Process Integration
Prof. Bikash Mohanty
Department of Chemical Engineering
Indian Institute of Technology, Roorkee

Module - 5
Pinch Design Method for HEN synthesis
Lecture - 12
Integration of Gas turbine with process- 1st Part

Welcome to the lecture series on Process Integration. The topic of the present lecture is integration of gas turbine with process, and this is part one of this lecture. We have seen in the heat exchanger network that a HEN, which is a heat exchanger network, needs hot utility and cold utility. Now these utilities are either used from the industry itself or are purchased utilities or we have to spend money on these utilities. Now imagine a case, when we are using a gas turbine for the generation of electricity and the hot gas which is coming out from the gas turbine is used as a heating media or heating utility for the HENs. Now in this case, the efficiency of gas turbine, the combined efficiency of the gas turbine will increase, and if we pay for the hot utility cost then electricity cost becomes free. Or If there we charge a cost the electricity which is being produced then the hot utility cost is almost free. Now if we work on such type of propositions then it appears that integration of gas turbine with process will be very helpful, and will decrease the operating cost of the HEN. Now based on this thinking, this integration of gas turbine with process, which is lecture eleven is being generated.

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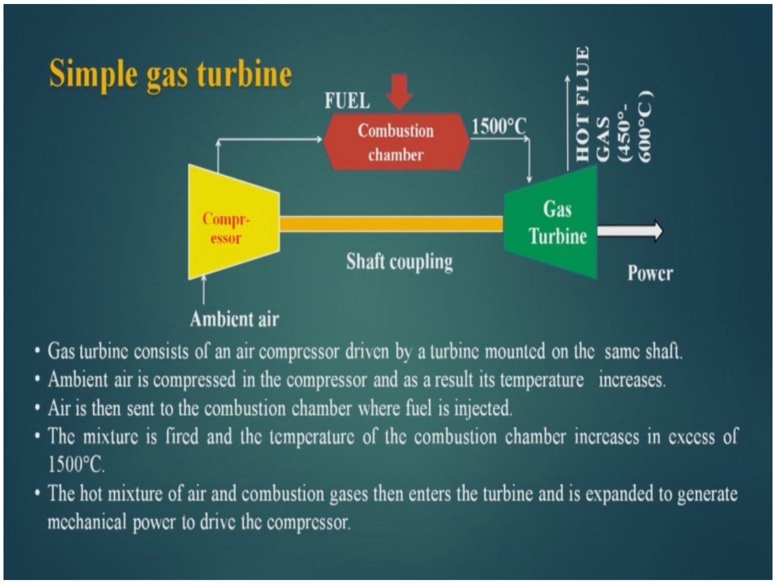

Now let us see first what is a simple gas turbine. Now the ambient air, this compressor takes the ambient air as input, it compresses it. Once it compresses it, its temperature increases then this air goes to a combustion chamber, where fuel is added to this and burning takes place. This creates a gas whose temperature is very high is around 1500 degree centigrade; this gas at high temperature and pressure goes to the gas turbine and it is expanded here. Once it expanded, this generate some work and this is connected to this compressor with a shaft, and this shaft is connected for the power system which generates the power. So it gives powers to the compressor as well as a generator or alternator wire electricity is being generated. And this hot gas goes out which is around 450 degree centigrade to 600 degree centigrade. Now this is hot enough to service the process, so if we use this part of the hot fuel or what flue gasses as heating heating utility in the process will be able to save a lot of money.

Now gas turbine consist of a air compressor driven by a turbine mounted on the same shaft, ambient air is compressed in the compressor, and as a result its temperature increases. Air is then sent to the combustion chamber, where fuel is injected, and the mixture is fired. And the temperature of the combustion chamber increases in excess of 1500 degree centigrade, the hot mixture of air and combustion gas then enters the turbine and is expanded to generate mechanical power to drive the compressor as well as the alternative.

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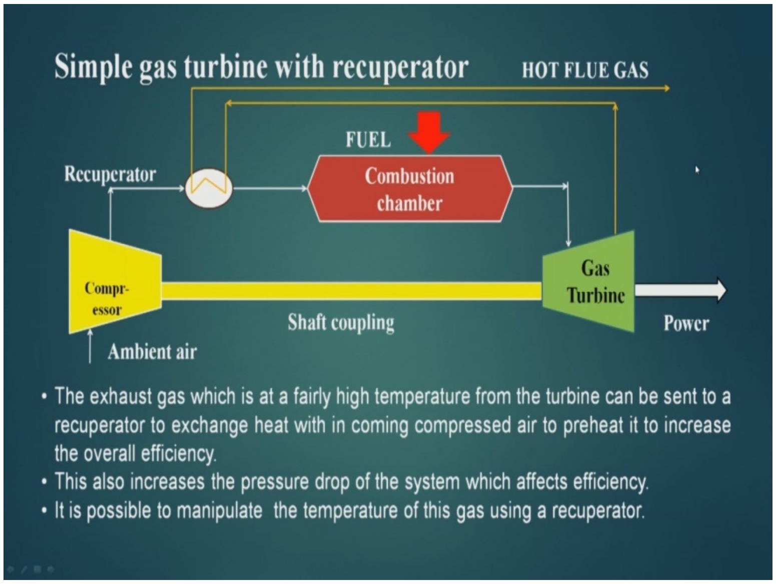

Now there can be a second type of gas turbine, which tries to use the hot flue gas its temperature to heat the air. Now this shows such a gas turbine, where this flue gas is routed in a recuperator to heat the incoming air. So if we heat the incoming compressed air, some of the heat from the exhaust gas or the hot flue gas will go to the air and thus the fuel consumption will decrease. So here the exhaust gas which is at a fairly high temperature from the turbine can be sent to a recuperator to exchange heat with in coming compressed air to preheat it to increase the overall efficiency. This in fact it decreases the fuel consumption part of it, and the rest is same. It is joint with a shaft coupling to the compressor and then a shaft to generate power. Now if we put a recuperator here, so this also increases the pressure drop of the system which affects slightly the efficiency. Now by putting a recuperator, this hot flue gas temperature can be manipulated to some extent and also at the same time increase the efficiency or decrease the fuel consumption of the gas turbine.

Let us see another type of gas turbine, which is as a after burner. Now the concept is that if the temperature of this exhaust gas from the gas turbine is low, then we can increase its temperature by using a after burner. Basically, we are trying to regulate the hot flue gas temperature somehow by using different techniques. One technique we have seen by using the recuperator, we can bring down the temperature of the hot flue gas, at the same time can increase the efficiency of the gas turbine, and decrease the fuel amount of fuel here. If we want to increase the hot flue gas temperature, we can use the after burner.

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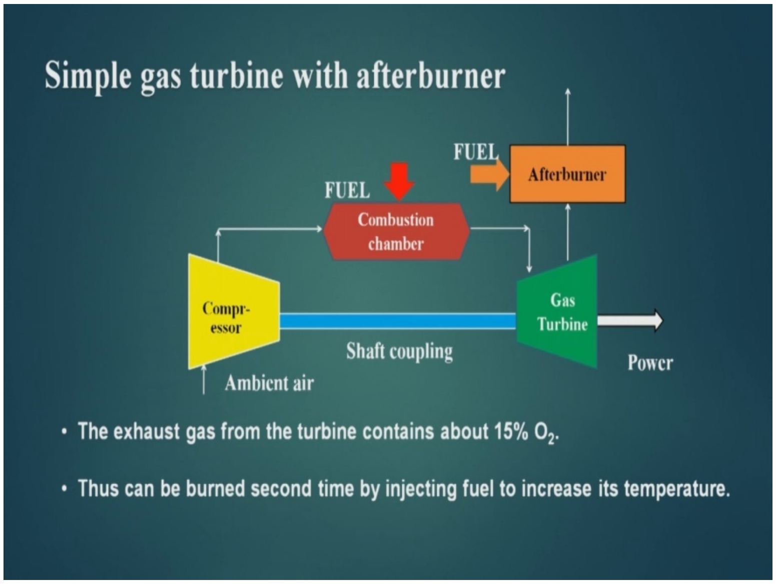

Now if you see analyze the exhaust gas then we find that the the exhaust gas from the turbine contains about 15 percent oxygen. So we can only add fuel to it, and we can re-burn it, so that the temperature of the exhaust gas can increase.

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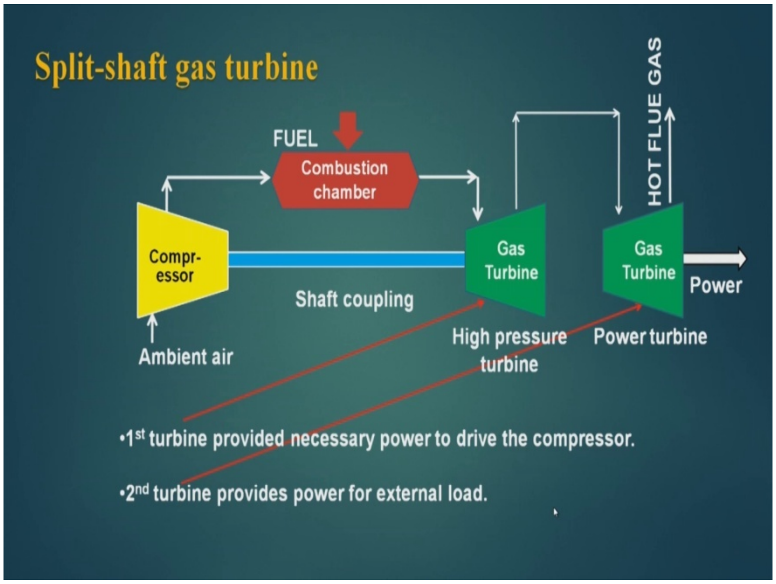

Now we see another type of gas turbine which is called split-shaft gas turbine. Here the ambient air is sucked into the compressor, it is compressed, it goes to the combustion chamber where fuel is added and it is ignited. The hot gas goes to the gas turbine, expanded and then this again goes to a second gas turbine, where it is further expanded and the power is generated, in this gas turbine and the hot flue gas is comes out of it. Now this turbine is exclusively used for driving this compressor, so it is broken into two parts. We are using two gas turbines- one gas turbine for running the compressor and the other gas turbine for generation of the power. And the hot flue gas which comes out of it can be used in the process has a heat hot utility.

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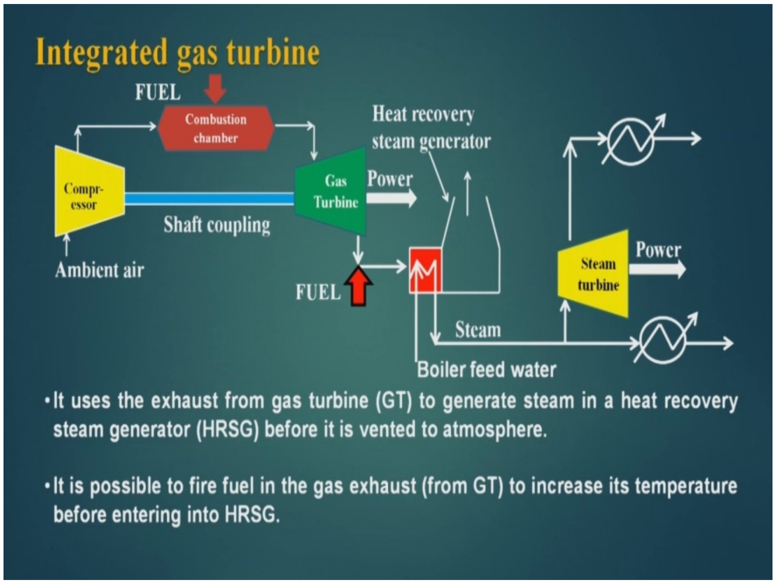

Now we can use an integrated gas turbine that means with the if this ambient air is sucked into the compressor, it is compressed then sent to the combustion chamber where fuel is added burned, this dries this gas turbine, and also dries this compressor and power is generated. Now the outlet gas, which comes out of the gas turbine is again mixed with the fuel and burnt here. In this turbine, heat recovery steam generator, and steam is generated and then this steam is supply to this steam turbine and again power is being generated. So it uses the exhaust gas from the turbine to generate steam in a heat recovery steam generator, before it is vented to atmosphere. It is possible to fire fuel in the exhaust gas from the GT to increase its temperature, before entering into HRSG that is heat recovery steam generator.

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Now let us see what are the important parameters governing gas turbine performance. Now the inlet temperature to the GT that is inlet air temperature, pressure ratio, ambient conditions, work load, specific work and backpressure. These are the different parameters which affect the running of a gas turbine. Why we are discussing thus, because when we will integrate the gas turbine with the process, we should know all the gas turbine works or integrates of the working of the gas turbines, and what are the different important parameters which affects the performance of gas turbine. One by one, we will see this parameter, this backpressure, inlet temperature, pressure ratio, ambient conditions, workload and specific work.

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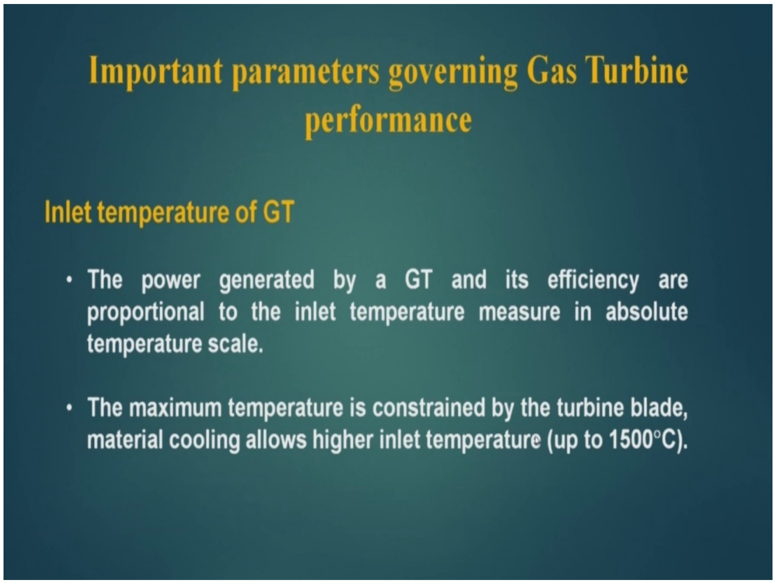

Now if you see the inlet temperature of G, the power generated by a gas turbine and its efficiency are proportional to the inlet temperature measured in absolute temperature scale. The second thing is the maximum temperature is constrained by the turbine blade, so see turbine blade decides that what should be the temperature of the gas which is entering into the turbine. If material cooling is allowed then higher inlet temperature up to 1500 can be reached.

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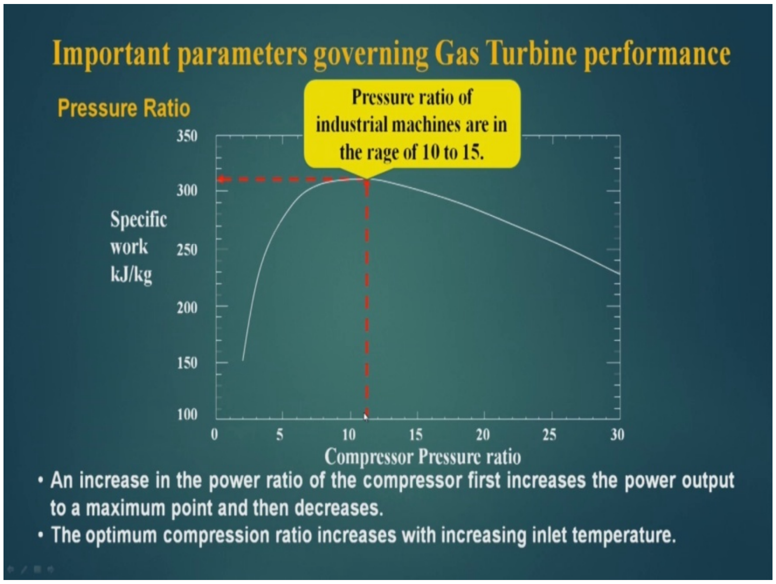

Second thing is pressure ratio. Now if you see the compressor pressure ratio here, this specific work, this is the work done per kg of the air takes such a unimodel shape. An increase in power ratio of the compressor or the pressure ratio of the compressor first increases the power output to a maximum point and then decreases. The optimum compression ratio increases with increase inlet temperature. Now this is the optimum compression ratio here which falls between 10 to 15 in an industrial machine. This ratio is also function of a inlet temperature and it increases with increasing inlet temperature.

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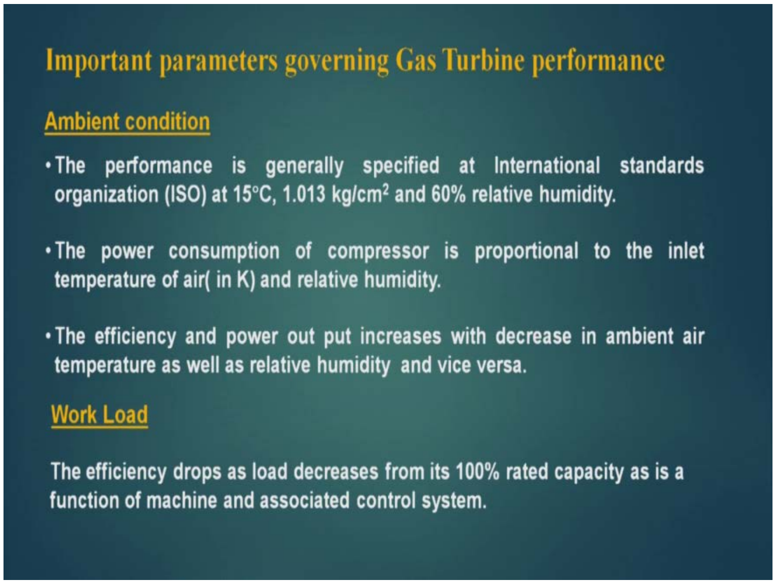

Then ambient condition the performance is generally specified at international standard organization ISO condition that is fifteen degree centigrade 1.013kg per centimeter square and 60 percent relative humidity. The power consumption of compressor is proportional to the inlet temperature of the air that we have already told and relative humidity also. The efficiency and power output increases with decrease in ambient air temperature as well as relative humidity and vice versa. Now work load - the efficiency drops as load decreases from its 100 percent rated capacity as is a function of machine and associated control system.

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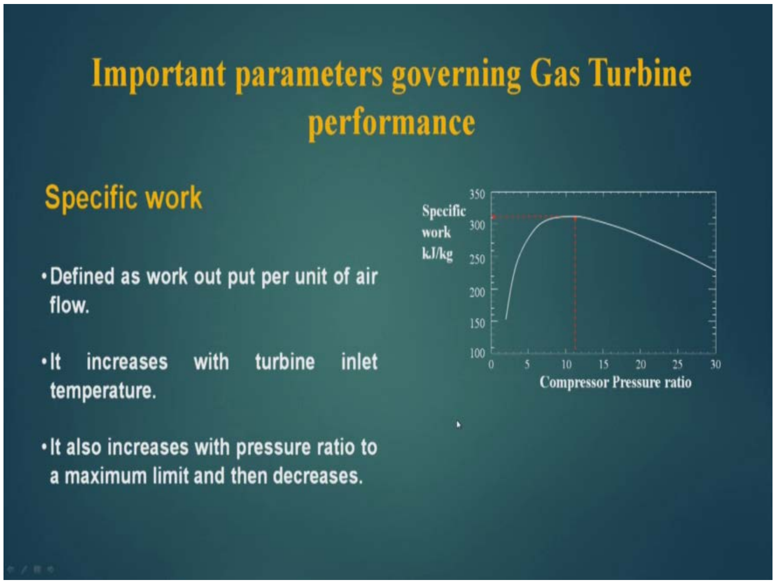

Specific work - it is defined as work out put per unit of air flow it increases with turbine inlet temperature. It also increases with pressure ratio to a maximum limit and then decreases and then this is the same of the curve.

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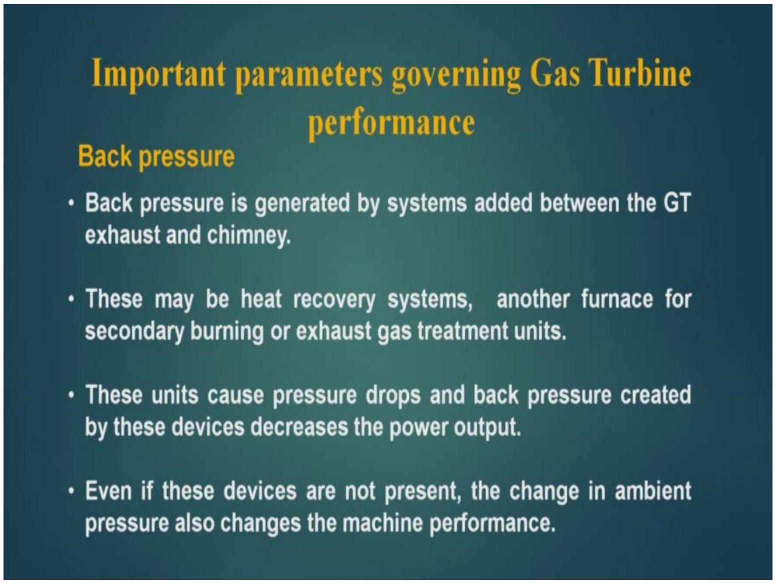

Backpressure - the backpressure is generated by systems added between the gas turbine exhaust and chimney like a recuperator. This may be heat recovery systems, another furnace for secondary burning or exhaust gas treatment units. These units cause pressure drop and back pressure created by these devices decreases the power output. Even if these devices are not present, the change in ambient pressure also changes the machine performance.

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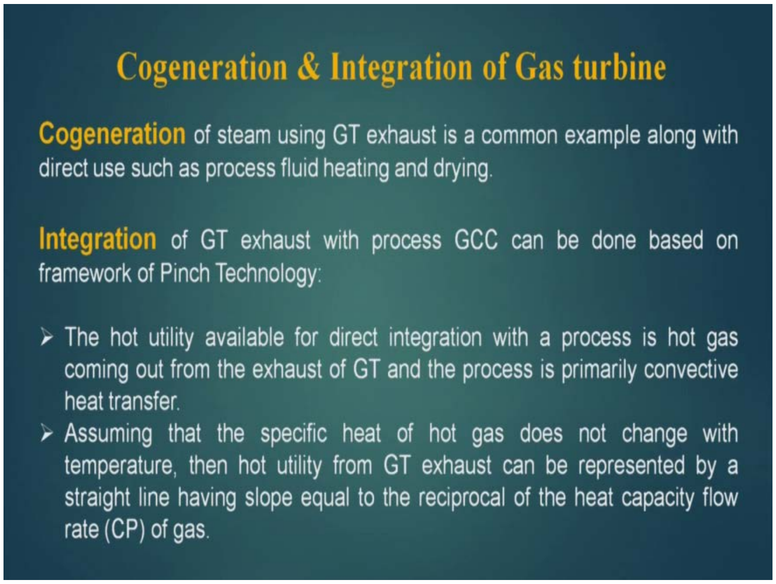

Now why we are talking about this, because we have to integrate the GT that is gas turbine with the process. The integration should be in such a way that it should not affect the gas turbines performance much, and at the same time, the heat which is coming out from the gas turbine is used to fullest capacity in the process. Now let us talk about the cogeneration and integration of gas turbine. Cogeneration of steam using gas turbine exhaust is a common example along with direct use of such process fluid heating and drying. So the heat which is coming out from the gas turbine can be used for process heating and drying also. And by this way, we can generate the electricity from the gas turbine as well use its heat in the process, and we can increase the overall efficiency to a very high value. Integration of gas turbine exhaust with process GCC can be done based on framework of pinch technology.

When we are going to integrate the gas turbine with process, the pinch technology helps us and this integration takes place with the help of GCC, because GCC tells us that how to integrate the hot utility and cold utility which are available at different levels with the process. So here whatever integration will do with the gas turbine, we will use the process GCC for its integration. The hot utility able for direct integration with the process is hot gas coming out from the exhaust of gas turbine, and the process is primarily convective heat transfer. Because the hot gas is coming out so the heat transfer which will take place with the process will be a convective heat transfer. And once the heat transfer takes place, the gas temperature will dropped out.

Assuming that the specific heat of the hot gas does not change with temperature then the hot utility from gas turbine exhaust can be represented by a straight line having slope equal to the reciprocal of the heat capacity flow rate. This we have seen when we are talking about the integration that is combined hot and combined cold curves or the composite hot and composite cold curves. There we have seen that if the CP remains constant, fairly for a large temperature difference, then the hot steam can be represented by a straight line. So the exhaust which is coming out from the g t can be taken as a hot steam, where CP is not changing much. And if so, it can be represented by a straight line. If the CP is changing obviously a non-linear relationship will exhaust, and it will be represented by a curved line.

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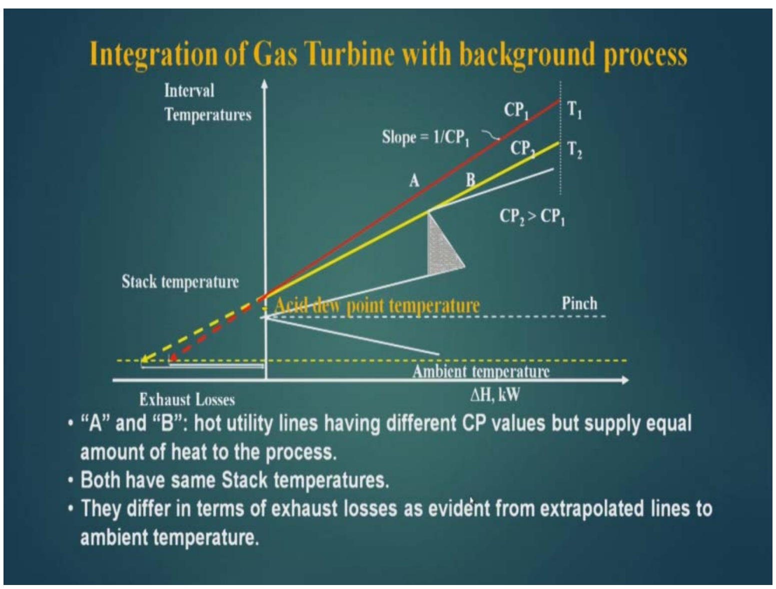

Now this shows the integration of gas turbine with the background process. The background process is thus shown by the GCC. So in this case, I am representing my background process which is a process unit by its GCC, and this straight lines, this line and this line is of the gas turbine. This is the gas turbine exhaust temperature, which transfers heat to this GCC, and in that process, it cools down. And this is my stack temperature, so the gas comes out at this temperature and goes to the ambient temperature, so this is my ambient temperature line. Now this is the acid dew point temperature. Now acid dew point temperature is more than the pinch temperature, so the exhaust generally is kept little bit higher than the acid dew point temperature, so that acid present in the gas does not condense. And if it will condense, it will corrode the metal part of the exchanges and so damage will takes place.

So here let us analyze the behavior of this. Now this is CP 2 this yellow line is for CP 2, and this red line is for CP 1, and this slope is one by C P 1. So if CP 1 is less, its slope will be more. If CP 2 is more, its slope will be less. Now I can draw a line from T 2 which is the entry temperature of the hot gas or we can say the exhaust temperature of the hot gas from the gas turbine. If I draw a line such that it touches this point then it satisfies the hot utility demand above the pinch for this GCC. I cannot go below this, because if I go below this, some part of my GCC will not be served that case we will see later on that. If it so happens, how to tackle the case. Now if I take temperature more here then this slope is more, and this reaches the ambient temperature here. Then what this part represents from here to here, this represents the heat lost of the ambient though these two lines represent different mass flow rate of gas at different temperatures. Also they have different heat losses from this stack this will analyze ends.

So A and B hot utility lines have different CP values, but supply equal amount of heat to the process, this is important because they are supplying, they were satisfying the hot utility demand of the GCC completely. And that is why they are supplying equal amount of heat both have same stack temperature, because they crossing here. So they have the same stack temperature but what is the difference but they differ in terms of exhaust losses as evident from extrapolated line to the ambient temperature. Now what is that exhaust loss from the stack, the hot gasses are coming out, the hot gasses will have some heat with it and that heat is the exhaust loss. Now if a exhaust loss is more that means I am spending more money for the heating; and if the exhaust loss is less then I am conserving and this will be reflect in terms of the fuel cost. If the exhaust loss is less my fuel cost will be less; if the exhaust loss is more, my fuel cost will be more. So, I will always try to minimize this exhaust loss.

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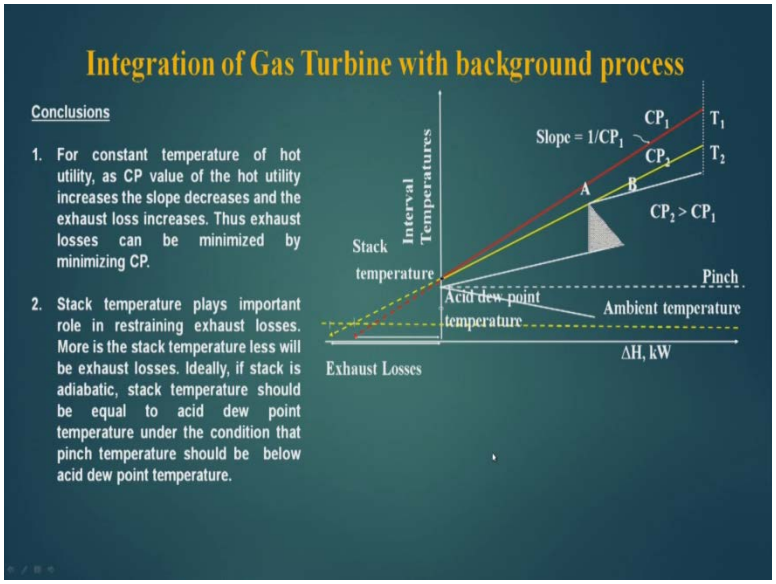

So what are the conclusions for constant temperature of hot utility. As CP value of the hot utility increases, the slope decreases; and the exhaust loss increases. If the slope is decreasing when I am going from A to B, my slope is decreasing. And once the slope decreases my exhaust loss is more. Thus exhaust losses can be minimize by minimizing CP. So I can select A CP in such a way that my exhaust loss is less. Stack temperature plays important role in restraining exhaust losses because stack temperature is also important. Where you are taking this temperature and this temperature is also important; more is the stack temperature less will be the exhaust losses more will be the stack temperature more will be the exhaust losses.

And if the stack is adiabatic stack temperature should be equal to the acid dew point temperature under the condition that the pinch temperature should be below the acid dew point. What does it mean, that I can bring down my stack temperature to the acid dew temperature little bit more than this acid dew temperature provided this pinch is below the acid dew temperature. If the pinch is above the acid dew temperature as in this case I cannot bring it down to the acid dew temperature. If I decrease the this stack temperature that means less energy will go to the exhaust losses, because it will have less energy in that case so if I increase stack temperature my losses will increase. If I decrease stack temperature my losses will decrease and at the most I can reach very close to the acid dew point provided that this pinch is below the acid dew point.

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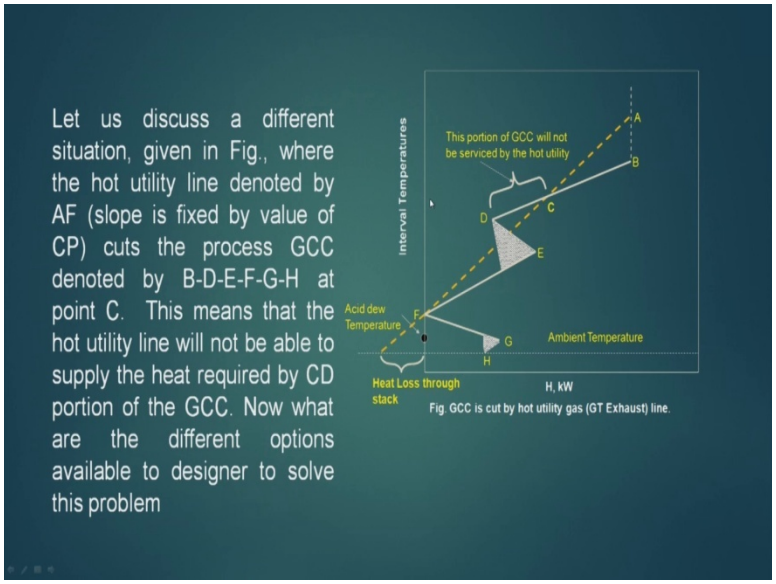

Now let us now discuss a different situation this is shown here. Where this GT line is cutting a part of the GCC. Now this is hot utility line which is exhaust from the GT A-F, it is cutting this line GCC line at C which means that now D to C part of the GCC will not serviced by the hot utility that means hot utility is not going to heat the steams which are here. In D to C that means from this temperature to this temperature, this increasing temperature of the combine steams which are here in the GCC will not take place.

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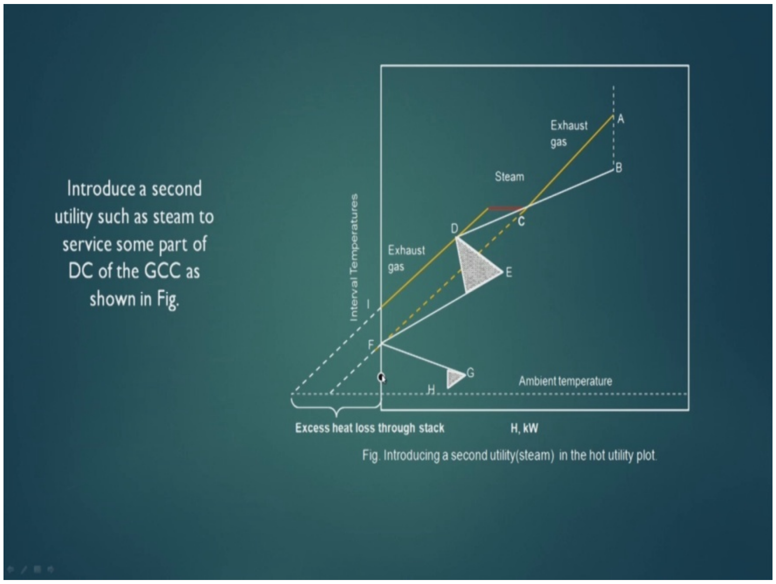

Now if it is the situation then how to tackle it. This part of the GCC is heated by this this part of the GCC is served by this, but this part is not served. Now if such a situation occurs then how to handle this. So let us see the methods to handle such a situation. Now this is a method where I can use A external heating medium steam here and by using this steam I can shift this line to this level. Why the temperature levels are not shifting, so now this line is able to service this part of GCC. So a solution is introduce a second utility such as to service some part of the D C, because steam is serve. Now from here to here up to this part will be service by this steam and rest will be service by this line of the hot utility.

However, when we will do so the exhaust losses will be will increase for this line the exhaust loss was from here to here. And when we do so then the exhaust loss increases from this to this why because this stack temperature now has increased from this point to this point and hence the exhaust loss also increases. This is my acid dew point which is below the pinch, so I cannot go up to this acid dew point only I can go up to the acid dew point when acid dew point is above the pinch.

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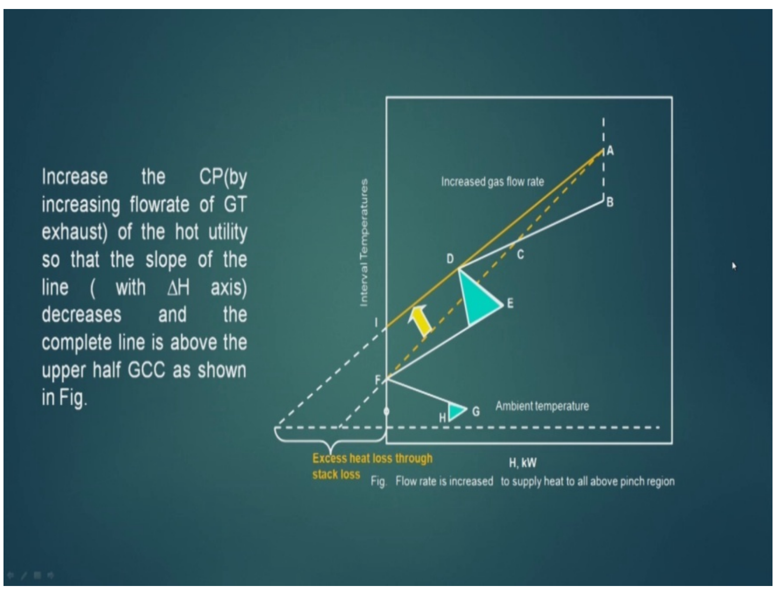

Now a second method is that increase the C p by increasing flow rate of GT exhaust that means if I am increasing CP my slope is decreasing. And when the slope decreases, this line will rotate from this point, so this is rotate like this is most like this. And we will touch this point, so this is the ideal point where I should keep my hot utility. So by changing the flow rate of the exhaust gas or by increasing the flow rate of the exhaust gas, I can solve the problem but exhaust gas flow rates are connected with the performance or power output of the gas turbine. So we have to see there whether there is a flexibility available with the gas turbine to do this or not so this is another method to solve and here also we have seen that while doing so the exhaust the loss heat loss from the exhaust will increase.

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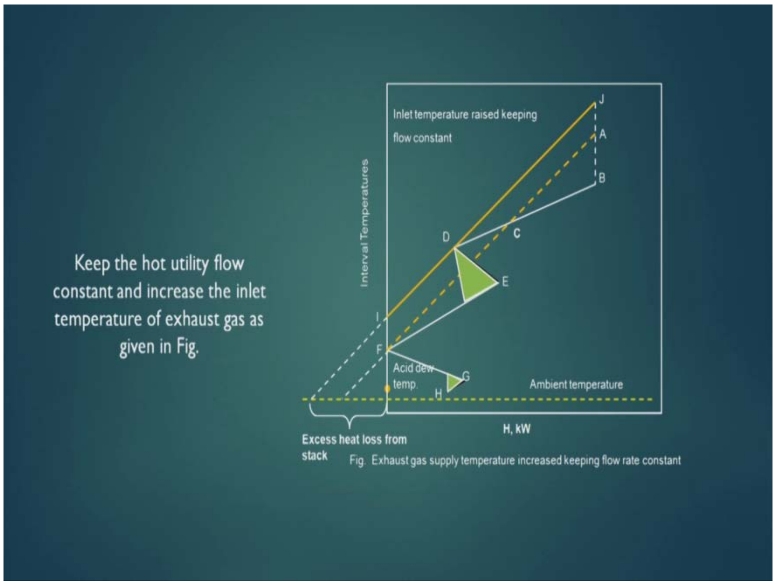

The third is that shifting keep the hot utility flow constant and increase the inlet temperature of the exhaust gas as given in the figure. So what we are doing we are shifting this point which is the entry point of the exhaust gas at A to J by doing, so we are solving this problem. Now at this state the hot utility line is ready to serve all part of the GCC whereas at this point because not able to serve the D to C part of the GCC curve. Now this is also has to be seen whether we can increase that much of temperature exhaust temperature of the GT if I do so obviously it will affect the performance of GT and that has to be examined.

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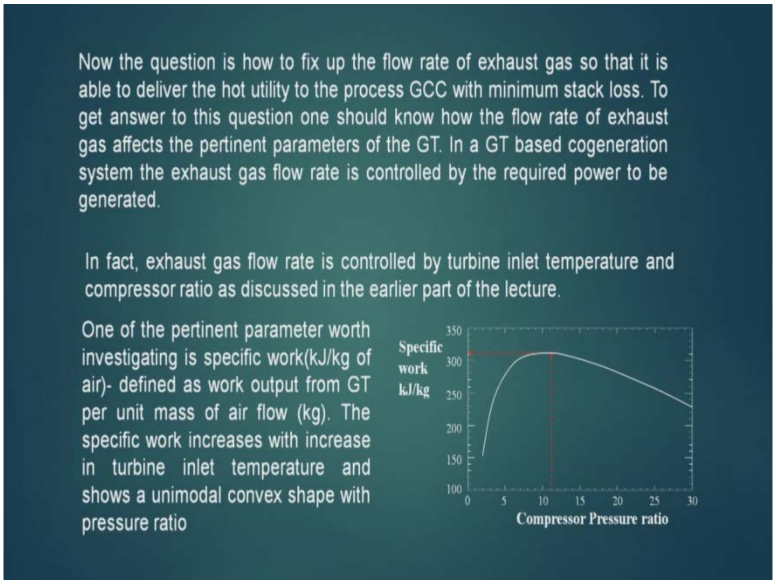

Now the question is how to fix up the flow rate of exhaust gas so that it is able to deliver the hot utility to the process GCC with minimum stack loss. This is a question before me and we have to answer this to gave the answer of this question, one should know how the flow rate of exhaust gas affects the pertinent parameters of the GT. In a GT based cogeneration, the exhaust gas flow rate is controlled by the required power to be generated. So once I fix up my power to be generated, I almost fix my exhaust gas flow rate in fact exhaust gas flow rate is controlled by turbine inlet temperature and the compressor ratio. As discussed in the earlier part of this lecture, one of the pertinent parameter worth investigating is the specific work that is work per kg of here defined as the work output of the GT per unit mass of air the specific work which is shown in this figure increases with compressor pressure ratio and then decreases. So I would like to operate my GT at this compressor pressure ratio, so that my specific work is maximized and once specific work is maximize my efficiency is maximize and my the cost of production of electricity will be less.

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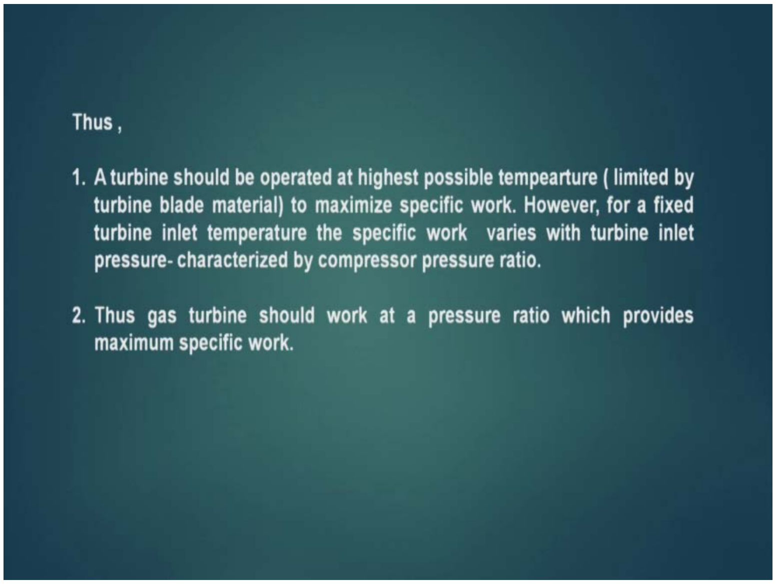

So what should be my operating parameters or the how I should operate a turbine should be operated at highest possible temperatures, and this highest possible temperature is limited by the turbine blade material. So that I should maximize my specific work however for a fixed turbine inlet temperature, the specific work varies with turbine inlet pressure-characterized by compressor pressure ratio that we have seen. So the gas turbine should work at a pressure ratio which provides maximum specific work so I should work with maximum temperature and optimum pressure ratio which provides me maximum specific work.

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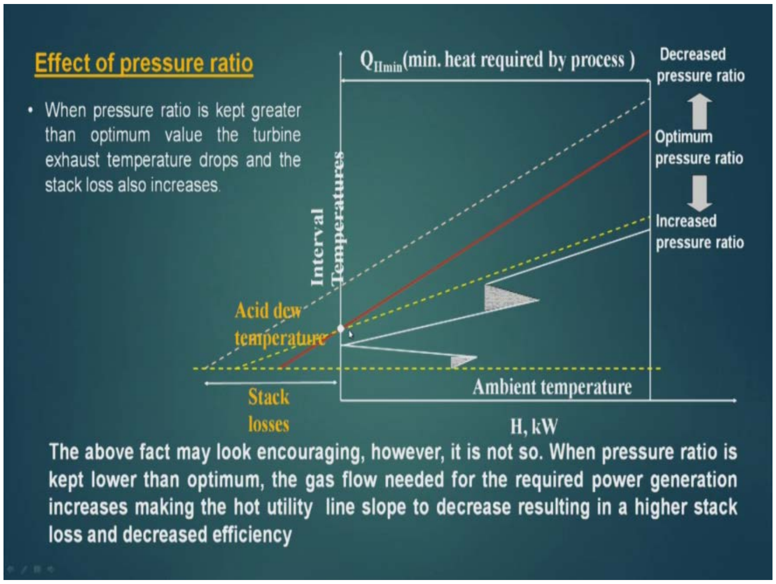

Now we see that what is the effect of pressure ratio. Now this is my optimum pressure ratio where my stack temperature is almost equal to the acid dew temperature and there is a small loss. Now if I decrease my pressure ratio, this line moves up; and if I increase this pressure ratio, this line goes down and the slope increases. So when the pressure ratio is kept greater than the optimum value, I am working in this range the turbine exhaust temperature drops and the stack losses increases. So here we have seen that if I drop down to here by increasing the pressure ratio my stack losses have been increased from this value to this value.

Now the second point is further when it is kept lower than the optimum value. I move in this direction, the exhaust temperature of the GT increases. So it may we may conclude that by decreasing the pressure ratio, I can increase my exhaust temperature. But it is not that simple the above fact may look encouraging. However it is not so when pressure ratio is kept lower than the optimum the gas flow needed for the required power generation increases making the hot utility line slope to decrease and resulting in a higher stack loss and decreased efficiency. So these are the interaction which takes place between the different pertinent parameters of the GT and we have to keep this in mind when fixing up or playing with this parameters to suit our process GCC.

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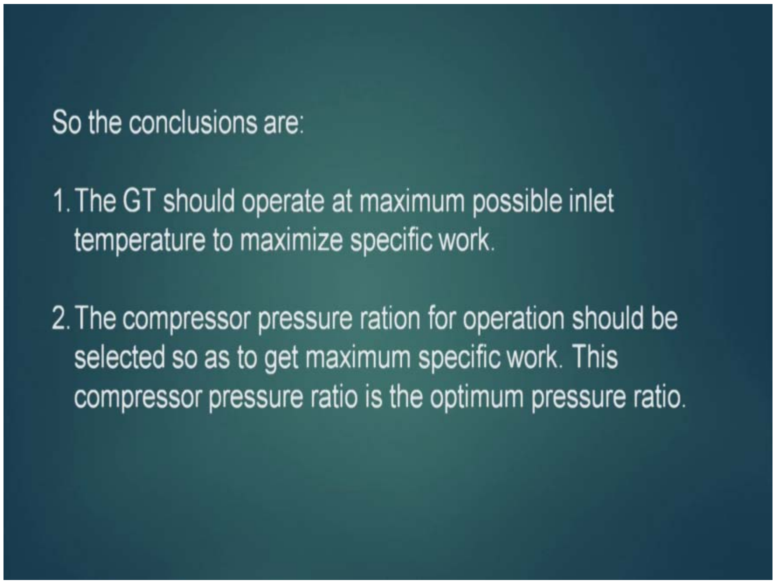

So the conclusions are the GT should operate at maximum possible inlet temperature to maximize specific work. This is one conclusion the second the compressor pressure ratio for operation should be selected so as to get maximum specific work, this compressor pressure ratio is the optimum pressure ratio.

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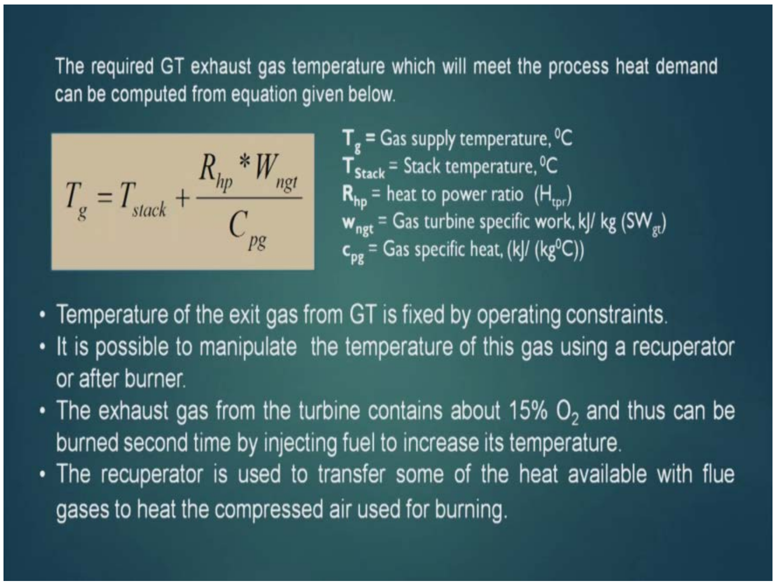

Now the required GT exhaust gas temperature which will meet the process heat demand can be computed from the equation given below. We can use this equation to compute a gas supply temperature which will meet our process demand so this is T g equal to T stack plus R hp into w ngt by C pg where T g is gas supply temperature, T is the stack temperature R h p is the heat to power ratio and w ngt is the gas turbine specific work and c pg is the specific heat. So now go for some sort of conclusion the temperature of the exit gas from GT is fixed by operating conditions. It is possible to manipulate the temperature of this gas using a recuperator or after burner.

Now the exhaust gas temperature is high then I can use the recuperator to bring it down but however it will somewhat affect the efficiency of the g t, because the back pressure will increase or if it is low I can use a after burner to increase the temperature. So by using the recuperator, I can manipulate the gas temperature and bring its temperature down or if I want more temperature I can use a after burner so this gives me flexibility to chase the output temperature or the exit temperature from the gas turbine. The exhaust gas from the turbine contains about 15 percent O 2 and thus can be burned second time by injecting fuel to increase its temperature using a after burner.

The recuperator is used to transfer some of the heat available with flue gasses to heat the compressed air used for burning, so when I am using a recuperator I am heating the compressed air and a hot gas is now being sent to the burner. This will decrease my fuel fins but at the same time backpressure will increase and it will affect to some extend the efficiency, so there is a complex interaction between the different parameters.

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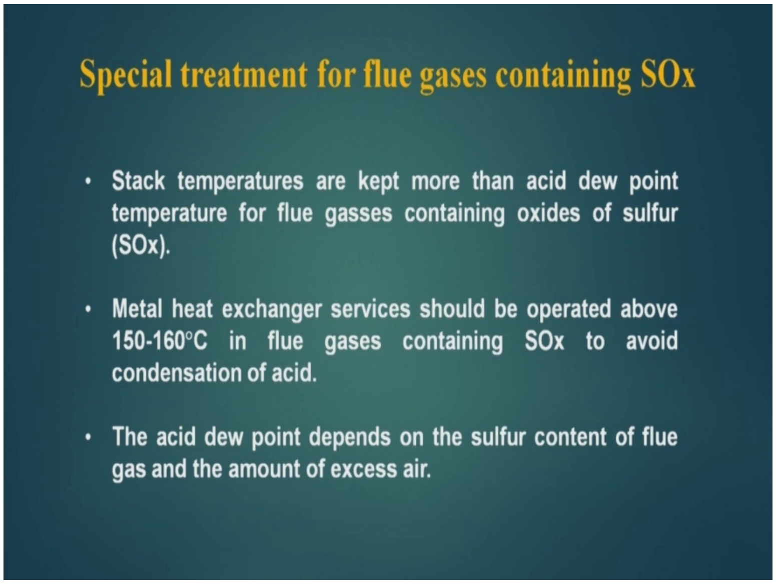

Now if the flue gas contains SOx sulfur oxides, then we have to treated properly this stack temperature. In this case, these stack temperatures are kept more than the acid dew point temperature for flue gasses containing oxides of sulfur why because the metal heat exchanges services should be operated above 150 to 160 degree centigrade. In flue gasses containing SOx to avoid condensation of acid that means when SOx is there we have to operate above the acid dew point, so that acid is not condensed on the metal heat exchanges. And they should not eroded the acid dew point depends on the sulfur content of the flue gas and the amount of excess air.

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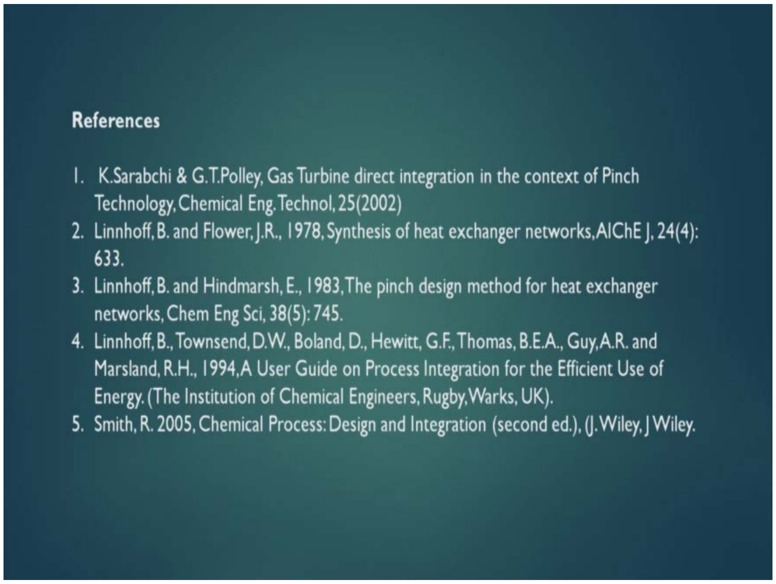

And these are the references.

Thank you.