Fuels, Refractory and Furnaces
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Lecture No. # 38
Miscellaneous Topics: Atmosphere in Furnace

In the series of lectures on Miscellaneous Topic, I will be dealing today electric resistance heating. You know conversion of electrical energy to heat energy is a very clean form of energy. I thought to include this topic, because many students of under graduates, metallurgical discipline are in any area, for various their laboratory work, for their project work, for their thesis work, they may be requiring to design a furnace.

In many instances for laboratory work, the furnace is required by an experiment may not be readymade available in the market; so one has to design the furnace depending on the requirement. So, it is with this objective, I thought to include this particular topic and today I will be addressing on electrical resistance heating, and if the time permits, I will also like to tell you how to design and construct a furnace.

Now, you know you all of us know, when a current flows through a material of certain resistance, heat energy is produced, that is (()). The object can be heated indirectly or can be heated directly by way of electrical energy, example of direct heating you must be knowing electrical furnace, direct heating you create an arc between anode and cathode, and heating is transmitted that is the electrical heating.

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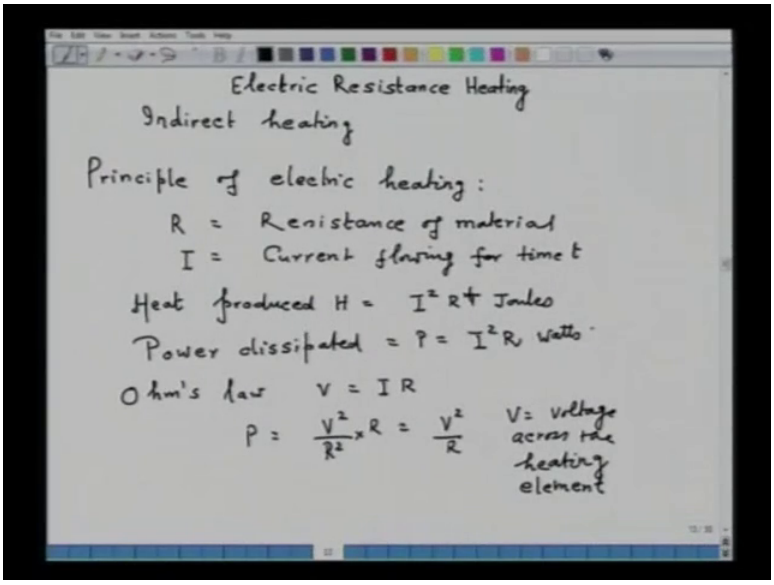

In indirect heating, you have to select a material which is heated, and that heat of the material is transfers its energy to the object. So, that is why we call, what we will be addressing today, that it is the we will be addressing indirect heating. Indirect heating which I mean, that the object is by the radiation of the heating element that is what the indirect heating. Now, it is also clear, that this is a very clear form of energy, with a clean form I mean a so far in the fuel fired furnaces, in several lectures, we addressed that energy from fuel is derived in the form of products of combustion.

And then they give its energy to the object and they exit the furnace, so it is not a clean form of energy; in that respect electrical energy is a very clean form of energy. Now, the principle of electric heating principle of electric heating, it can be initiated in the following way, for suppose R is resistance of the material R is resistance of material and I is the current flowing for unit time, current flowing in a material for let us say time t.

Then heat produced H heat produced H that is equal to I square R and T joules, let us say t is the time; now we know power dissipated power dissipated, that is equal to P and that is equal to I square into R, that will be in watts. Now, we know Ohm's law, this ohms law states that V that is equal to I into R, so we can get now power P that is equal to V square upon R square into T that is equal to V square upon R, were v is the voltage across the heating element across the heating element.

So, that is how for the calculation purposes of how much watts, voltage difference R and I they are connected and that is one can calculate the so called power. Now, what are the requirements of heating element, now so far we know that when a current is passed through a material of resistance R, heating is produced, and heat energy is produced. And we can quantify P is equal to V into I, that is power, that is obtained when a voltage difference across the heating element is produced.

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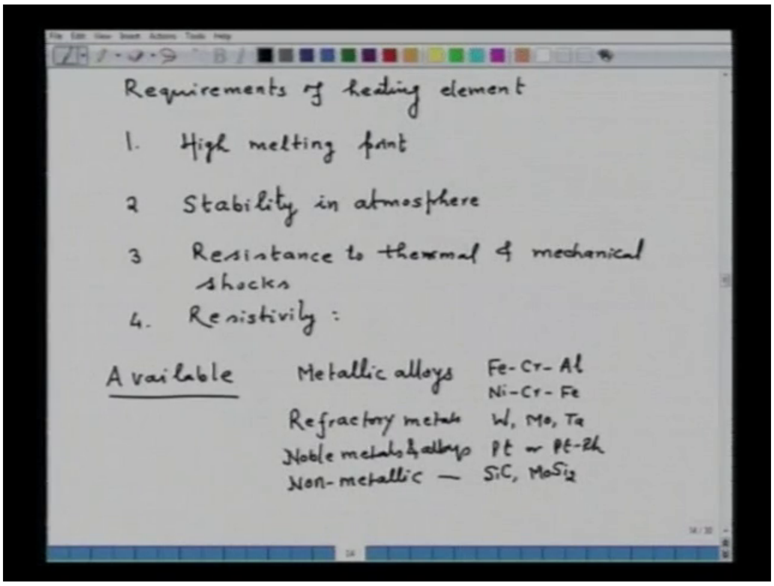

Now, what are the requirements for the heating element requirements of heating element, now I am using the term heating element, because they are again the materials and since, they are used for heating, so we call them heating element or also in fact, they are the material, they are used for heating, that is why we call them as a heating element. So, the first requirement is that a material should have high melting point should have high melting point, that is the first requirement.

Of course, the melting point of the material should be much much higher than, the temperature to which the object is to be heated, that is very important thing. Seconds is that stability in atmosphere stability in atmosphere, with that you are employing the heating element, say under endothermic atmosphere or exothermic atmosphere or reducing atmosphere, then the material should be stable against corrosion and chemical reaction with the atmosphere.

Because, you have seen in the earlier lecture, the furnaces employed different types of atmosphere; so in selecting the material for heating element, a precaution is to be taken that, the selected heating element, it is (()) to the atmosphere which is chosen for heating, second important point. Third important point is resistance to thermal and mechanical shocks resistance to thermal and mechanical shocks, because many times when the furnaces are heated up, you pass the large amount of current through the heating element, and then you decrease the amount of current, depending on the temperature that is required. For those thermal gradients, the heating element should be able to sustain those thermal gradients, and also mechanically induced forces; so that it should not crack or it should not be, it should be remain stable.

Fourth important point is resistivity, in fact resistivity is the ability of a material to inhibit, the flow of current in presence of an applied voltage. That means, if you have longer is the larger is the resistivity more will be the heating, because it inhibits the flow of current in accordingly, large amount of heat will be produced. These are some of the requirements of course, if you have many, you can include more some of the important, which I have listed over.

Now considering this what are the available to us, so the available materials available materials say one is the metallic alloys metallic alloys and these alloys are based on system iron, chromium and aluminum. You know this is the all of you (()) this iron, chromium, aluminum, they are called the Kental wires another is the nickel, chromium, and iron and you know they are all the Nichrome wires, these names you must have heard.

Second available material, they are the refractory metals refractory metals say for example, tungsten, molybdenum and tantalum, they have very high melting point and they can also be used for heating element. Third is noble metal and alloys noble metals and alloys and in this case platinum or platinum rhodium, they are also used to construct a furnace, although they will be very expensive, because they are the platinum wire is also a very expensive thing.

Another type of heating element, they are the non-metallic heating element non-metallic heating element and under non-metallic the one of the most important, that all of you know is also that are the silicon carbide. Another important is the molybdenum disilicide, so these are the material which is available for high temperature, indirect heating applications.

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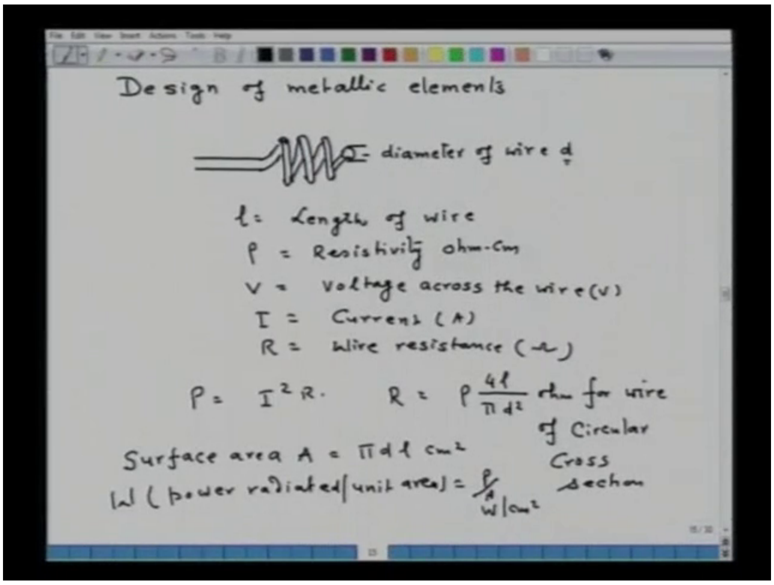

Now, let us see little bit a design of metallic element design of metallic elements metallic, now for example, let us consider a wire say sample this (No audio from 12:27 to 12:40) the wire (No audio from 12:41 to 12:55). And this wire, let us say this is the diameter of wire this is the diameter of wire, let us say the diameter is equal to d, if l is the length of wire l is length of wire this is the resistivity of the wire resistivity of wire in Ohm centimeter.

And V is the voltage across the wire voltage across the wire, I is current and R is the wire resistance wire resistance, that we give in Ohm, that is say in (()), that is in volt, then we know power, that is equal to I square into R and R is equal to resistivity 4 l upon pi d square in Ohm that is for circular cross section wire, for wire of circular cross section circular cross section. Now, say surface area of wire, say surface area of wire A that is equal to pi d l that is in centimeter square therefore, we say what, that is power radiated per unit area power radiated per unit area that will be equal to P upon A.

And the dimensions are watt per centimeter square, this is a very important component of the design of the furnace using metal element, you must know what is the power radiated per unit area. That is what per centimeter square, so that the wire can sustain, the flow of current.

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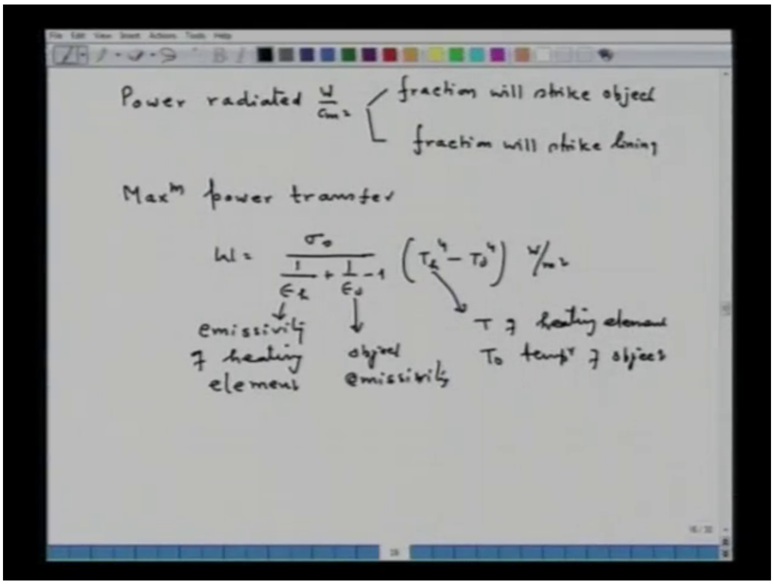

Now, this power radiated per unit area for heating element, say power radiated that is watt per centimeter square, and say that is the important part for design of the furnace, you must see that most of the power, radiated by the wire is available to the work. The more the power available from the heating element to the work, the work will be heated up faster, what I mean to say is that, when these heating elements are installed in the furnace, you pass the you other apply the volt, current will be produced wire will be heated up.

And it is radiation of the wire, that does that transfers the heat to the surroundings, and the surroundings consist of the object as well as lining wall. So, you objective should be that the maximum amount of heat is to strike the object, and less fraction should strike the lining, that means power radiated, the fraction will strike the object fraction will strike object, and the fraction will strike the lining fraction will strike lining. Of course, from the lining these will be reflected absorbed, and the losses all these thing are associated.

So, what I mean, that the radiation of the heating element, it should be maximized, so that maximum amount of heat is strikes the object; that means the heating element should be inserted in the furnace such that, the object gets maximum amount of radiation. Now, here the shape of the heating element, support will effect also the heat transfer say for example, imagine the heating element they are freely suspended, then heat transfer will offer in all direction. If they are supported in group, then the heat transfer will be offered through the group, so what (()) these are they say methods of arranging the heating elements in the furnace. Now, say maximum power transfer maximum power transfer say W that is equal to sigma 0 1 upon epsilon h plus 1 upon epsilon 0 minus 1 T h 4 minus T 0 to the power 4, that is what per meter square, were epsilon h is emissivity of the heating element emissivity of heating element epsilon 0 emissivity of object, object emissivity T h is temperature of the heating element, T of heating element and T 0 is the temperature of the object.

So, this is the maximum power, that is available however, this equation does not consider the losses through the lining, and these things are not in the equation, and what these equations says, that is the maximum amount of power is available. Now, once power is known, then we can calculate surface loading is important, then we have to select wire of appropriate size, and area, service life of the wire is also very important. In fact, the surface loading of the wire is many times is specified by the manufacturer, that means how much amount of load, the wire can sustain that is specified by the manufacturer those information are to be collected.

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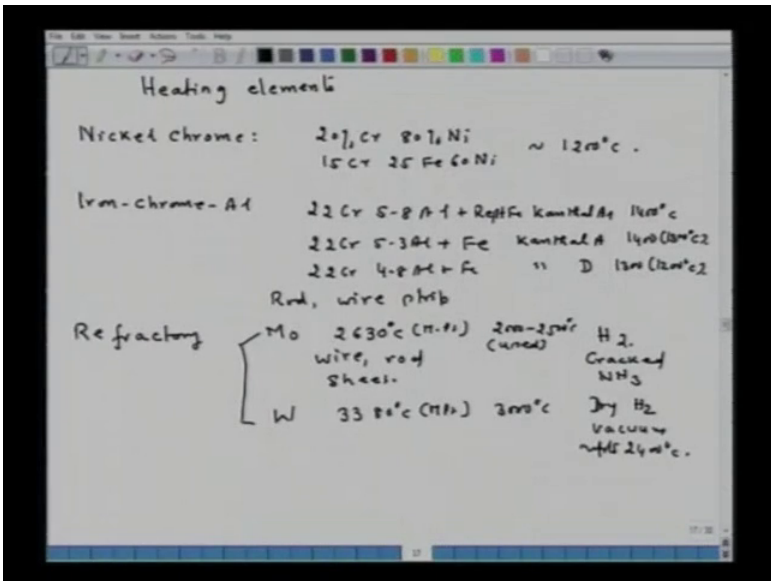

Now, certain say important some certain important heating element certain important heating element, say we take say for example, nickel chrome nickel chrome, now nickel chrome it has chromium and chromium on heating forms Cr2O3 and that protects the wire that that protects the wire against further oxidation, where Cr2O3 is stable, and the material is prevented from further oxidation. Similarly, the compositions are 20 percent chromium 80 percent nickel or 15 chromium 25 irons and 60 nickel all these different types of materials are available, and they can be used until maximum up to 1200 degree celsius. Another type of this is iron-chrome-aluminum, iron-chrome-A l that is all of us know, they are the mechanical wires, now here the aluminium it forms Al2O3 and further oxidation is protected.

Say for example, 22 chromium 5.8 aluminum and rest iron, that is called Kental A 1 and the different grades of chemical wire is available, and that can sustain temperature of 1400 degree celsius, then you have say 22 chromium 5.3 aluminum plus iron rest, this is Kental A, that can go up to 1400 however, recommended is 1300 degree celsius. Another grade, say 22 chromium 4.8 aluminum plus iron this is called Kental d 1300 but, the recommended is 1200 degree celsius.

Now, here they are available in (()) form wire or in strip size, all shapes are also important, another say we have refractory metals, refractory metals we have molybdenum and molybdenum melting point is 2630 degree celsius, that it is its melting point. It can be used safely from 2000 to 2500 degree celsius that is used in this particular range, available in wire rod or in sheet form. Now, this molybdenum heating element can be used safely in say hydrogen atmosphere or in crack ammonium atmosphere crack NH3 atmosphere.

Another important, we have a tungsten heating element, its melting point is 3380 degree celsius, it can be used safely up to 3000 degree celsius and it is also available in the form of wire, rod and sheet, it is specifically used for in the atmosphere dry hydrogen, and vacuum, up to 2400 degree celsius.

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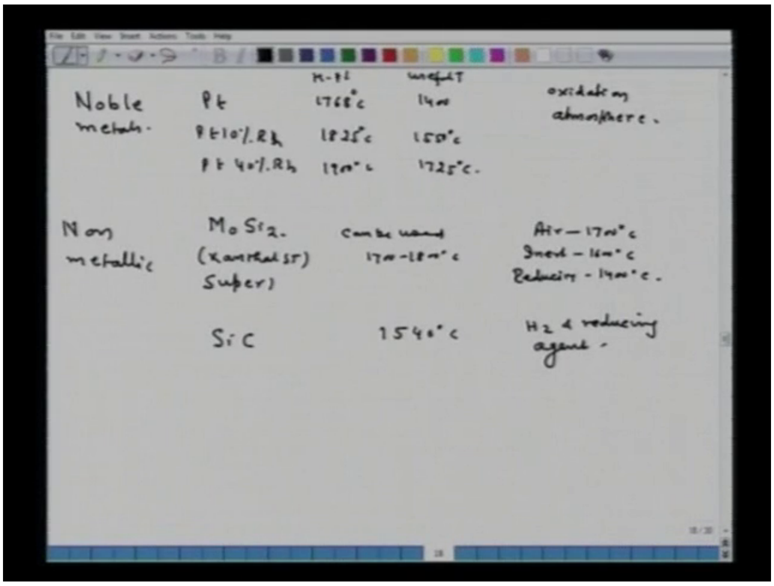

Then we have say noble metals as the heating element, and under noble metals we have pure platinum or platinum 10 percent rhodium or platinum 40 percent rhodium, these are the available. Now, the melting point of all of them here is 1768 degree celsius, 1825 degree celsius and 1900 degree celsius; now useful useful temperature it can be applied safely up to 1400, 1500 and 50 degree celsius, and 1700 and 25 degree celsius, they are also available wire, rod, strip form, and they can be used in oxidation atmosphere oxidation atmosphere.

And then non-metallic element category and the non metallic element category, one we have say molybdenum disilicide, that is also called kantar S T super, they are here different grades are also available, it can be used can be used safely up to 1700 to 1800 degree celsius. However, in air it can be used up to 1700 degree celsius, under (()) atmosphere 1600 degree celsius, and reducing can be used maximum up to 1400 degree celsius. Another important heating element is silicon carbide, now silicon carbide can be used up to 1500 and 40 degree celsius, good for hydrogen and reducing agent and reducing agent. So, these are the certain heating elements.

Now, say silicon carbide rods have two distinct zones, there is a heating zone and that heating zone is a very important thing, and that is the central portion of the rod is the most probably heating zone, and then they are the supporting zone. Molybdenum disilicide heating element, they are brittle and careful handling is needed; now suppose say, now (()) given this idea about the different heating elements, their service conditions, temperature, limitations and so on.

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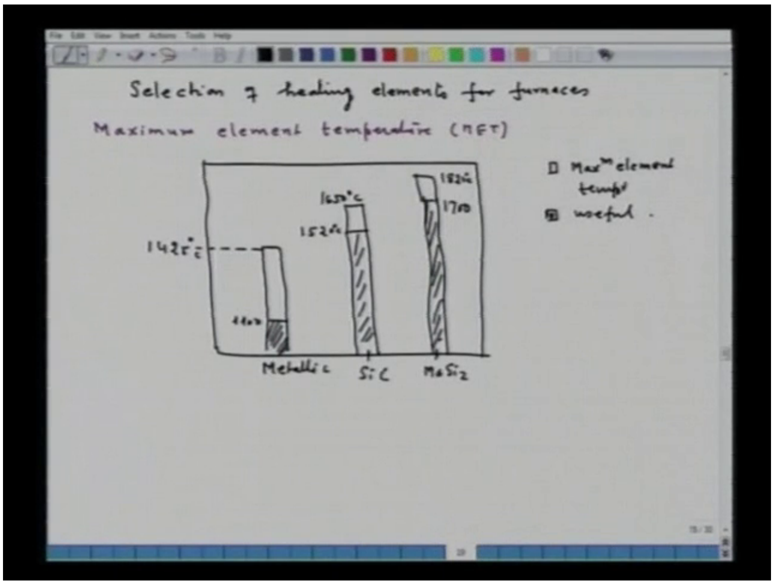

Now, selection of heating element for electrical furnaces selection of heating element for furnaces, so here some of the important criteria, one criterion is the what is the maximum what is the maximum element temperature what is the maximum element temperature, let us say n E T of the heating element. Now, for that selecting three different type of heating element, that I am putting it over here say for example, here I take metallic heating element, this is metallic, this is silicon carbide, and this is MoSio2. So, I am comparing now, these three heating elements for the selection purposes.

So, the metallic elements, they can be used say this temperature is around 1400 and 25 degree celsius, and this temperature is around 1100 degree celsius, so this area represent maximum element temperature maximum element temperature, and this this thing is the useful limit. Now, similarly, if I consider silicon carbide, then silicon carbide, this is for the silicon carbide and silicon carbide it can be safely used up to 1500 and 20 degree celsius, the maximum element temperature this is 1600 and 50 degree celsius.

Then if I take molybdenum disilicide, then (No audio from: 29:23 to 29:35) (Refer Slide Time: 29:136) this temperature is around 1700 degree celsius, and this temperature is around 1800 and 20 degree celsius. So, this is the information about the maximum element temperature that is one thing we require, now their response to the atmosphere will also be different.

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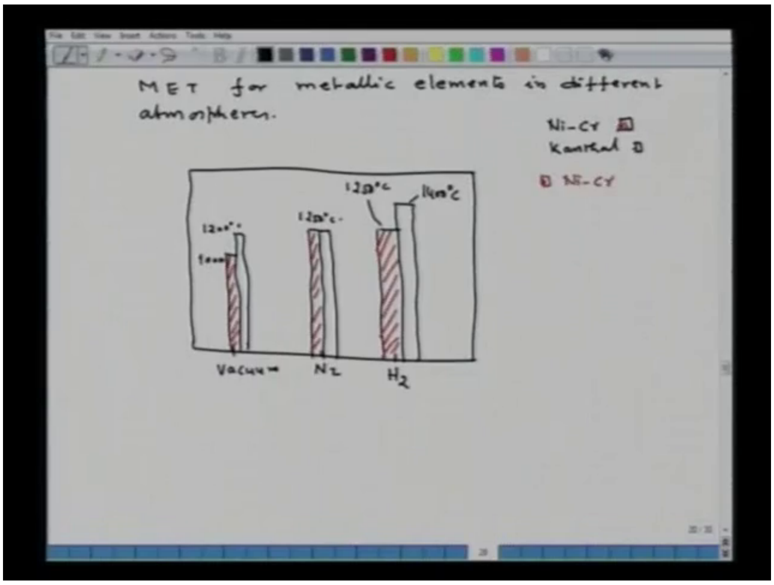

So, let us consider now say maximum element temperature for metallic elements for metallic elements in different atmospheres in different atmospheres, again I plot here, I have taken two thermo couples two heating elements, one is the nickel chromium, that is nichrome and another is the Kental. So, under vacuum, say (No audio from: 30:49 to 30:58) under vacuum this one say this one is in fact, nickel chromium whereas, this one is is the Kental.

So, what I am comparing nickel chromium versus Kental for example, in vacuum atmosphere, in atmosphere vacuum, so nickel chromium can be used this is 1000 degree celsius, and this goes up to 1200 degree celsius. So, Kental in fact, is represented by this and nickel chrome I will be representing by this particular line (Refer Slide Time: 31:36). Now, simply for example, if I take now under nitrogen atmosphere, I take nitrogen atmosphere and for nitrogen atmosphere, say both the elements they can be used safely, up to 1200 degree celsius.

This is again nickel chrome and this temperature is 1250 degree celsius, if I take for example, hydrogen atmosphere, this is I take hydrogen atmosphere then under hydrogen atmosphere, this is for the nickel chrome and this is for the Kental (Refer Slide Time: 32:08). So, this one is for nickel chrome and the temperature for this is 1250 degree celsius, whereas, Kental can be safely used up to 1400 degree celsius. Similarly, the response of response of other element can also be determined, in order to select a heating element for a particular application.

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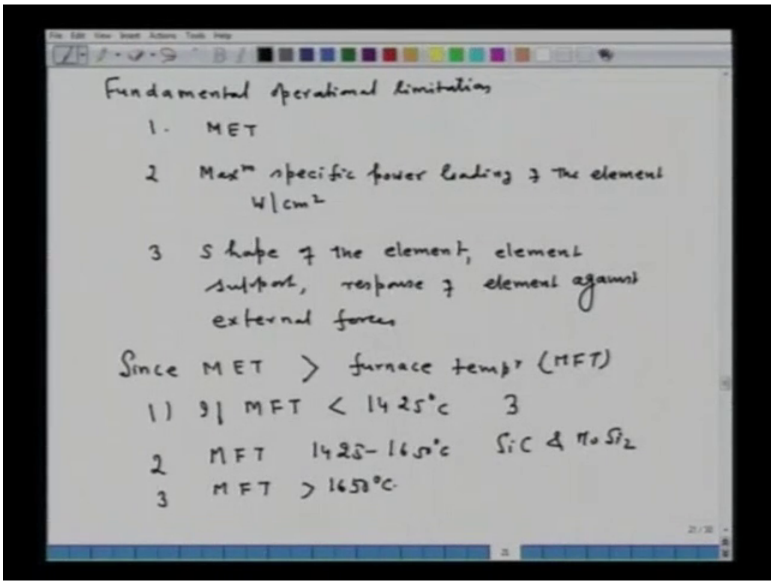

So the fundamental operational limitations are fundamental operational limits or operational limitations number one maximum element temperature. Now, maximum element temperature should be greater than the temperature required or than the temperature of the furnace. Second maximum specific power loading maximum specific power loading of the element that is in watt per centimeter square that will decide the watt loading. And third important thing is that, shape of the element, what shape you are going to select, shape of the element.

Now, element then shape of the element, element support system element support then response of element response of element against external forces for example, mechanical or thermal or electromagnetic and so on so four. So, these are the operational limitations. Now for example, now since, maximum element temperature will always be greater than furnace temperature than furnace temperature, and then if you consider those two figures then the following conclusion emerges.

One say, if maximum furnace temperature maximum furnace temperature I will call this MFT, if maximum furnace temperature for example, is 1400 less than 1425 degree celsius, then all three type of elements nichrome, molybdenum disilicide and silicon carbide can be used. The application will only depend upon the economic considerations, because silicon carbide and molybdenum disilicide they are expensive. Second is MFT or maximum furnace temperature is in between 1425 to 1650 degree celsius, then only silicon carbide and (()) can be used, if see the previous figures. Third if say maximum furnace temperature is greater than

1650 degree celsius, then only molybdenum disilicide is a possibility, no other heating element can be used.

So, the choice of course, depends upon what is the maximum furnace temperature is required, in addition to this metallic wires are available both in wire and in strip form; metallic wires can be operated with the line voltage. But silicon carbide and molybdenum disilicide heating element, it cannot be operated with line voltage, for that you require the so called transformers. So, of course, these are the some considerations for selection of the heating element.

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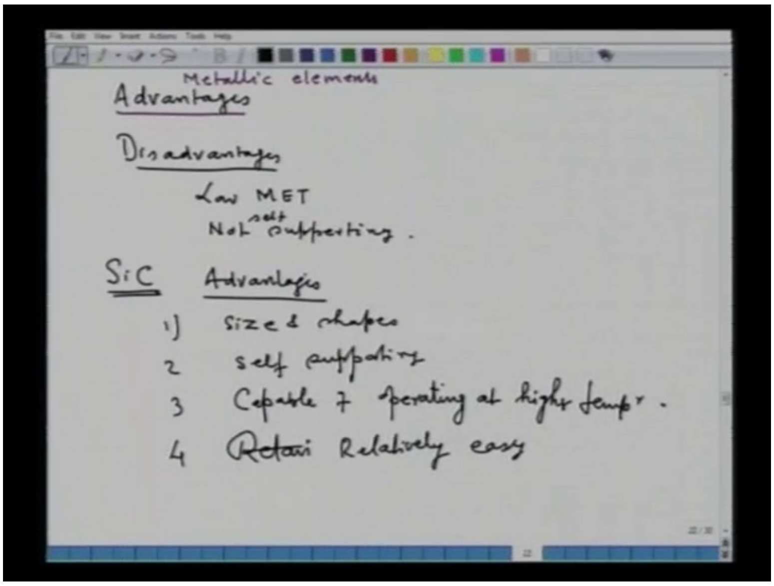

Now, say some of the advantages of heating element, advantages and disadvantages, see for example, I take first metallic elements metallic elements, see some of the advantages of metallic elements, one they are available in wire and strip form, it can be fabricated with the conventional metal forming techniques, in to a variety of shapes and size. Second heating system can be worked with the line voltage, they are less expensive than (()) and molybdenum disilicide heating element, these are the advantages. Now, under disadvantages under disadvantages say one of the main disadvantages is they are low maximum element temperature, not self supporting with the required support, not self supporting their resistance also increases with time, due to reduction in cross section, by oxidation and elongation, resulting in decreased power, output and eventual failure, these are certain advantages, one is to compromise between these two things.

Now, if we take say silicon carbide heating element now silicon carbide heating element their advantage, again they are available in all sizes and shapes all sizes and shapes they are available, they are self supporting self supporting then higher temperature capable of operating at higher temperature, capable of operating at higher temperature. And another important relatively easy relatively easy to change, when the furnace is hot, so that is also can be considered as an advantage.

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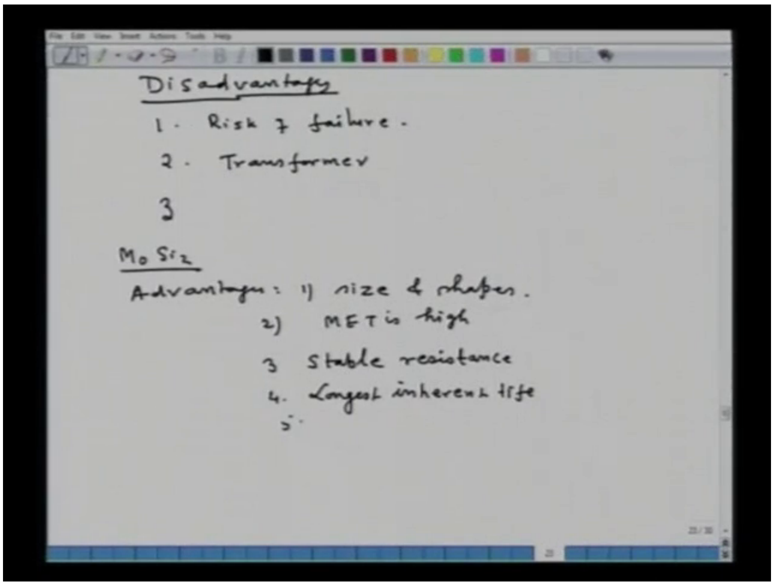

Now, under the disadvantages of silicon carbide heating element, disadvantages disadvantages are say, they are ceramic materials therefore, risk of failure, so brittle risk of failure is one particular disadvantage. Second disadvantage is, see you require transformer to operate them require transformer to operate them, and third electrical resistance also increases with time, that is ageing, meaning more maintenance attention is required. So, these are certain advantages and disadvantages, certain disadvantages of this.

Another say molybdenum disilicide, advantages again available in variety of size and shapes, almost all sizes and shapes are available, most important advantage is that, they can be operated their maximum element temperature is very high , that is very high very high element temperature is there, and as a consequence the furnace can be operated at high temperature. Third say stable resistance, stable resistance that is old and new molybdenum disilicide element can be joined in series, fourth longest inherent life longest inherent life of all thermal elements. And fifth advantage is that, fast thermal cycling is possible without element degradation that is you can apply a fast heating cycle without degradation of the material.

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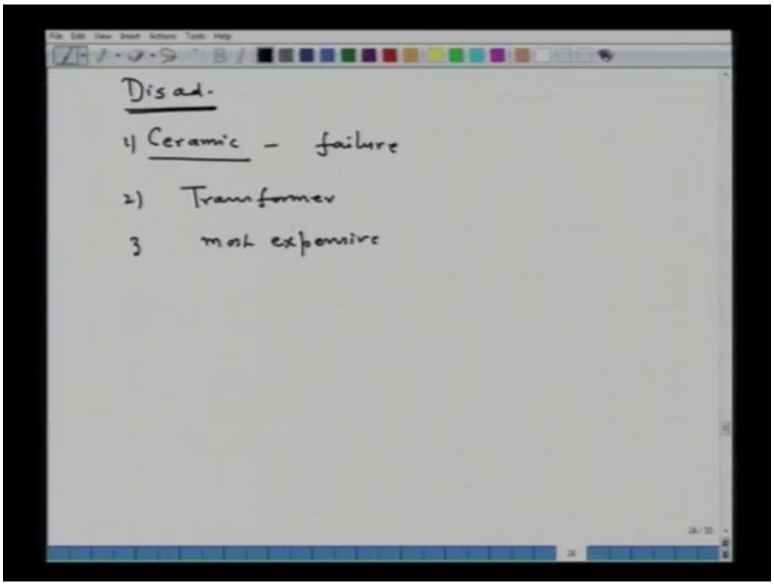

Now, under the category of disadvantages under the category of disadvantages, that is again this is ceramic material, risk of failure. Second we require a transformer, just with the line voltage these molybdenum disilicide material cannot be operated, and third it is the most expensive it is most expensive under the heating element, which we have considered. Now, in brief I will like to illustrate you, say what is required when you want to design a furnace.

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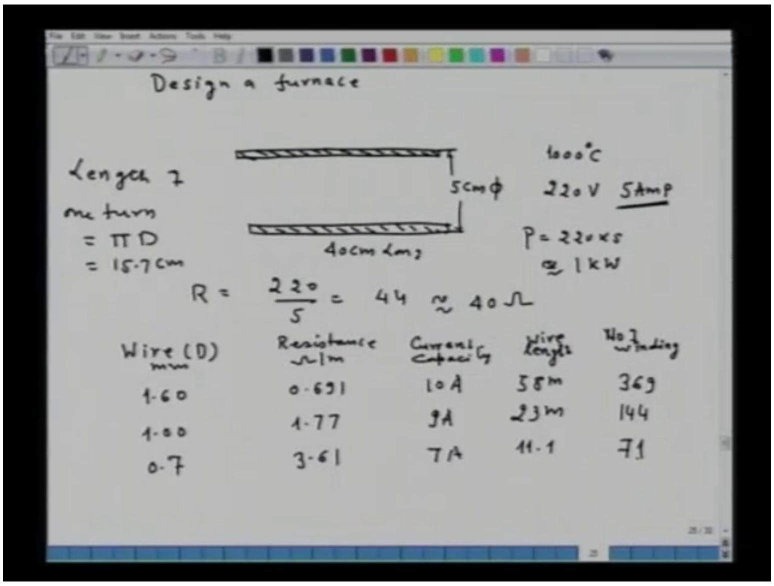

Now for example, for designing a furnace, tell about the type of furnace, a designing a furnace what is required. Now for example, I take a ceramic tube, it is a ceramic tube whose outer diameter, whose this is outer diameter, and let us take this ceramic tube is 40 centimeter long, and its outer diameter is 5 centimeter. We want to design this furnace to operate at 100 degree celsius, operated at 220 volt line, and line has 5 ampere current socket, this is what is given to us, how to go ahead for this?

So, first of all we calculate the wire, the power that is power will be 220 into 5 that will be approximately I will say 1 kilo watt, now I can calculate say R resistance, that will be equal to 220 upon 5, that will be 44 time taking approximately 40 Ohm, that is I have to design the furnace for 40 Ohm resistance. So, now I will go for selection of the wire, so that will be the, now my specification for design of the furnace, the furnace will consist of 1 kilo watt, the resistance of the furnace will be 40, approximately 40. Now, I will have selected the wire, so that I can meet this specification, in order to create a temperature of 1000 degree celsius.

Now what is done, so now I calculated the ohms that is required for design of the furnace, what I have to do know, I have to select the length of the wire right and then the number of turns, so what I do now, I select the wire, so I have put here wire diameter, say in d which is in millimeter, then resistance of the wire, that is in Ohm per meter then you must also know current capacity, current capacity. Now, current capacity of the wire should not be less than 5 ampere, because 5 ampere is the design value, the wire will burn it should be more than 5 ampere. Now, wire length and number of winding that is required number of windings, number of windings you can calculate pi d that is the circumference you can calculate that. So, I select the wire for example, one is 1.60 millimeter, the resistance is given 0.691, current capacity is 10 ampere that that falls within my region of 5 ampere, and the wire length it comes 40 divided by 0.691, that is 58 meter.

And if I use this wire, then I have to have approximately 369 windings on this particular tube, that is 5 centimeter diameter, that is that may not be possible, so I go to the next wire, I take now 1 millimeter its resistance is 1.77, its current capacity is 9 ampere, wire length is 23 meter and I get number of windings 144, for discussion I am taking another wire of 0.7 millimeter 3.61 and 7 ampere, number of windings wire length is 11.1 meter and number of windings is 71. So, now I have to plan, how I am going to wind this wire.

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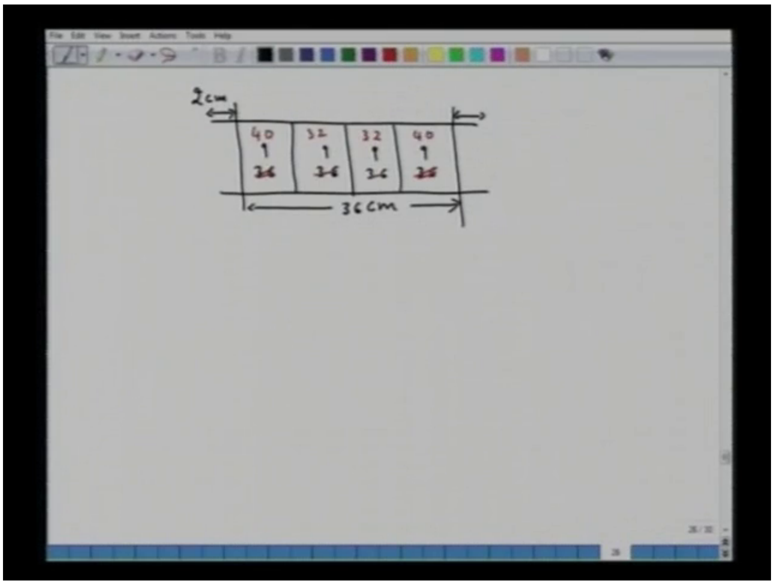

Now let us see, so I take this is the tube, 40 centimeter well I have to leave somewhere here, 2 centimeter on this side, 2 centimeter on this side, what for that is 1, that will be going out of the your say furnace. So, the winding length is is approximately, let us say 36 centimeter, number of windings corresponding to 369 is not possible in this particular length of the furnace. So, we go to next 144 number of windings, so I divide minus for example, in 4 part 1, 2, 3; the 9 centimeter, 9 centimeter, 9 centimeter and 9 centimeter. Now, per in each 9 centimeter I have here 36 winding, here 36 winding, here 36 winding, here 36 winding, I can do that, now one of the important message that I want to give you, when you want to design a furnace (Refer Slide Time: 48:15). See that the ends of the furnace, they are thickly wound is compared to middle of the furnace why, because those ends will be heated at higher temperature, so heat transfer will occur from end to the middle part, so that you can get a uniform temperature zone, within the central part of the furnace.

So, with this objective what we do is that, in the end portion we take 40 windings here, here also we take 40 windings here, so we get here 32 windings now, and 32 windings now and that can be very easily compensated, in a length of 36 centimeter (Refer Slide Time: 48:55). So, that is how I thought to illustrate, how to design a furnace because, many times you may be doing a B.Tech project or whatever you may be doing you may be designing a furnace or you are because, those specification may not be available for whatever the reason may be this can help you, it is because of this I put it here. Now, as an end of the lecture I would like to give you, some of the self assessment questions.

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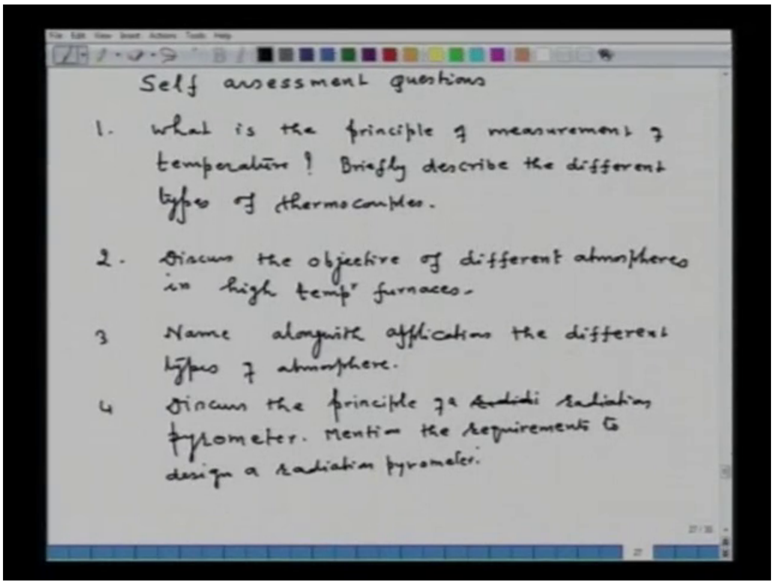

Self assessment questions on miscellaneous topics, now the first say, what is the principle of measurement of temperature what is the principle of measurement of temperature, I discussed those thing in the lecture, so you can make the appropriate answer, briefly describe briefly describe the different types of thermocouples the different types of thermocouples, that is also I have given and you can see that you update your. Second discuss the objectives of different atmospheres of different atmospheres in high temperature furnaces high temperature furnaces; now in your discussion you can also include the objective of the furnace. For example, you are (()) for (()) or (()) material or (()) the material, so depending on the objective you can discuss the type of atmosphere that is needed to perform that metallurgical function.

Third question, that I will like to give you name, along with applications along with applications the different types of atmosphere different types of atmosphere, now what I want here is that in fact, what are the different atmosphere, and if you can aid line, how these atmospheres are created, and what are the important requisite. For example, in endothermic atmosphere, we use air less than the (()) amount, so extra amount of heat is required, that is what in fact, if we include those thing also here, you can get update knowledge of the various atmosphere for high temperature purposes.

Fourth discuss the principle of radiation pyrometer discuss the principle of a radiation pyrometer, radiation pyrometer mention the requirements to design a radiation pyrometer design a radiation pyrometer. Now, with this I mean, because the pyrometer has two essential components as I have illustrated in my lecture, the important is the sensor to detect in the electronic socket; and all these requirements you should include over here.

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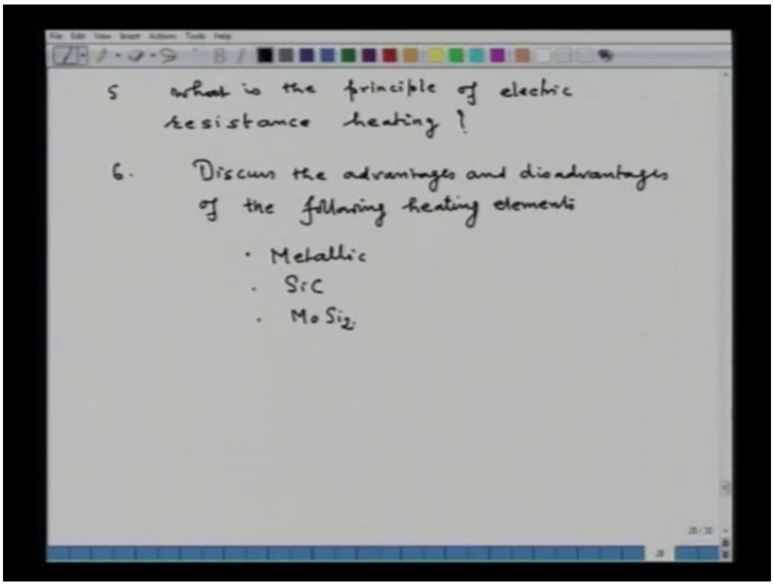

Now, the next question that I want to give is, fifth one what is the principle of electric resistance heating what is the principle of electric resistance heating (No audio from 53:52 to 54:06), the sixth question that I would like to give you, discuss the advantages advantages and disadvantages of the following heating elements of the following heating elements. One, take metallic one, say under metallic I mean nickel chromium and Kental wire these are the thing under consideration; second silicon carbide, and third is the molybdenum disilicide.