Fuels, Refractory and Furnaces

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Lecture No. # 34
Exercise on Heat Flow in Furnaces and Heat Exchange

In this lecture, I will be illustrating the theory and fundamentals on heat transfer in furnaces that we have covered in lectures 28 to 32. I have found several examples in order to illustrate the theory which here presented in the said lectures. Now, in various situations, when we design a furnace, it is often important to know the heat losses which are occurring through furnace. Heat losses that means I am strictly meaning here the losses which are occurring through the walls of the furnace that is through the lining of the furnace.

Two situations are possible. In one case, there is already a furnace and you are required to know how much amount of losses that are occurring through the walls of the lining in order to modify because you know that the loss of heat through the lining is in fact that so-called loss of calorific value of the fuel. That is in fact loss of heat or the heat losses is equal to loss of fuel and whatever amount of heat that you are going to reduce through the losses, you are going to save the fuel.

In another situation, you are designing a new furnace and you want to find out what should be the optimum thickness for particular fuel consumption. So, keeping both objects in mind, let us see a particular problem to illustrate whatever I said in my introductory remark. All the theory and the necessary formula have been given in the lectures 28 to 32. Please see those lectures for the formula and the necessary details. Here, I am writing a problem and let us solve that problem to illustrate the thing which I have said.

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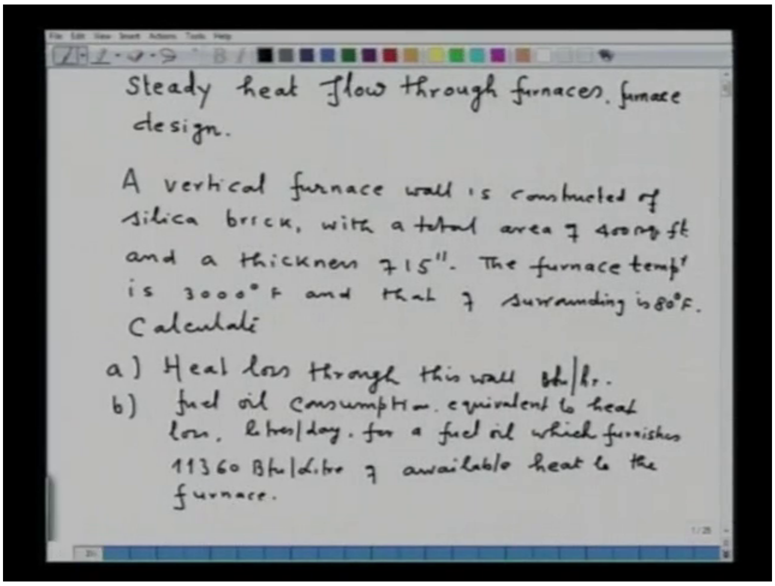

So, a vertical furnace wall is constructed of silica brick with a total area of 400 square feet and I have purposely used FPA system just to illustrate the various dimensions and unites and a thickness of 15 inch. The furnace temperature is 3000 degree Fahrenheit and that of surrounding is 80 degree Fahrenheit.

Now, calculate a heat loss through this wall, of course in British thermal unit per hour. Calculate fuel oil consumption. Let fuel oil consumption equivalent to heat loss say in liters per day for a fuel oil which furnishes 11360 British thermal unit per liter of available heat to the furnace.

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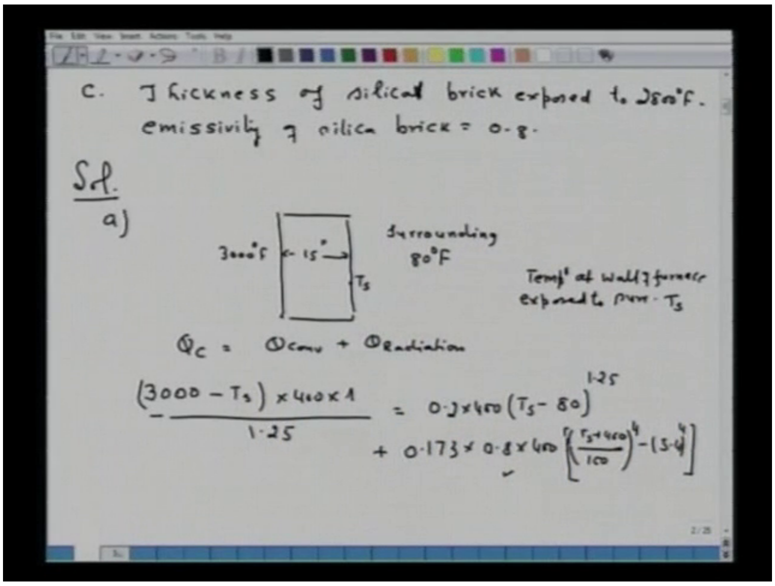

C, you have to calculate thickness of the silica brick exposed to 2800 degree Fahrenheit. Now, here you will take emissivity of silica brick, take equal to 0.8. Now, let us see how to solve this particular problem. Now, say if I take a solution, say if I see the furnace. This is one, this is the thickness and thickness is given to us is 15 inch. 15 inch is the thickness and if this is the furnace, then the furnace temperature is 3000 degree Fahrenheit whereas, this is the surrounding and this temperature is given to us 80 degree Fahrenheit. Now, naturally here as I said that the heat transfer will locker from furnace to the wall conduction and from the wall to the radiation and conversion.

So, in fact q conduction, that is equal to q convection plus q radiation. So, given this heat transfer from the furnace to the wall of the silica about to the wall which is exposed to the surrounding will locker by the conduction and from the wall which is exposed to the surrounding, the loss will locker through the convection and radiation. All that we have to say is equalize both of them and we can do that, so few conduction. So, let us assume that the temperature at wall of furnace exposed to surrounding, that is equal to 2S.

So, that means this temperature, let us see this temperature is TS. So, in fact TS temperature is unknown. So, q conduction and straight way writing down 3000 minus t sin to 400 into 1 upon 1.25. That will be equal to 0.2 into 400 TS minus 80 raise to the power 1.25 plus 0.173 into 0.8 which is emissivity into 400 TS plus 460 upon 100 raise to the power 4 minus 5.4

raise to the power 4. So, what I have done is I simply utilized the left hand side. It is a heat transfer by conduction, the famous four years law. The right hand side is a heat transfer by convection which is HA into delta t and I already have given this particular expression for convection and this is for radiation. So, all that we have to solve this equation and this equation can be solved only by trial and error.

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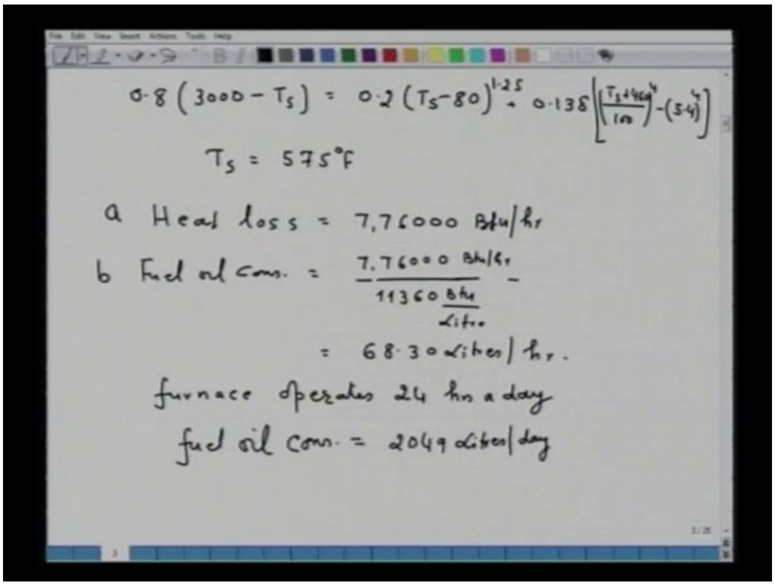

So, we get by rearrangement at 3000 minus T S, that is equal to 0.2 T S minus 80 to the power 1.25 plus 0.138 into T S plus 160 upon 100 raise to the power 4 minus 5.4 raise to the power 4. So, if you solve by trial and error, we get T S, that is equal to 575 degree Fahrenheit.

You all know the formulae which have been used to solve this particular problem. They are given in the lectures 28 to 32. Now, we can calculate heat loss. So, the heat loss that is simply by conduction, that is 3000 and so on. This heat loss will be equal to 776 Btu per hour through a 400 square feet wall. Now, we can calculate the fuel oil conception and that will give you a feel which I said in introductory remark that heat loss directly corresponds to the fuel oil conception. So, fuel oil conception that is this is your heat loss and fuel oil furnishes 11360 Btu per liter of the available heat and this is in Btu per hour. So, if you solve, we get 68.30 liters per hour. So, if you assume that the furnace operates 24 hours a day, then the fuel oil conception that will be equal to 2049 liters per day.

So, you can imagine in this particular furnace though is losing heat, so this loss of heat, it corresponds to loss of fuel and you can see per day 2049 liters of oil is just consumed to maintain their heat loss which are accruing through the furnace. So, here you must be appreciating also that for efficient furnace design, it is necessary to optimize the lining thickness and thermal conductive, so that the heat losses are minimum because whatever amount of heat losses, that is the loss of fuel and whatever you can save, your contributing to the fuel saving and hence, to the inner the securities as well as environment sustainability also because whatever amount of fuel will be saving, less will be discharged to the environment.

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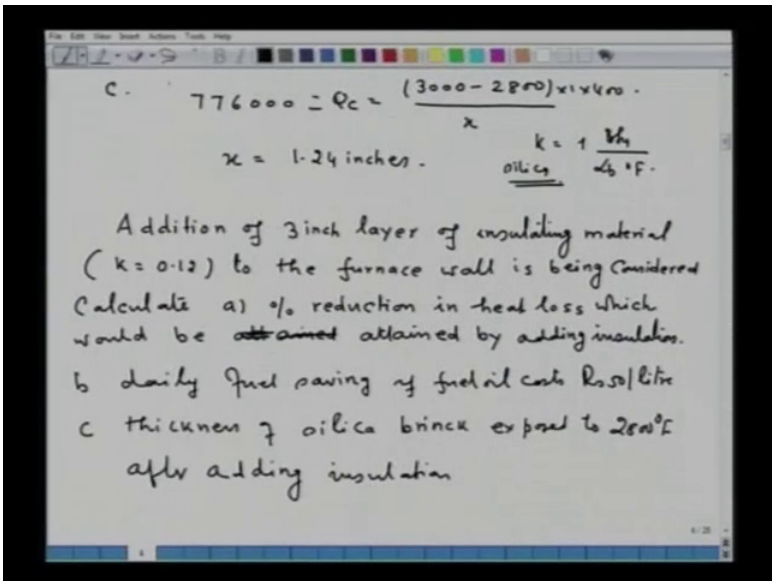

Now, c portrait will calculate the thickness of the brick which is exposed 2800 degree Celsius. So, the c part straight away 776, that is equal to Q c that is equal to 3000 minus 2800 upon x if x is the thickness which is exposed to 2800 degree Fahrenheit into 1 into 400. So, this x thickness will come to 1.24 inches. So, that means the wall of the furnace which is exposed to 2800 degree Fahrenheit is at 1.24 inch thickness. Now, let us extend this particular problem to another situation.

Now, say addition of three inch layer of insulating material whose k equal to 0.122 the furnace wall two is being considered. Why? Because he wants to see whether we can minimize the heat losses or not. Now, here calculate a percent reduction in heat loss which would be attained by heading the insulation.

B. Daily fuel saving. If fuel oil cost Rupees 50 per liter, you may substitute the actual prize also here and c thickness of silica brick exposed to 2800 degree Fahrenheit after adding insulation. That is what you have done. We have simply now modified the furnace by heading an extra insulating thickness whose thermal conductivities 0.12. Mind you in the earlier case, the thermal conductivity of the brick k was 1 Btu per pound degree Fahrenheit. This is k of silica brick in earlier problem. Now, if we try to calculate this one same formula we have to apply. Now, what we have to do? What we have done here?

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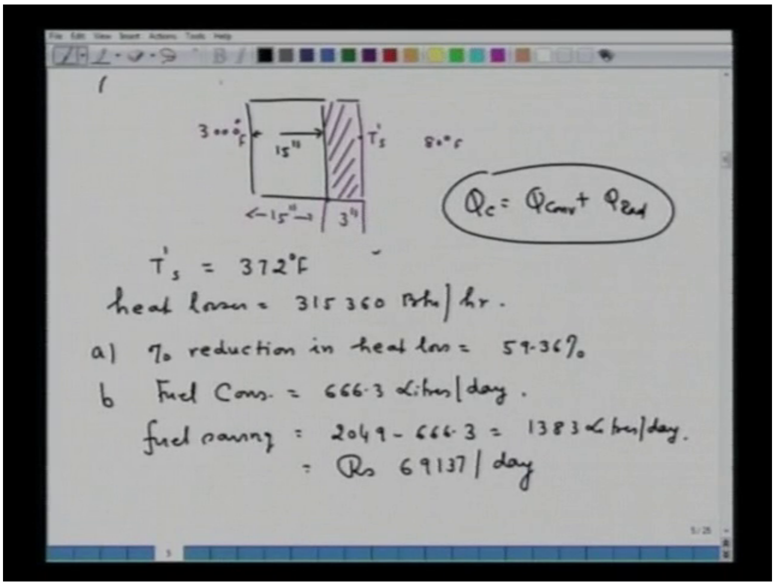

Say, we have this was our original say 15 inch silica brick and now, we are adding an insulation brick whose thickness is 3 inch. Say, this is 15 inch and this is 3 inch. So, here the temperature is 3000 degree Fahrenheit, here you have 80 degree Fahrenheit and here again surface temperature one has to recalculate t dash s. Now, here this is a multi layered lining problem. So, you have to again apply that multi layered at lining formula, again equate conduction is equal to convection plus radiation. I am omitting that step and I will like you to do that step, rate it and get the surface temperature T S which I am writing in case that will come out to be equal to 372 degree Fahrenheit.

You have to do what? That is you have to again q conduction that is equal to q convection plus q radiation. Only difference between is here you have thermal resistance offered by multi layer. That is the only difference. So, then the heat losses that will be equal to 315360 Btu per liter, Btu per hour. So, answer a percent reduction in heat loss that will be equal to 59.36

percent. So, you can see now heading a three inch insulating thickness of thermal conductive 0.12. It has decreased the heat loss to the tune of 59.360 percent. Now, b. The fuel conception has also decreased as now 660.3 liters per day. So, fuel saving now either result of this particular measure. That means addition of 3 inch insulating thickness. The fuel saving is now 2049 minus 666.3, that is equal to 1383 liters per day. So, that will correspond to at the rate which I mentioned around 69137 rupees per day.

You are going to save by putting an extra insulation and if you can convert on monthly basis, on annual basis by putting an extra insulating layer thickness on the existing furnaces, there will be a saving of money. Not only money, but also you are going to save a huge amount of oil to that. That is what to illustrate this particular problem that the fuel saving and the economics, they are inter related. Now, the last portion we have to calculate the thickness of the silica brick exposed to 2800 degree Fahrenheit is similar way.

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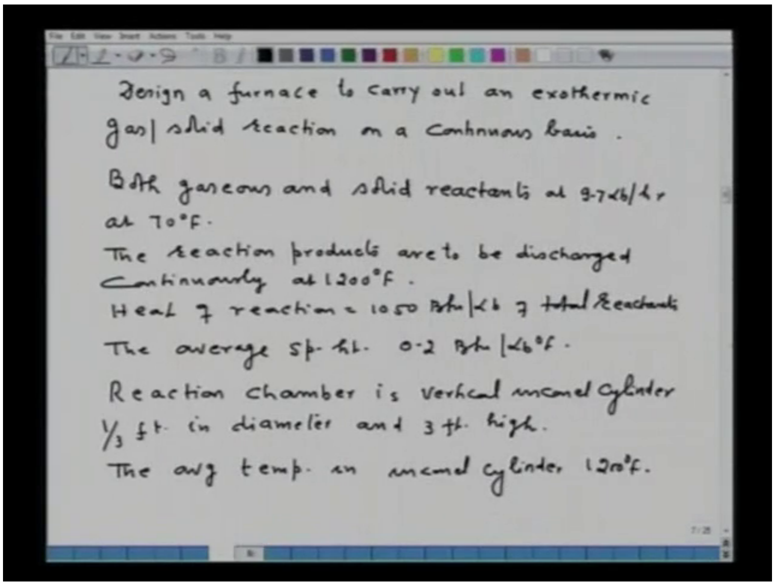

So, you have the losses 315360. That will be equal to 400 into 200 upon x dash. I am omitting the steps. You can write down. So, the thickness of the layer which is exposed to 2800 degree Fahrenheit is equal to 3.04 inch. So, this problem illustrate the so-called use of the heat transfer in order to optimize the lining design fuel saving and the associated phenomena like reduction in palliation because you are saving the fuel in. Hence, you are saving the palliation.

Now, let us take another problem which concern to the design of furnace. Now, in several situations so far doing an experimental work, you require to design a furnace for doing certain experiment on the liberty scale. The smaller furnace not be getting in the market, so you have to design the furnace. Now, let us take an example. So, we have to design a furnace, say design a furnace to carry out an exothermic solid gas solid reaction on continuous basics. Both gaseous and solid reactants are fate continuously at 9.7 pound per hour at 7000 at 70 degree Fahrenheit. The reaction products are to be discharged continuously at 1200 degree Fahrenheit heat of reaction that is equal to 1050 Btu per pound of total reactant, the average a specific heat.

The average specific heat of product of combustions is 0.2 Btu per pound degree Fahrenheit. Reaction chamber is vertical inconel cylinder one by three feet in 9 meter and 3 feet high. It has all facilities to feet and discharged the product continuously. The average temperature inconel cylinder is maintained at 1200 degree Fahrenheit.

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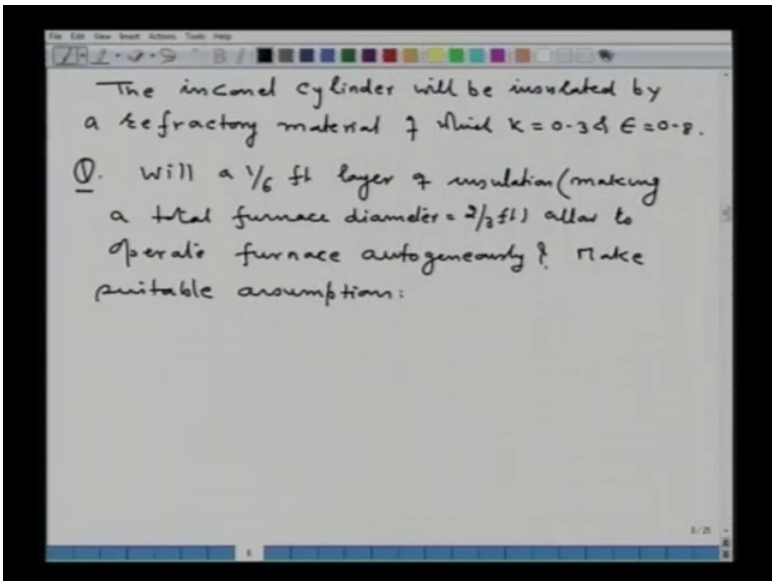

Now, the inconel cylinder is insulated. The inconel cylinder will be insulated by a refractory material of which k is equal to 0.3 and emissivity is equal to 2.8. Question- Will a one by six feet layer of insulation making a total furnace diameter of equal to two by three feet allow to operate furnace autogenously? Make suitable assumptions.

So, this type of requirement is commonly at the under gradually or post gradually level of mate logical engineering discipline. You are required to design a furnace, so that the reactions r k d dot autogenously. That means you are not supposed to supply any heat from the outside. Whatever heat which is generated by the reaction, it has to be utilized for the reaction continuously. So, that is the problem and considering you to answer and you have to see whether one by six feet layer of insulation is sufficient or not. That means reaction should be carried out at 1200 degrees Fahrenheit. Its temperature should not increase and should not decrease. Also, you are not supplying any heat from our outside, remember?

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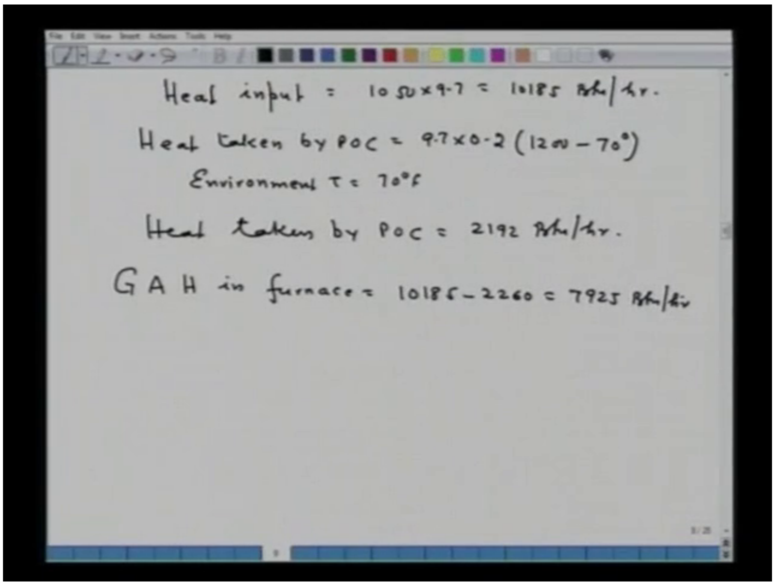

So, first of all let us calculate heat input. You have to calculate heat input is straight away it is 1050 into 9.7. That will be equal to 10185 Btu per hour. Now, heat taken by POC because it is continuous and heat taken by POC will be equal to 9.7 into 0.2. It's CP and temperature 1200 take environment temperature is 70 degree Fahrenheit. So, let us take an environment temperature equal to 70 degree Fahrenheit. So, heat taken by POC will be equal to 2192 Btu per hour.

So, that means the gross available heat. The concept already I introduced in earlier lecture in furnace. That will be equal to 10185 minus 2260. That will be equal to 7925 Btu per hour. Now, mind you what does it mean? This means that 7925 Btu per hour of heat is to be transported from the furnace through the lining to the environment. If the heat transfer is less than the temperature of the furnace will increase and you are not satisfying the requirement of the reaction to be carried out at 1200 degree celcius. If the heat transfer is more, the temperature will drop. So, the requirement is now what should be the thickness of the lining.

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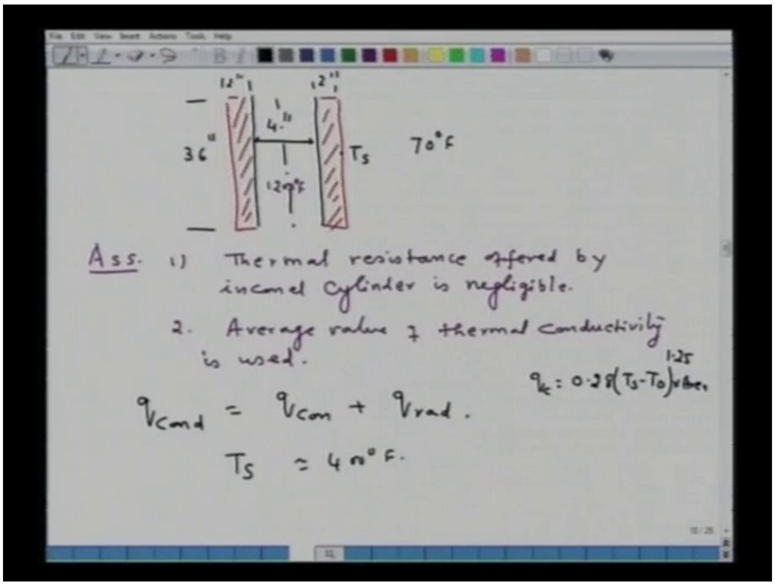

So, in fact if I see, so this is what the furnace is a vertical inconel cylinder. This is the propose thickness of the lining. This is given as 4 inch and here this is 2 inch and this is also 2 inch. This height is given as 36 inches. So, this temperature is ATS and environment temperature is 78 degree Fahrenheit and this temperature is 1200 degree Fahrenheit. So, we have to see whether this 2 inch layer thickness is sufficient or not. So, we make sustain as assumptions.

Here, assumption number one that thermal resistance offered by then cornel cylinder is negligible. We have to justify because inconel cylinder is very high thermal conductivity. So, that will not offer any thermal resistance to heat flow and second assumption that we are doing is we will be taking average value of thermal conductivity. How were you now the thermal conductive is a function or temperature and such one has to take for accurate calculation. K as a function or a temperature and recording integrate it, but to illustrate the problem, we are making some simplified assumption.

Now, same as earlier problem we have to do two conductions, that is equal to q convection plus q radiation. Now, all that you have to substitute the formula and q convection as already I have told you for convict heat transfer in my lecture, that is say q c that is equal to 0.28 TS minus 20 raise to the power 1.25 into area. So, this formula is already known to you. So, if you substitute all these values, a conduction in fact cylindrical type of furnace. So, you have to substitute the value accordingly. I am leaving this problem. You should do it. I will simply write down the answer, so if you calculate the TS by putting left hand side and right hand side formula and insert the numeral value which are given, the TS will come approximately 400 degree Fahrenheit and corresponding to 400 degree Fahrenheit.

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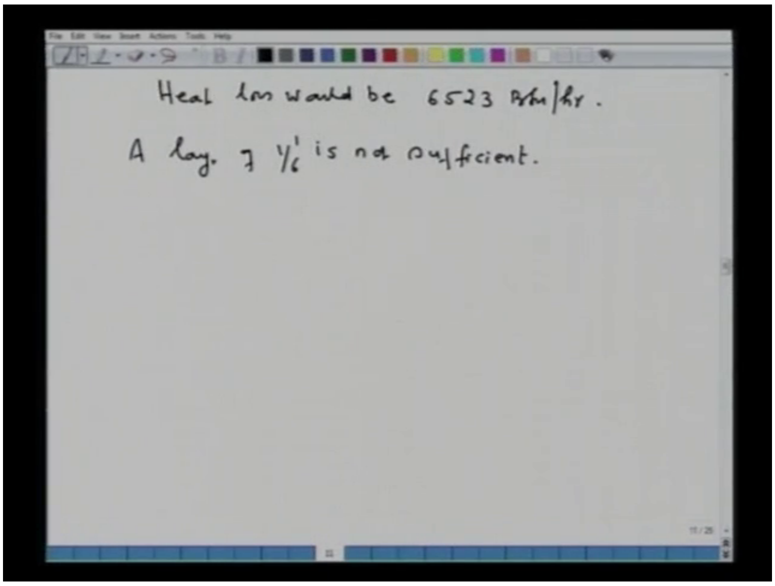

The heat loss would be 6523 Btu per hour. In fact, you should lose 7925 Btu per hour. So, what is the conclusion? The conclusion is that a layer of one by six feet is not sufficient on the argument that the heat losses are much less than heat remain in the inside. What will happen?

It will raise the temperature of the inconel cylinder and hence, the reaction will not be carried out that the desert temperature. So, a layer of one by six feet is not sufficient to carry out the reaction at the temperature which is mentioned in the problem. So, the solution would be you have to think of other insulating material of other thermal conductive or you have to increase the thickness of the lining, whatever the solution is available to you at that point of time. So, this is what in majority of the cases. You are required to design a furnace and see whether you meet your objectives or not and this problem was in fact to illustrate those particular ideas. Now, in the next two problems, I will be illustrating the heat transfer coefficient heat losses by convection and radiation and they are comparison the problem is as under.

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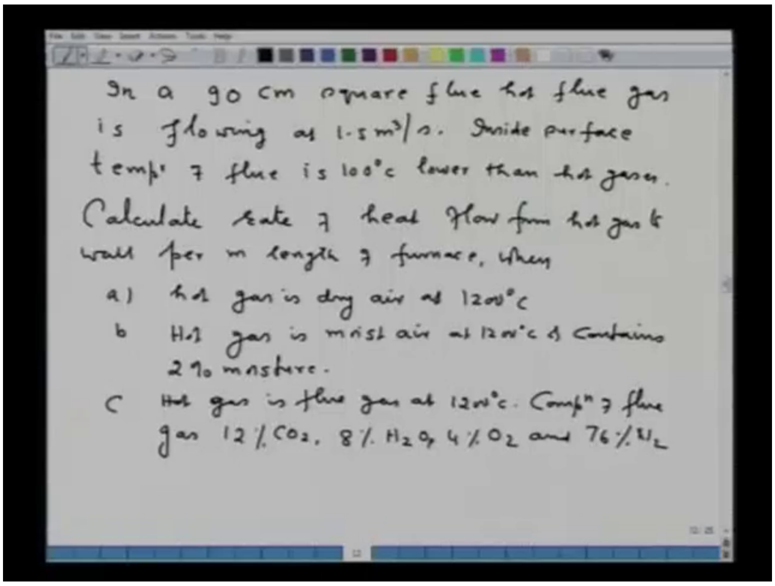

In a 90 centimeter square flue hot fuel gas is flowing at 1.5 meter cube per second. Inside surface temperature of flue is 100 degrees celcius lower than hot gases. Calculate rate of heat flow from hot gas to wall per meter length of furnace, when hot gas is dry air at 1200 degree celcius under three conditions. You have to calculate the hot gas is moisture and see hot gas is fuel gas. The whole idea giving this problem is to let to feel that the radiation is through dry atomic gases. So, if you take the salutation of problem under a hot gas is dry air.

So, here dry air contain oxygen and nitrogen and heat transfer will purely occur by convection because for the radiation to occur, dry atomic gases like CO2 and H2O should be there. So, in 8 you have to calculate the heat transfer by convection.

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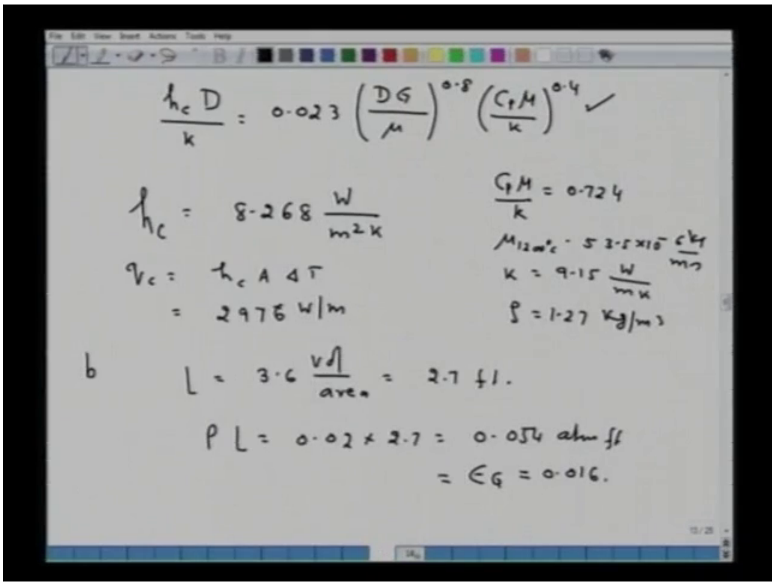

First of all, you have to calculate the heat transfer coefficient and this co-relation has been already given in earlier lecture. I am giving you the required values. So, if we substitute all these values into this expression, you will be getting HC. You can calculate the heat transfer coefficient for convection, that is equal to 8.268 watt per meter square Kelvin. Remember the heat transfer will occur only by convection because there are no dry atomic gases present. That is what the idea of illustration of this particular problem. So, all that you have to calculate is the heat loss by convection.

So, heat loss by convection QC that will be equal to HCA into delta t and all values are given. So, I will be getting 2976 watt per meter length of the pi, whatever flue that is given to so that I calculate. Now, in another situation, it is given that the gas is moisture details the gas is moisture at 1200 degree celcius with 2 percent moisture. Now, remember here the heat transfer will occur by convection once by radiation because it has 2 percent moisture. So, you have to also calculate the heat transfer by radiation here. So, in this b case, the heat transfer will occur by both convection as well as radiation.

So, for radiation I illustrate earlier lecture 31. You have to find out first of all the length of the gas body with this formula 3.6 volume upon area. So, that will become 2.7 feet. Then, you have to find out product of p into l, that is 0.022 percent moisture into 2.7. That will be 0.054

atmosphere feet and as I said over there, you have to find out the emissivity and with that emissivity that is epsilon g that will be equal to 0.016.

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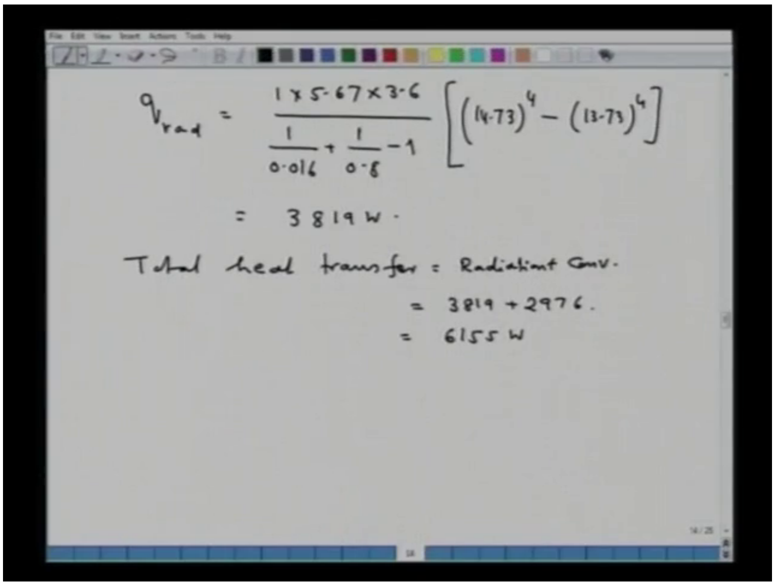

So, what I have to do now is I have to substitute q radiation as a formula which we derived. I am not writing the formula, that is 1 into 5.67 into 3.6 is the area upon 1 upon 0.016 plus 1 upon 0.8 minus 14.73 raise to the power 4 minus 13.73 raise to the power 4. So, if you solve, you will be getting, this will become up to 3819 watt. So, total heat transfer when the gases as 2 percent moisture, that will be equal to radiation plus convection. So, radiation is 3819 and convection is that we have to determine q convection that is 2976, so plus 29.

Seven six so the total heat transfer will be equal to six one five five watt per meter length listen that is the whole idea is to give you feel that well in presence of moisture there is a tri-atomic gas the heat transfer will occur will both by conduction and by convection and radiation and this is very important when you consider the heat transfer in furnaces which contains zero to end h two o now the c part is a flue gas again you have to calculate p in to l now here the same formula you will repeat

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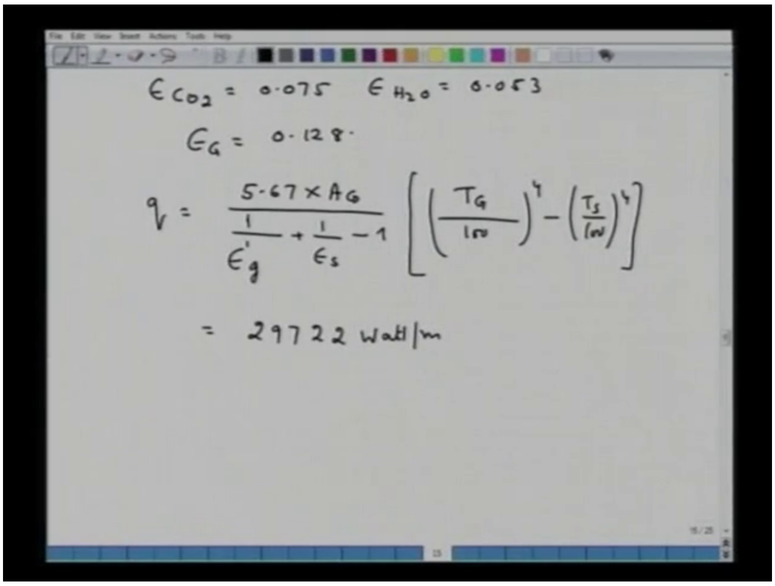

So, I have to determine epsilon CO2 that will be equal to 0.075, epsilon H2O that is equal to 0.053. So, epsilon g which is some total of both that is equal to 0.128 and I am writing repeating the formula q, that is equal to 5.67 into area of the gas body upon 1 upon gas emissivity plus emissivity of the surface minus 1 TG upon 100 raise to the power of 4 minus TS upon 100 raise to the power 4. So, substitute then q radiation and that will be equal to 29720 per meter. You see the heat transfer by radiation in presence of tri-atomic gas is a very important thing and substantial amount of heat is transferred when the gases contains like tri-atomics gases.

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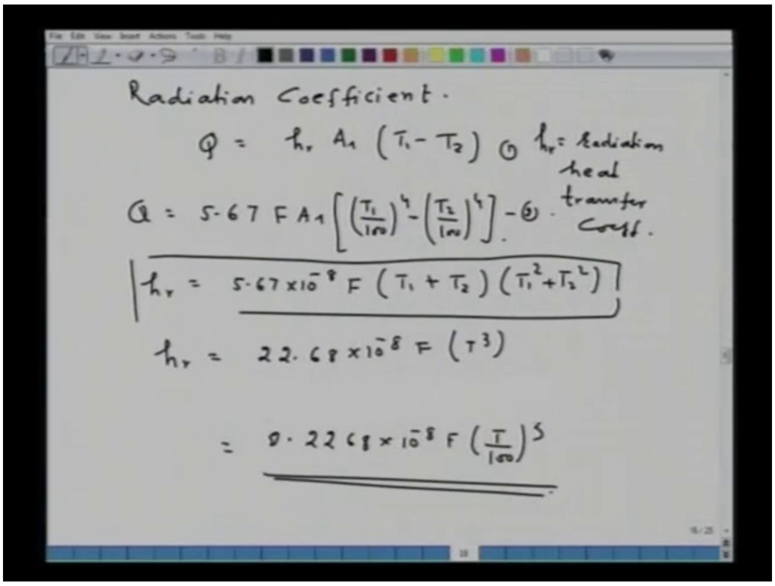

Now, another important thing is that to give you feel about the radiation coefficient. Now, as you have seen the thermal resistances offered by convection by conduction as thermal repentances can also be offered by radiation. We can consider the heat transfer by radiation in terms of the thermal resistances. So, we can state, we write down say q that is heat loss, that is equal to HR into a 1 into t 1 minus t 2 heat transfer i convection. We wrote q is equal to x c into a into t 1 minus t 2. Here, h r is the radiation, heat transfer coefficient is the radiation, heat transfer coefficient. Now, we can compare this equation say q.

We already know that 5.67 fa 1 t 1 upon 100 to the power 4 minus t 2 upon 100 to the power 4. This equation we already know. Now, if we compare equation one and equation two, then we can get h r value that will be equal to 5.67 into 10 to the power minus 8 into f t 1 plus t 2 into t 1 is square plus t 2 square is very simple. You just have to compare one and two, eliminate and will get the value of h r. So, this is the heat transfer coefficient can be determined by using this formula. Now, if the temperature difference between t 1 and t 2 is very small, say t 1 and t 2 are nearly equal, then we can approximate this h r. That will be equal to 22.68 into 10 to the power minus 8 into f t to the power q.

Now, remember f is a view factor here. So, h r that will be equal to 0.268 into 10 to the power minus 8 f t upon 100 to the power q. So, with formula one, we can determine the value of the heat transfer coefficient by radiation.

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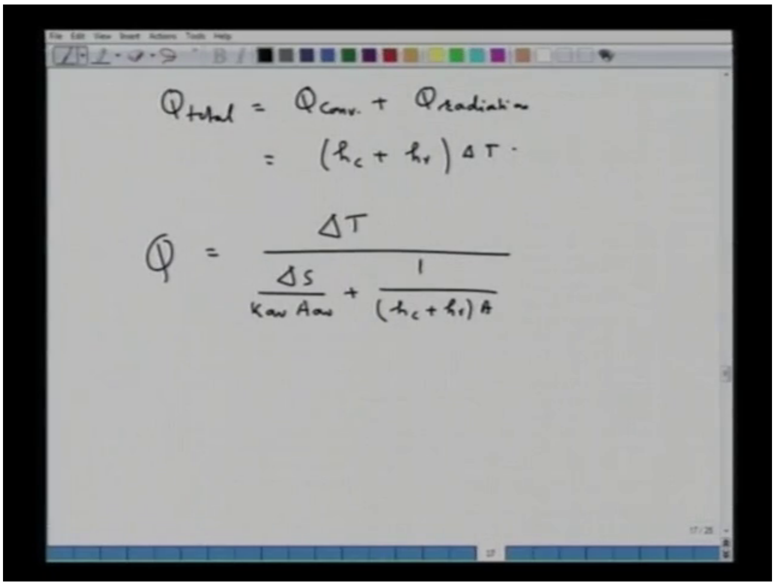

So, when heat transfer involve both convection and radiation, then q total that will be equal to q convection plus q radiation that will be equal to h c plus h r into delta t. So, if the heat flow path involves the circuit of conduction to the surface and convection and radiation from surface to the surrounding with over all temperature difference delta t, then one can write down q. That will be equal to delta t upon delta s upon k average into an average. This is the thermal resistance offered by the conduction and plus 1 upon hc plus hr. This is the combine resistance offered by convection and radiation into a. So, this is what another approach to determine a combined heat flow path from the furnace to the surrounding.

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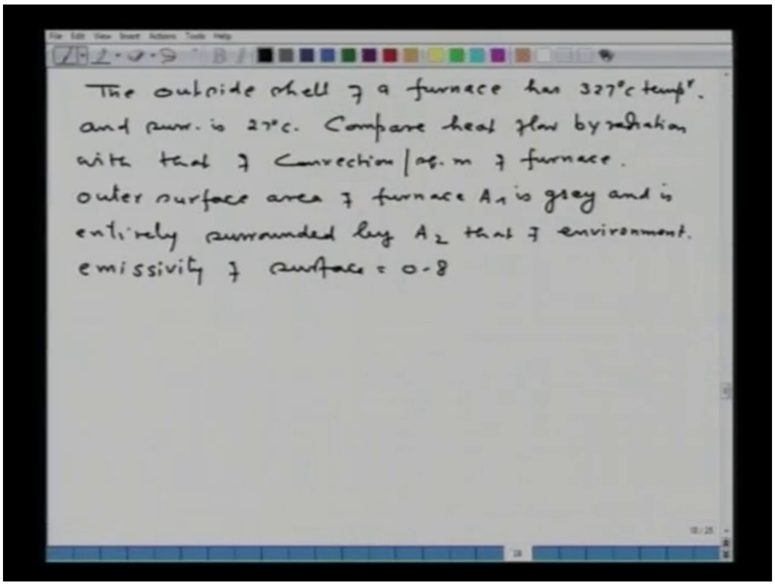

Now, to illustrate the problem, this particular formula mentioned I will write problem. The outside shell of a furnace has 327 degree temperature and surrounding is at 27 degree celcius. Compare heat flow by radiation with that of convection per square meter of furnace. Outer surface area furnace is completely surrounded by the environment and emissivity of surface. Let us take equal to 0.8.

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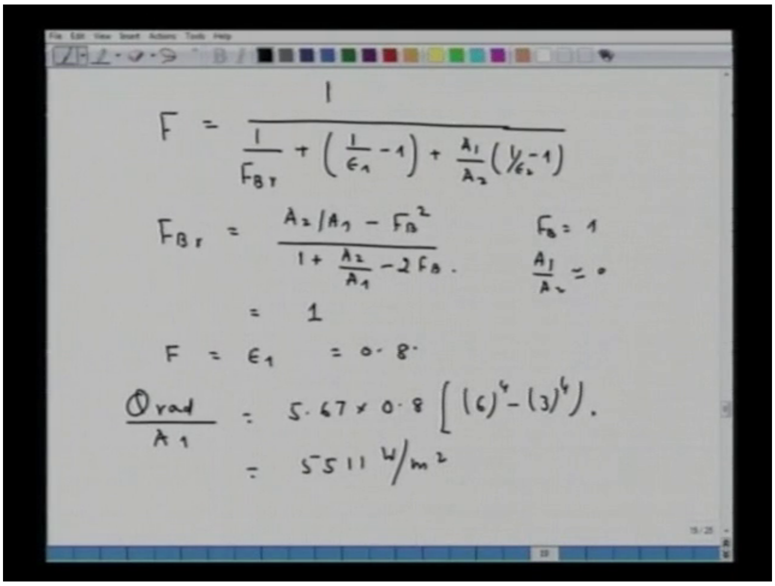

Now, here again you have to invoke. First of all, you have to calculate the value of f and f is equal to recall 1 upon f b r plus 1 upon f epsilon 1 minus 1 plus a 1 upon a 2 1 upon epsilon 2 minus 1. That is what from the formula we derived earlier and you also know that f b r that is equal to a 2 upon a 1 minus f b square upon 1 plus a 2 upon a 1 minus 2 f b.

Now, here say since this furnace is completely seen by the surrounding, so f b is equal to 1 and a 1 upon a 2 is approximately equal to 0 because a 2 surrounding area is very large. So, we can find out the value of f b r that will be equal to 1 and hence, we can find out the value of f. That will come out to be equal to epsilon 1 and if you take the emissivity equal to 0.8, so we can substitute into the formula say q radiation upon a 1 that is equal to 5.67 into 0.86 to the power 4 minus 3 to the power 4. So, that will be coming equal to 5511 watt per meter square. So, this is what now here again just illustrate, we can find out the heat transfer coefficient by radiation.

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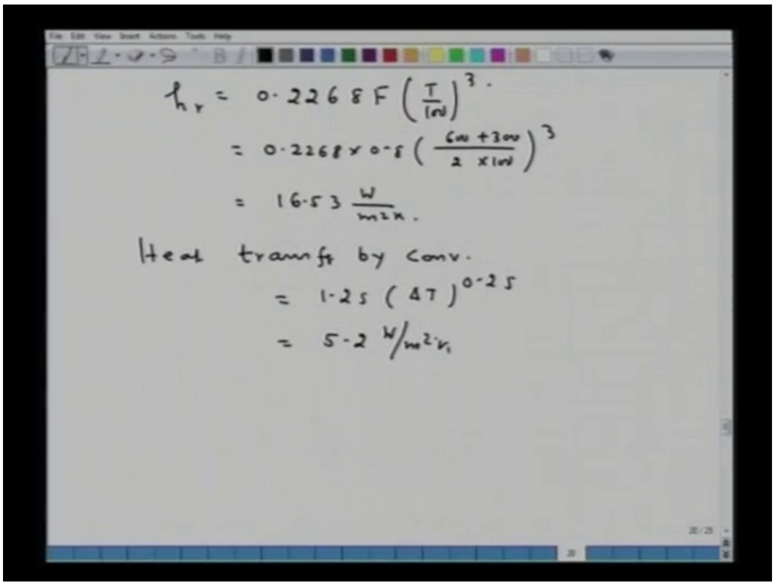

So, hr that is equal to 0.2268 f t upon 100 to the power q, so if he substitute all these values, t is the average temperature 0.2268 f e 0.8 and t is 600 plus 300 by 2 into 100 power cube. So, heat transfer coefficient by radiation is 16.53 watt per meter square Kelvin whereas, heat transfer by convection we can say that is equal to 1.25 into delta t to the power 9.25. The formula already had determined.

So, we determine substitute the value will get 5.2 watt per meter Kelvin. So, by seeing these values of heat transfer coefficient by radiation and it transfers coefficient by convection. It is very clear that heat transfer by radiation is much higher than heat transferred by convection. This was the porous of the lecture was to illustrate the fundamentals of heat transfer by radiation in the furnace design and that I have done through four problems.