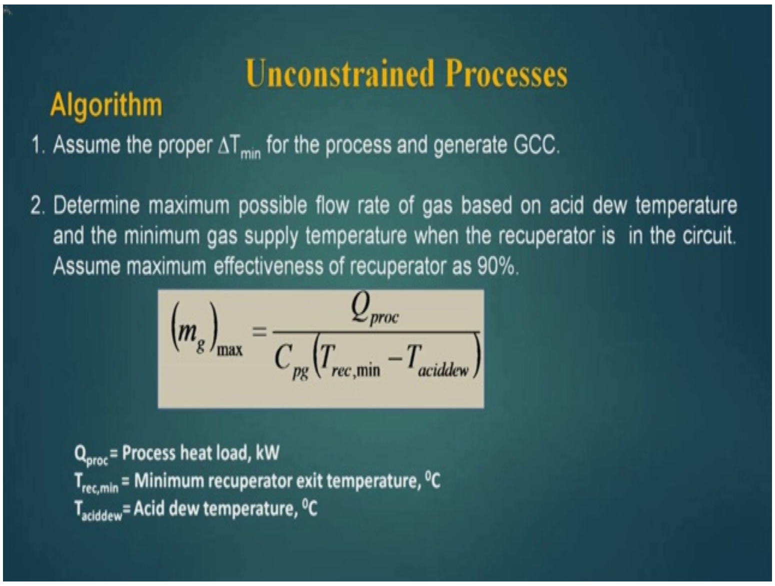

The algorithm is that assume the proper delta T minimum for the process and generate G C C. I have already told you that a G C C is dependent on delta T minimum, and the delta T minimum decides, what is the hot utility load and what is the cold utility load of a process. Now, we have two distinct zones of application that what should be the optimum delta T minimum of the process, and what should be the optimum operating condition of the G T, we should satisfy the heat load of the process G C C and will produce the maximum power.

So, these two problems are sandwiched and if you solve this problem, we get a better answer of the our problem and whole integrated system runs on maximum profit, and that is our aim. The second point is determine maximum possible flow rate of gas, based on acid dew temperature and the minimum gas supply temperature, when the recuperator is in the circuit. Assume maximum effectiveness of the recuperator as 90 percent during calculation. So, based on this calculation I can calculate the m g maximum that means, maximum mass of the gas which is coming out from the gas turbine.

This along with the C p g will decide this sloe of the G T exhaust gas profile, which will satisfy the hot utility demand of the G C C. And this is being computed using this formula, where Q process is equal to the process heat load. That means hot utility demand of the process T r e c minimum is minimum recuperator exist, exit temperature in degree centigrade. And T a c dew is the acid dew temperature if all these known and C p g is know which is obviously known, then we can find out what is the maximum amount of mass, which is flowing with the flow gas the gas turbine.

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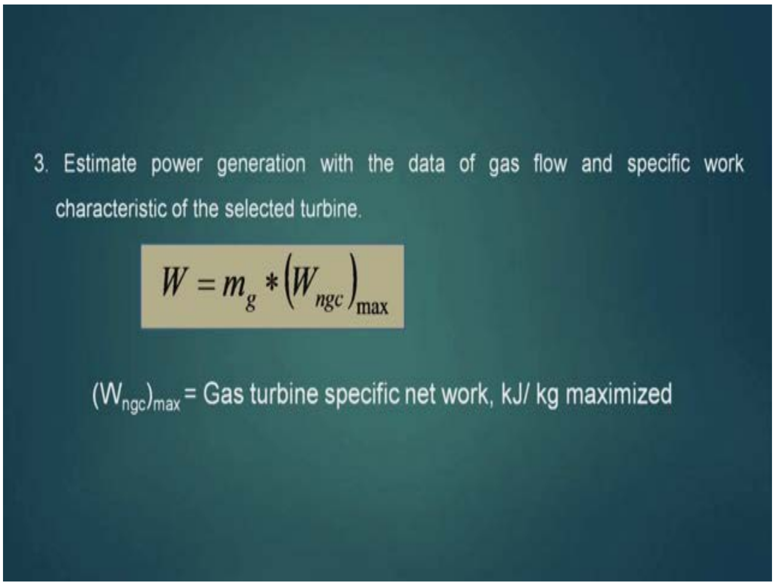

The third point is that estimate power generation with the data of gas flow and specific work characteristic of the selected turbine. Once you select a turbine, the specifications are almost selected. That means how this specific with this specific work and compression ratio the power output will change, what will be the efficiency etcetera, etcetera. So, we have to find out the power generation with the data of the gas flow and specific work characteristic of the selected turbine. And the equation which should be use this W equal to M G which will come from the earlier equation and W n g c max. So, W n g c max is the gas turbine specific network kilo joule per k g maximized. And how to do this maximization we have seen in the earlier lecture.

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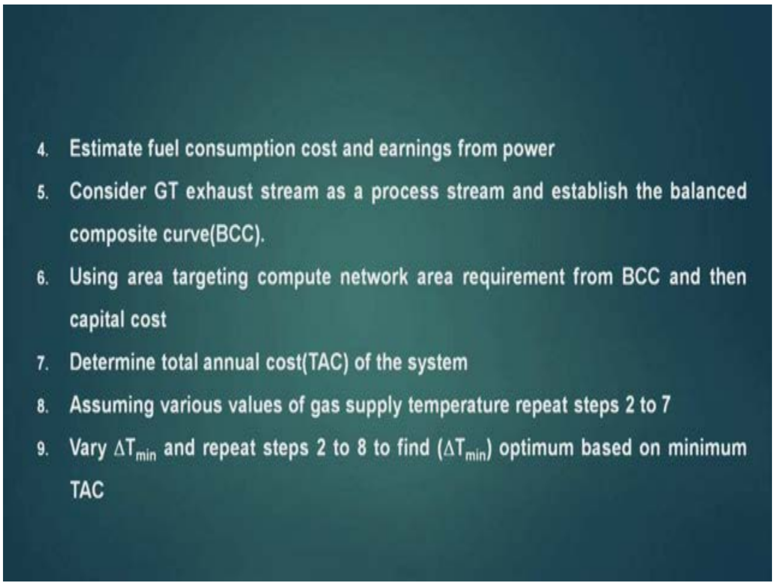

The forth point is estimate fuel consumption cost and earnings from the power, so that can be done. We have already shown in the expression show to calculate the fuel cost, and we can find out what will be the earning from the power. The fifth is consider G T exhaust stream as a process stream and establish the balanced composite curve. Now, we are moving towards computing the stack of the heat exchanger network, and for that we need G T exhaust gas stream profile. Because this is a hot stream and it is satisfy the hot utility demand of the G C C. And hence it has to be included there to find out the balance composite curve, when the balance composite curve the cold utility as well as hot utility both are to be included.

And once the balance composite curves are being created then will go for the area targeting, the area targeting using the balanced composite curve we have learnt in the area targeting lecture how to so this, and this will give us the capital cost of the network. Then we can go for the we can determine the total annual cost of the system, the total annual cost has got two parts one the fixed cost part and the operating cost part.

So, in the operating cost will take the call will take the cost of the utilities hot utilities, and cold utilities annually. And for the fixed cost fact will calculate the capitalized or annualized capital cost. That means capital cost will be expressed in annually, so when we add these two terms then we get the stack value. Assuming various values for the gas supply temperature repeat step 2 to step 7. So, we can find it out step 2 to step 7 for different values of gas supply temperature, that means we are presuming the different gas supply temperature and we can compute all this thing.

Then vary delta T minimum and repeat step 2 to 8 to find delta T minimum optimum. And already told you then when where designing a heat exchanger network, we are assuming certain value of delta T minimum. So, this value is adoc value that has to be some logic behind this that at worth value of the delta T minimum the heat exchanger network will operate. And the logic is that we will compute for different delta T minimum, this heat exchanger network tag cost.

And then we will find out delta T minimum value in which the stack cost is minimum this we have already done in the lecture of super targeting. So, once these are fixed we can find out a optimum value of the operation and design for the heat exchanger network as well as for the gas turbine of operating conditions. So, which will gives us the maximum profit for the integration of gas turbine with G C C of the process here process is represented by the G C C. And the heat turbine exhaust gas profile tells us how the heat turbine gas turbines should be operated, so that the integration is proper and the whole system runs on minimum stack value.

Now, the second considers a when the pinch is creating constraint we have seen that many times pinch will create a constraint, and it will not allow the gas turbine temperature to go up to the dew point. Or it can create some other problem in which, we will not able to give the full heat up the gas turbine exist to the process, and there will be a lot of stack losses. And if is the cases so and how to tackle this. You can seen that the location of the pinch point on the temperature axis holds the key to fuel economy.

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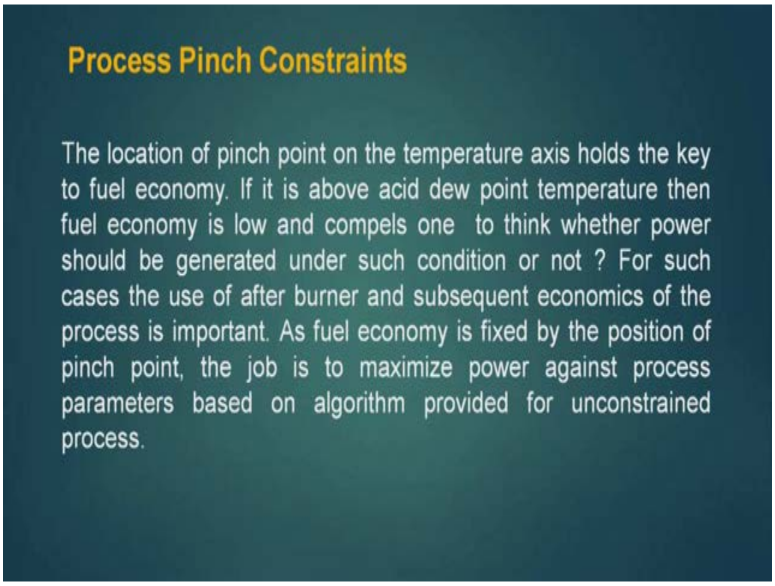

This we have seen, there it two conditions we have seen that when dew point is below the pinch point of the G C C curve, and when the dew point is above the pinch point. Now, if it is the below the pinch point we cannot achieve fuel economy and we have to avoid such problems, if it is above the pinch point then utility pinches may create problem and do not allow the G T exhaust gas profile to reach to the dew point. So, we will only take a pick case when pinch point is above, the pinch the dew point is above the pinch point.

So, if it is above the dew point temperature then fuel economy is low and compares one to thing whether power should be generated under such conditions or not. That we have seen that we will avoid such cases, for such cases the use of after burner or subsequently economics of the processes important as fuel economy is fixed by the position of the pinch point. The job is to maximize power against process parameters faced on the algorithm provide for constraint processes, unconstrained processes. So, if it is so then we will try to maximize the power generation, under that condition and will use the algorithm of unconstrained processes to tackle such cases.

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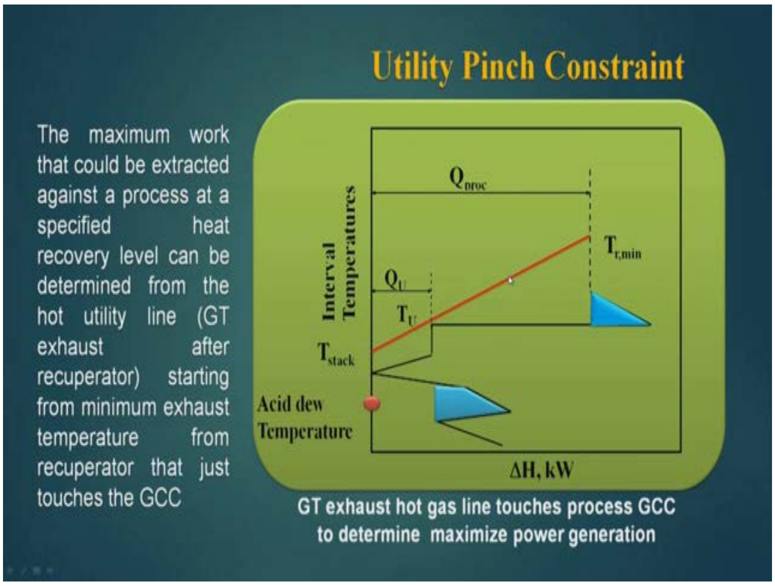

Now, let us take that how if this is the case, the acid dew point is here and this is a pinch point and I can go up to this point only. And this is my heat duty requirement for this G C C. So, obviously I have to suffer a large stack loss here and I am not able to use my it is heat available with this properly. So, we call this temperature T u this is Q u this is T stack and this is T r minimum this is the inlet temperature of the flow gas coming out from the G T. Now, in such a situation the G T exhaust gas hot gas line touches the process G C C to determine maximum power generation.

So, under such condition I have to maximize the power generation because I cannot improve this due to the pinch constraint. So, what will be my aim or what will be my style of functioning, or style of designing. The maximum work that could be extracted against a process at a specified heat recovery level, can be determined from the hot utility line with G T exhaust after recuperator, starting from minimum exhaust temperature from the recuperator that just touches the G C C. So, by using a recuperator can bring down this temperature to a level where it just touches this.

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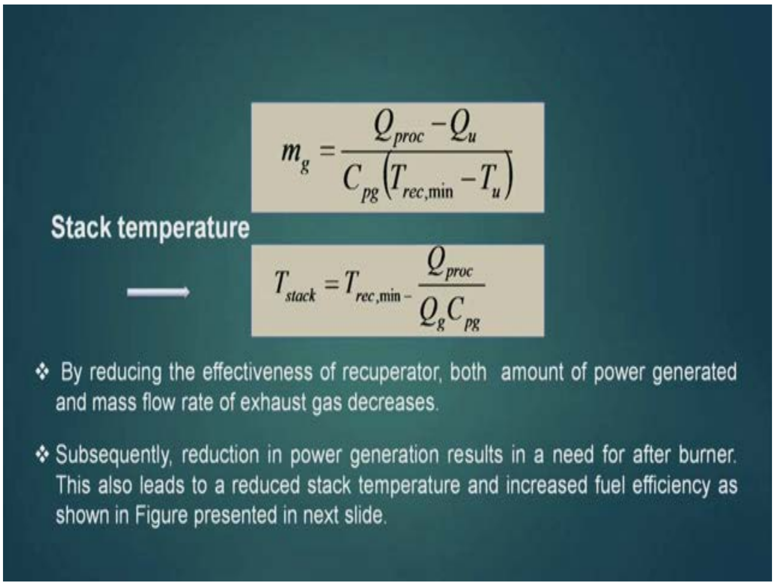

Now, these are the equations which are given for calculating the mass flow rate of gas, of the exhaust gas from the G T and the tees stack during such a situation, where I am using Q u and T u, T u which is from the graph itself. So, by reducing the effectiveness of the recuperator both amount of power generated and mass flow rate of exhaust gas decreases. So, when I am decreasing the temperature by reducing the effectiveness of the recuperator. So, both the amount of power generated and mass flow rate of exhaust gas will decrease. Subsequently reduction in power generation results in a need for after burner, this also leads to a reduced stack temperature and increased fuel efficiency as shown in the figure presented in the next slide.

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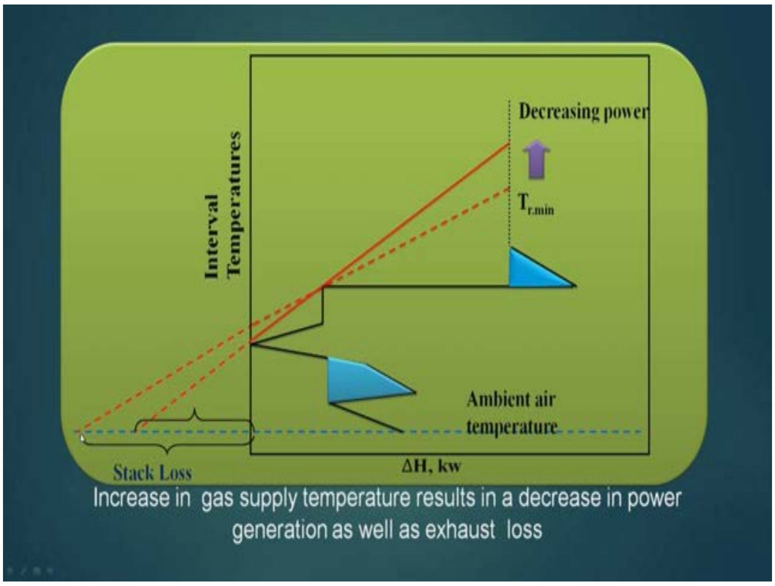

Now if I go up, so this is a ambient temperature this was the earlier temperature touches this. So, I will have a large stack loss by increasing in temperature I can make it more stiff, and my stack loss will decrease, but however this increase slope means less mass of the gas in the existing flow gas form the G T, and that will decrease my power. So, I am getting decreased power here, but I am saving this stack loss, that means I am saving the fuel. So, there is a trade up between these two and we have to check this trade up and this will give us that what temperature I should operate here, and what should be the my gas flow rate. Increase in gas supply temperature results in a decrease in power generation, but at the same time I will get a exhaust loss, which will be less than the earlier one.

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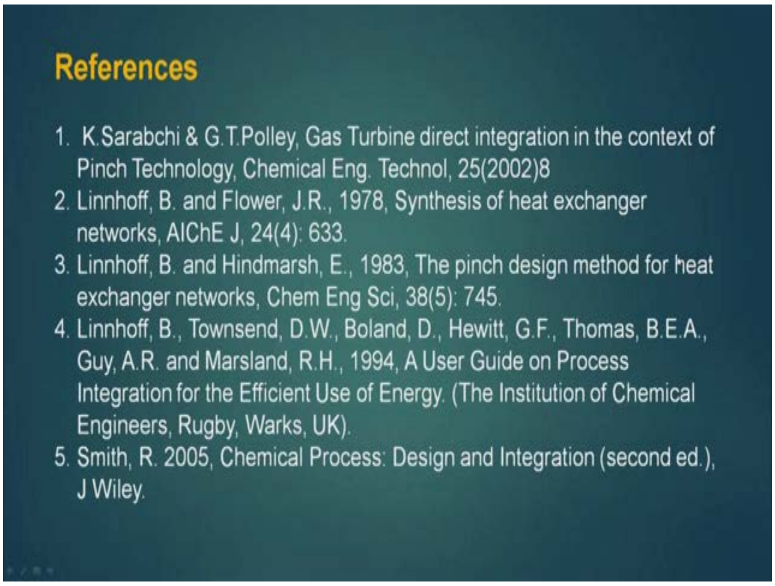

So, these are the references.

Thank you.