Fuel, Refractory and Furnaces
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Lecture No. # 36
Miscellaneous Topics: Pyrometry

Today, in the series of lectures on Miscellaneous Topics, I will be talking on temperature measurements. You know the objective of the furnace is to heat the raw materials at a particular temperature, and this temperature is a very, very important for certain refining, heating, sintering operations or whatever metallurgical objectives, for which the metallurgical furnace, is being employed.

What I wanted to convey that measurement of temperature is one of the very critical area, and the technology of the measurement of temperature and very adverse condition it has to be done; with the adverse condition, I mean say for example, take a fuel fired furnace, where the temperature is very high, how we are going to measure the temperature. In liquids the flow is turbulent, the gases are evolving, so the under these advance conditions, we have to measure temperature, because control of temperature is also a very, very important from reaction point of view.

So, let us see about the temperature measurement, you know I do not think we can measure temperature directly, what we have to do, we have to measure a change in property with the temperature; and ultimately that has to be calibrated, in terms of the temperature. For example, expansion of the fuel, if it is a function of temperature, we must know how the temperature is varying the expansion of the fluid or for example, resistances of the (( )), if it is a function of temperature.

Then for the various temperatures, we determine the resistances and from resistances we back calculate or we back relate with the temperature or radiation to that extent. So, that means, the temperature is the rather measure indirectly from the response of the change in some property with the temperature.

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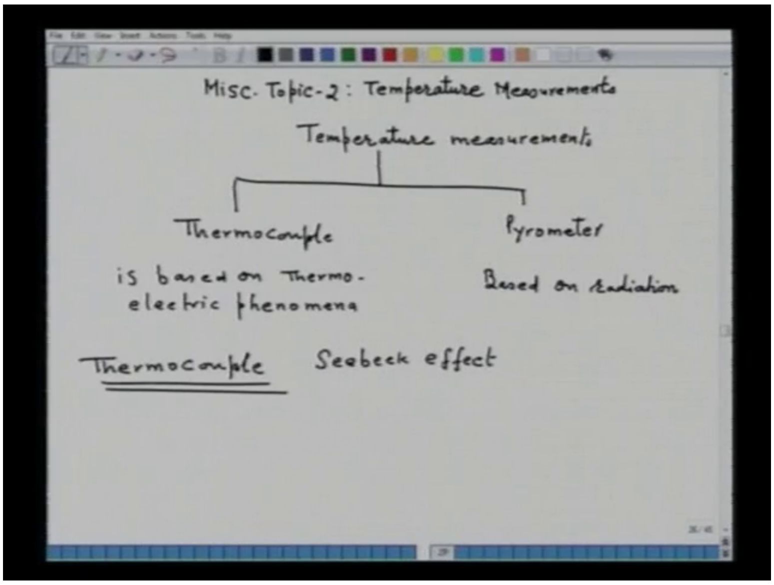

So, accordingly the temperature measurements at high temperature temperature measurements at high temperature it is done, one by the thermocouple and second by the pyrometer; these are two technologies for measurement of the temperature, say high temperature. I am not addressing to the thermometer which are used for relatively very low temperature, for example, boiling point of water are 200 degree plus and so on. I am apprising the issues, were we are amazing the temperature of the order 700, 800, 1000 dot, 1400 dot, 1600 degree celsius.

So, it is in that references, the technologies which are available for measurement of temperature are thermocouple, and pyrometer. Thermocouple is based on, the measurement of temperature by thermocouple is based on, thermo electrical phenomena based on thermo electrical phenomena, were as the principle of measurement of temperature to pyrometer, it is based on radiation based on radiation. So, let us take first of all thermocouple thermocouple, now it is well known that mean, two dissimilar metals are join together and electromotive force is established.

So, our problem is solved of measurement of temperature, we take two dissimilar wires, join them, and put that beat or that join at high temperature; we can measure the change in the volte. So, we got the technology of the measurement of the temperature that means all that we require to measure the temperature by thermocouple is to search two dissimilar, metals and join them. In fact, the the fundamental principle line this technology is seebeck effect, which probably must be your from your knowledge of physics.

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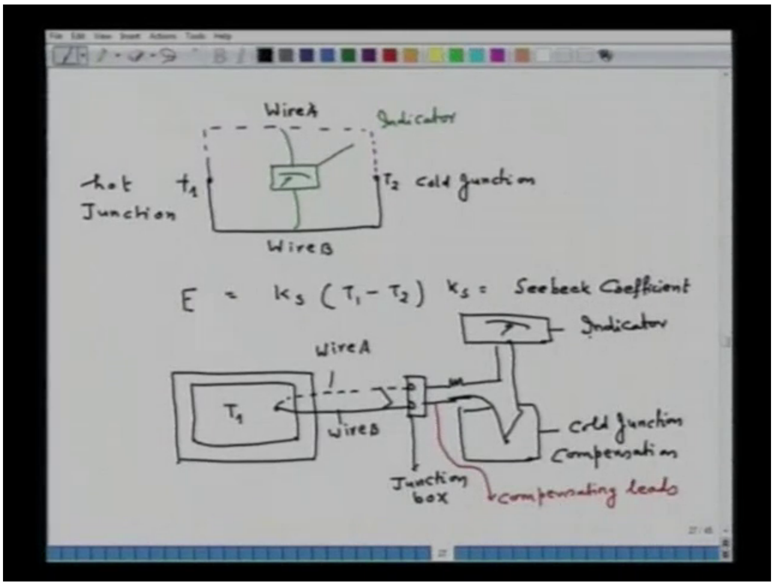

So, the seebeck effect is can be easily illustrated for example, I take two junctions, the one is created by one type of wire, and another by another type of wire he let us take this is wire B, this is wire A and this is t 1 or let us say t 1 which is hot junction and this one, let us take T 2 this is cold junction, this cold junction. Now, in between this two, if I put an indicator, it records the EMF this is an indicator, and I put this indicator and I connect it; so this is an indicator, then I will able to record the EMF produced by this particular thermocouple.

In fact, the thermocouple which have found is by joining wire A and wire B, so this is in fact, the seebeck effect and this E potential difference which is created, that is equal to K s into T 1 minus T 2 were k s that is equal to seebeck or seebeck coefficient, seebeck coefficient. So, what you notice from here, that in the measurement or temperature by the use of the thermocouple, there is a hot junction and there is a cold junction.

So, if you want to employ this technology for the measurement of temperature in the furnace, say let us take for example, this is a furnace this is a furnace obtain, this is a enclose, this is a furnace which is for example, maintain a temperature T 1 (Refer Slide Time: 07:53). And I took a thermocouple produce by one type of wire here, and another wire is here, and I make a sort of a join and then I connect it throw an indicator and then here, by do (No audio from: 08:47 to 08:58) (Refer Slide Time: 07:47). So, in fact, now this is this is the wire A, wire B and the whole I call it to be thermocouple, this one is a junction box junction box, that is their I have connected both the leads of thermocouple. In fact, this this is both this form a thermocouple, and this one is a cold junction compensation this a cold junction compensation, and this is an indicator this is an indicator and this let me put the red ink, so this one, they are the compensating leads compensating leads.

So, you note that, in order to measure the temperature of the furnace it is a T 1, I have taken thermocouple, I inserted it then I made a junction box, and the another in should be cold junction. So, in between hot and cold junction, I will be reading temperature or a potential difference which will be correlated to the temperature.

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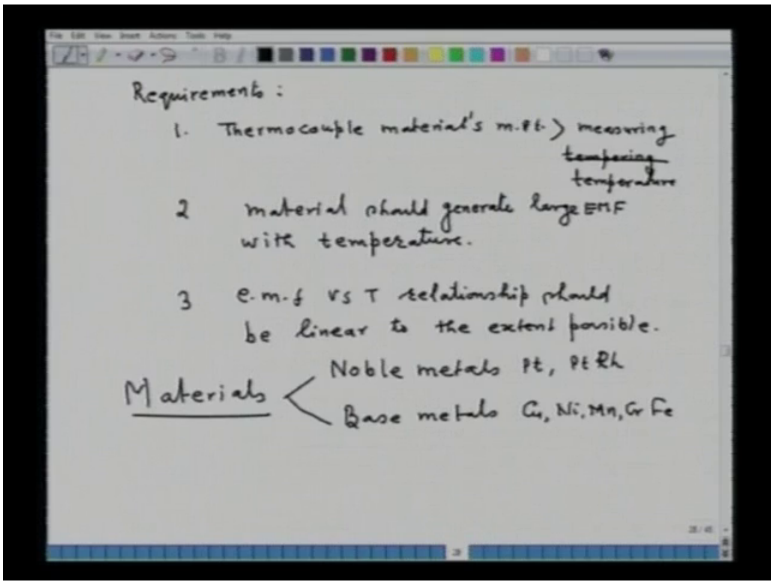

So, the requirements for such a measurement, the requirements or the thermocouple, the first requirements is that the thermocouple material thermocouple material its melting point of course, thermocouples material melting point, it must be greater than measuring temperature than measuring temperature measuring temperature. It is very simple, when you inside a thermocouple, it is a metal wire, it should not melt, and melting point should be higher then what you are measuring.

Second important thing that, because you are choosing two dissimilar material, so better would be if those dissimilar material would able to generate large value of EMF or a small change in a temperature. Then the accurse will be higher, say if you are able to generate a large EMF a small increment in the temperature, then the accurse will be high.

Second important thing is that, the dissimilar the they are the material or thermocouple material should generate should generate large EMF with change in temperature or with temperature; that is the second important requirement, this is from accurse point of view. Third as for as possible EMF verse temperature relationship verse temperature relationship should be linear should be linear to the extent possible. Now, why this is required, again I repeated and I am telling you, the output of thermocouple is not temperature, the output of thermocouple is EMF that is in volte.

So, what you will be doing, you will be taking a thermocouple, you have you will put in different temperatures, and you will be record the value of temperature, and corresponding to the temperature, you will record the volte. So, you get a relation or you get a value the volt against the temperature, then for in unknown situation you will insert that thermocouple; if then you read the EMF value or the volte value, then you back to your data and hit that particular volte and then you say this is a temperature.

So, remember the output of a thermocouple is not temperature is the volte that means you are indirectly measuring the temperature of the objector of the furnace. So, for that purpose, it is the calibration of the thermocouple is a very important issue; how we are going calibration from the thermocouple, we will come back to a little late. So, now the different materials, the materials for thermocouple they are two types, one based on noble metals say for example, platinum and platinum, rhodium and like this.

And another material they are base metals they are base metals for example, copper, nickel, magnesium, chromium, and iron. Now, I will give you some important thermocouple, which are frequently used with they are composition, temperature range, and maximum temperature range. So, I will make table for you, on the say international standard, the thermocouples are classified by a letter B E J K N R S M T.

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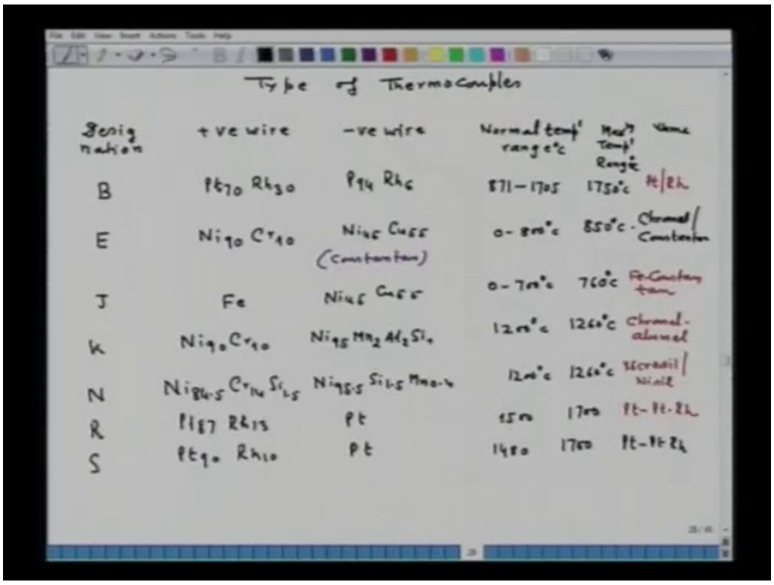

So, accordingly I am going to write, so the type of thermocouples, and make a table type of thermocouples, see I will put first of all designation, then the positive wire, and check then the negative wire; then normal temperature range normal temperature range and maximum temperature range maximum temperature range, and here I will put name of thermocouple, name. So first of all, let us take the designation for example, one is B and B the positive wire is, the platinum 70, rhodium 30, 70 percent platinum and 30 percent rhodium.

Negative wire is platinum 94, rhodium 6, normal temperature range 871 to 1700 and 5, this is I am putting in degree celsius, and this is also in degree celsius (Refer Slide Time: 17:14). Maximum temperature range is 1700 and 50 degree celsius, and this thermocouple is called a platinum, platinum, rhodium thermocouple. Another designation is E, E is saving nickel 90 (()) 10 and here nickel 45 and cropper 55, you know this composition is called constantan, constantan.

This one and the range, normal temperature range it can be measure 0 to 800 degree celsius, maximum temperature range is 800 and 50 degree celsius; so this thermocouple is chromel, constantan thermocouple constantan thermocouple. Third type of the classification is J, were the positive wire is iron here is same nickel 45 and copper 55, the normal temperature range is 0 to 700 degree celsius, the major up to 760 degree celsius and this thermocouple is called iron, constantan thermocouple.

Then here K, in the positive wire is nickel 90 chromyl 10, negative wire is nickel 95 magnesium 2 and aluminum 2 and silicon 1, we can go up to 1200 degree celsius and maximum you can go up to 1260 degree celsius, and this all of us know this is chromel, alumel thermocouple. Then we have another which is called N, this is nickel 84.5 chromium 14 and silicon 1.5, negative wire is nickel 95.5 silicon 1.5 magnesium 0.4, and also go up to 1200 degree celsius, is 1260 degree, and the name of the thermocouple is Nicrosil Nicrosil and nisil.

So, that is what the thing and then you have R, in the R we have say platinum 87 rhodium 13 platinum, then go up to 1500 degree celsius, maximum is a 1700 degree celsius and thermocouple is known platinum-platinum rhodium thermocouple.

Then again, we have one more variety that is S, which is platinum 90 rhodium 10 platinum is the negative wire, then go up to 1400 and 80 degree celsius maximum is 1700 and it is also name platinum-platinum rhodium thermocouple. So, these are this is a type of thermocouple which you can get in the market, and of the common you must you heard the name of chromel alumel or platinum-platinum rhodium thermocouple, platinum-platinum rhodium thermocouple with expensive, chromel alumel is by the used.

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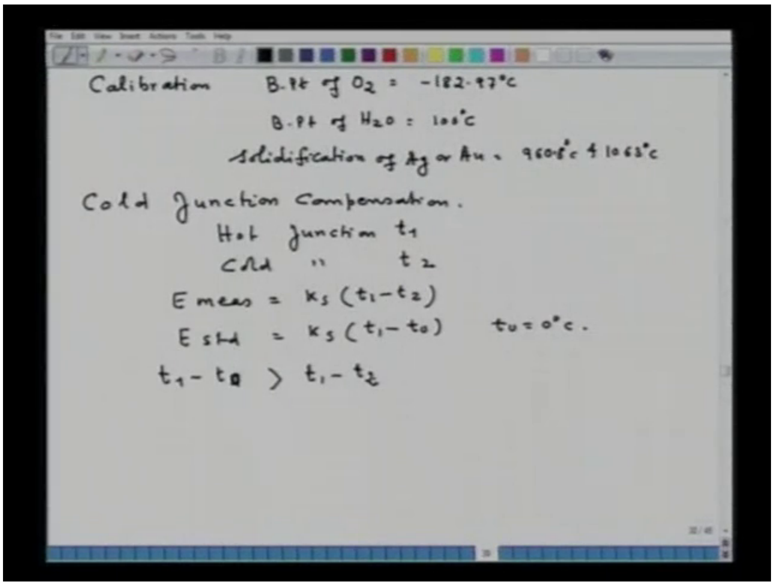

Now, say one the important thing is the calibration of the thermocouple, so calibration of thermocouple calibration of thermocouple is done by using some of the standard temperature of some of the elements, one of this using by using the boiling point of oxygen. The boiling point of oxygen is at a fixed temperature and that is equal to minus 182.97 degree celsius; so one can calibrate the thermocouple against the boiling point of oxygen or one can also calibrate the thermocouple, against the boiling point of water.

Boiling point of water, which is equal to 100 celsius or one, can also calibrate thermocouple by measuring temperature of solidification solidification of silver or gold, the respective melting points are 960.8 degree celsius and 1063 degree celsius, this is how the calibration is done. Now, one of the most important thing that you have seen, in case of measurement of temperature by thermocouple, is there are two junction involved, one hot junction and another is the cold junction.

Normally, the cold junction should be 80 degree celsius, because what tables of of EMF against temperature, which are being created, they are created by taking the cold junction to be at 0 degree temperature, because what voltage difference you are recording you are recording the voltage difference between hot junction and cold junction. So, cold junction is also to be (()), then for all standard condition the cold junction should be (()) 80 degree celsius, for any another temperature accordingly, correction is to be deployed and that is very important.

So, in this way, I will go for cold junction compensation cold junction compensation, now we consider that, we are putting a cold junction at certain non-zero temperature for example, t 2. Let us say, the hot junction temperature hot junction temperature, let us take a t 1 and cold junction temperature let us take t 2, then E measure that will be equal to k s into t 1 minus t 2; because you are measuring that the voltage across the two junctions, one is hot junction and another is cold junction.

Now, the standard EMF tables, in the standard EMF tables t 2 is taken equal to 0, this tables are prepared by considering t 2 equal to 0, so E standard that you will get equal to k s in to t 1 minus t 0, were t 0 is maintained at 0 degree celsius, so with the condition that your t 1 minus t 0 is greater than t 1 minus t 2. So, the indicator will record less value of EMF, because your cold junction temperature is other than 0 degree celsius.

So, accordingly we have to make cold junction compensation, if you do not do the cold junction compensation, then accordingly our temperature measurement will have certain amount error, and that error will correspond to the difference in temperature from 0 to the temperature of the cold junction. So, that is an important, they are (()) or they designs to rectify the source of error in temperature measurement, and these are called cold junction compensation.

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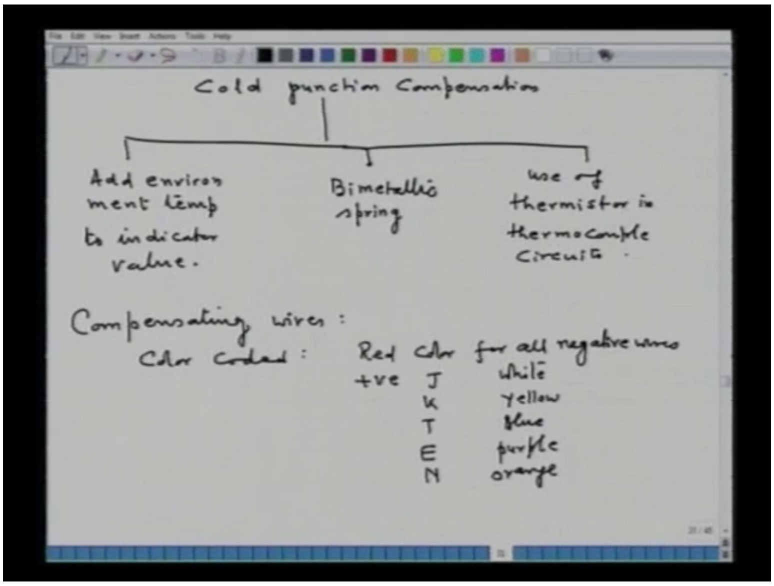

So, the cold junction compensation method cold junction compensation, they can be done in several way is the one of the way, the time listing for example, we have got the EMF value, and from EMF we have noted down the temperature, and to that the temperature at the environmental temperature. So, one method is that add environment add environment temperature to the indicator value to indicator value, this is one way; another way, little bit sophisticated way, the indicator needle is connected to a bimetallic spring, that means use of bimetallic spring.

That means indicator needle is connected to a bimetallic spring, which expense or contracts, depending on the changes in the environment temperature. So, as such, your recording the value after correction of the cold junction temperature, because you have now bimetallic spring, and they expand or contracts depending on the temperature, this is another way. Third way is that, say use of thermistor in thermocouple circuits in thermocouple circuits, so this is how you are going to do, the cold junction compensation, remember this cold junction compensation is a very important issue.

Now, in this connection which is also important, because you are connecting the thermocouple wire and from thermocouple wire you are going to the indicator, so some wire you will be using out, so they are also called as compensation wires compensation wires.

Now, normally this compensating wires should have the same, should be the same EMF is that of the thermocouple wire otherwise, you will again record the wrong value.

Normally, they are colour coded colour coded say in fact, red colour for all negative wires all negative wires, were as the positive wire say for a thermocouple J type it is white, for thermocouple K type it is yellow. In the previous table I listed J, K and all for T type it is blue, for E type it is purple, and for N type it is orange. So, accordingly these wires should be used.

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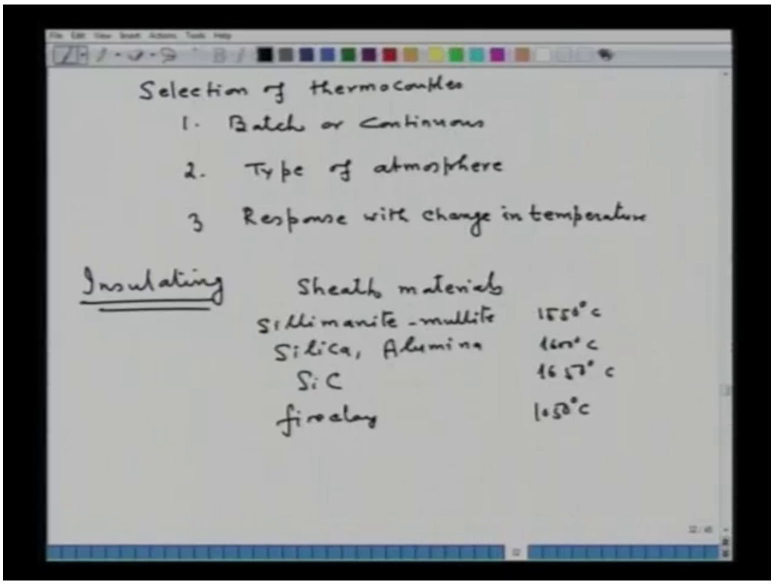

Then another important thing is the selection of thermocouple selection of thermocouple, there are so many different types of thermocouple couple are available. So, the selection, criteria selection of 1, whether you are having batch furnace or continuous furnace batch or continuous , which is one search, that whether batch wise that means whether you are measuring the temperature, in in a batch or continuously you are measurement the temperature, that is one important thing.

And another important thing is type of atmosphere type of atmosphere, because in the previous lecture, which are in the atmosphere you have seen, that they oxidizing atmosphere, reducing atmosphere, neutral atmosphere. For neutral, there is no probing but, for oxidizing a neutral atmosphere, when is to be careful about the selection of the thermocouple. Third important criteria selection is, the response with change in temperatures response with change in temperatures; now here it is important that to select the thermocouple, which is little little large variation in the volte, when the temperature is change, so these are the important thing. Another important thing is the insulating tubes, because you are not putting the thermocouple there into the furnace, you are inserting in a insulating tube.

And normally, this insulating tube for twin hole, ceramic tube and to twin hole you put in to one hole, the positive wire and another hole you put a negative wire, and at one end of the wire both the wires are join by and that join is called beat, that is the scolded join, and then rest of the connected to the indicator and so on. So, normally the insulator material that is called sheath, and the sheath, various sheath materials are sheath materials are sillimanite, mullite that can be used up to 1500 and 50 degree celsius.

Then you have silica, alumina that can go up to 1600 degree celsius, then you silicon carbohydrate it can also go up to 1600 and 50 degree celsius and fireclay of course, it cannot go above 100 degree celsius safe is 1000 and 50 degree celsius. So, these are the say some of the important issues, in case of thermocouple measurement; now one of the important things is that, when we measure the temperature of gas, with help of thermocouple.

So, I will address the issue, because in many situation when the gases are flowing, we want know what is the temperature of the gas; so it is also important the gas velocity, the heat will transfer by convention and radiation to the thermocouple B. The thermocouple will also radiate depending on the wall temperature of the duct.

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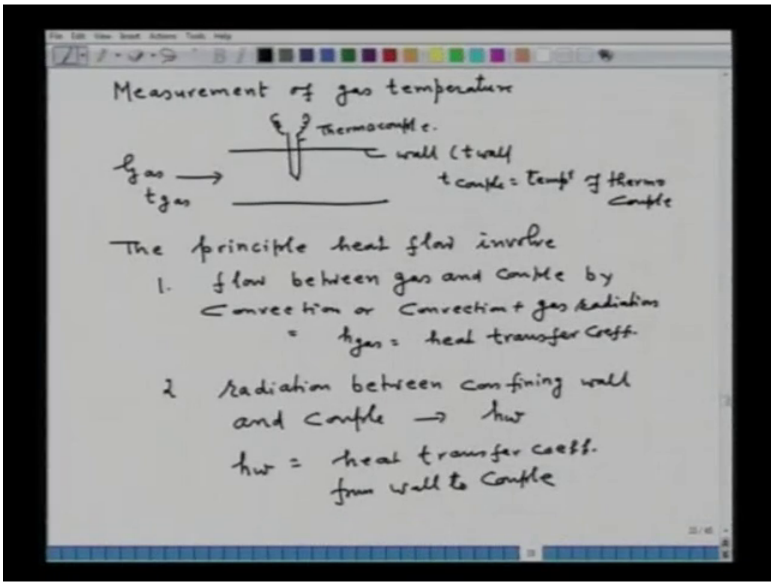

So, as such the measurement of gas temperature measurement of gas temperature with the help of thermocouple, now consider say this the furnace and the gas is flowing and we put a thermocouple, this is the weight of the thermocouple, and they are the wires, this is the thermocouple, this is the wall is some temperature and gas is also flowing at certain temperature. Now, the principle heat flow in wall, the gas is also in some temperature let us put, the temperature of gas is t gas, temperature of the wall is t wall, and t couple that is the temperature of thermocouple temperature of thermocouple right.

Now, the principle heat flowing involve are the principle heat flowing involve, in this one say flow of heat between gas and couple, that is thermocouple this will be by convention this will be by convention, because the gas is flowing or by a mechanism of convention plus gas radiation plus gas radiation. And this will be control by the so called h gas which is heat transfer coefficient h gas is the heat transfer coefficient heat transfer coefficient from gas to the couple, this is what the heat flow that involve is one this one (Refer Slide Time: 35:48).

And second as the sheet of the thermocouple also gas heated up, it will also radiated (()), so the radiation radiation between confining wall and couple, that will we gas we will say it is h w, were h w is heat transfer coefficient h w is heat transfer coefficient from wall to couple couple thermocouple.

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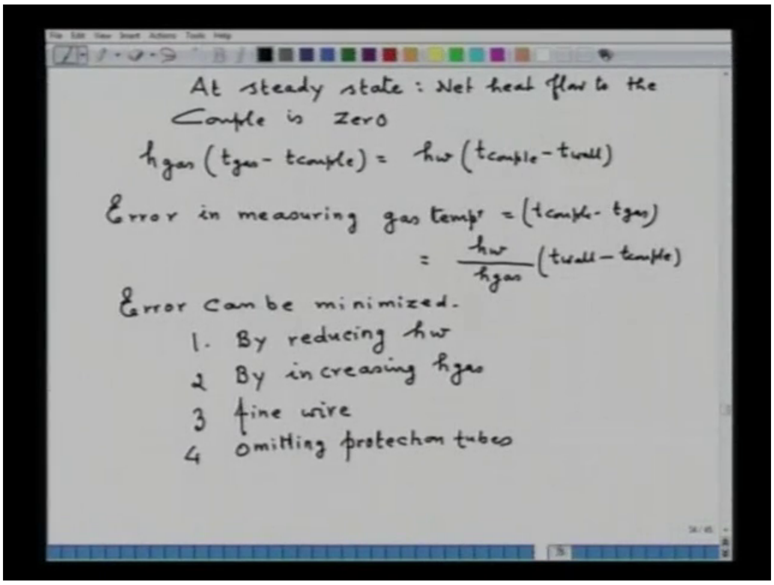

Now, at the steady state, what will happen, the net heat flow to the couple is 0 right, so at the steady state at the steady state, net heat flow to the couple is 0, net heat flow to the couple, if means the thermocouple is 0, and we can quantify this the heat transfer from gas to couple, that is t gas minus t couple, that will be equal to h w into t couple minus t wall. Remember, here t gas t couple and t wall, they are the steady state temperature of gas thermocouple and wall. So, now error error in measuring error in measuring the gas temperature that will be equal to t couple minus t gas, if that is equal to 0 then there is no error.

So, this is the error which is introduced by this heat transfer mechanism, and this error if we put this equation, then this error is equal to h w upon h gas into t wall minus t couple, so we can straight way think of the methods to minimize the error. So, error can be minimized error can be minimized, one by reducing h w by reducing h w or by measuring when wall and gas temperature are equal, then you start to measure the temperature of to the thermocouple.

Another way is that by increasing by increasing h gas, how you will increase the h gas, h gas is the convective heat transfer of coefficient to know flow of turbulent, if you want to increase the heat transfer coefficient, then you have to increase the velocity of the gas. So, another way is that to increase h gas by increasing for example, velocity of the gas, third we use a fine wire, fourth omitting protection tubes omitting protection tubes.

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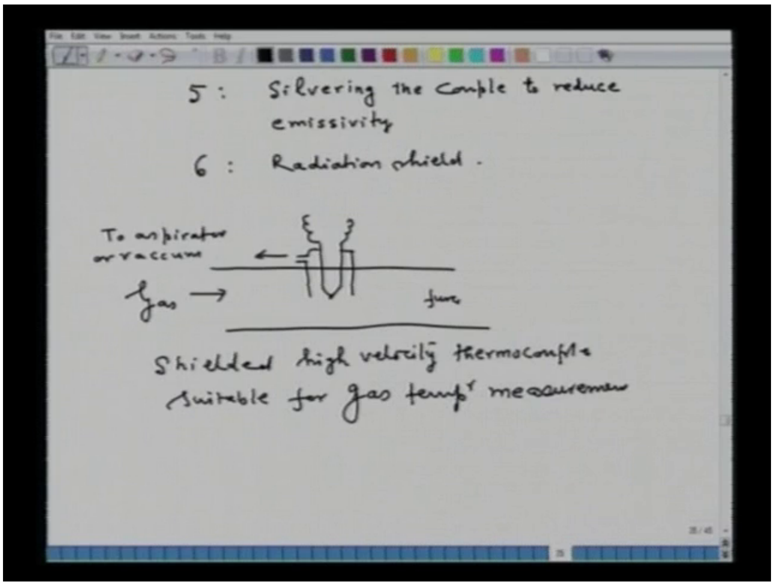

Fifth silvering the couple silvering silvering the couple to reduce its emissivity, have in this will help to reduce emissivity to reduce emissivity, and six we use radiation shields radiation shields say for example, in one of the case what we can do, we can this is a furnace, have we insert a thermocouple is the beat of thermocouple. And they are the wires and what we do here, this is the gas flow direction, and this one is connected to aspirated or vacuum.

This is the shielded, high velocity high velocity thermocouple suitable for gas temperature measurement for gas temperature measurement, were this is the furnace or this is the duct, whatever you want say, when the gas flow it is sucked (Refer Slide Time: 42:57). So, this is the way of say minimizing the error and what the but I have to say about the thermocouple.

Now, towards the end I would like to illustrate you, the error that one can make in the temperature measurement, particularly when the gases are, when the hot gases are flowing, then what error you can make and how to minimize those error.

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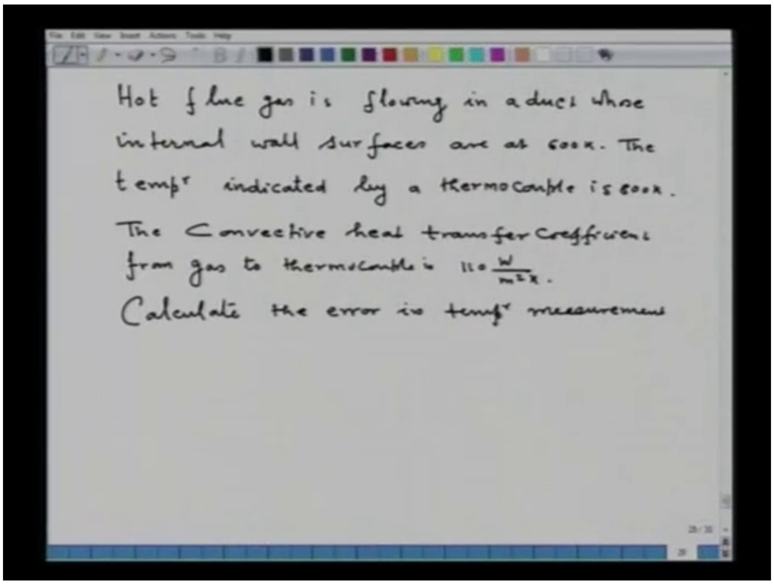

Now, for example, that let us consider the problem, say hot flue gas hot flue gas is flowing in a duct is flowing in a duct, whose internal wall surfaces are whose internal wall surfaces are at 600 calorie. The temperature indicated by a thermocouple the temperature indicated by a thermocouple is 800 calorie. The convective heat transfer coefficient the convective heat transfer coefficient from gas to thermocouple gas to thermocouple is given; say it is 110 watt per meter square calorie.

Now, you have to calculate the error in temperature method error in temperature method that is you to have calculated t g minus t couple, if there is no error then t g minus t couple should be 0 and t g is equal to t couple. So, let us see, now this typical ha heat transfer problem.

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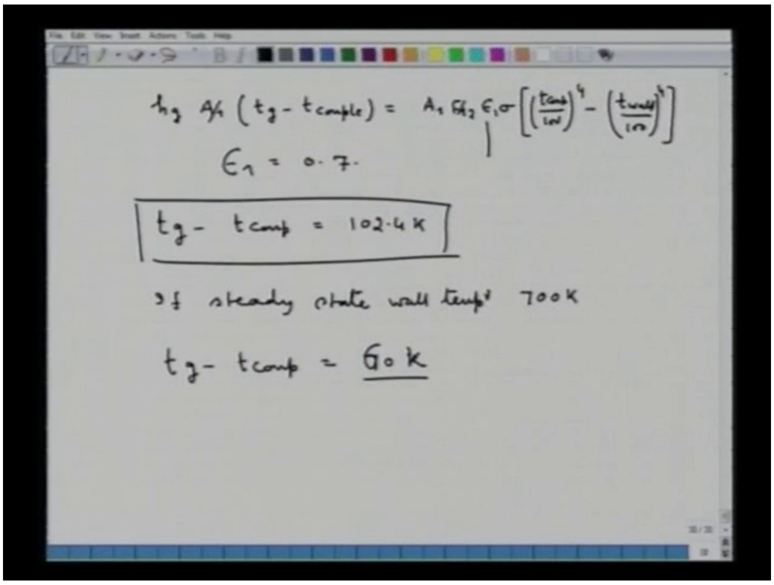

You know that, if you do the heat balance, that is the heat approaching to the thermocouple, heat transfer coefficient A 1 that is the area, t g minus t couple that should be equal to A 1 heat radiation right, from the from the thermocouple to the wall or wall to the thermocouple. A 1 F 1 2 is the view factor, epsilon 1 is the emissivity, and sigma is the Stefan's Boltzmann's constant, that is t couple upon 100 rest to the power 4 minus t wall upon 100 rest to the power4, all the value values are known to us.

Now, here say A 1, A 1 cancel because, the area of the thermocouple is same epsilon 1 is the emissivity of the thermocouple shield, so epsilon 1 they you take emissivity of the shield, let us take equal to 0.7, so f g is known to you, t couple is given t wall is also known to you, the t couple is 800, t wall is 600. (()) substitute the values there is no need format to substitute, so straight way I go to the answer, so I can see now, that the t g minus t couple, that comes out to be equal to 102.4 calorie.

So, you see this is the mistake or this is the error, you are making in making in measuring the temperature of gas by thermocouple 102 calorie, now suppose you want to minimize the error. So, what I do now, say earlier my steady state wall temperature was 600 calorie, now what I do, I I measure when the wall temperature attend 700 calorie. Now, if the steady state, wall temperature increases to let us say 700 calories, then t wall becomes 700 (()) substitute, and then calculate the error get t g minus t couple that is equal to 70 calorie sorry that is equal to 60 calorie.

So, you see now one of the method of reduction, in the measurement of temperature of gases by thermocouple is to see, that the wall temperature should sufficiently a higher or other way, also you decrease the temperature by increasing the convective heat transfer coefficient; how you can increase, the convective heat transfer coefficient depending on the velocity, so increase the fluid. So, this is the problem I thought, may be it is very important for high temperature, metro logiest say how to measurement temperature and correction factor to incorporate in it.

Now, next thing is that as I said that the temperature can be measure, one way was thermoelectrically phenomenon, and the issue related to thermoelectrically phenomenon, I will at rest, now another way is to measure the radiation, and this is called radiation pyrometer this is called radiation pyrometer.

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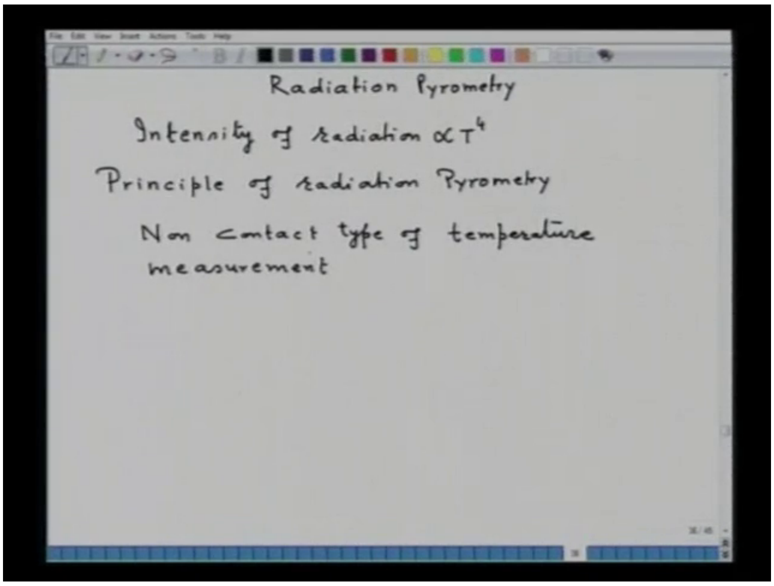

Now, as all of know a body at higher temperature, it emanates electromagnetic radiation, this is a known fact, and this intensity of radiation the intensity of radiation intensity of radiation is propositional to T to the power 4, this is well known Stefan's Boltzmann's law. Now, the principle of radiation pyrometry, the principle of radiation pyrometry is in fact based on Stefan's Boltzmann's law. Now the radiation can be measure directly by a sensor, and this can be compared to the radiation of body of known temperature that means, we try to measure or if you can measure the intensity of radiation emitted by a body and if you can compare this radiation with standard body, then we can say this is the temperature of the body. So, this is in fact the principle of radiation pyrometry that means we need a system, which can see the radiation, we have to design a sensor which can the see radiation, and then it can compare those radiation with the known body of that radiation, that is the principle of radiation pyrometry.

Another important thing is that radiation pyrometry is a non contact type of temperature measure non contact type of temperature measurement whereas, thermocouple was contact type measurement, because in thermocouple, you insert thermocouple in the sheet, and that the thermocouple it rather immerses either in the gas or in the liquid or it touches the solid that means, it is a contact type of temperature measurement, whereas a radiation pyrometry, it is a non contact type of temperature measurement, and the further principle of the radiation pyrometry, I will be discus in the next lecture.