Materials and Energy Balance in Metallurgical Processes

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Module No. # 01

Lecture No. # 40

Thoughts on Application of Energy Balance

I have thought - let me close the lectures on material and heat balance, by giving a lecture on thoughts on Energy Balance. In the lectures on material and heat balance, we have done enough about fuel saving and Carbon credit; both the concepts, I have illustrated by solving the problems.

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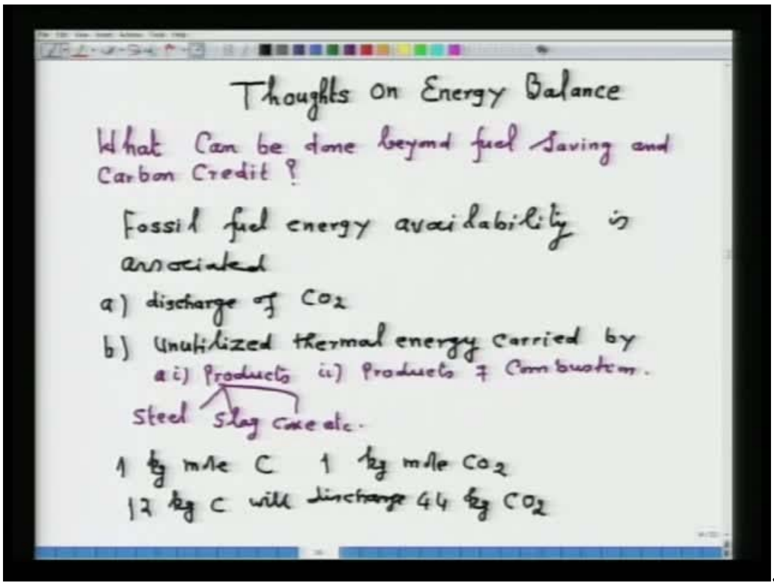

Now, what can be done beyond fuel saving and Carbon credit? I have given a thought over it. Let us think, what in fact, we can do beyond fuel saving and Carbon credit calculations.

We have recognized that, fossil fuel energy availability is associated with (a) discharge of CO 2 in the environment along with other harmful impurities. It is also associated with unutilized thermal energy carried by (a) or (( )) carried by (i) product; so far, we have not paid any attention to the product and (b) by products of combustion. In the product, several types of products are being produced. For example, you read the Steel; so Steel discharge, as I said, is 1200 degree Celsius.

So, the product - that could be depending on the objective: it could be Steel, it could be slag, it could be coke oven gas, because their objective is to produce a coke. I mean it is the coke and like other. So far, we have not addressed what can be done by the heat which is carried by the product.

Now, for example, say 1 kg mole Carbon, on combustion, gives 1 kg mole CO_2. Therefore, 12 kg Carbon will discharge 44 kg of Carbon dioxide. This is one particular thing. Also, we have said that, large amount of heat will also be carried away by the product and products of combustion, and we call that heat - sensible heat.

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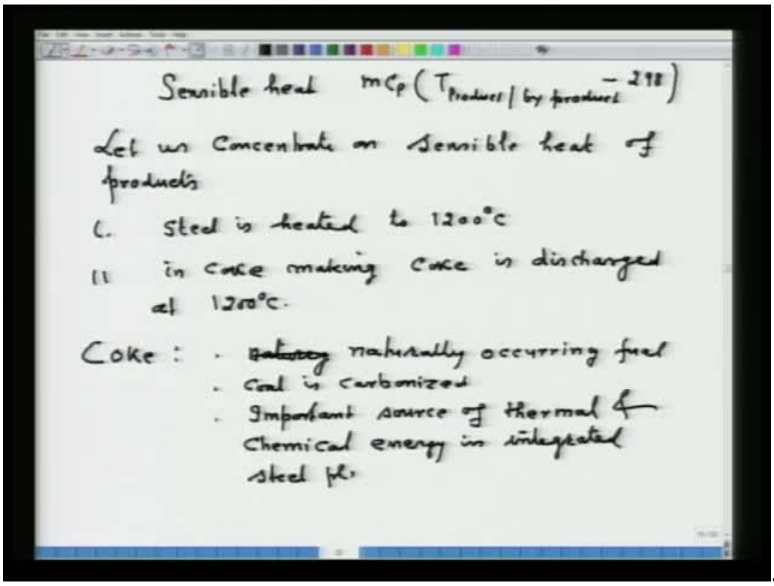

Sensible heat - you know, I am not talking at the moment the calorific value; I am talking of the sensible heat. So, sensible heat; that is mC p (T - a product or by product minus 298), if 298 Kelvin is taken as a basis of calculation.

Depending on the temperature of the product, a large amount of sensible heat will also be carried away. We have already addressed, what can be done by the sensible heat of the by-products. We have tried to recover recycle into the furnace and did lot of calculation.

Now, this sensible heat is also very important; say, in sensible heat, for example, in by product for example, the gases are there. So, the gases are discharged, also at 1100 or 1200 degree Celsius depending on the temperature of the furnace; unless the gases are cleaned, they cannot be use directly.

Then what happens to the sensible heat of the product?

Now, let us consider and concentrate. Now, let us concentrate on sensible heat of products. So, for example, (i) for thermo mechanical processing, Steel is heated to 1200 degree Celsius approximately, and its heat which is available with the Steel is utilized for thermal mechanical processing, that is, for direct rolling. You must have also seen - in coke making, coke is discharged at around 1200 degree Celsius. It is very difficult to store the coke at this particular temperature. So, for this purpose, coke is water quenched and brought to the temperature of 25 for storing purposes. In an attempt to water quench coke, large amount of water is used; water contains large amount of contaminants; large emissions due to wet quenching of coke is discharged in to the environment.

What I have thought - let us consider coke making and what can be done with the sensible heat of coke. So, I will concentrate my lecture on the sensible heat in coke.

Now, first of all, as we already seen in the lecture on coke making, for example, in lecture 27 - that coke is not a naturally occurring fuel; number (ii) Coal is Carbonized - the details you can find in the lecture 27; also, coke is an important source of thermal and chemical energy in integrated Steel plants.

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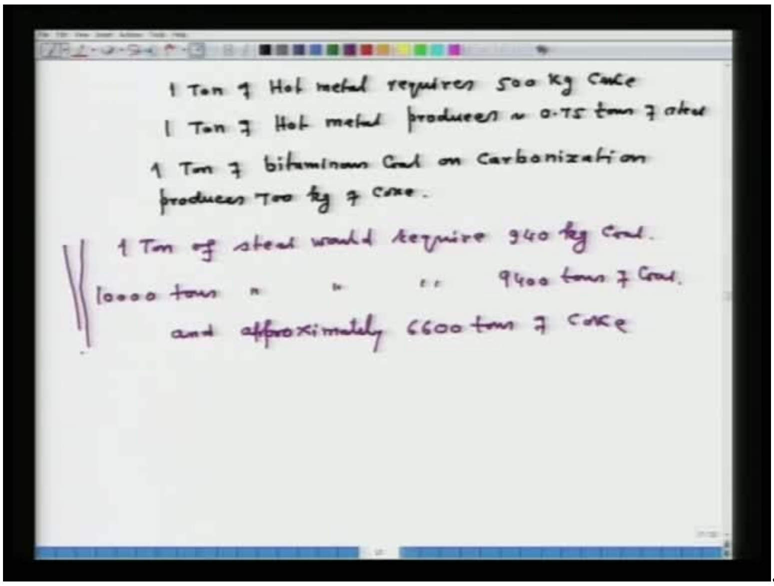

Now, just to give you a figure, say one ton of hot metal, hot metal means the pig iron - it requires 500 kg of coke, approximately. The figure may vary, but just I am taking an example.

One ton of hot metal produces approximately 0.75 tons of Steel. Now, one ton of bituminous Coal on Carbonization produces 700 kg of coke. That means, now, if I combine all together, then I can say that, one ton of Steel would require 940 kg of Coal. If I take 10000 tons of Steel, that would require 9400 tons of Coal, and approximately 6600 tons of coke. What does it mean? You are not producing 10000 tons annually; you are producing million tons of Steel; a huge amount of coke is required in almost all integrated Steel plants.

So, that means the conversion of Coal to coke, and the sensible heat which is available in coke, is a very important thing to consider what can be done. So, let me give you a heat balance of a typical by-product, coke oven.

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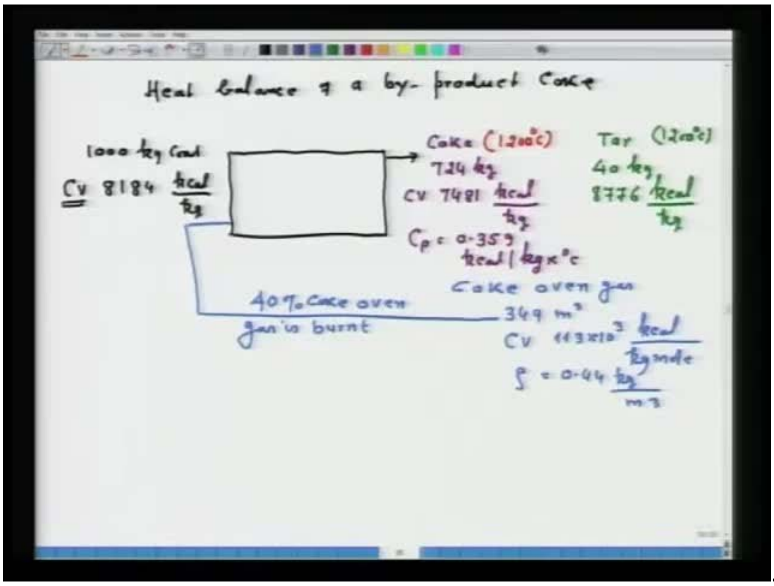

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Let us consider the heat balance of a by-product coke oven. Now, here I have selected the heat balance; basically this material balance - first we have to do it. In the lecture 27 which is material balance in coke making, one of the examples which I presented over there, I have used the data of material balance to illustrate the energy balance or heat balance over here.

So, I am just putting in a form of a diagram. So, here, I am presenting the heat balance. So, here what are we doing? I am putting 1000 kg Coal, whose calorific value is 8184 kilo calorie per kg; Cv so far you must have known, stands for calorific value. So, on discharge, we get coke; its amount is 724 kg; its calorific value is 7481 kilo calorie per kg; its Cp - that is equal to 0.359 kilo calorie per kg into degree Celsius and it is discharged at temperature 1200 degree Celsius - that is what we are considering.

Another product as we have shown here is a tar, whose amount is 40 kg and its calorific value is 8776 kilo calorie per kg. It is also discharged at 1200 degree Celsius.

Then, another product is say coke oven gas, whose amount was 349 meter cube; calorific value 103 into 10 to the power 3 kilo calorie per kg mole; its density is 0.44 kilogram per meter cube.

Now, what am I doing?

This coke oven gas, say 40 percent of coke oven gas is burnt and it is used to reheat the walls of the by-product coke oven; you know that, there is an indirect heating. So, given all these figures, now, we can do the heat balance and let us see what the heat balance brings. So, I will use the next page.

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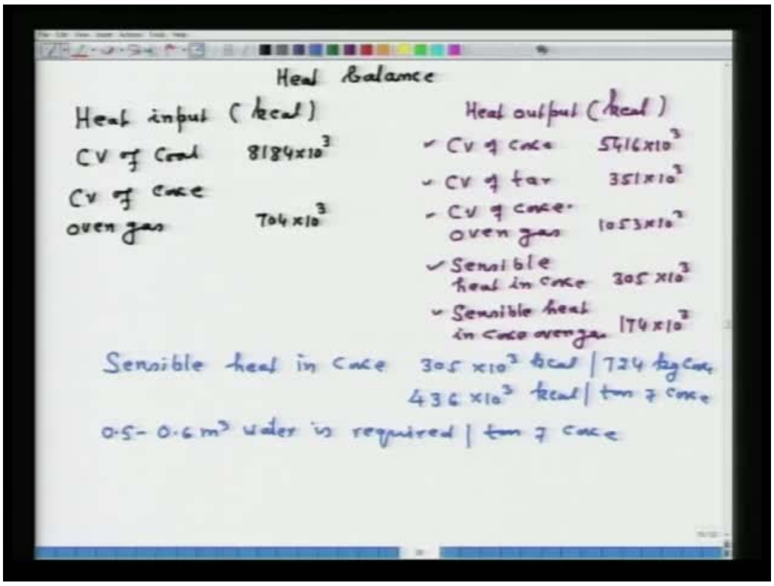

So, let us do the heat balance typically: heat input in kilo calorie, Cv of Coal, and then we have Cv of coke oven gas. Because you are combusting it, Cv of Coal is 8184 in to 10 to the power 3 and that is 704 and 10 to the power 3 here (Refer Slide Time: 15:23).

Now, let us go on the heat output, again in kilo calorie. Then, Cv of coke - we have one; then Cv of tar - we have another; then Cv of coke oven gas; then important - sensible heat in coke and sensible heat in coke oven gas. Now, let me just concentrate on this one - sensible heat and sensible heat in coke oven gas.

Now, these values are over here that is 5416 into 10 to the power 3. Here 351 in to 10 to the power 3; here it is 1053 in to 10 to the power 3(Refer Slide Time: 16:23 to 16:34); sensible heat in coke - 305 into 10 to the power 3 and sensible heat in coke oven gas - 174 in to 10 to the power 3. Now, this is a heat balance picture that is before us. For example, calorific value of the coke - that is not lost even in the water quenching; on combustion, this energy will be available, no problem.

Cv of tar - it is also available because it is the potential energy. Similarly, calorific value of coke oven gas is also available because it relates to the potential energy; on combustion, you will be getting.

What about sensible heat in coke oven gas? You know, the coke oven gas contains large amount of entrained particles. So, you have no option except to cool the gas and clean the gas, and you can use only its potential energy. Unless you have Unless the gas is very clean, the sensible heat of the coke oven gas is not possible to you. For that matter, any gas which is coming out if it, containing entrained solid particles, is very difficult to use because it will contaminate all the appliances which you use for recovering the heat. In this particular case, what happens to sensible heat in coke?

Sensible heat in coke - you cannot use it because it has to be wet quenched in order to story it. You cannot store coke at around 1200 degree Celsius. So, that means what? We can see from here, that sensible heat in coke which is very large in amount, at present it is 305 in to 10 to the power 3 kilo calorie per 724 kg of coke which is equivalent 436 into 10 to the power 3 kilo calorie per ton of coke.

What happens? On wet quenching, this energy is lost. So, what you are doing? On wet quenching, one thing that you are doing, that is, you are losing the sensible heat. But the second thing that you are doing is - you are harming the environment; you are using a very large amount of water; approximately 0.5 to 0.6 meter cube of water is required per ton of coke for wet quenching.

Now, the water is spread on hot surface of coke which has 1200 degree Celsius. Water is vaporized along with the contaminants because water nearby the integrated Steel plant is not pure; it has lot of contamination. So, all those contaminations are evaporated into the atmosphere. So, large amount of emissions are discharged into the environment. So, that means, along with this, air bound coke dust - that is also discharged in the environment.

Now, considering the amount that you are converting per day or the Coal which is carbonized per day in a plant - it could be 10000 tons or whatever.

You can imagine the amount of heat which is being lost by wet quenching and the emissions which are being produced in the environment. Don’t you think that, this particular heat balance which you have done - it provocates you to think, can we do something on the sensible heat of coke? Is it not possible to do something on sensible heat of coke which is largely going to waste, not only waste, but it is also polluting environment?

Don’t you think that this heat balance exercise that you have done for the coke by-product coke oven plant - does it not to help you to innovate or to think along the lines that, can we do something to use a sensible heat of coke.

It is this particular thought that I want to tell you, that, if you do the energy balance and if you try to analyze as we have done analysis of each of the output heat - if you do that analysis, then you will come across innovative ideas which is a need of the hour because everywhere, we are talking on the energy security at environment sustainability. If you do this, you will come with an idea.

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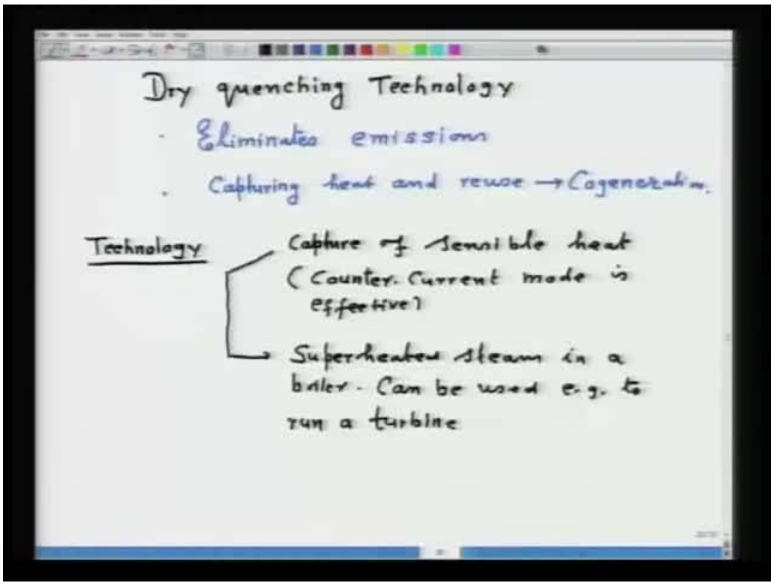

In fact that idea is working in the plant; why not to evolve a mechanism of quenching of coke not by water, but by gas? This mechanism is called dry quenching technology.

So, that is what my objective of this particular lecture is to provocate you to think after doing the heat balance, to think in terms of - can we save energy? number 1; number 2 - can we contribute to the environment sustainability or not? That is quite possible; you are seeing now.

Also, if the magnitude of the heat is also available, that is important. So, this is a thought process which has given the so called dry quenching technology. Dry quenching technology can also be conceder under the Kyoto protocol as a technology which contributes to clean development mechanism; in short, it is called CDM. There are several clean development technologies; sintering, pelletizing; this is one.

I will illustrate what can be done by performing heat balance of a high temperature process? So, dry quenching technology - you can call it as a technology which contributes to clean development mechanism, which means that, this technology reduces the emissions in the environment.

So, in fact, the advantages of this dry quenching technology: first of all, it eliminates it emission; of course, because now, we are dry quenching; may be you are using air here, but air you cannot use because that will react with the coke; you are using inert gas; it could be Organ, Nitrogen or whatever. So, it eliminates emission.

Second important thing that you are doing by dry quenching is that, you can capture the sensible heat and you can re-use it. That means you can invoke the basic concept of energy security in environment sustainability; that is capture and re-use. So, the second thing that you are doing is - you are capturing the heat and reusing it. That is called cogeneration. This is an idea which has emerged. This can be done and these are the benefits.

Now, comes the question of development of technology because when we talk of the technology, it is related with the finances; that technology should be workable. Now, this is well established technology, but what I am telling - if those ideas, if it is to be translated on the technological thing, several other things are required.

Now, this technology should have at least two components.

One component is, say, capture of sensible heat. Now, this can be done, in which a gas is flowing counter current to the flow of coke. That is you have to design a reactor where coke may be flowing from top and discharged from the bottom, and the gas is flowing from the bottom in a reactor and discharged from the top because a counter current mode of heat exchange is a very very efficient method of heat transfer.

So, the one component - it should have a capture of sensible heat. However, you have to have a mechanism to charge the coke to have a in light for gas and so on, are the part of the technological development and important component is the capture of sensible heat. Of course, here, a counter current mode is very effective because you have to synchronize with the flow or with the amount of coke that is dropping and amount of gas and this synchronization is a part of the development of the technology.

Another component is… what you have done with this? You have passed the gas at 25 degree Celsius, and coke for example, at 1200 degree Celsius; you allowed enough residence time so that the gas is heated; for example, 400 or 500 degree Celsius or 600 degree Celsius. What will you do with that gas? You have a gas which is super-heated; I mean I do not use the term super-heated, but is heated to 600 depending on the residence time and height of the reactor; it may go even higher temperature; 600, 700 degree Celsius you have heated the gas. What are you going to do with that gas?

So, the second component is used. The heat which is available to you in the gas to produce, for example, super-heated steam, or there could be other uses also. You want to heat some appliance or something which I do not know, anything could be. Because now, you have the heat which is available to you in a flowing gas and it has to be used. One of the important uses is to produce a super-heated steam.

Now, super-heated steam means because your temperature of 600 degree Celsius of the gas, water evaporates 100 degree Celsius. If it comes in to contact, water may be - the evaporated water may be at 300, 400 degree Celsius. So, it is a super-heated steam. Large amount of pressure will be generated. So, super-heated steam: Now, for example, in a boiler, super-heated steam in a boiler; you think what you are going to do with that super-heated steam? Large amount of steam you have stored. What are you going to do? You can do nothing. So, that idea should also be there.

This super-heated steam can be used, for example, to run a turbine. So, I mean to say that these are the things or these are the technological challenges which have merged out of heat balance, and after giving a sincere thought on what can be done with the available heat.

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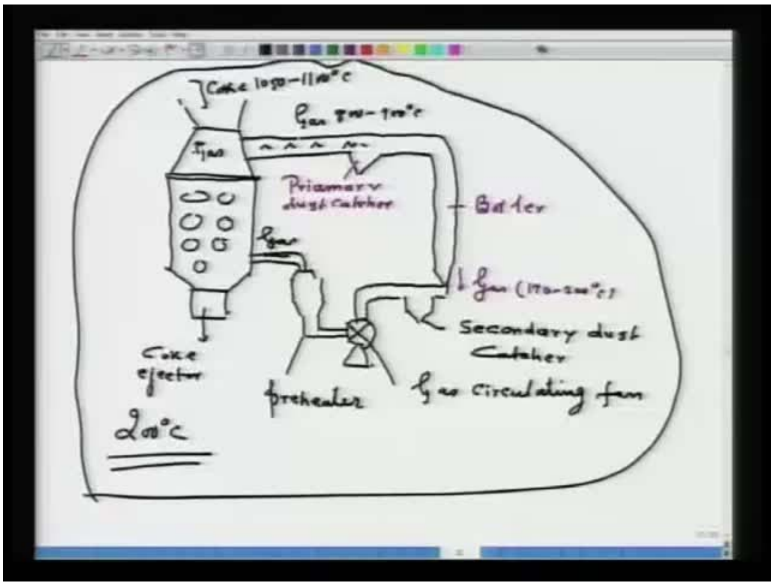

Now, I will just give you a flow diagram of a technology which works on the dry quenching. So, here what do you have? You have a reactor; for example, this is a reactor.

So, here you have this - so called coke ejector; this is the coke ejector. Here you have a hopper; here is a coke, take for example, 1050 to 1100 degree Celsius is charged. So, the coke moves downward. As the heated coke moves downward and cooled, the coke is discharged through the bottom.

Now, the hot gases from here - this is the gas. (Refer Slide Time: 30:22) They are collected here and the hot gases are taken in a boiler. So, this is a line for hot gas and here, somewhere you have a primary dust catcher (Refer Slide Time: 30:35). So, this line enters into a boiler. This is sort of boiler. So, this is the gas; it passes here at the temperature 800 to 900 degree Celsius and this is the primary dust catcher. You know, it is important to remove the dust. This is the primary dust catcher. This is what I mean. These are the components of the technologies: you have a reactor, you have the gas flowing pipe line, you have the primary dust catcher which rather removes the dust, then you have to the pass through the boiler so that water get heated up.

Now, the gas which is cooled, say it may have - it may not have 800 temperature, it may be around 170 to 200 degree Celsius. You have to think, what you are going to do with that gas. Now, another dust catcher; this is a so called secondary dust catcher (Refer Slide Time: 31:56). You know, you require because you have to be sure that the particles which are there may not contaminate the boiler and so on. So, you require all these small small things, but then you must think and then you might require a pump to boost the pressure so that the gas can flow. So, this may be a pump over here. So, this is a sort of a gas circulating fan. Now, from here, it goes to a preheater (Refer Slide Time: 32:37). Let me try it. This one - this is just a preheater, and from the preheater, the gas again enters over here. So, here again, this is the gas and this is the so called preheater. The coke ejector now, when the coke it comes out, it is around 200 degree Celsius.

So, you see, by developing this particular technology which is called the dry quenching technology, you have contributed not only to recover the sensible heat, but also you have created an environment where steam can be produced and turbine can also be run. So, this is a typical example of this. So, let me now illustrate, another example of fuel saving - though I have illustrated in my earlier lecture, I thought let me do once again, here.

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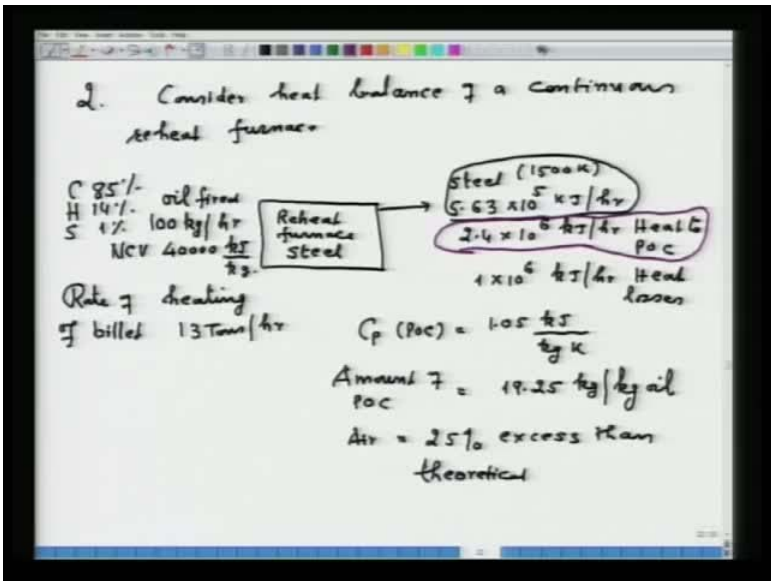

So, I will create a different problem, say on second case. Now, consider heat balance. Consider heat balance of a continuous reheat furnace. I will not be going into detail of all calculations; you can do yourself, what I am representing.

So, let us take it now. This is a reheat furnace which is used to heat Steel to for example, 1400 degree Kelvin typically for rolling operation. Now, this furnace is, let us say, oil fired and consumption of oil is 100 kg per hour; its net calorific value is 40000 kilojoule per kg; rate of heating of billet say it is 13 tons per hour; it is a huge furnace. The composition of oil: Carbon - 85 percent, Hydrogen - 14 percent and Sulfur is 1 percent.

Now, I have calculated the heat output in terms of heat output for example, Steel. To calculate the heat output, what I have done? It is 5.63 into 10 to the power 5 kilojoule per hour. You can calculate from MCp. Delta TM is already given to you which is 13 tons per hour and temperature is the Steel. I have considered here, the discharge temperature of Steel is 1500 Kelvin. So, that can be done because we have done at several places. Then 2.4 into 10 the power 6 kilojoule per hour is heat to POC. Now, this much amount of heat is the heat 2, which is taken away by the Steel. Then, 1 into 10 to the power 6 kilojoule per hour is the amount of heat losses.

Now, some data I am given here. What have I taken? Cp of POC. I have taken average Cp of POC - that is 1.05 kilojoule per kg Kelvin. Amount of POC: you can calculate amount of POC - that is 19.25 kg - per kg oil. Then amount of air -that is equal to 25 percent excess than theoretical. So, given this data, you do this calculation.

My objective here is to show you by calculation, in this particular scenario, where we are not using any heat, then the fuel consumption is 100 kg per hour.

Now, again if we see this heat balance in the form, you note that the heat which is taken away by the steam nothing can be done; only the Steel is directly taken to the rolling mill. So, you do not require giving the heat for rolling purposes - that is one heat loss. You also cannot do it because it is limited by the several parameters: a water cooling, opening of the door through the walls, and so on; these also cannot be done.

Now, if you think in terms of bringing down the fuel conception of 100 kg per hour to a lower value, the only alternative that seems to be applicable in this particular scenario is what can be done with the heat to POC. What I mean - if you are working in a plant or in a rolling mill where rolling is done, Steel is heated to that temperature; they are not using that particular heat and heat balance is before you, you should think what can be done to bring down the fuel conception in the existing furnace. Mind you, I am talking of existing furnace. Here, by this heat balance, comes to the knowledge or it comes your knowledge that this 2.4 into 10 to the power of 6 kilojoule per hour of heat is going to be taken by the POC.

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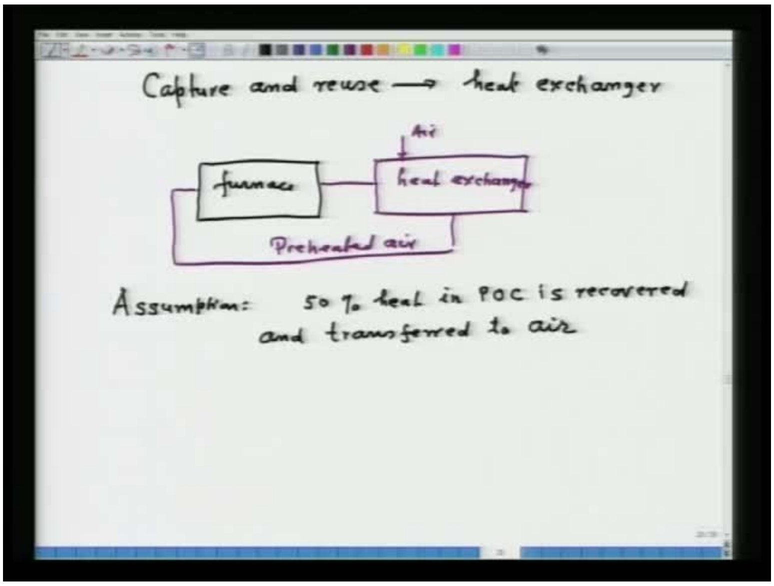

So, naturally, this heat balance gives you an idea that - why not to capture and re-use the heat simultaneously. So, the concept of simultaneous use of capture and reuse, concept of unutilized heat - it can be only done by installing a heat exchanger. So, my idea of going to this presentation is very simple. It is to provocate you that, after doing a heat balance, you should exercise your mind to think what can be done. So, simultaneously, capture and re-use. It can be done through the heat exchanger.

So, Now, I will show that, by heat exchanger, how much amount of fuel can be saved. That means without noting what I am doing, this is my furnace, and to this furnace I am attaching a heat exchanger; so, this is a heat exchanger and this is a furnace (Refer Slide Time: 40:38). Same amount of POC that we have calculated earlier. Here, say, I am putting air over here at 25 degree Celsius and preheated air is now passing into the furnace; rest all parameters are same. Heat to Steel will be same, heat losses are same, only air is being preheated by the heat recovered from the heat exchanger, and transferred to air.

So, here, although we can calculate, I am making this assumption that 50 percent of heat in POC is recovered and transferred to air. That is what we are doing. That means our heat exchanger is working to a capacity so that it can recover 50 percent of heat and transfer all 50 percent of heat to the incoming air. Naturally, now, since additional heat is being supplied to the furnace, we are not changing the rate of heating of Steel. That is we are still keeping 13 tons per hour. It is constant.

Now, since we are supplying additional amount of heat, we are not allowed to increase the temperature of Steel. So, the only alternative is to reduce the fuel consumption. There is no other way. Otherwise, the temperature of Steel will increase because you are supplying additional amount of heat.

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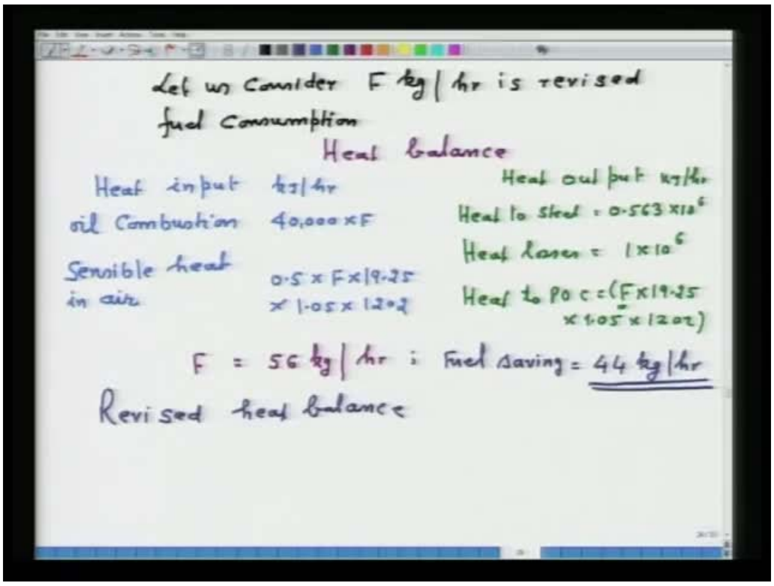

So, let us consider now, F kg per hour is our revised fuel consumption. Now, we can do heat balance. Let us see what heat balance gives us. We can do heat balance. For the heat balance, we take one heat input and heat input is say oil combustion; that will be in kilojoule per hour.

Now, F kg per hour. So, it will be 40000 which is a calorific value into F, sensible heat in air. We are recovering 50 percent. So, it will be 0.5. Our products of combustion - that will be F into 19.25, that is our kg - per kg into 1.05 is its heat capacity into its discharge at 1500 Kelvin; so, 1500 minus 298 into 1202. That is what our sensible heat in air.

Now, let us see heat output. As I have said, the rolling mill has to work how it was working earlier. So, heat to Steel - it will remain same. Heat to Steel - that is 0.563 into

10 to the power 6 kilojoule per hour, will remain the same. Heat losses will also remain same as it was in our earlier example, 1 into 10 to the power 6.

What about heat to POC? Heat to POC - that will change because now, our fuel consumption is F per kg. 19.25 kg per kg of fuel is the amount of POC into its specific heat is 1.05 into 1202. So, that is the heat to POC. That is what now, the heat balance before us.

Now, what can we do? Now, heat input - if you do the heat output then you can calculate the unknown value of F. This exercise, I will leave on you. So, if you do that, we calculate F - that is the revised fuel consumption. Now, it comes to 56 kg per hour; that means, the fuel saving at least on the calculation front - that is equal to 44 kg per hour.

Now, you can extend. If the furnace operates 15 hours per day per month, how much can you save? So, what I wanted to illustrate through this example is that, just think beyond after performing the heat balance. This particular exercise will give you many innovative technologies and one particular example, I mean 2 examples I have given; 1 in case of coke making and another in case of a reheating furnace.

So, these are the important things that I thought I will illustrate here itself to complete the problem. You can now perform revised heat balance; no problem, you can make it now. Revised heat balance - you can do it now. Revised heat balance and the heat input, heat output, but that is not my objective.

My objective is simply to provocate you that, wherever you are, in the plant where high temperature appliances are there, you must make an attempt to do the heat balance and do not stop just by doing heat balance, but think beyond, analyze each heat output step and see what can be done.

Here, the concept of capture, concept of reuse and the third concept which we have not explored over here is - the concept of switch; that is, from fuel oil can you switch over to another type of fuel or a mixture of fuel.

So, these are the three concepts, along which you must analyze your heat balance and that is what is the objective of this lecture Now, with this, I hope that some of you must be having and or must be encouraged to do this exercise, so that my lectures will be useful.