Fuels, Refractory and Furnaces

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Lecture No. # 20

Heat Utilization in Furnaces: Heat Recovery Concepts and Illustrations

We were considering heat utilization in furnaces and in the previous lecture to this, we were discussing role of heat recovery and efficiencies and there I have taken two cases. One case was, 110 percent excess air and no air leakage and case 2 was, 110 percent and 15 percent air leakage and there we have found that, air leakage is detrimental to the operation of the furnace, as well as to the fuel consumption; and through the illustration, it was possible to illustrate, the increase in fuel consumption due to air leakage. Now, physically, you can think, whatever amount of air that is leaked into the furnace, that particular amount of air will not be passing through the heat exchanger or a regenerator. And, it is obvious, because you are working with the total amount of air. You are keeping total amount of air constant. So, whatever air which is leaked, that will be not passing through the regenerator and hence, that much amount of air will not be preheated and accordingly, less sensible heat will be input into the furnace, and obviously, it will lead to increase in fuel consumption.

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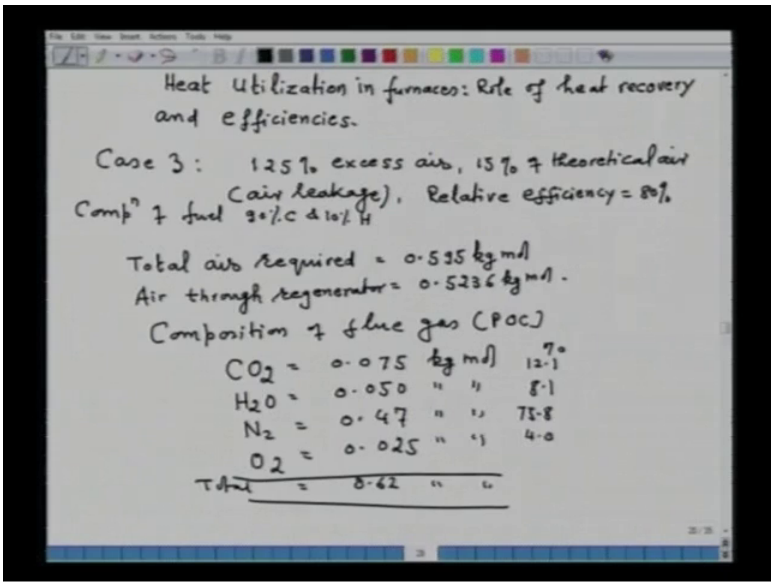

Now, let me take another case, the case 3 if I take, and case 3 concerns, say, now, I am using 125 percent excess air, 125 percent excess air and air leakage is 15 percent of theoretical air; this is the air leakage. Air leakage is 15 percent of theoretical air and we are retaining relative efficiency of regenerator, we are retaining relative efficiency of regenerator, that is around 80 percent. Now, here, I must tell you something. Now, since we have increased the amount of air, we have increased the amount of air than the previous case, previously it was 110 percent; now, we increase it to 125 percent. As a result of increase in excess amount of air, there will be increase in the volume of the products of combustion and as such, the heat exchanger, which is of same cross section as it was in the previous case, so, products of combustion will be moving faster than case 1; because here, the more volume of the product; cross section area is the same; velocity will be higher. So, it is quite possible that, the relative efficiency will be somewhat lower than what we have assumed here, 80 percent; but well, for the sake of comparison, we are not touching the relative efficiency; we are keeping same, as it was in case 1 and case 2, equal to 80 percent.

But this point is to be remembered, because heat exchange occurs between the flue gas and air. So, accordingly, residence time is important. In spite of that, for comparison purposes, we are keeping relative efficiency to be same. Now, so, again, we have to calculate afresh, the amount of air and amount of P O C. Now, if you calculate the total air required, total air required, that will be equal to now, 0.595 kg moles. Now, air through the regenerator, air through regenerator, that will be equal to 0.5236 kg mole. So, now we know, mind you, here, the composition of the fuel is same as in case 1 and case 2, and just for repetition, I write down the composition of fuel. Composition of fuel is 90 percent carbon and 10 percent hydrogen, as it was in the previous case. So, now, if I wish to represent the material balance of this particular furnace which is equipped with the regenerator, then, I have to calculate also, the flue gas. So, the composition of flue gas, or you can also call P O C. Now, this composition will consist of C O 2 and this will be equal to 0.075 kg moles. Now, remember, by taking excess air, the amount of the C O 2 is not going to change. Similarly, that of H 2 O, that will be equal to 0.050 kg mole. Amount of nitrogen, that will be equal to 0.47 kg mole. And, amount of oxygen, that will be equal to 0.025 kg mole.

So, the total amount of, total amount of P O C, that is equal to 0.62 kg mole, or if you want to know the percent, in percent, the C O 2, 12.1, 8.1, 75.8 and 4.0. Obviously, with the increase in air, the percent C O 2, H 2 O, N 2 and O 2 will be different, than what they were in case 1 and case 2. Now, we can represent this on a material balance diagram, which is as follows.

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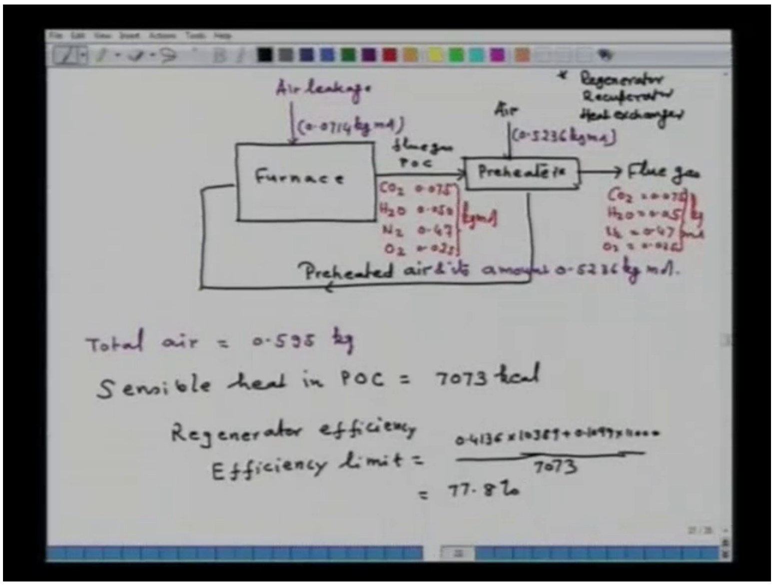

So, I just represent it by a box, which is normal, when you want to represent the material balance. So, this is a furnace, which is same as it was earlier. Now, this is the P O C or flue gas, whatever you would like to call. This is entering into a preheater, or this, you can also call as a regenerator, or a recuperator. This preheater, it could be or it is simply a heat exchanger. So, this preheater could be anything. Now, here, flue gas exits. Now, from here, air will enter and the…So, this is the preheated air. Now, total air in furnace, total air that is required for combustion, that is equal to 0.595, as I wrote down earlier. So, here, air leakage is 15 percent of the theoretical air; you have to calculate the theoretical amount. So, the air leakage now, as I wrote earlier, that is 0.0714 kg mole. This is the air leakage and the air which is used for preheating, that will be 0.5236 kg mole and this amount of air, preheated air and its amount will be how much? 0.5236 kg mole. That will be the material balance. Now, here, for the, for the sake of illustration, I can also represent the flue gas C O 2, H 2 O, N 2 and O 2. So, C O 2 here, is 0.075, 0.050, 0.47 kg mole and 0.025; mind you, they are all in kg mole.

Now, same flue gas will be out, because the moles are not consumed; only heat exchange is there. So, C O 2 which is exiting, that will also be equal to 0.075; H 2 O, that is equal to 0.05; N 2, that is equal to 0.47 and O 2, that will be equal to 0.025; mind you, they are all in kg moles. So, that is how the heat balance heat appears. Now, what to do? What we can do, we can calculate again, the efficiency limit and so on. So, if I calculate now, sensible heat in P O C, sensible heat in P O C, the values I have already given. So, if I substitute all these values, then, sensible heat in P O C, it comes out to be equal to 7073 kilo calorie. You have to make…You have to simply multiply the heat contained C O 2, H 2 O, N 2 and O 2, at the respective temperature and you will get the sensible heat in P O C, because temperature is same as it was earlier. So, now, we have to calculate regenerator efficiency, regenerator efficiency. So, first we will calculate efficiency limit. Efficiency limit, that will be equal to, amount of heat at the flue gas temperature. So, that will be equal to 0.4136 into 10389 is the heat contained in nitrogen, plus 0.1099 into 11000 divided by 7073. So, the efficiency limit is now 77.8 percent.

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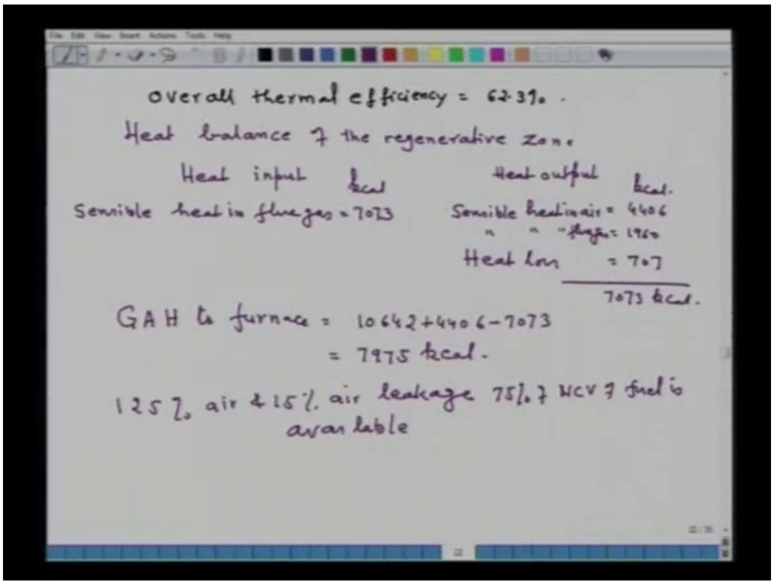

We have got this efficiency limit of 77.8 percent. Now, we can calculate overall thermal efficiency. Overall thermal efficiency, that will be efficiency limit into relative efficiency. So, multiply it, we will be getting 62.3 percent. So, what does it mean? Only 62.3 percent of the heat content of flue gas will be available in the form of preheating air. Now, if I make the heat balance of the regenerative zone, heat balance of the regenerative zone, then, it will look…Again, I will have to do heat input and heat output. So, heat input, that is sensible heat in flue gas, sensible heat in flue gas and that is equal to 7073 kilo calorie. So, heat output, sensible heat in air that we could recover, 4406, all in kilo calorie. Sensible heat in flue gas which is leaving the regenerator, 1960 and we are assuming 10 percent losses of the sensible heat input to the regenerator. So, heat loss, 10 percent of this, that is, 707. So, total, we will be getting 7073 kilo calorie.

So, now, we can calculate the gross available heat to furnace; that will be equal to 10642, which was the calorific value of the fuel, because you are using the same amount of fuel, with the same calorific value, plus 4406 is the heat added, minus 7073 is the heat taken out by the, by the P O C. Gross available heat is 7975 kilo calorie. So, what we note from here, say with 125 percent air and 15 percent air leakage, and 15 percent air leakage, now 75 percent of N C V of fuel is available, is available. So, in this particular example, what we have done, we have used the same fuel, 90 percent carbon, 10 percent hydrogen of the same calorific value; it was 10642 as I had given in, just in the previous lecture; all that we have found out now, with 125 percent air and 15 percent air leakage, now, 75 percent of N C V of fuel is available. So, I will wait for the analysis of the answer, till I do one more case.

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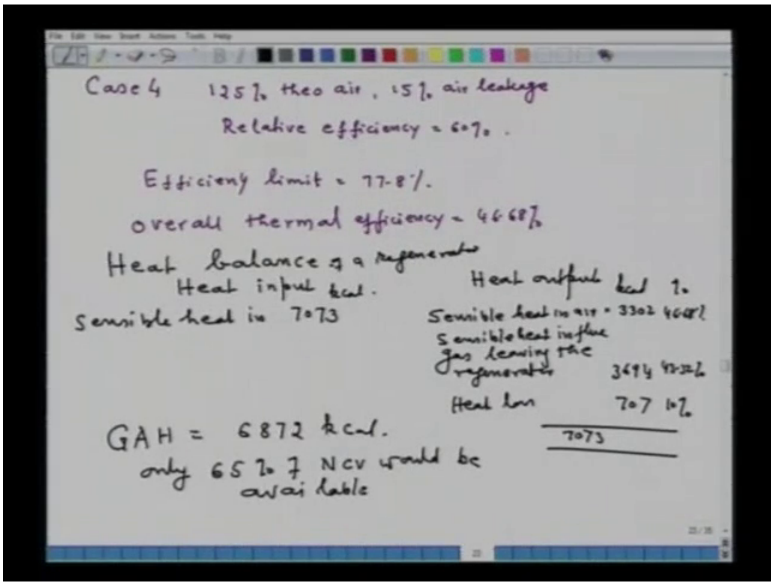

Let us take it now, case 4. Now, case 4 comprises of the 125 percent theoretical air, 15 percent air leakage, but relative efficiency of the regenerator is now 60 percent. Now, since the amount of theoretical air is same as that of case 3, air leakage is also same as that of case 3. Only relative efficiency has changed to 60 percent. As a result of the change in relative efficiency, overall efficiency will change and efficiency limit will remain same as that of earlier. So, now we can calculate, say, efficiency limit, as you have just calculated; efficiency limit, we found 77.8 percent. So, we can find out overall thermal efficiency; overall thermal efficiency, that will be equal to 46.68 percent. So, now, if I do the heat balance, now, if I do the heat balance, then, heat input and heat output. So, you see now, sensible heat in…Now, heat balance of a regenerator. So, sensible heat in, that is equal to 7073 kilo calorie. Sensible heat in air output, in air, that is equal to 3302 kilo calorie. Sensible heat in flue gas leaving the regenerator, leaving the regenerator, that is equal to now, 3694 and heat loss are same; heat loss are 707. So, total again is 7073.

So, what you note from here, in terms of percentage, we are able to recover only 46.68 percent, but 43.32 percent of the heat of the flue gas is lost and of course, this is the 10 percent which we have assumed. So, now if we calculate gross available heat to the working chamber, you can calculate, this will come out to be 6872 kilo calorie. Now, only 65 percent of N C V would be available, would be available. Now, just as a further, if we calculate, what will be the effect on fuel consumption…

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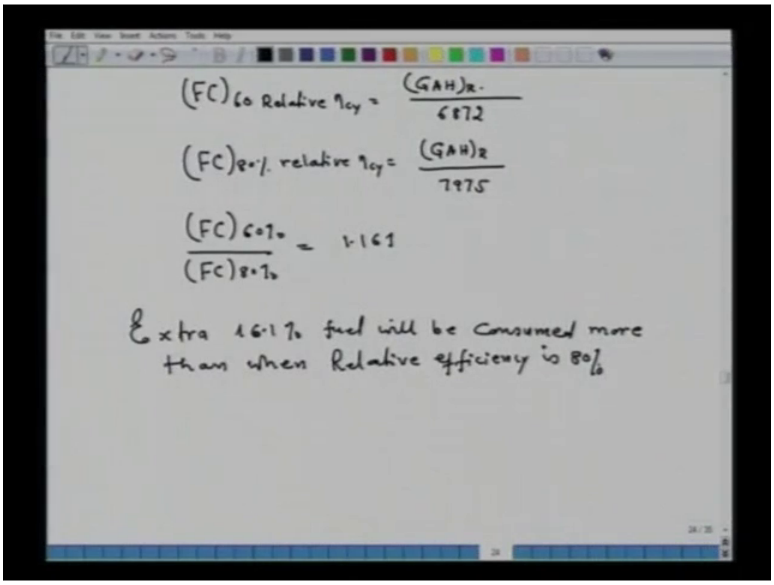

So, we can calculate now, say, fuel consumption for 60 percent relative efficiency, that will be equal to, say, gross available heat requirement is, you know this formula, upon

6872, now the heat available and fuel consumption for 80 percent relative efficiency, that will be equal to gross heat available requirement would be same; it is 7975. So, if you calculate the increase in fuel consumption, so, you note that, due to decrease in relative efficiency of the regenerator, it is obvious, since the gross available heat to the furnace has decreased. So, naturally, the fuel consumption will increase.

So, I can calculate from here now, say, fuel consumption at 60 percent divided by fuel consumption at 80 percent that will come out to be equal to 1.161. So, straight away extra 16.1 percent fuel will be consumed more, than when relative efficiency is 80 percent. So, now you can understand the importance of, the importance of a heat recovery device. A heat recovery device, if it is more efficient in terms of extracting the heat from the flue gases, as well as transferring the heat to the incoming air, it will be more efficient. And, as you see from here with this illustration, that higher relative efficiency, of course, lower will be fuel consumption and lower relative efficiency will increase the fuel consumption, as you see.

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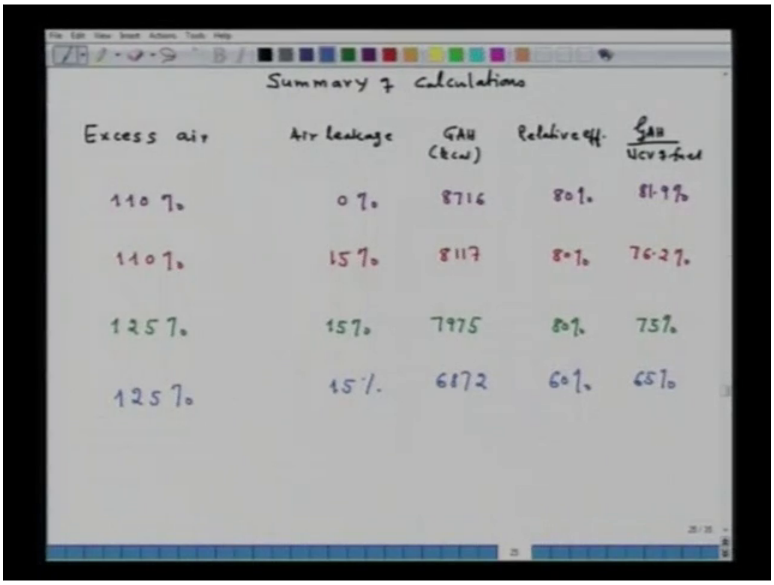

Now, if I summarize the contents of both the lectures, then, the following result will come. So, if I do summary of calculation, summary of calculations, it results say, what we have done, we have taken excess air, then, air leakage, then, gross available heat in kilo calorie, then, relative efficiency and then, gross available heat upon N C V of fuel, that is what we have calculated. Now, we have taken 110 percent excess air; air leakage was first of all 0 percent; gross available heat was 8716 and relative efficiency, we assumed 80 percent and this figure we got 81.9 percent. Now, second case, we have taken 110 percent of excess air, 15 percent air leakage; 8117 is the gross available heat; we assumed 80 percent relative efficiency and we got 76.2 percent of gross available heat could be recovered. Third case, we have taken 125 percent excess air, 15 percent air leakage; gross available heat was 7975. We assumed again, 80 percent is the relative efficiency and the heat available was 75 percent of the gross available heat, of the net calorific value of fuel. The fourth case we have taken, 125 percent excess air, 15 percent air leakage, 6872, 60 percent and 65 percent over here.

Instantly we can see from here that, air leakage, it decreases the gross available heat. Also, instantly you can see from here, increase in excess air, which is now 125, now, if you compare red with the green one, that is 110 percent and 15 percent air leakage, compared to 125 percent excess air and 15 percent air leakage, then the, there is very slight difference in the amount of heat which is, which is referred to the N C V of the fuel; so, 76.2 percent and 75 percent. So, the air leakage could be, to some extent, can be compensated by the use of excess air. Now, let us summarize this whole thing.

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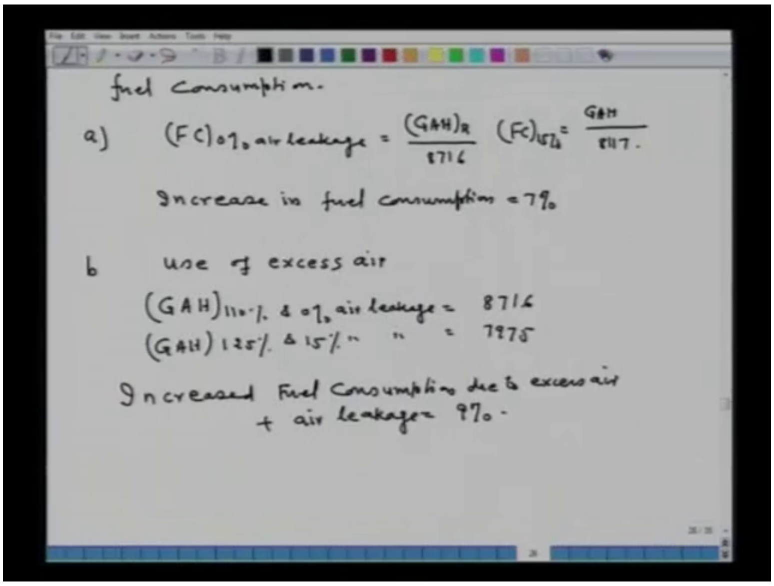

So, what it leads to, for example, in the first case, say, we calculate now, say, we consider now, fuel consumption. a, say in the above case, for example, if we take F C 0 percent air leakage, that will be equal to gross available heat required upon 8716 and F C 15 percent air leakage, that will be equal to gross available heat upon 8117. So, the increase in fuel consumption, increase in fuel consumption, that will be around 7 percent. So, this will illustrate the effect of air leakage on the fuel consumption. Now, b, say use of excess air, use of excess air, with the same air leakage, 15 percent air leakage. Now, we calculate now, say for example, G A H 110 percent and 0 percent air leakage, that is, was 8716 and G A H with 125 percent and 15 percent air leakage, that is equal to 7975. So, if you calculate now, increased fuel consumption, increased fuel consumption, now here, due to excess air plus air leakage, that is equal to 9 percent. Now, if you compare case a with case b, in case a, 15 percent excess air use was giving you only 7 percent increase in fuel consumption. Now, increase the excess air, air leakage, I, I kept of the 15 percent; increase in fuel consumption is only 9 percent. It is obvious, because what I am doing now, the extra amount of air which I have put, it is also being preheated in the regenerator. So, that is an important thing now.

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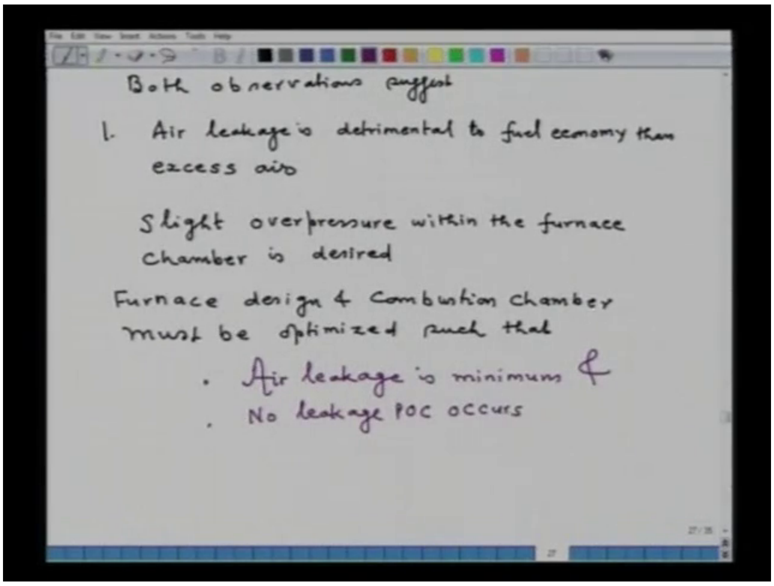

So, both these observations, now both the observations suggest, both observations suggest, number 1, air leakage is detrimental to fuel economy, it is relative, than excess air. As you have seen this calculation, therefore, furnace design should ensure minimum air leakage into the furnace. And, that is a very important conclusion. Now, anywhere, there are cracks in the refractory design, or whatever the sources of leakage of air, that should be minimized to the extent possible, because this is much detrimental to the fuel consumption, as compared with slightly amount of excess air. Now, therefore, slight overpressure, slight overpressure, slight overpressure within the furnace chamber, within the furnace chamber is desired to avoid the leakage of air; but one should be careful that, if the, if the pressure inside the chamber is higher, then, the leakage of the products of combustion is very much possible. So, the furnace design and combustion chamber pressure, furnace design and combustion chamber pressure must be optimized, must be optimized such that, such that air leakage is minimum, air leakage is minimum and no leakage of product of combustion occurs. Mind you, the products of combustion, in many instances, it contains C O also. It is highly hazardous and if one is not careful, then, it will pollute the environment. So, it is in this respect, one should work; that is, the air leakage should be minimum, and no leakage of P O C occurs.

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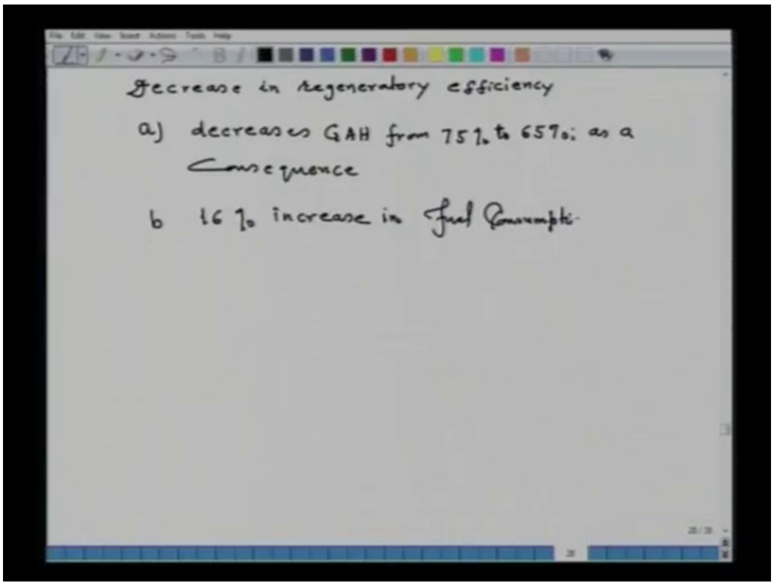

Now, another thing that we have seen also, the effect regenerator efficiency. Now, what we noted in the calculation, that a decrease in regenerator efficiency, decrease in regenerator efficiency, decrease in regenerator efficiency…(no audio from 34:32 to 51:26).

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