Machinery Fault Diagnosis and Signal Processing
Prof. A. R. Mohanty
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 48
Thermography

In this lecture, we always talk about a new area all together and that is known as thermography. By now, we have a knowledge of how vibration can be used for machinery health monitoring or condition monitoring and then in the previous classes, you saw how motor current signature analysis can be used to find out faults in mechanical systems being driven by electrical machines and also find out the faults in the electrical machines themselves.

But today, we will discuss on a new topic called thermography, essentially by the measure of thermal energy emitted from a body as you know, any machine, it generates heat because of friction between the moving parts sliding over one another, there will be lot of heat generation and this heat generation increases with the frictional force and frictional force will increase the normal forces onto the surfaces increase. Now this normal force could increase because of a defect.

So, thermal imaging gives us easy clue as to that an abnormal excessive force is coming on to this machine particularly, for example, I will just give you an example here.

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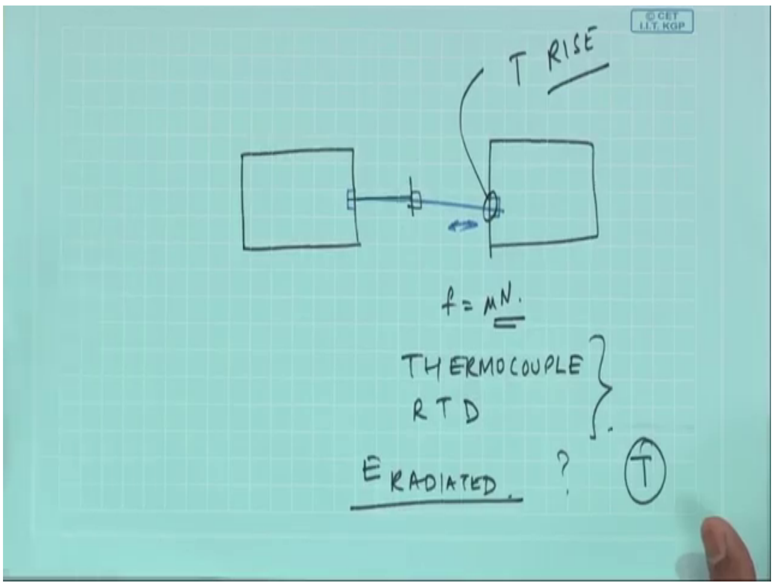

I have two machines and then there is a strong bit of misalignment between these two shafts. So, there will be a push pull force onto the surface of these bearings. So, what happens; the frictional force whatever be the direction ok, it is normal to the direction of the normal force.

Now, if this friction force increases and there will be lot of heat generation ok, if heat generation is there; obviously, the temperature is going to rise. So, indirectly by measuring the rise in temperature, we can say that an abnormal force has happened, well, how can we measure temperature, we know to use thermocouple, to use an resistance temperature detector; RTD, etcetera, we can measure the temperature of any surface, but mind you, these are contacting surfaces, I mean these are contact type sensors. So, we have to embed these sensors in the area where we are going to measure the temperature.

Rather there is another method by which we can measure the temperature is you know because the energy will be radiated thermal energy will be radiated. So, if we can somehow measure this radiated energy, we can get a clue as to; what is the surface temperature and that is essentially, what we are going to talk about in today's lecture on thermography.

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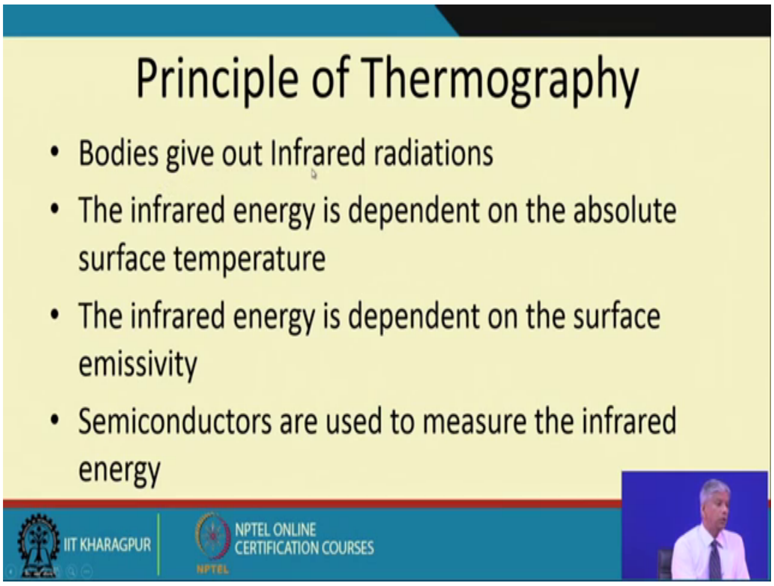

So, the principle of thermography is bodies actually give out infrared radiations, you know these are electromagnetic radiations like, we have the visible light anywhere from 4000 to 7000 angstroms is the wavelength and by the way this visible light or electromagnetic waves travel at the speed of light 3 into 10 to the power 8 meters per second speed of and later on we will see the entire spectrum.

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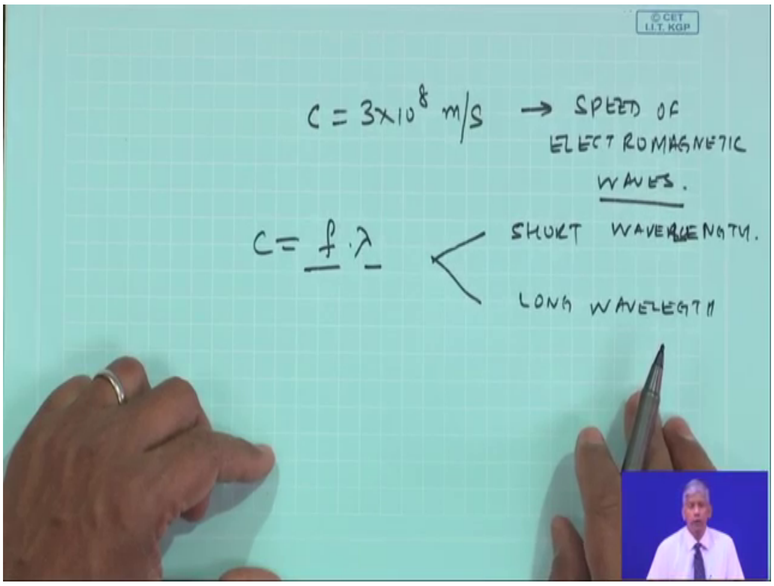

So, depending on the frequency, you know C is equal to depending on the frequency of the wavelength, we can classify a short wavelength long wavelength you know and so on. So, if wavelength is high the frequency is low and wavelength is short the frequency is high.

So, if we talk about you know TV signals, radio signals, gamma rays, X-rays you know ultraviolet rays, infrared bodies always give out infrared radiation and this infrared energy is dependent on the absolute surface temperature, you will recall there is a nice law in heat transfer the Stefan Boltzmann law, which we will discuss in a later on and of course, this infrared energy is dependent on the surface emissivity and there are certain special types of semiconductors on which if this infrared energy is incident they will develop a voltage ok.

So, that is essentially the principle beyond thermography.

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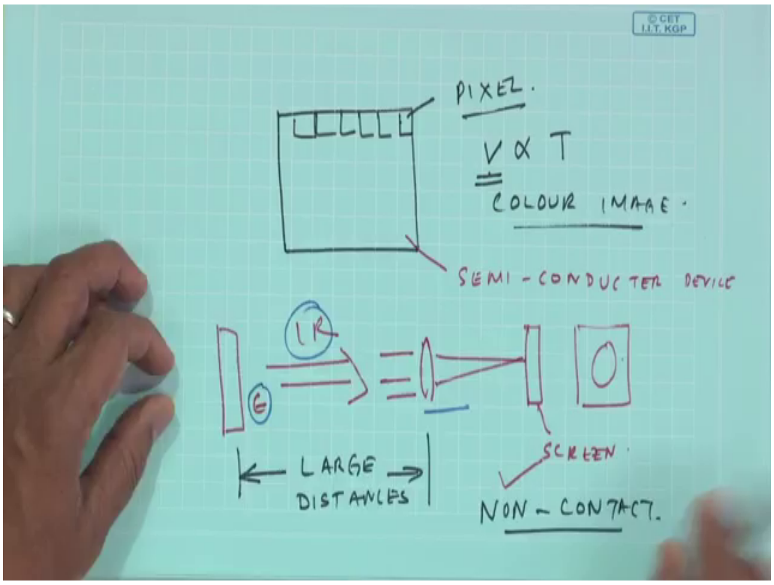

So, if I have a screen, on to which infrared radiations are focused and they are pixel by pixel each pixel and they will generate a voltage proportional to the temperature of the body surface temperature. So, if the; you know body is hot you can have a different voltage and then you can you know colour image them. So, it is only because of these particular semiconductor devices.

So, basically I have a body which is giving out infrared radiations. So, this depends on the surface emissivity I have some optical systems which will focus all this into a screen which is made of a semiconductor device and this screen looks like this will give you a voltage which could be in and in through a software you can get an image which could be colour coded. So, the body's temperature you will get.

So, this is essentially how the principal I mean the thermography principal works and we will see what sort of a body conditions is important how do we estimate IR in a emissivity how do we calibrate this and what kind of camera system we require to get an image.

And the practical applications of thermography are tremendous because the ease at which you can measure because this can be at large distances and that is the essential advantage of thermography large distances and they are non contact imagine you have you know in the last class, I was just mentioning about condition mounting of switch gears imagine you have a large transmission power and it is carrying a conductor with a switch gear and some sort of contact, it has to make because there are insulators are not going to talk about them suppose there is a loose contact. So, with loose contact there will be lot of sparking and there will be heat generation.

So, we can we can be standing here on the ground and this could be you know maybe forty meters from the ground. So, it could always shoot an IR beam and put a hold a camera IR camera and measure this temperature and if it is high than the other transmission towers or it is higher than the ambient you know a loose contact is occurred otherwise you imagine how do you detect such loose contacts you will see lot of voltage drops etcetera.

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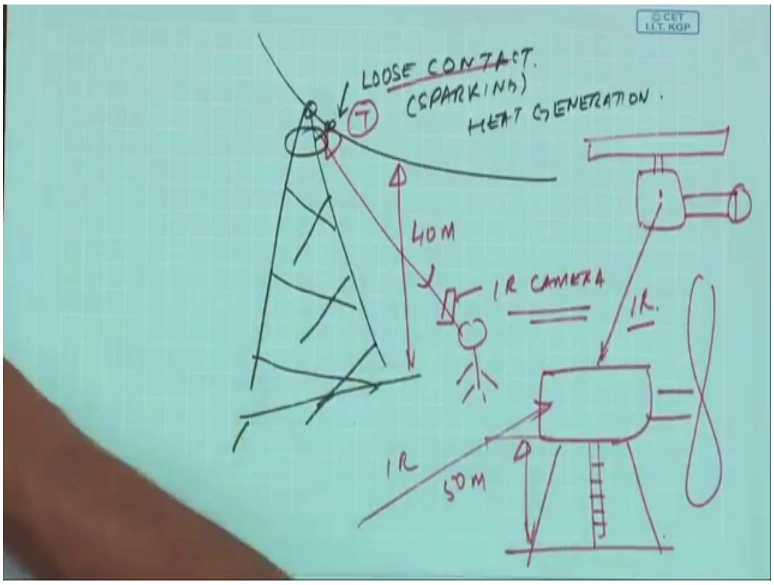

So, this is one typical advantage of IR cameras and same is true for windmills suppose we have a windmill wherein we have a gear box mounted very high again this is maybe fifty meters from the ground. So, you know if somebody was to make a contact type measurement one has to climb up the stairs to go up to the gear box, but rather you can shoot from an IR. In fact, there have been cases where people shoot IR cameras from helicopters to monitor the temperature of a machine.

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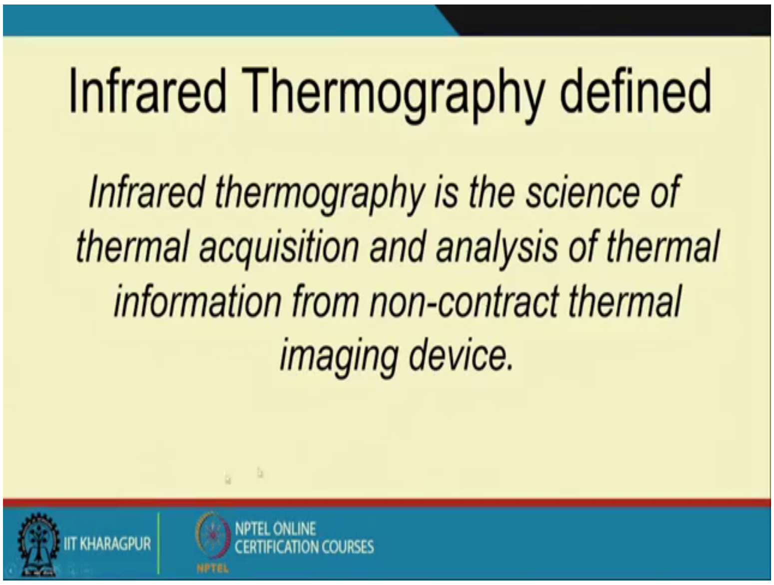

So, infrared thermography is defined is the science of thermal equation and analysis of thermal information from non contact thermal imaging device, it is non contact.

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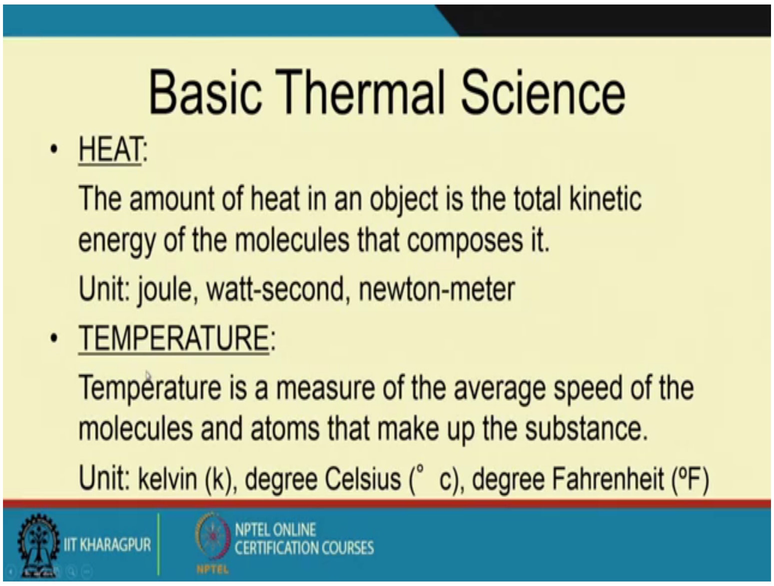

So, you all know this is just a recap the amount of heat in an object is the total kinetic energy of the molecules that composes its joules and temperature is a measure of the average speed of the molecules and atoms that makes up this substance ok.

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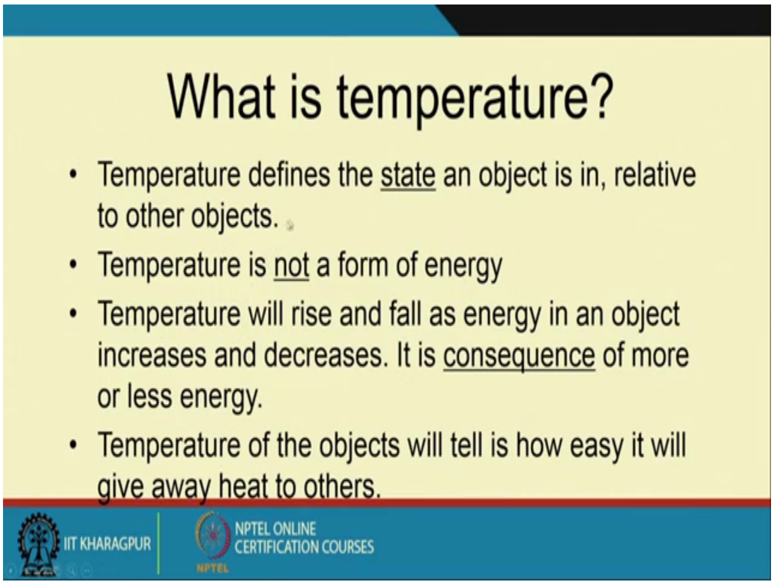

So, temperature defines the state an object is in relative to other objects. So, temperature is an indicator of energy though it is not a form of energy. So, temperature will rise and fall as energy in an object increases and decreases it is a consequence of more or less energy. So, temperature of the objects will tell us how easy it is give away heat to others somebody at a higher temperature will; obviously, energy heat energy will flow from a high temperature body to a low temperature body ok.

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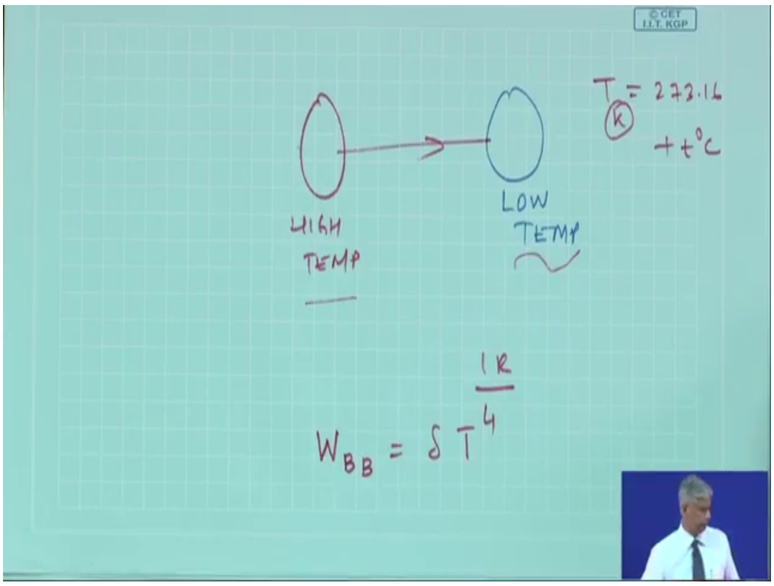

But if they are at equilibrium they all will be same. So, to see any momentary rise in temperatures or in rise in temperature above the normal, we can use IR thermography.

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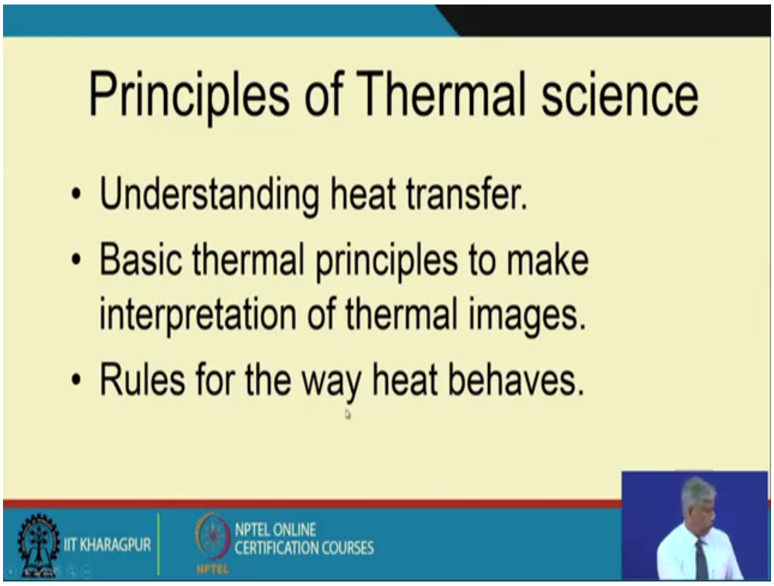

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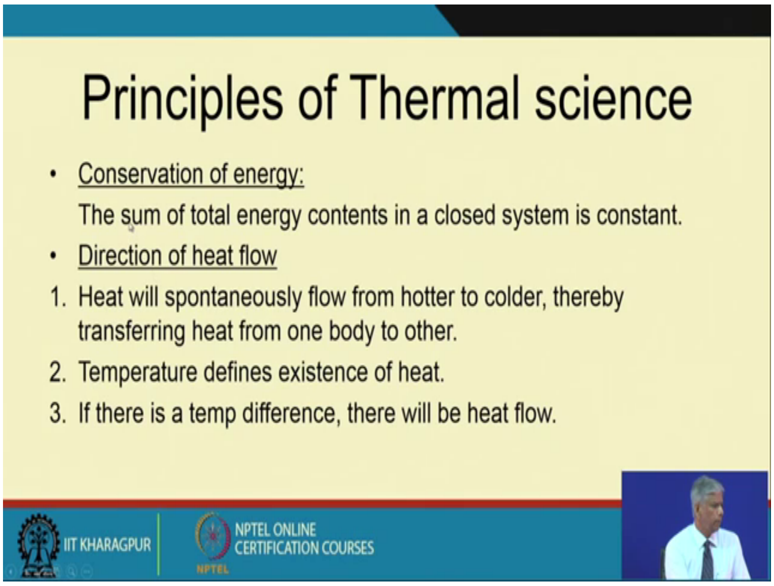

So, all the modes of heat transfer does work, the direction of heat flow heat flow heat will spontaneously flow from hotter to colder thereby transferring heat from one body to another.

So, temperature defines the existence of heat and if there is a temperature difference there will be a heat flow.

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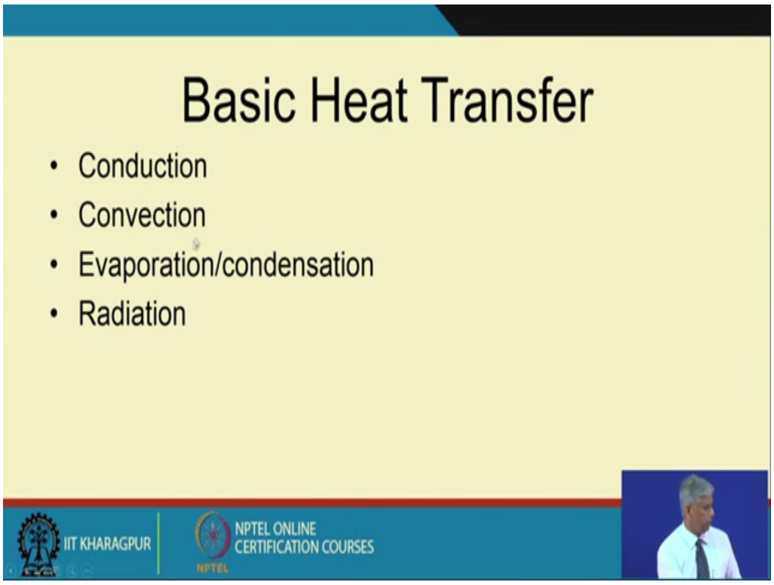

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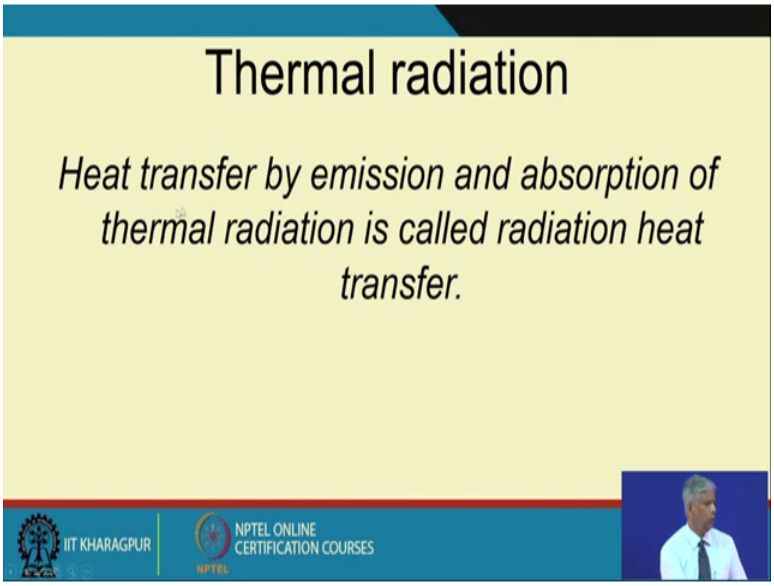

So, basic mode of heat transfer are these three modes heat transfer by emission and absorption of thermal radiation is called radiative heat transfer and this is what we are going to focus on.

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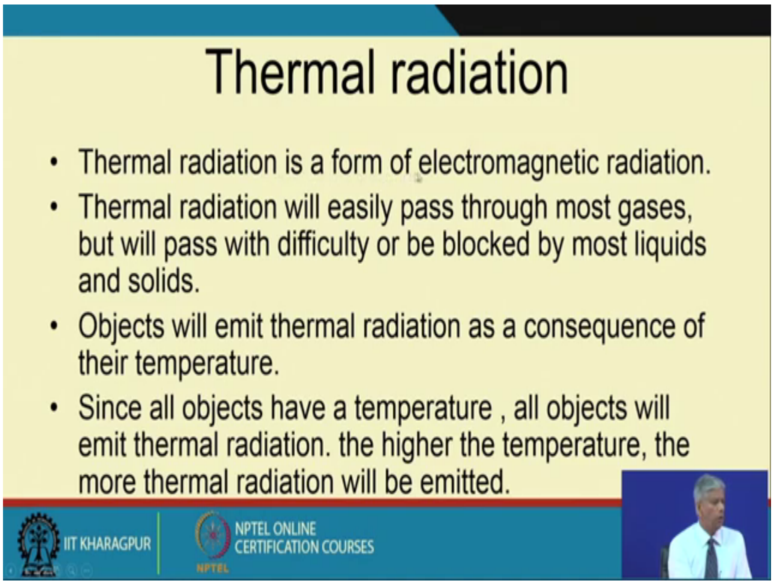

So, this thermal radiation is a form of electromagnetic radiation thermal radiation will easily pass through most gases, but will pass with difficulty or be blocked by most liquids and solids.

So, objects will emit thermal radiation as a consequence of the temperature. So, since all objects have a temperature all objects will emit thermal radiation the higher the temperature the more thermal emission thermal radiation will be emitted. So, our objective is to measure this infrared emitted radiative thermal energy by a system which is usually this thermal-imaging camera which essentially has a semiconductor device onto which this thermal energy is focused and this thermal semiconductor device on a pixel to pixel basis is going to give us a proportional voltage and through the appropriate software we could have a 2D image wherein we can have a colour image of the body whose temperature is being measured.

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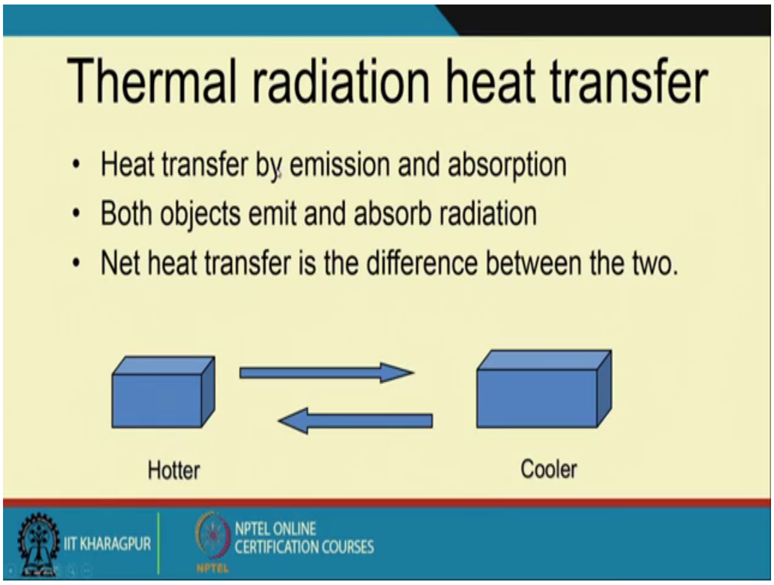

So, heat transfer is by emission and absorption both objects emit and absorb radiation. So, there is no heat transfer is the difference between the two; now I just mentioned about this infrared.

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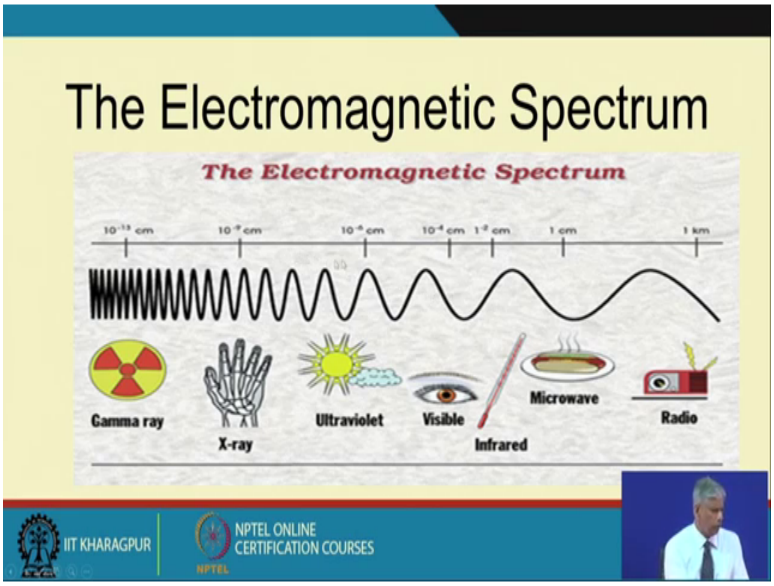

So, the electromagnetic spectrum, if you see at the high frequencies know, we have very low wavelengths and then we have relatively high wavelengths and the frequencies are lower relatively.

So, beyond just after the visible range we have what is known as the narrow infrared region where is very easily this infrared energy can influence a semiconductor some of this energies you know and these waves have very very high power and they are used for penetrating metals x-rays or penetrating solid devices where this cannot ok.

So, depending on the frequency, the intensity of this energy is can be calculated and infrareds are that way not harmful and they can be used to measure the temperature of a body, we will see how.

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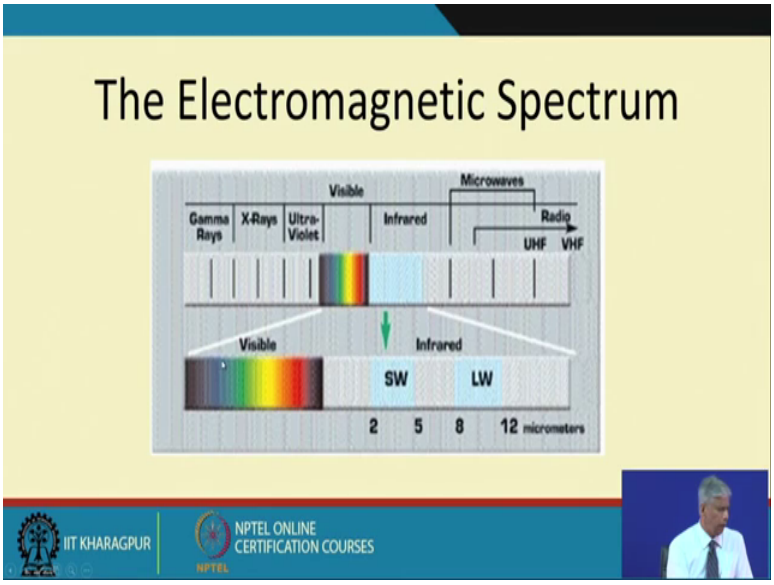

So, infrared, if this is the typical reason wherein infrared in terms of the micrometers you can say from 2 to about 12 micrometers is the wavelength of infrared waves.

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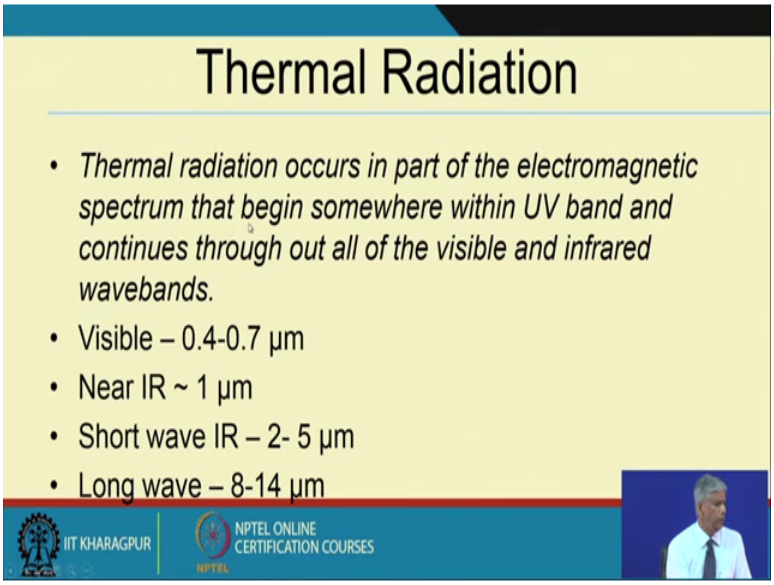

So, thermal radiation occurs in part of the electromagnetic radiation that begins somewhere within the UV band and continues throughout all of the visible infrared wavelengths wavebands. So, visible is you know about 4000 to 7000 angstrom near infrared about 10,000 angstrom and then short wavelength long wavelength and so on.

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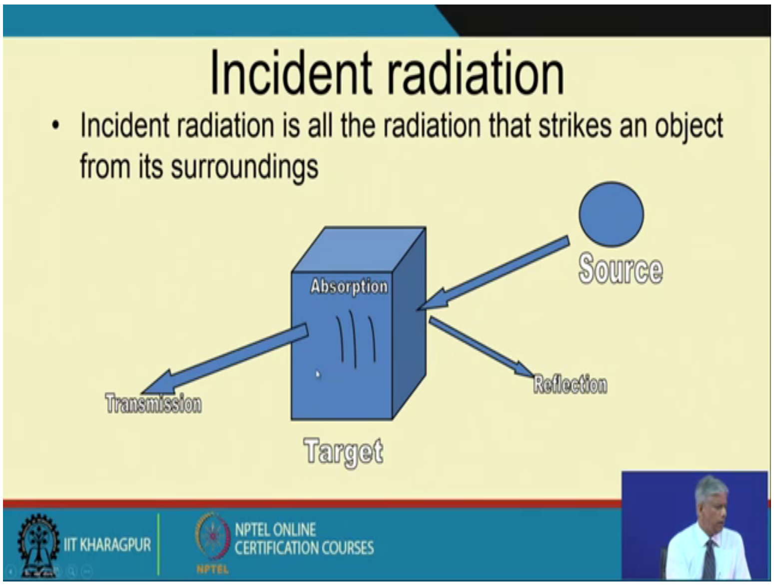

So, when an incident energy is striking a body, from it will absorb something, it will reflect and it will transmit.

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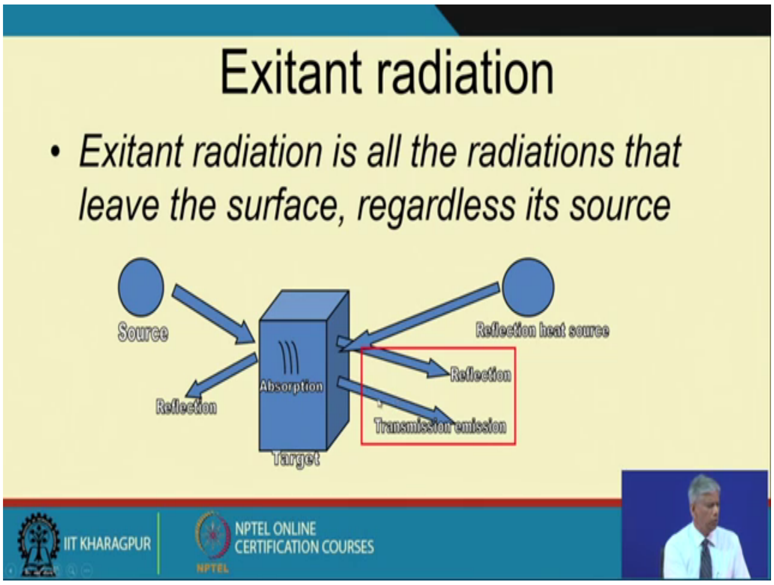

So, this emission is this radiation that leads the surface regardless of its source. So, we are trying to measure this emission.

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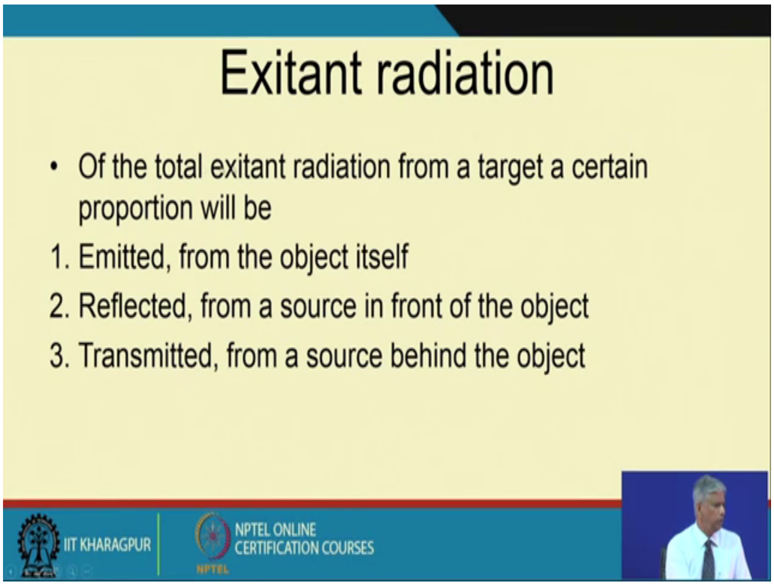

So, Exitant radiation is the total radiation from a target a certain proportion will be emitted from the object itself reflected from the source in front of the object transmitted source from behind the object.

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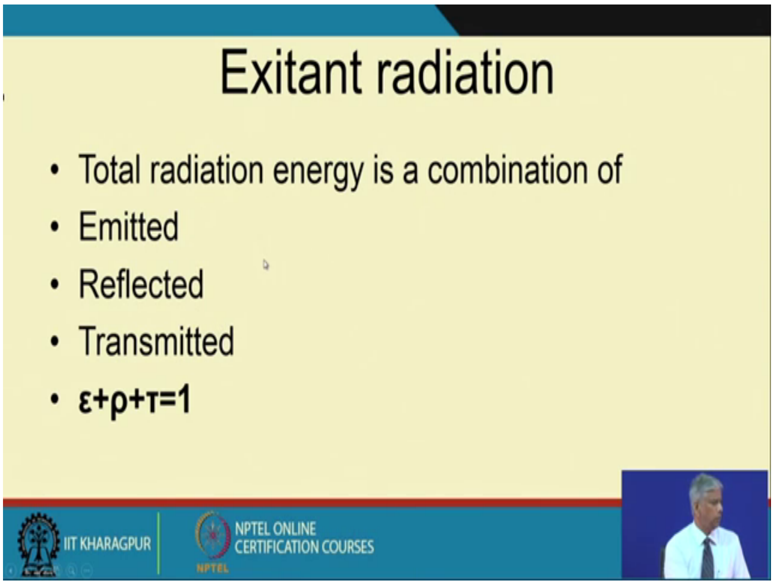

So, total energy is nothing, but a combination of emitted reflected and transmitted.

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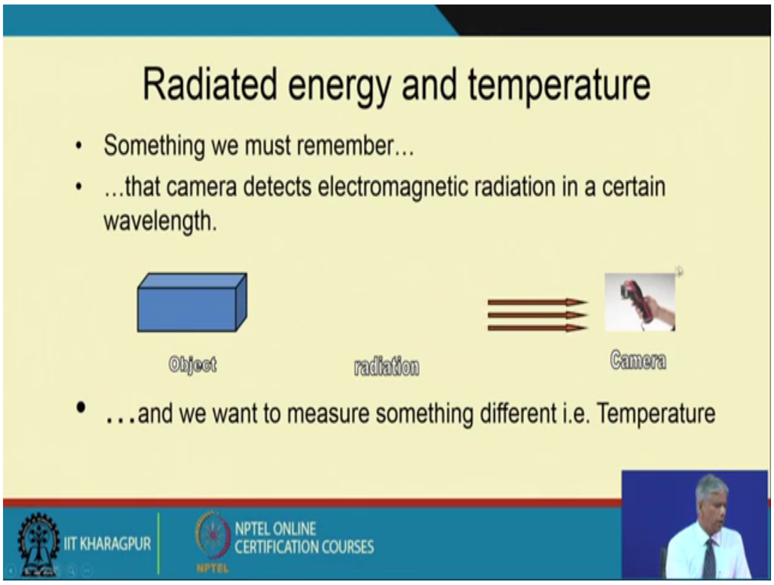

So, this camera; this is typically a handle infrared camera which is being held ok. So, an object is in emitting infrared radiations and we can measure it.

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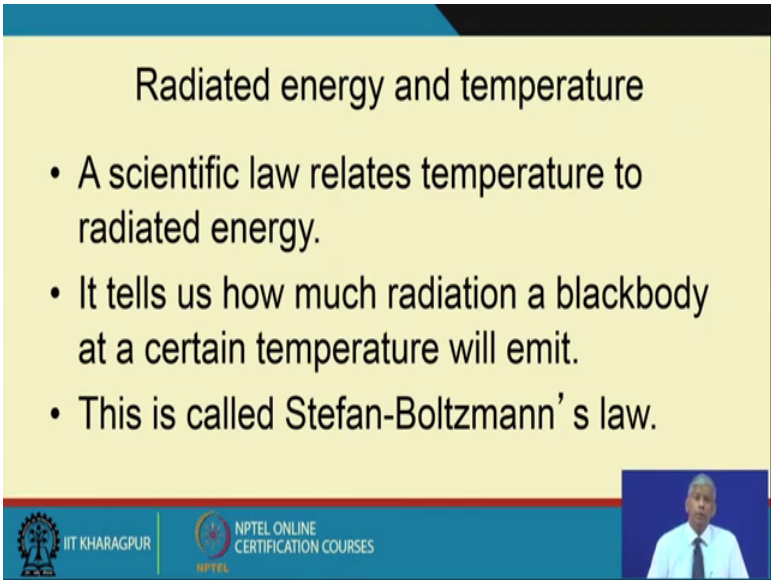

So, this scientific law which I just mentioned before relates temperature to the radiative energy and it tells us how much radiation a blackbody at a certain temperature will emit and all of you perhaps will recall from your high school physics that this is called the Stefan-Boltzmann law and the Stefan-Boltzmann law states that the total energy radiated per unit surface area of a black body in unit time is directly proportional to the fourth power of the black body's absolute temperature capital T.

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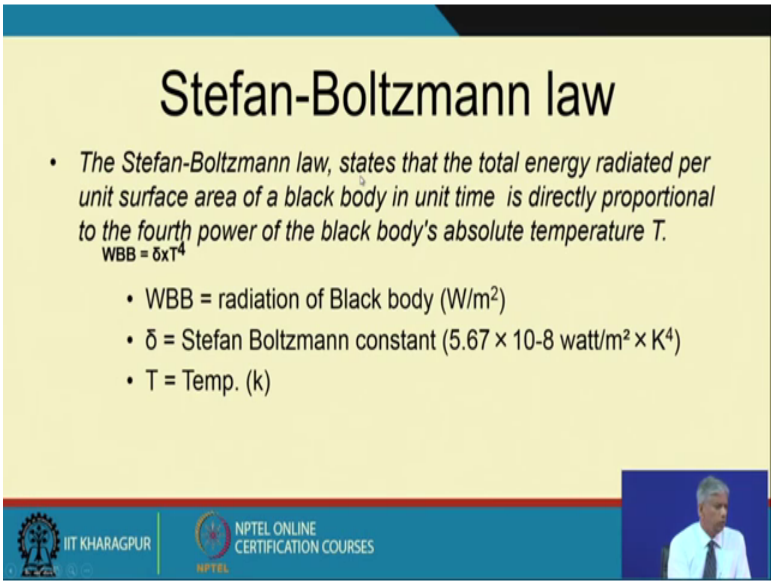

So, this energy w blackbody is nothing, but where T is 273.16 plus T in degree Celsius whole thing in T is in Kelvin and this is an universal constant the Stefan Boltzmann constant.

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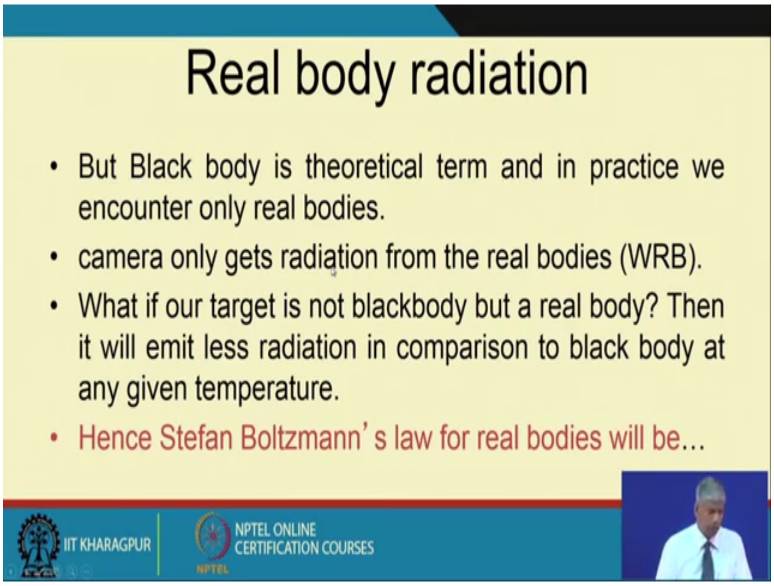

So, but you know this blackbody is something very theoretical, but we have a real body where the emissivity is not equal to 1. So, then it will give less emission or radiation in comparison to blackbody and Stefan-Boltzmann for real bodies will be this, ok.

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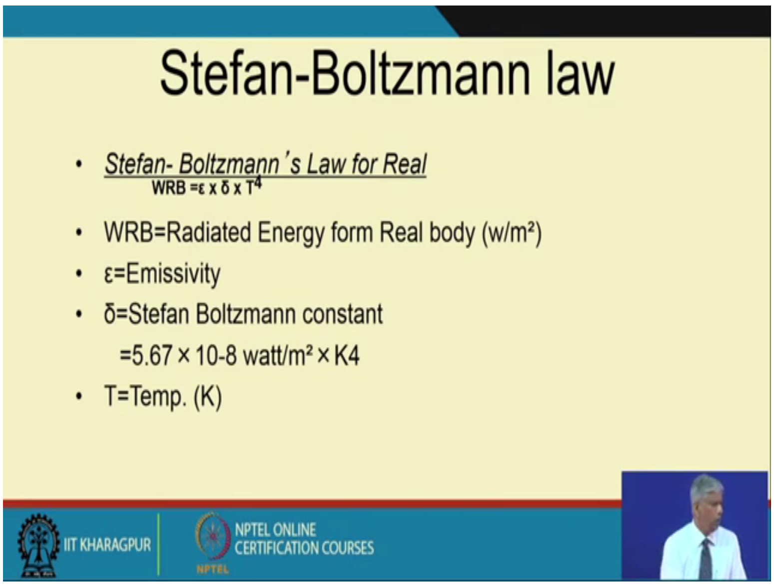

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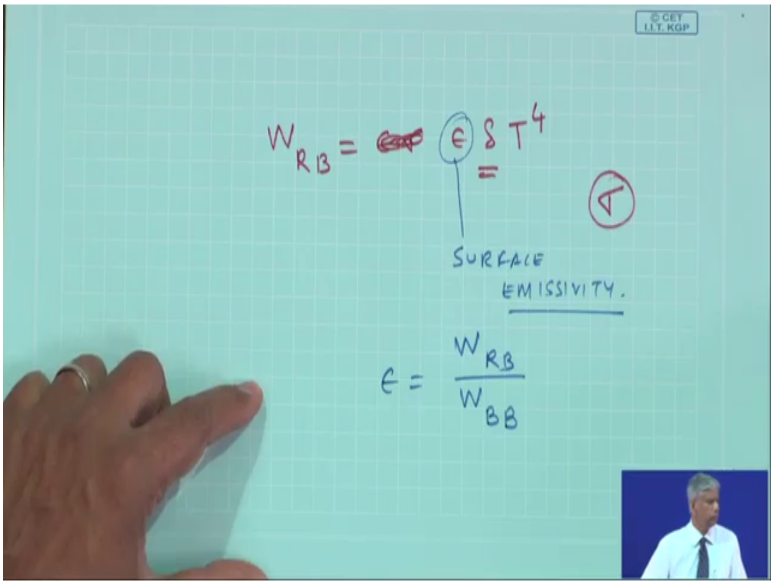

So, we see this for the real body w real body is nothing, but surface emissivity times, sorry, Boltzmann constant, I have denoted this and some book you will see the symbol this ok.

So, the idea is; how do I find out the emissivity of a real body. So, one which we will talk about emissivity; so, emissivity; obviously, will be nothing, but.

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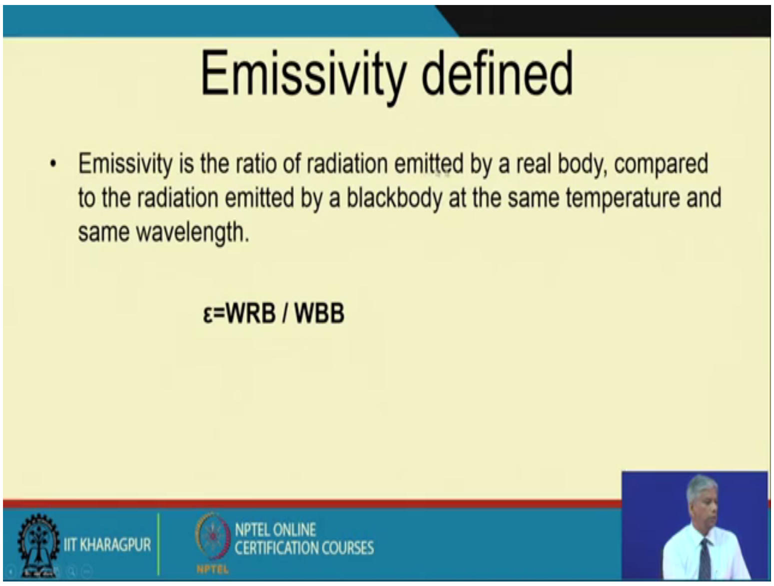

So, it is the ratio of radiated emitted radiation emitted by a real body compared to the radiation emitted by a blackbody at the same temperature and same wavelength.

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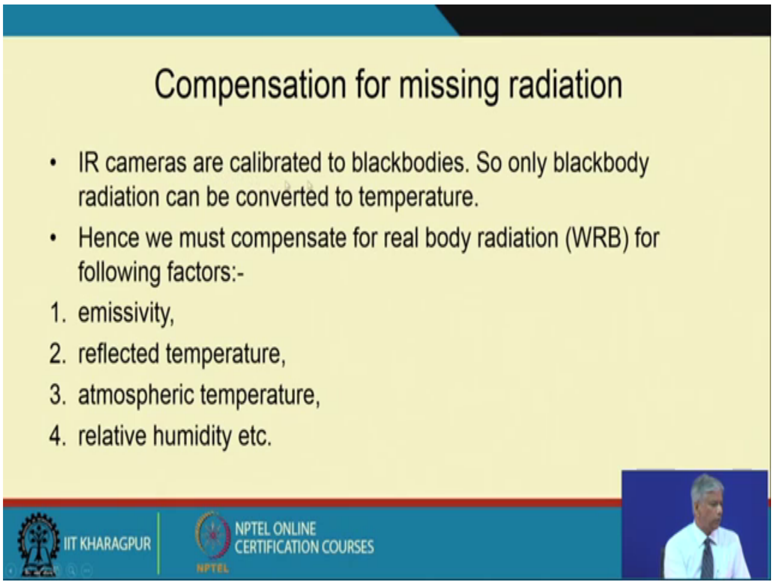

So, IR cameras are calibrated to blackbody. So, only blackbody radiation can be converted to temperature. So, hence we must compensate for real body by the following factors emissivity temperature reflected temperature sorry, emissivity reflected temperature, atmospheric temperature, humidity so on.

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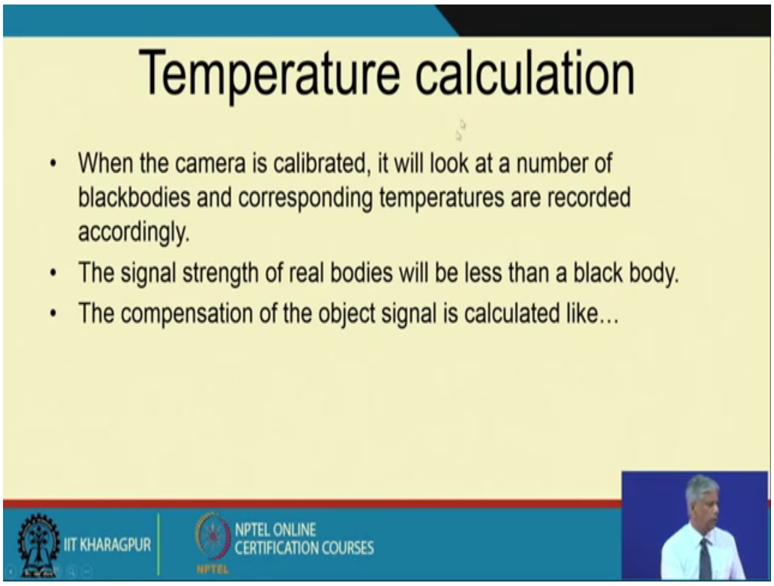

So, we have to calculate and compensate for the real body, ok.

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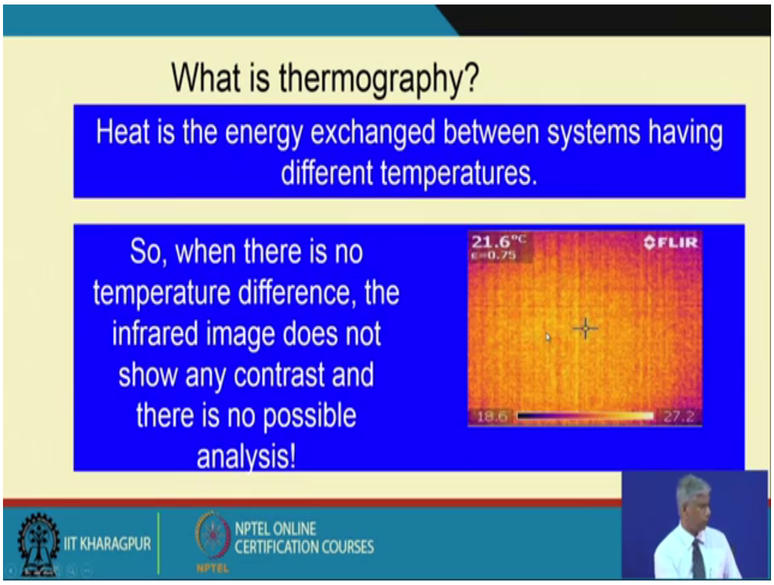

So, we will see how it is done. So, if the bodies are in the same temperature, there will be no colour contrast because there is no temperature difference.

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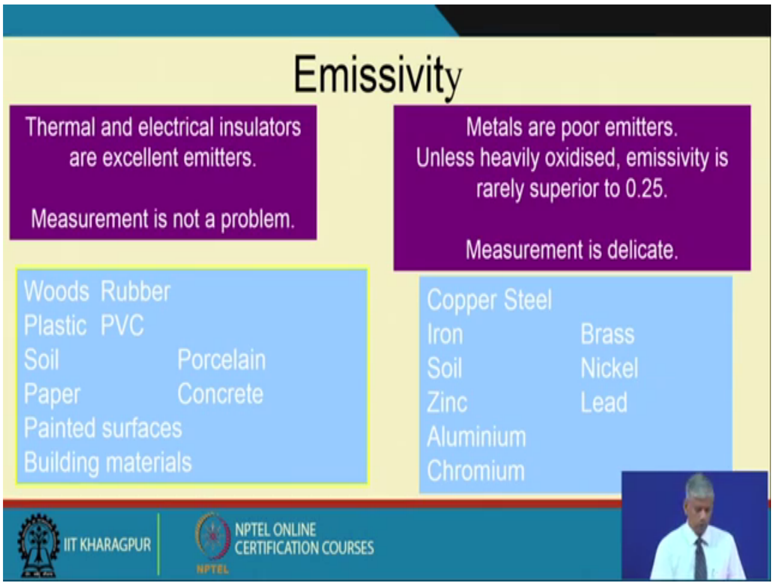

So, coming back to the emissivity sorry thermal and electrical insulators are excellent emitters. So, measurement is not a problem woods rubber plastic PVC soil paper painted surface building material porcelain concrete they are all having an high emissivity and then we can use this to measure the surface temperature by IR.

But metals are poor emitters unless heavily oxidized. So, emissivity is rarely superior to greater than 0.25 like all these metals or any shiny surfaces. So, that is what we have to careful about in one of the examples, I will show you how this is taken care off.

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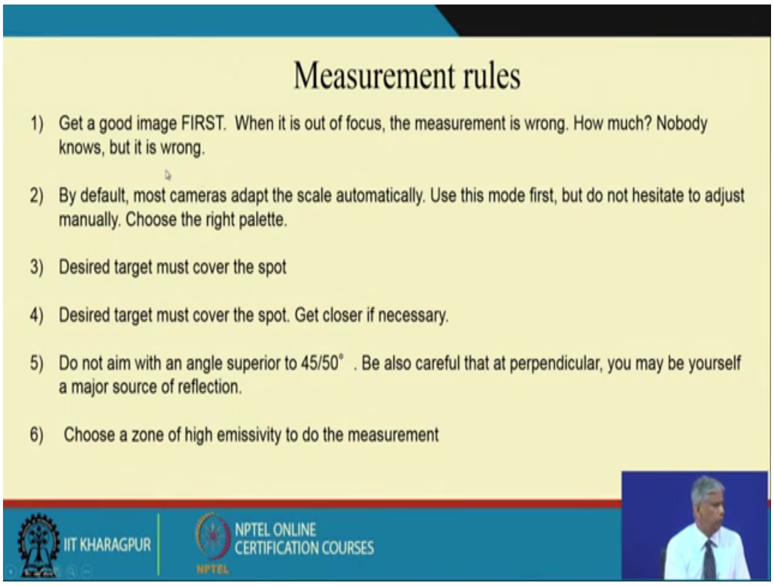

So, some of the measurement rule is get a good image first by this focusing system and then target must cover this part do not aim beyond this. So, that and try to measure in high-end emissivity and see make sure that your body reflection does not come on to you.

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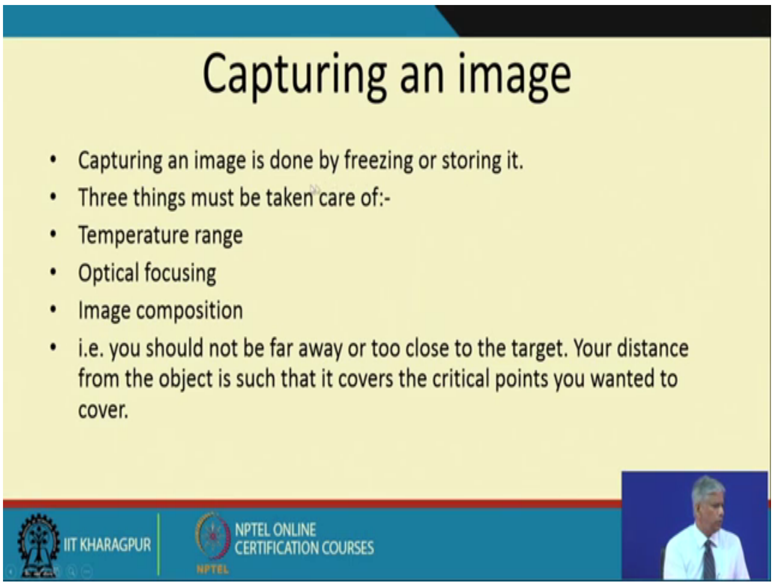

So, capturing and images, freeze it you have to know about the temperature range the focusing and image composition, you should not be far away or too close to the target your distance from the object is such that it covers the critical points, you want to cover reflected apparent temperature the apparent temperature of bodies that result in radiation that is reflected by the target and into the camera. So, we have to careful about this.

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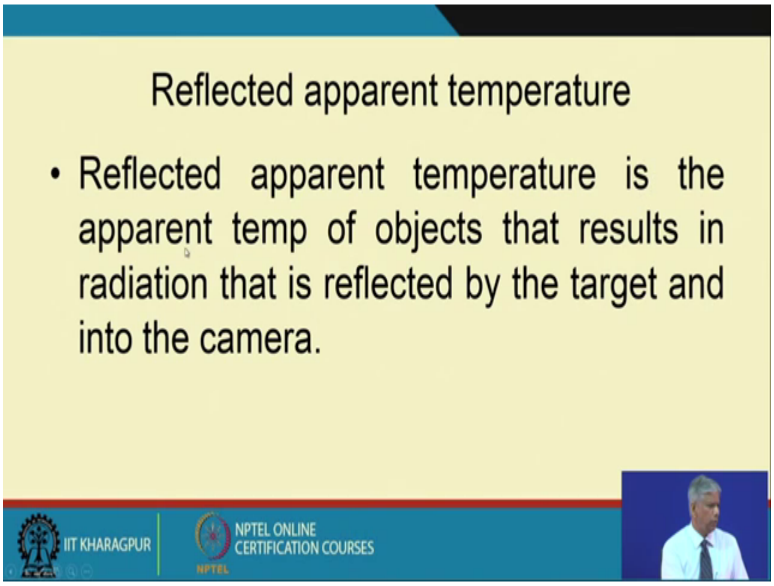

So, measuring reflected temperature make sure that there is a reflecting what is reflecting in your target set the emissivity one and distance to 0, put a box with average temperature measurement note the temperature this is your T reference and measuring emissivity.

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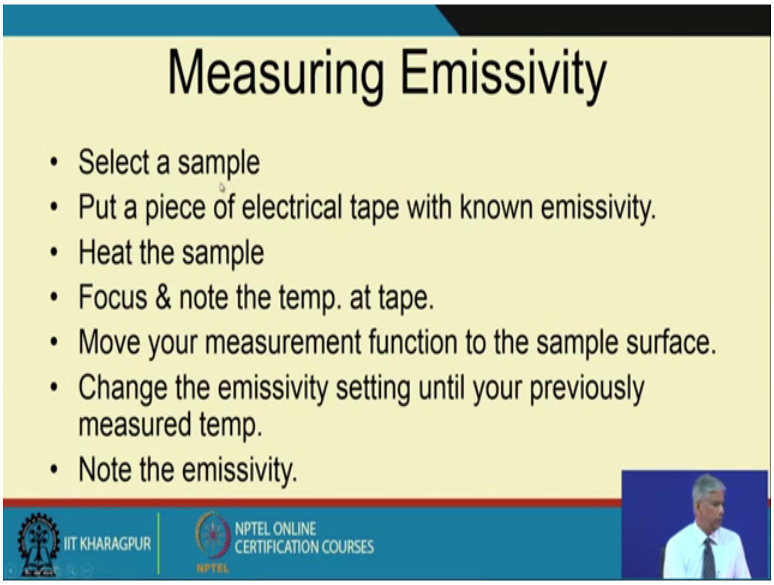

Select a sample, put a piece of electrical tape with known emissivity and heat the sample focus and note the temperature at tape and move your measurement function to a sample surface change the emissivity until and note the emissivity, this is a very simple way to do it, I will explain you how.

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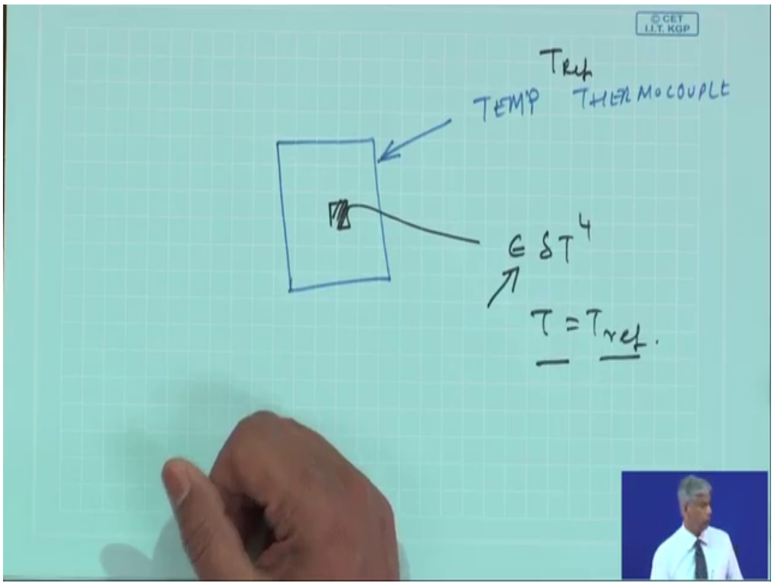

I will have a surface whose temperature is known to me, maybe by a thermocouple. So, I will put some sort of a patch and focus there and measure through I do not know the emissivity, I will measure through this and get a temperature ok. So, I will vary this emissivity till I get this T equal to the T reference ok. So, this is all very easily you can know the emissivity of an unknown surface or many times, you can go to the handbooks and see the emissivity of different surfaces ok.

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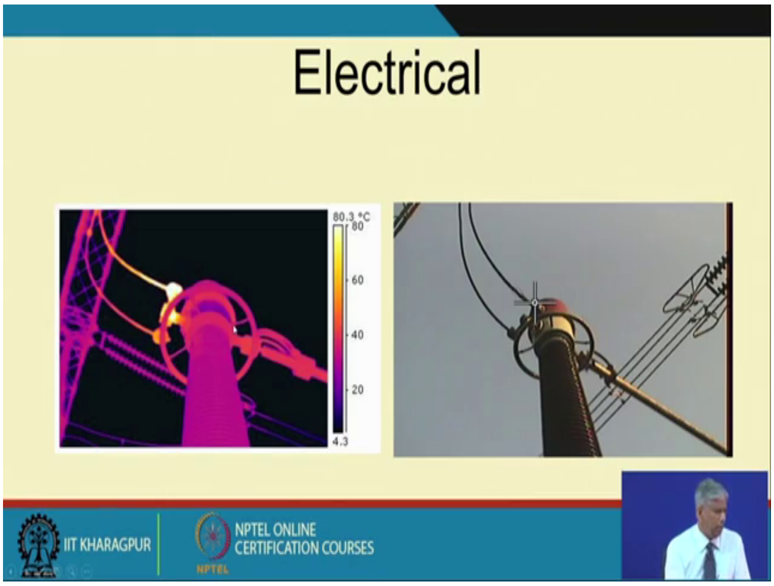

Now, I will show you some typical examples wherein in a colour code you can see typical measurements of these infrared thermal imaging cameras. So, this is an electrical switch gear wherein some loose contact is there and there is high up from the ground. So, we can have a thermal imaging camera and you can see the hot spots being measured by such thermal imaging camera while in operation.

So, you know there is something happening here this temperature is very high ok, then later on you can go ahead and make some diagnostic measures as to how to reduce that a motor electrical motor drive in some unit.

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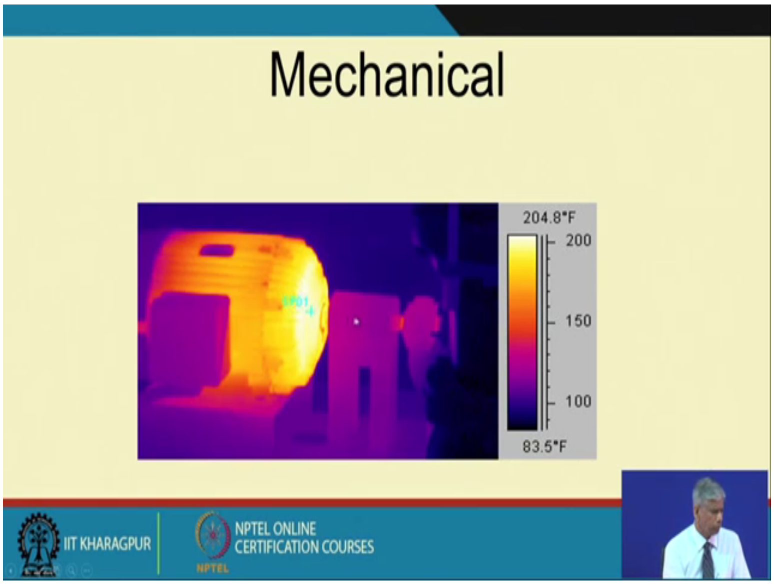

There is the high temperature here close to 200 degree Celsius, very easily we can measure from a distance that something is wrong at this end of the electrical motor ok.

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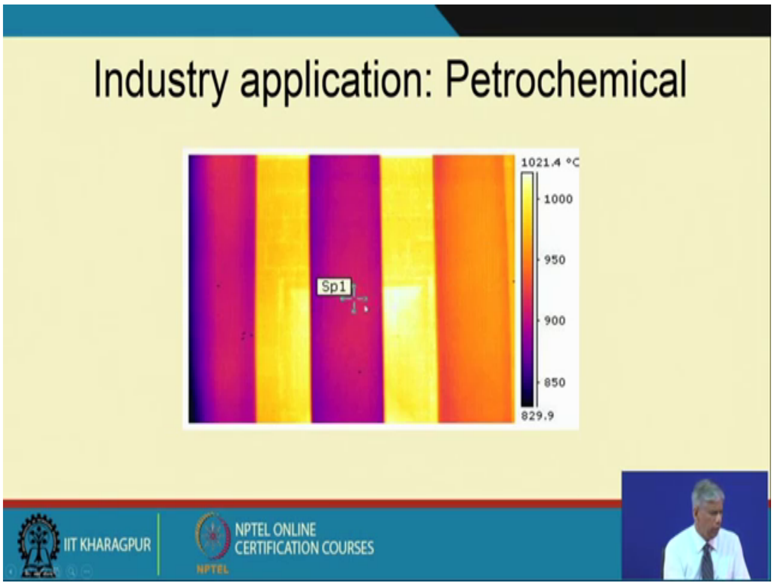

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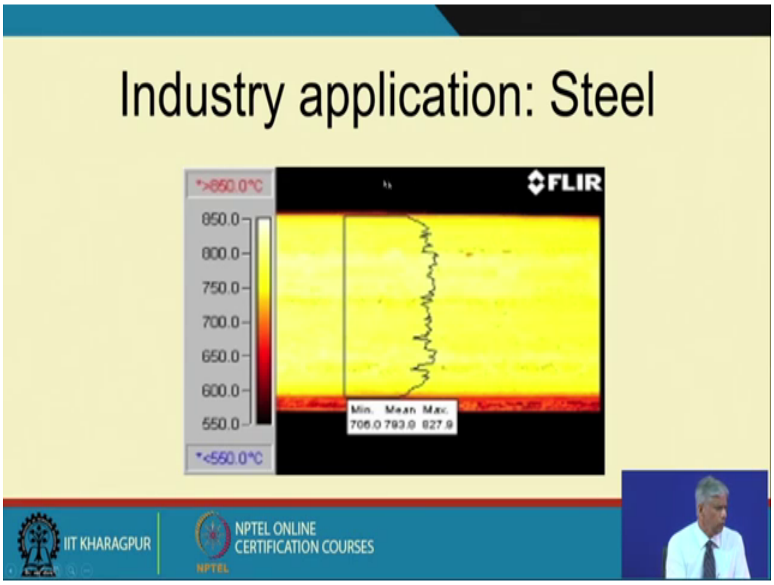

In petrochemical, if there is a variation in the temperature, you can see in any applications, what the temperature is application in steel mills rolling mills; we can measure through infrared temperatures with some of these IR cameras available in the market.

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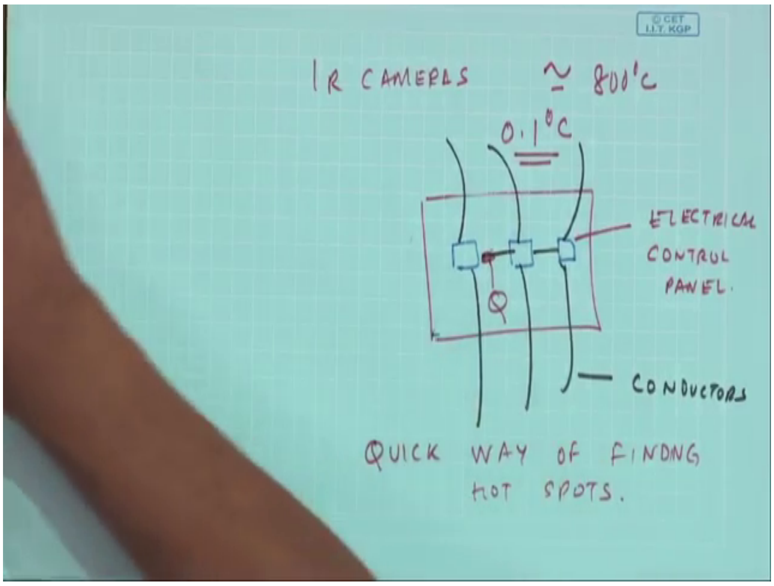

We can measure around 800 degrees Celsius with an accuracy of 0.1 degree Celsius imagine you know this is very powerful in the sense any place you want to measure you can very easily do it.

I will give you another example wherein electrical control panel very quickly you would like to know because you know you just have some few switches. So, and there are lot of conductors you know and the maze of conductors and this black conductors are not visible to you because they are behind this panel ok.

So, what can happen is you can always take a thermal image and suppose there is some short circuit or some loose connections. So, a lot of heat generation is there. So, by doing a quick thermal imaging scanning on the surface you can find out what the temperature of this area is and where the short circuit is, then later on you can do a diagnostic to find out why that short circuit happen.

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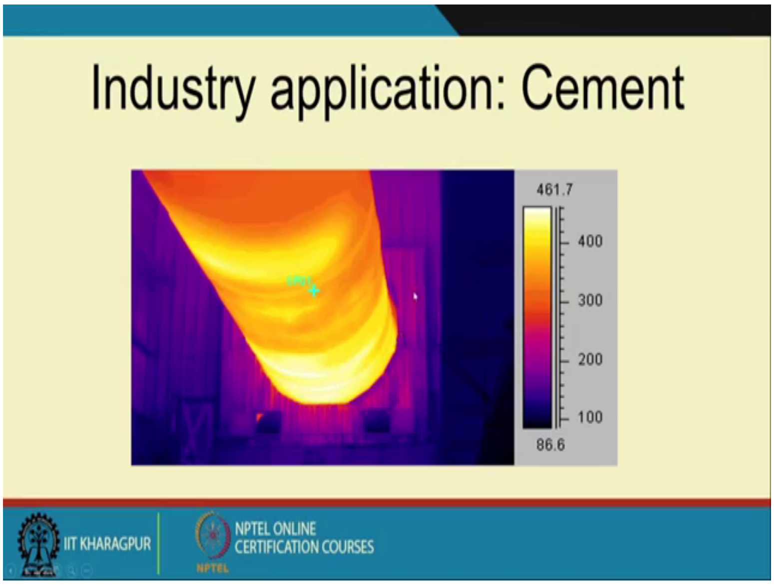

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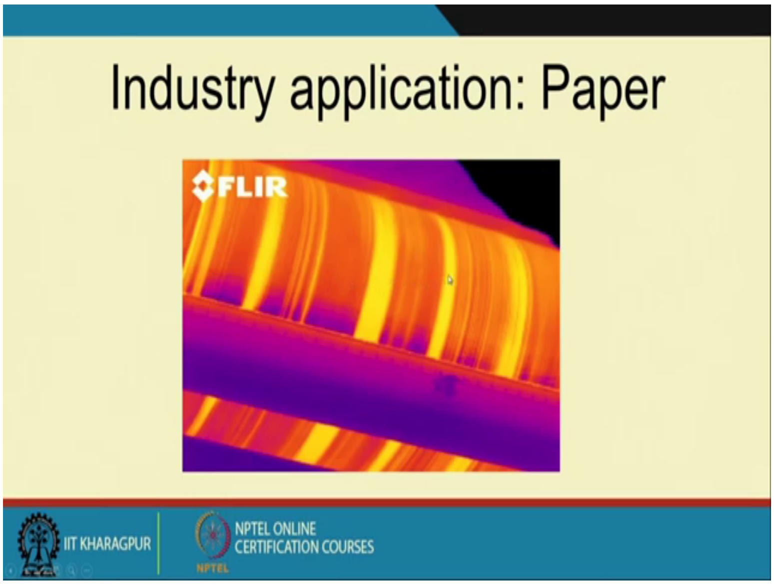

So, thermography is a very quick way of finding hot spots particularly in the cement plant in paper mills, you can say lot of hot areas are there.

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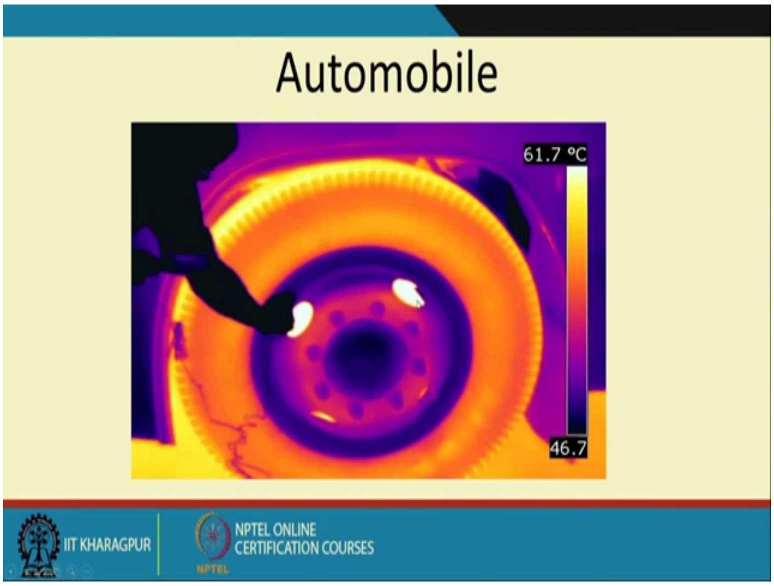

Neros automobile, you know for example, this brake drum or the rotor has heated, you can see very easily such things particularly in electronic circuits if some particular component is not getting power supply, it would not heat.

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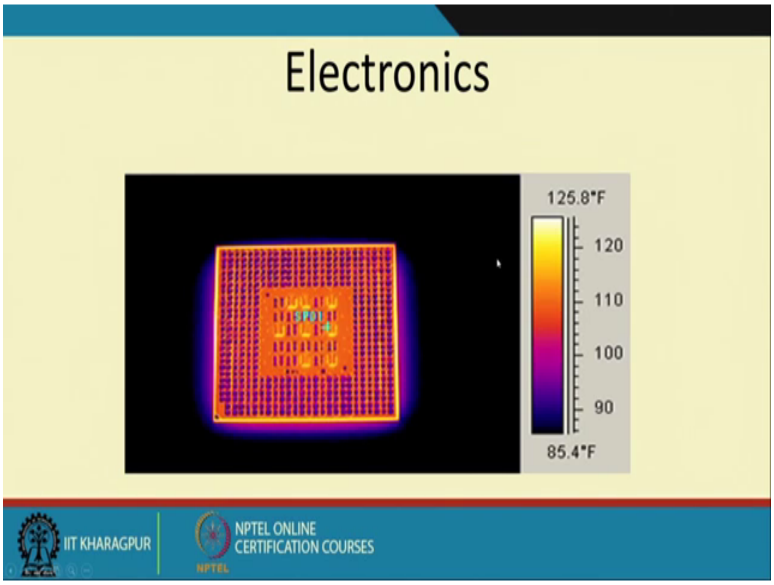

So, you can see some cold spots and then you can say, perhaps, this device semiconductor device or whatever this IC chip is dead because you know you know anywhere in a circuit, I will have this energy depending on the square of the current and that will be the heat generation. So, this I can very easily through a thermal imaging in a TV circuit, you can find out whether a semiconductor is not powder different surveillance, you know lot of IR cameras are used for surveillance, ok.

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Finding out hot surfaces, you know, the cops running after robber, you know if somebody is running, you can find out the body temperatures rise.

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For example, look at how elude in this temperatures could be you know in a coal mine vary of dumb, ok, there are a lot of hot spots ok, they all you can see slag has been deposited and then you can see underneath this you have very high temperature infrared image.

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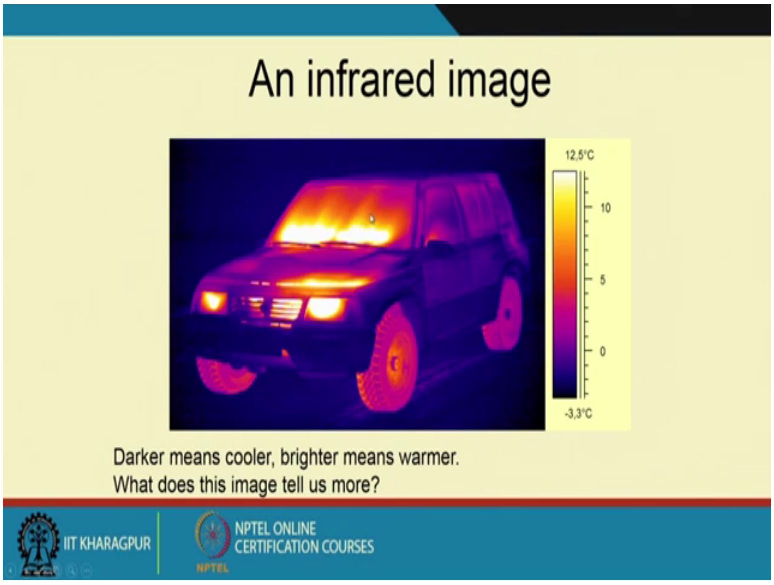

You can find out where there is a cold air conditioning this is a hot air coming out darker means cooler. So, this image says you know is the headlights engine is radiating heat the heater in the vehicle is running so that you can see lot of hot areas.

So, these are all very easy areas to find out maybe there is not enough heater coming out here you can find out where the flow is cold and flow is hot. So, maybe this passage is choke.

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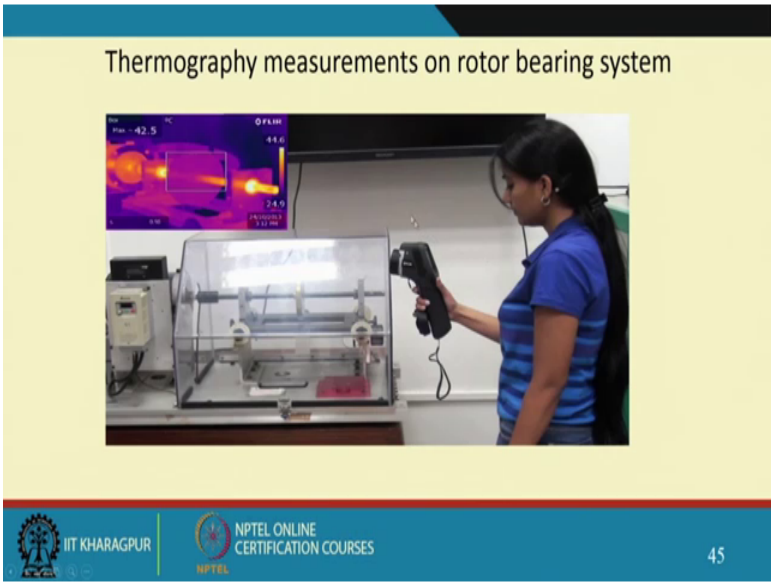

So, very quickly you can find out through thermal imaging, here in the laboratory, we are doing a thermal imaging to find out the bearings temperature rising because of a misalignment in the shaft and this is again in the laboratory wherein the backside of a refrigerator see this backside.

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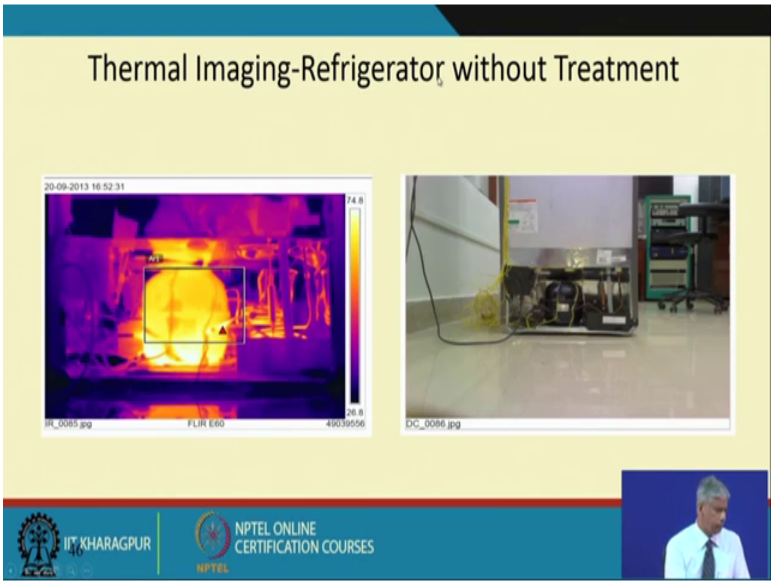

It is a metal, it is a very bad emitter, but this compressor is black and dull on the outside. So, it is a good emitter. So, you can very easily measure the temperature of the compressor and all the conductors by using a thermal imaging. So, these are some of the applications of thermography for finding out quick ways to find out faults and more of this, you will find in my book.

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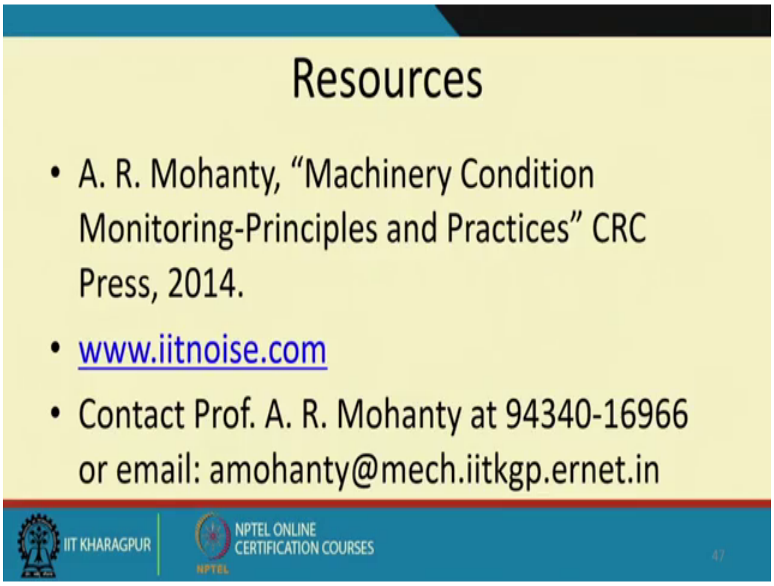

Thank you.