Cryogenic Engineering
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Module No. # 01
Lecture No. # 40
Instrumentation in Cryogenics

So welcome to the lecture number forty on cryogenic engineering under the NPTEL program.

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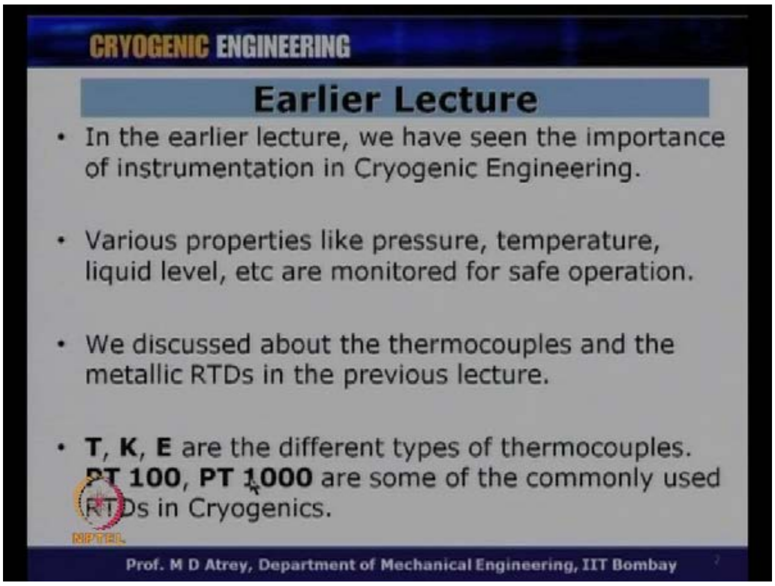

In the earlier lecture we have seen the importance of Instrumentation in cryogenic engineering and various properties like pressure, temperature, liquid level. These what these are the properties which we want to study in this lectures etc are monitored for safe operation every cryogenic operation needs to monitors these parameters. There are various parameters but, mostly pressure, temperature, liquid levels are very important parameters which are generally monitored. So we started with temperature begin with and we are still continuing with temperature. So we discussed about the thermocouples and the metallic RTD resistance temperature dependent parameters in the previous lecture.

We found that t type, k type, e type are the different types of thermocouples that are normally used and we talked about platinum RTD's PT100 and PT1000 where 100 and

1000 are the resistances of this sensor at 0 degree centigrade and these are normally used some of the commonly used RTD's in cryogenics. So we talked about thermocouple, we talked about RTD's or platinum based RTD's that are used for temperature measurements.

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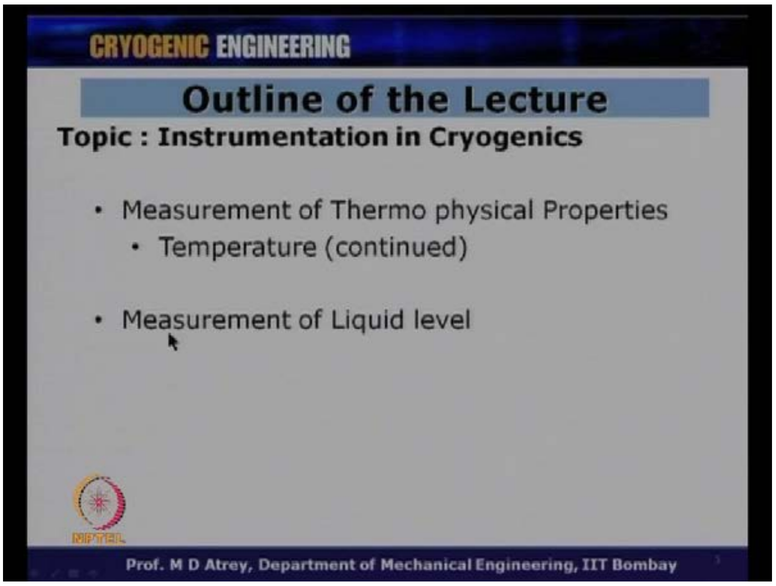

Now, in this particular lecture we will take the temperature topic ahead and we will talk about measurement of thermo physical properties that is temperature and we continue with that and we will go to lastly the measurement of liquid level at the end of this lecture.

So in earlier lecture we have seen a metallic RTD in which the resistance of a conductor changes with a temperature. This is what we have seen. We found that as a temperature decreases the resistance decreases as far as this RTD's are considered.

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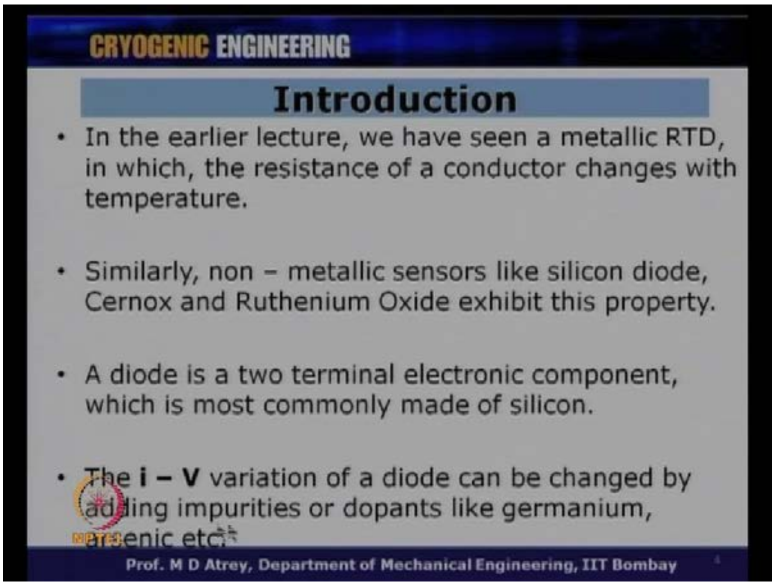

Similarly, now a non-metallic sensors many times we preferred to have a non-metallic sensors also because of various other reason because we can actually make a kind of sensor which we want all right. So non-metallic sensors like silicon diode, cernox and ruthenium oxide they also exhibit this temperature dependent properties.

So we had a metallic sensors earlier and now we got a non-metallic sensors like silicon diode cernox ruthenium oxide exhibiting such property where resistance also changes. Resistance changes with temperatures again ok.

So we know what is diode. A diode is a 2 terminal electrical component which is most commonly made of silicon. So, we talk about silicon diode the properties of diode, you know basically allows the current to go through only 1 direction while does not allow the current to go in opposite direction.

Also, it has got some temperature resistance dependence current properties also and that is what we utilize for temperature detection. The I versus v characteristics or I v variations of a the current voltage variation of a diode can be changed by adding impurities or dopants like germanium, arsenic etc

And therefore, we can have the kind of properties which we want that various temperatures. You can add dopant to diode and you can change the characteristics or the I v variation of this diodes.

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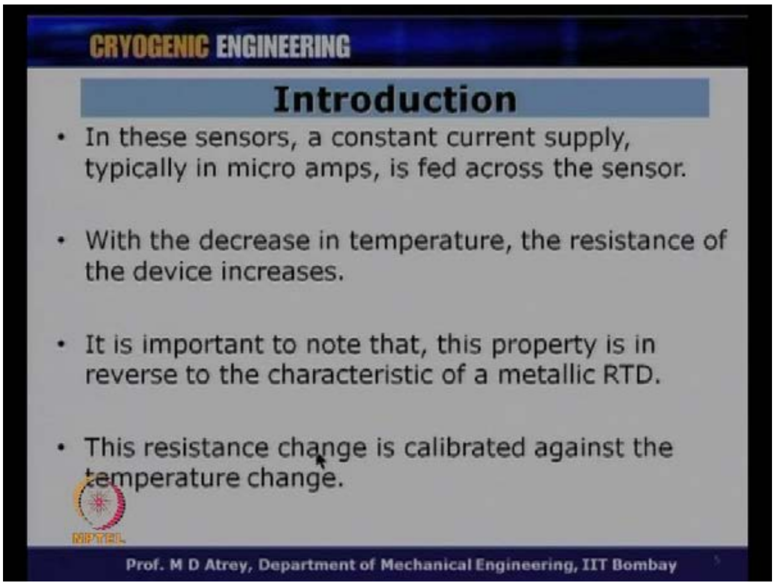

In these sensors a constant current supply typically in micro amps, very small current in earlier case we had a mille amp current now. But, in these diodes in cernox is they got a constant current supply typically in micro amps is fed across the sensor. That means you got a very low current flowing through it and therefore, we got a very low heat generation in the sensor also.

The high sphere are also is very very small and therefore, [area is] involved are also going to be very very small in this cases with the decrease in temperature the resistance of the device increases all right. So, if you remember in case of p t hundred for example, with the decrease in temperature the resistance of the device or the RTD had increased while in this cases with the decrease in temperature the resistance of the device increases as a temperature decreases.

So, it is important to note that this property is in reverse to the characteristic of metallic RTD which is what in in metallic RTD what what happened? The temperature decreases the resistance came down. This resistance change is calibrated against the temperature change so as it was in the metallic RTD’s. In this cases also this resistance change becomes a function of temperature and 1 can do a calibration 1 can (( )) an curve so that the resistance changes with temperature can be calibrated properly.

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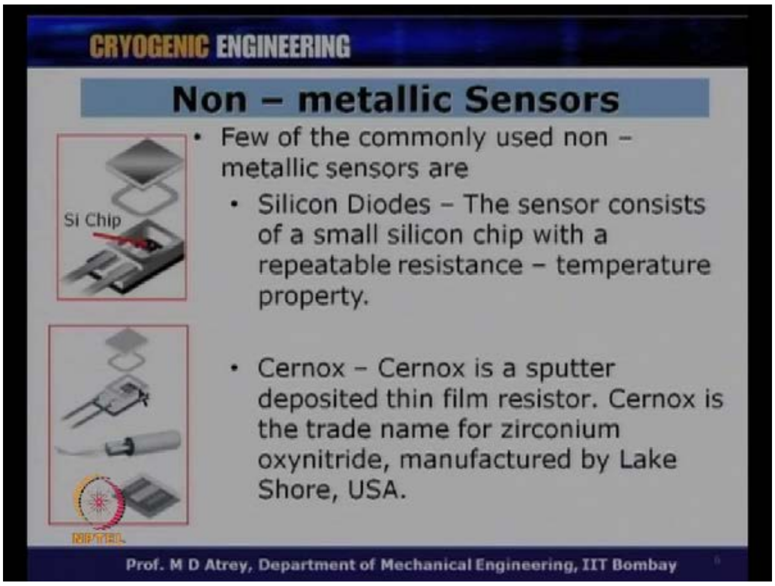

So let us come to the non-metallic sensors. Few of the commonly used non-metallic sensors are silicon diode silicon diodes the sensor consists of a small silicon chip with a repeatable resistance temperature property. So, typically a sensor would look like this, a diode would look like this right. It has got 2 outputs or 2 wires which coming out to this and this small casing in which silicon chip is kept which is having cover and some kind of sealing also, this will come down on this and this will constitute a silicon diode all right.

So this is what predominantly will be used. Then we got a cernox a similar look is cernox like a silicon diode. So, cernox is a sputter deposited thin film resistor you know thin films basically. So, this thin films are having the particular I v characteristics all right.

So you can make thin film you can have thick films and they have got different characteristics. Cernox is a basically a trade mark, this a trade name for lake shore company. But, typically it represent sputter deposited thin film resistor. Cernox is the trade name for zirconium ox nitride manufactured by lake shore USA.

So typical cernox would look like this. Again it has got chip which is going into this or a thin film going into this and again it is housed in a small you know kind of a casing.

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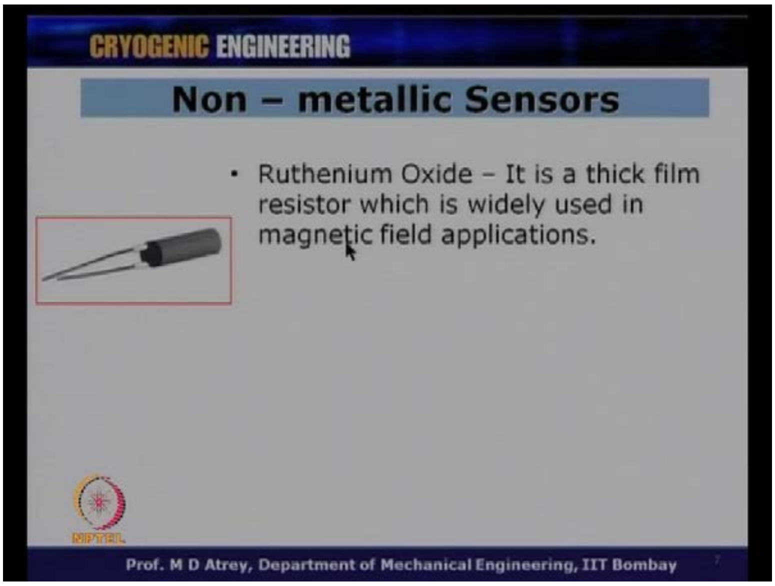

And then we got a third category also which is ruthenium oxide it is thick film resistor which is widely used in magnetic field applications. So, whenever you have got a high magnetic field environment ruthenium oxide will be preferred. It works in a similar principle as a change of temperature will result in change of resistance.

So, typically we have got a three different kinds which we discussed. There are plenty of other things also we got germanium we got you know gallium aluminum arsenide and thing like that all the do pants could be used. But, typically most commonly that the sensors which are used are silicon diodes, cernox and cernox.

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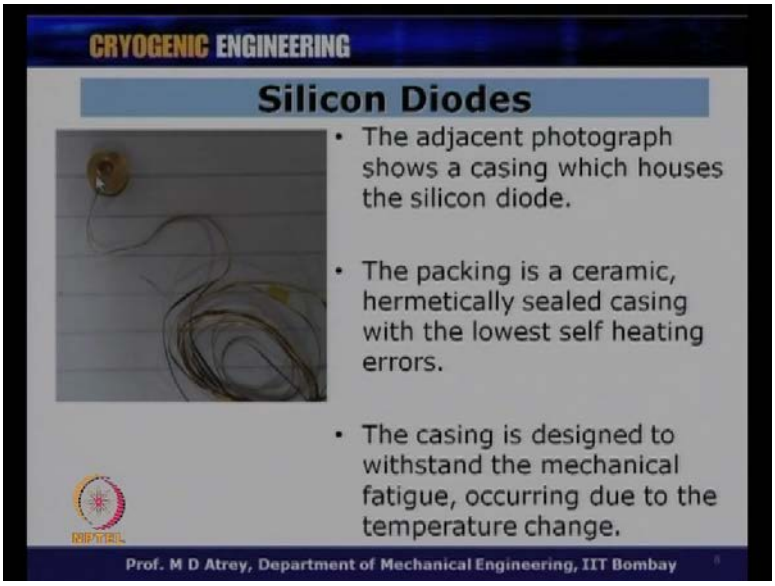

So let us study silicon diode little bit in details all right. So, you can see a silicon diode the adjacent photograph shows a casing which houses the silicon diode. We saw the photograph of silicon diode earlier and it is a very small thing and it is a very costly and therefore, normally one need not touch the silicon diode directly it is always kept in some kind of casing. So, you can see a copper casing over here and but, it has got small hole also with which you can actually have a brass you know nut kind of a thing which is screw kind of a thing with which it can be attached to the surface of with temperature has to be measured.

And these are the wires which will come out basically. This casing is actually housing the silicon diode. The packing is a ceramic hermetically sealed casing with the lowest self-heating errors all right and the casing is designed to withstand the mechanical fatigue occurring due to the temperature change.

So, all those properties have to be taken into account to find out particular casing for the silicon diode. Normally one should not buy the silicon diode only, one should buy the silicon diode with this cases. So, that handling become very simple you’re not touching the silicon diode directly and also the placement of the silicon diode on the surface of which temperature has to be measured can be connected. It can be in good thermal contact with the area of which the temperature has to be measured.

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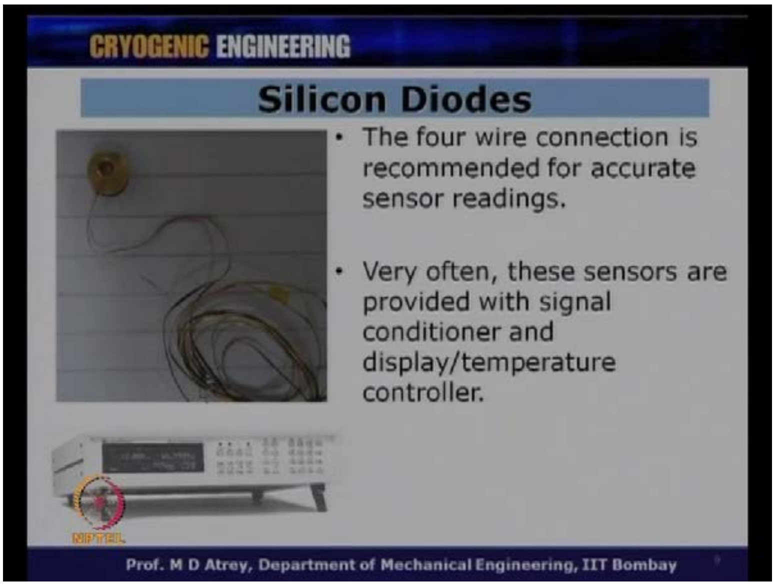

The 4 wire connection is recommended for accurate sensor reading. Very often, these sensors are provided with signal conditioner and display temperature controller. So, I am showing here lake shore temperature controller and this wires will be connected to this and you can see the kind of sensor you have bought. One can select the kind of sensors on this particular display and the calibration curves are normally fed.

So, calibration curve for a particular diode which you are using can directly be fed to this temperature controller and you can have a display has shown over here all right.

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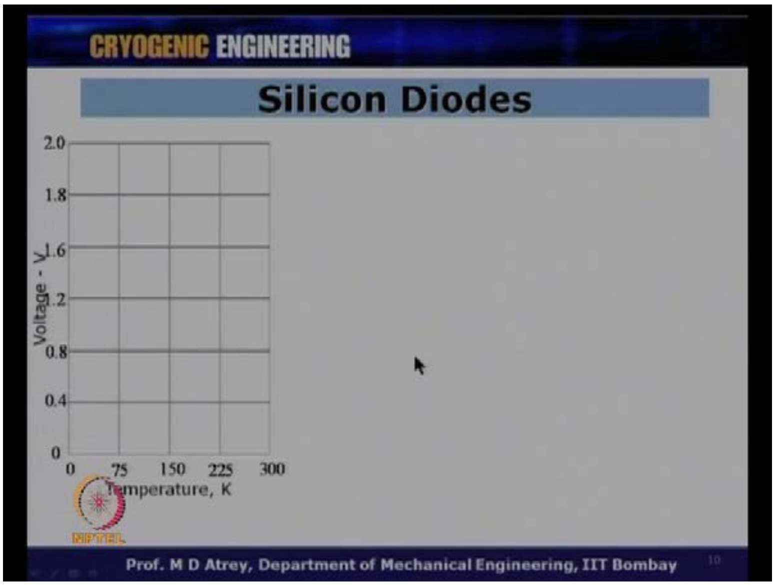

So before I go to silicon diode, I just want to show the picture I, I want to show the silicon diode here and we can have a look at this silicon diode.

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So, what I just showed to you you can actually see the entire things over here. So, you got a silicon diode which is put in this casing and the 2 wires the 4 wires are coming from here and these this is the hole through which a nut can be you know screw can be put it and if I want to measure a temperature of these I can just put it down over here and get a good thermal contact with the surface of which that temperature requires would measure all right.

Let us go back to the slide.

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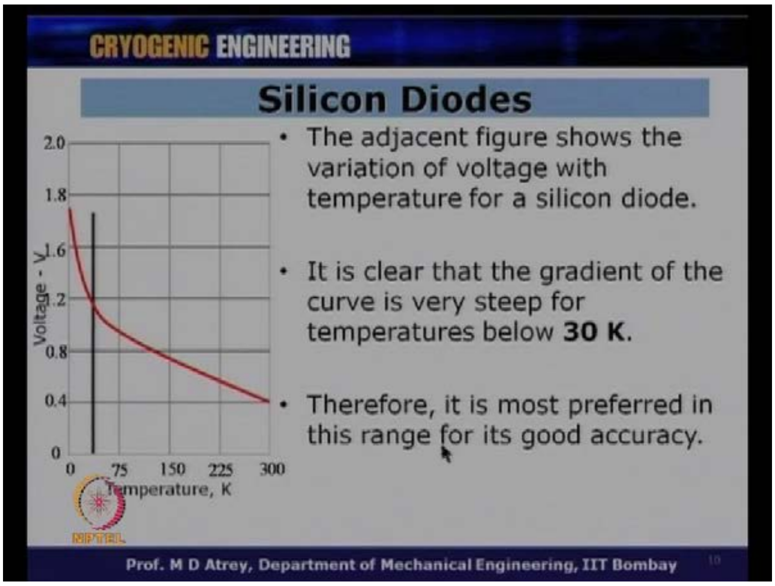

So, if I see now the silicon diodes and its temperature characteristics will look like this. The adjacent figure shows the variation of voltage with temperature for a silicon diode and you can see this is the voltage on the y axis and got a temperature here on the x axis and if you remember in case PT100 this curve was coming like this the voltage was higher and as you come down the temperature it was in opposite direction.

While in silicon diode you can see that it is opposite direction. That means as the temperature decreases the voltage increases. So, the sensitivity can be negative over here all right. Also you can see that as you go down the temperature up to let say fifty Kelvin it is going in a linear fashion in one line with a some different slope and there also you can see some linear variation below fifty Kelvin also we got a linear variation.

So you can have a good linear variation that means the measurement you can you can have a very good line feet in order to get a good calibration curve for such diodes. It is clear that the gradient of the curve is very steep for temperature below thirty Kelvin.

So, let us say this is thirty Kelvin and you can see how the gradient as increase as compared to the rest of the temperature range. Therefore, it is most preferred in this range for good accuracy. So, what we want is basically a steep change so that the sensitivity increases all right.

So below thirty Kelvin's that means as you come down lower the temperature these are the sensor which should be preferred when it comes to comparison for against the PT100 or thermocouples.

So, at lower and lower temperatures silicon diodes are most preferred. So, below thirty Kelvin have always preferred to have a silicon diode and not PT100 and not thermocouples because of such characteristics of the silicon diode. Therefore, it is most preferred in this range for its good accuracy.

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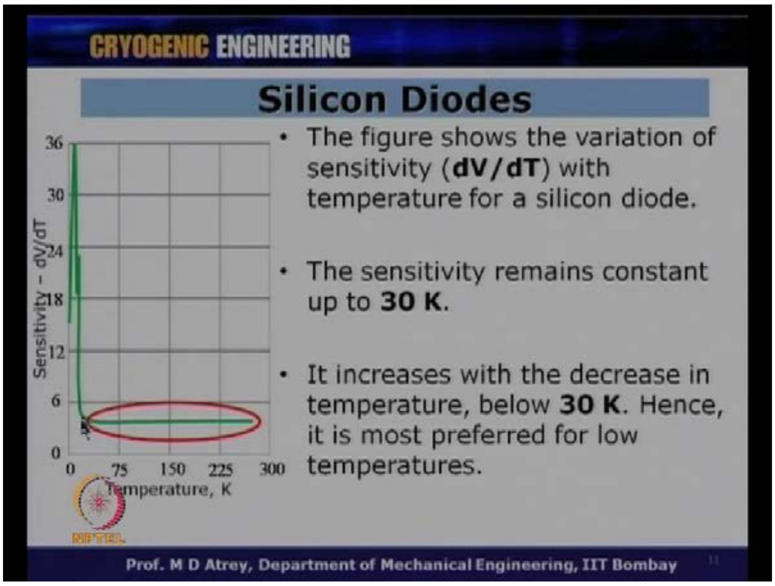

The figure shows the variation of sensitivity d v by d t with temperature for a silicon diode. So, based on what we saw earlier the sensitivity remains constant is actually a slope of what we saw earlier all right. Slope remains constant up to a vertical level and the slope increases.

The sensitivity remains constant up to thirty Kelvin this is what we can see and suddenly this slope increases. It increases with the decrease in temperature below thirty Kelvin hence it is most preferred for, that means the [sensitivity] higher for lower temperatures as a sensitivity still higher actually from room temperature till around thirty Kelvin all right. But it it increases below thirty Kelvin.

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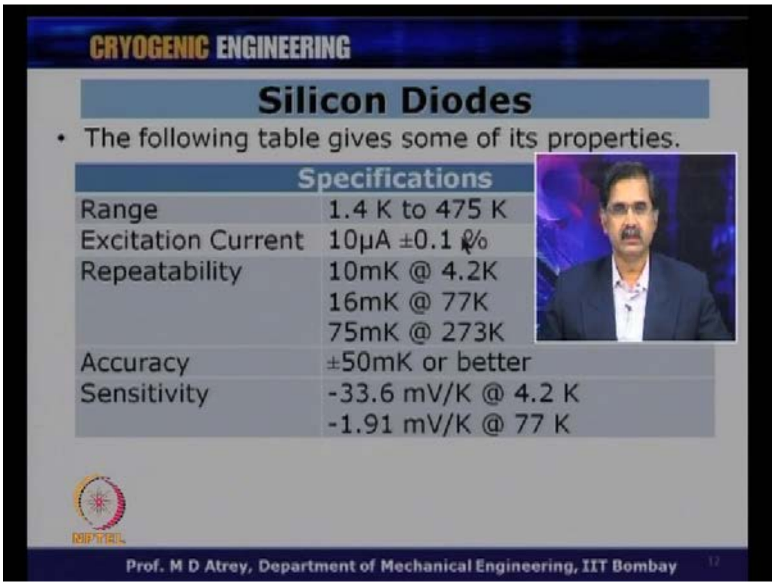

The following table gives some of its properties. So, you can see that the range for which the silicon diodes are used is 1.4 Kelvin to 475 Kelvin. So, why too low temperature? We can come almost close to 1 Kelvin and you can go up to 475 Kelvin while using silicon diode.

The excitement current is ten micro amp. It is a very small current the repeatability is very good ten mille Kelvin at 4.2 Kelvin, sixteen mille Kelvin at 7.7, 75 mille Kelvin at 275. So repeatability is very good actually in the range of ten milli Kelvin at lower temperature because of high sensitivity.

The accuracy is around plus minus fifty milli Kelvin or better. So, this is a very good accuracy as far as temperatures you know at low temperatures are considered sensitivity is very high minus thirty 3.6 milli volt per Kelvin at 4.2 Kelvin. We can see the sensitivity is high at 4.2 Kelvin as compared what it is at 77 Kelvin. So, sensitivity is just minus 1.91 milli volt per Kelvin at 77 Kelvin. These are some some figures which we have taken from various references. Most of the silicon diodes would have their values around these values only. There all demonstrative just representative values basically ok.

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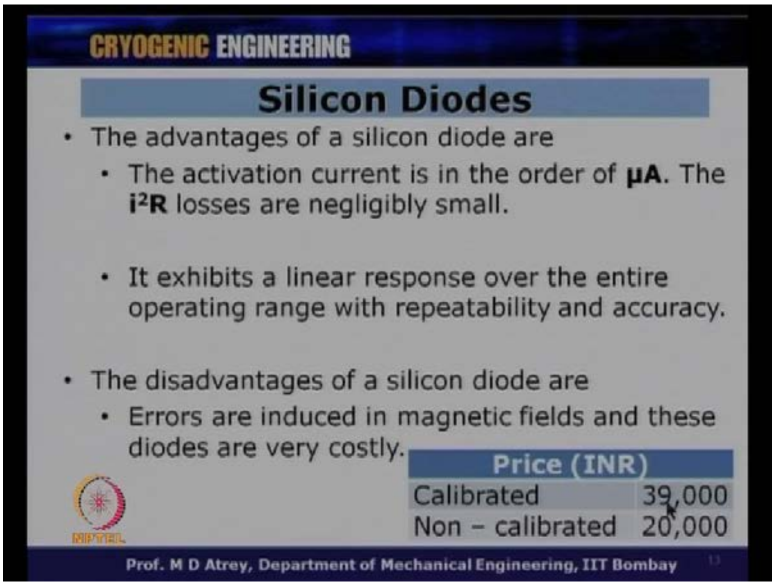

The advantages of a silicon diode are the activation current is in the order of micro amps, we saw just ten micro amps. Therefore, the I square r losses are negligibly small. It is clear. It exhibits a linear response over the entire operating range and repeatability and accuracy. So, we got a linear response which is what is expected from a good sensor and it does show these characteristics.

What are the disadvantages? The disadvantages of a silicon diode are errors are induced in magnetic field and this is very important disadvantage which has to be considered because most of the cryogenic operations happen in some kind of magnetic field. So, if you got a atmosphere or environment of magnetic field when the temperature measurement is carried out then the silicon diode will not give good results all right.

So, if you got a good to have a very small magnetic field but, you could have a some magnetic field it will show some now wired reading basically all right. So, silicon diode cannot be used in magnetic field active places and the second disadvantage is the diodes are of course, costly I mean this sensors are much costly as compared to thermocouples and PT100.

So, 1 one has to really justify if you want to measure 4.2 Kelvin, ten Kelvin or temperature below thirty Kelvin and that to more most accurately then such sensors need to be place silicon that has to be thought about for 4.2 Kelvin or if you are working with helium cryogenics levels all right below 20 Kelvin and so the representative prices are let us say calibrated silicon that would cost 39000 rupees. This is just the cost of sensor, then you got the cost of casing if you want have then cost of transport and thing packaging and thing like that and non-calibrated (( )) will be almost half the cost. Then you have got to calibrate it also all right.

So, depending on what you want, what temperature you want to measured, one should buy silicon diodes. Now, the next is cernox.

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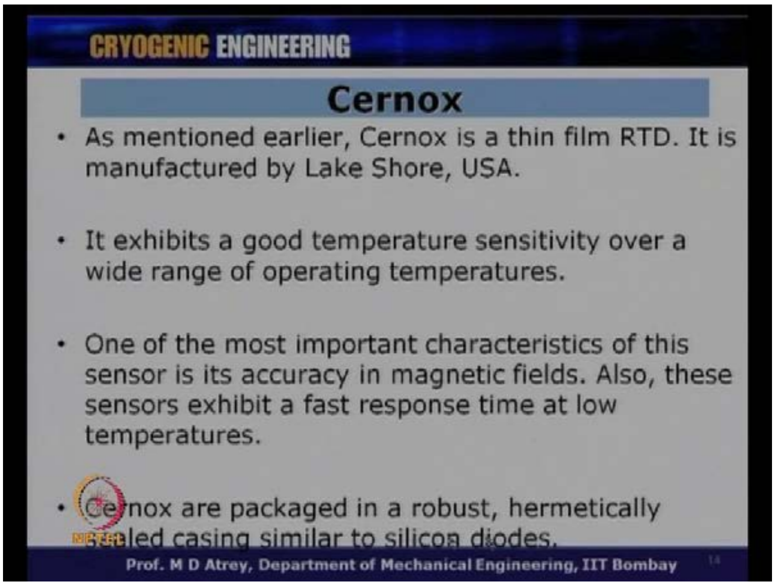

As mentioned earlier cernox is a thin film RTD it is manufactured by lake shore USA which is straight name and which is also which is very commonly used sensor or helium temperature levels. It exhibits a good temperature sensitivity over a wide range of operating temperatures. One of the most important characteristics of this sensor is it accuracy its accuracy in magnetic field. Now, this is the very important characteristic and as I said most of the cryogenic experiments, cryogenic measurements are done in the magnetic field environment.

For example if you working with m r I, m n r you know you have got a magnet you have got a superconducting magnet many times where you want to do temperature measurements and therefore, your sensors will be always be surrounded or it will always be in some magnetic field and therefore, for accurate temperature measurement cernox visible solution. Also these sensors exhibit a fast response time at low temperature all right.

So cernox is always preferred at low temperatures when the magnetic field environment is prevalent. Cernox are packaged in a robust hermetically sealed casing similar to silicon diodes. So, again you got to buy them incasing or you of preferred it is preferred that cernox is get packaged in a robust hermetically sealed casing.

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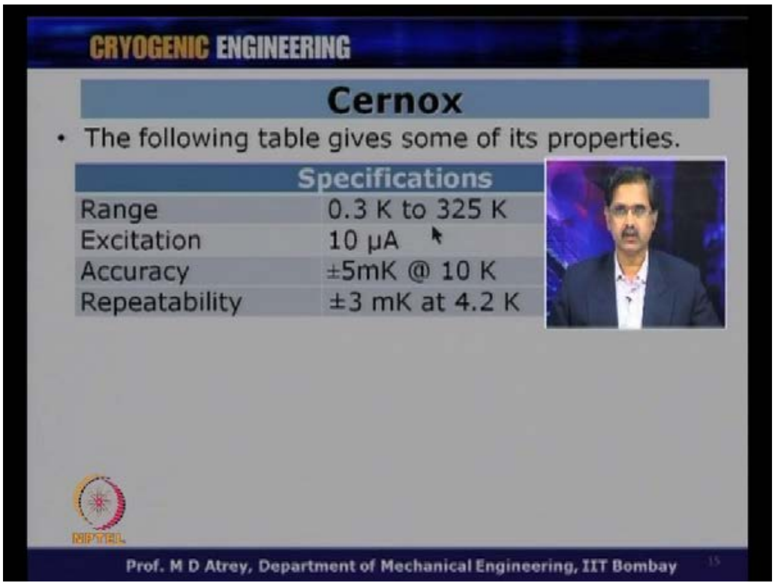

The following table gives some of its properties as we saw for silicon diode. Similarly, we got a properties of cernoxes or the range you can see form 0.3 Kelvin to 325 Kelvin while silicon diode from 1.4 to 475. That representative value of course, in this case we can come down below 1 Kelvin for cernox.

Again the excitation is of the order of ten micro amps. The accuracy is plus minus 5 milli Kelvin at ten Kelvin while the repeatability also is plus minus 3 milli Kelvin at 4.2 Kelvin. These are some of the properties specifications for cernox.

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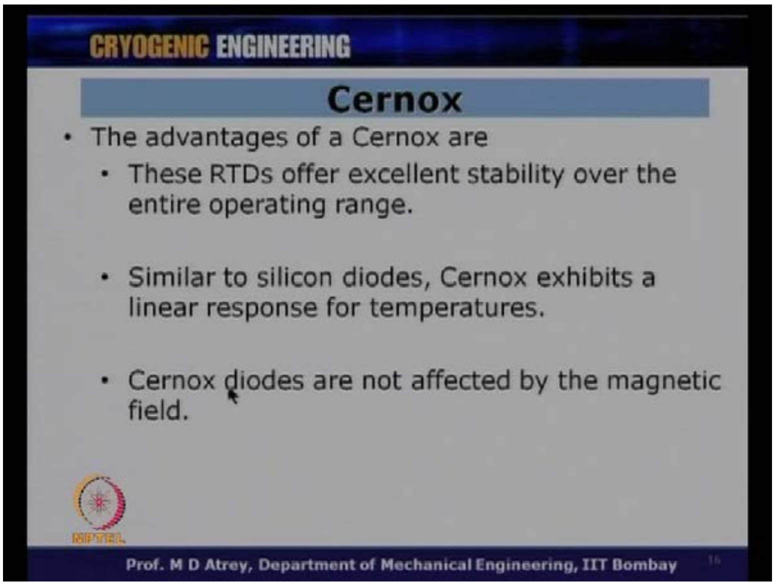

The advantages of cernox are these RTD's offer excellent stability over the entire operating range. Similar to silicon diodes cernox exhibits a linear response for temperatures. So, behavior is similar to what we saw silicon diode cernox diodes are not affected by the magnetic field and this is what is one of the most or the biggest disadvantages of the cernox.

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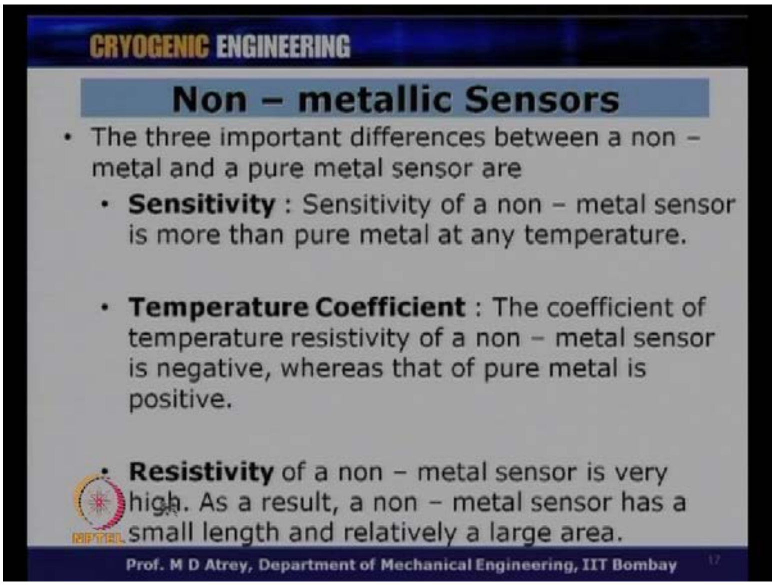

So typically non-metallic sensor; the three important differences between a non-metal and a pure metal sensor the non-metallic sensor what we saw are the cernox and silicon diode and the pure metal sensor. What we saw that the thermocouple and PT100 in terms of sensitivity. The sensitivity of a non-metal sensor is more than pure metal at any temperature.

So, basically non-metal is what we are talking about semiconductor diode is a kind of semiconductor right. So sensitivity of a semiconductor always is more than pure metal at any temperature.

Temperature coefficient; the coefficient of temperature resistivity of a non-metal sensor is negative. This is what we saw. When temperature decreases the voltage increases. Therefore, the coefficient d v by d t of a non-metal sensor is negative whereas, for pure metal for PT100 for example, d v by d t was positive. Temperature decreases voltage decreased. This is a major change when you go from a metal to non-metal. Resistivity: Resistivity of a non-metal sensor is very high. This is a very important all right. Resistivity high as a result a non-metal sensor has a small length and relatively a large area.

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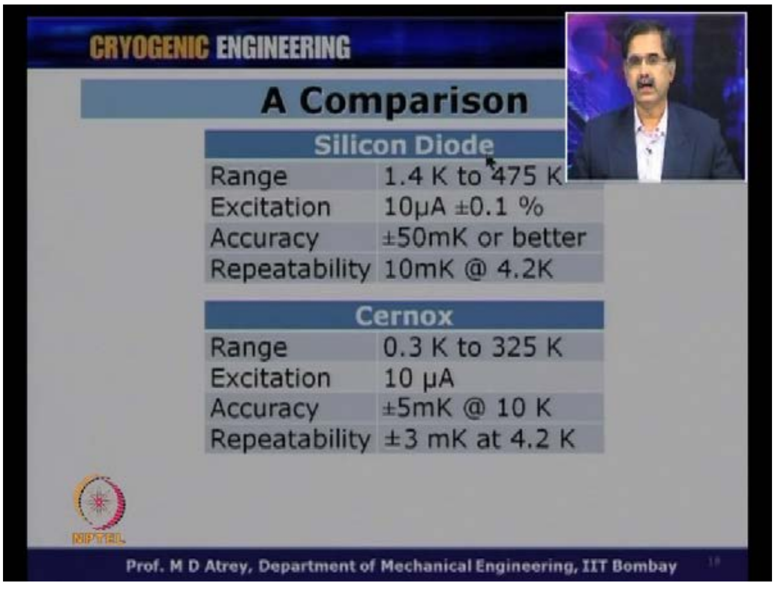

So, because the resistivity is very high and you are talking about variation of resistivity with temperature, variation of resistance with temperature and resistance depend on the resistivity, length, area etc.

So because the rho parameter or the resistivity parameter is very high; you can have a non-metal sensor has a small length and small and relatively large area because area will come in the denominator. So, rho into l by A if you have you can have the resistance parameter and resistivity is very high in those cases.

See if I want to compare silicon diode and cernox; this is the table where you can see that silicon diode normally will be used from 1.4 Kelvin to 475 Kelvin where cernox will be used from 0.3 to 375 325, you got a excitation of ten micro amp ten micro amps. Accuracy is fifty milli Kelvin. 5 milli Kelvin at ten Kelvin and the repeatability also is plus minus 3 milli Kelvin which is good and plus minus ten milli Kelvin at 4.2 Kelvin for silicon diode.

So, this is just to have some representative facts, some comparative data which are taken from various references. Compare a silicon diode with cernox. So, various thermo physical quantities which we wanted to study and we want to measure in cryogenic engineering are;

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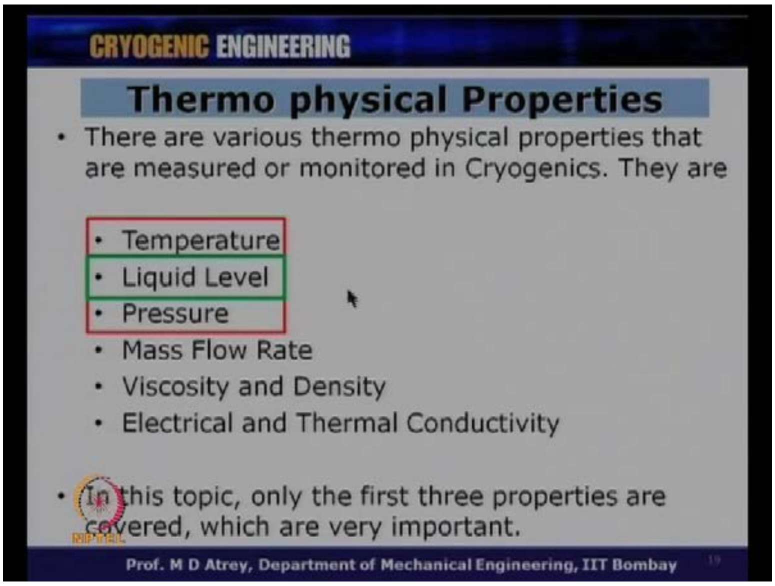

There are various thermo physical properties that are measured or monitored in cryogenics. They are temperature, liquid level, pressure, mass flow, rate, viscosity and density, electrical and thermal conductivity. These are very important properties that normally one needs to monitor in cryogenic experiments.

However, we are going to talk about the top three temperature liquid level and pressure of which till now we have talked about temperature measurement that can be done by using thermocouple PT100 and silicon diode cernox etc.

We will now get to you know what is this liquid level measurement. So, cryogen level is a very important parameter and we will talk about that now. We will talk about liquid level measurement for cryogen level measurement in this topic. Only the first three properties are covered which are very important I am I am taking only three properties which are normally very very important to be measure in cryogenic engineering and therefore, now we will go for liquid level.

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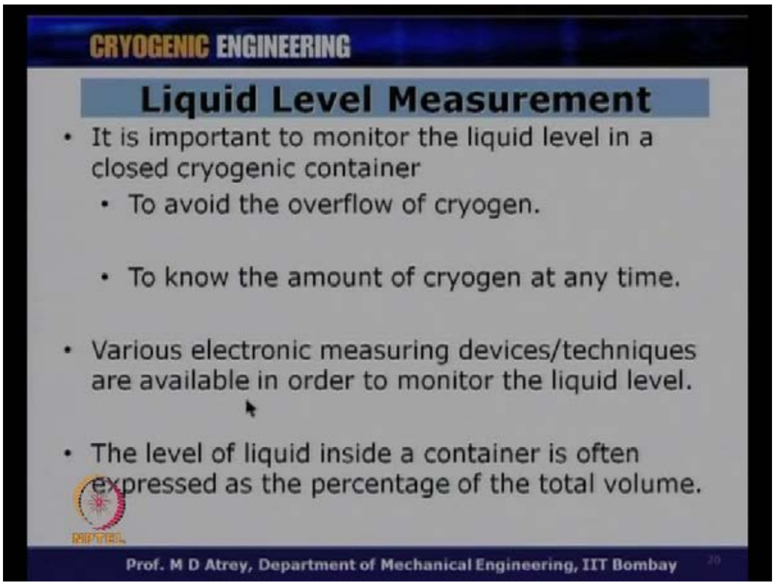

So, liquid level measurement: it is important to monitor the liquid level in a closed cryogenic container. Now, it is a very important because you got to plan your experiments in cryogenics and you have got to know what is the liquid nitrogen level. You have that means how many liters of liquid nitrogen you have, how many liters of liquid helium you have and accordingly it is important that the cryogenic containers are never emptied. For example, you have got a cryostat and you always return some liquid helium at the bottom and before the, it gets finish completely. You should have the next lot of liquid helium over in that basically all right.

So toping up has to be done when there is some liquid helium is left at the bottom. Many a time for super conducting magnet also you should ensure that the magnet does not become normal or the magnet does not change and it is very important. Therefore, to monitor the liquid helium level or liquid nitrogen level in such applications this is the very important parameter which needs always all the liquid nitrogen containers liquid helium give us. You will, I will always have a level gauge over there. It tells you, it monitors how many liters of liquid helium or nitrogen is left there and therefore, correspondingly you can have your experiments plan.

So, the liquid level monitoring is very important to avoid overflow of cryogen. That is to know the amount of cryogen left at any time. This is very important. Various electronic measuring devices techniques are available in order to monitor the liquid level so various ways of monitor because it is not a very quiet different from monitoring other liquid levels but, do not forget that this measurements are going to be done at very very low temperature. For example, liquid nitrogen minus 196 degree centigrade or 77 Kelvin liquid helium 4.2 Kelvin

So, whatever device you use, whatever technique you use you have to understand that the sensor is going to see very very low temperature and therefore, a new sensor has to be design for monitoring the liquid level for cryogenic conditions.

The level of the liquid inside the container is often expressed as the percentage of total volume. Normally, you will say 100 percent field, 50 percent field and things like that and you know that entire thing can have 200 liter or 500 level. So, from there you can calculate how much percentage of liquid, how many liters of liquid has been there in the container.

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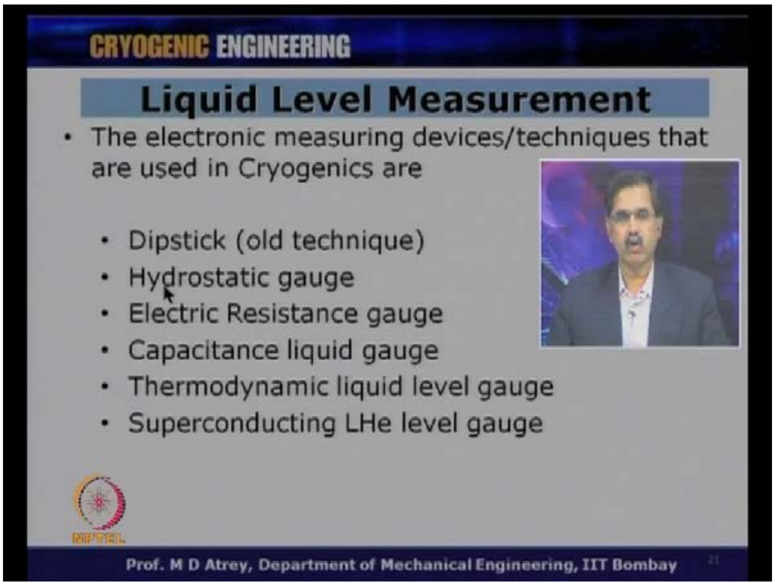

The electronic measuring device technique that are used in cryogenics are dipstick measurement. I mean the approximate liquid level can be understood for common cryogenics like nitrogen. You can do because this technique cannot be used for helium for example.

But for nitrogen this can definitely be used and this still be used just to an approximate level of what is the liquid level of nitrogen available in the open container right. Then we got a hydrostatic gauge, we got something like electric resistance gauge and we know that the resistance changes at low and lower temperatures. So, these are the facts that that are used to indicate the level in cryogenic cryogen containers.

Capacitance liquid gauge: So you got a resistance gauge you got a capacitance liquid gauge. We got a thermodynamic liquid level gauge, you got a superconducting liquid helium level gauge. So, you got a various base to have this liquid level measurement all right one can use any kind of this level gauge depending on what cryogen level you want to measure right. Certain things cannot be used for helium or certain techniques cannot be used for nitrogen for example.

So one has to really you know understand which level gets should be should be used to monitor a particular cryogen while dipstick is a very simple technique that is still being used when you want to have approximate level indication. So let us see what dipstick technique is.

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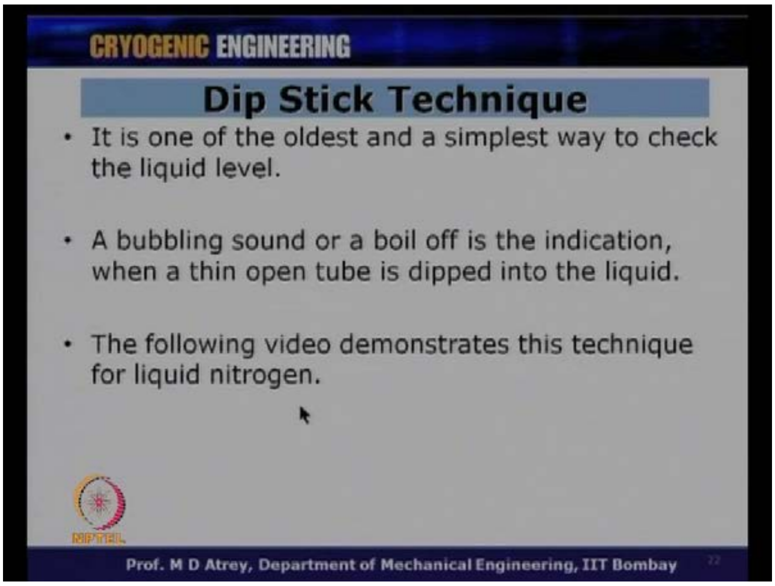

It is one of the oldest and simplest ways to check the liquid level. As soon as you got a empty tube actually which could be of you know stainless steel or it could be of any thing, any material basically and you start inserting that liquid dipstick in the liquid or a container of which you want to measure the level.

So as soon as the the open stick you know touches the liquid the boil off happens because your stick is going to be at 300 Kelvin. So, as soon as it touches nitrogen, a boil off could happen and this boil off would come through this tube up. So, as soon as it touches the liquid level, you can hear a bubbling sound first or a boil off and that is a indication where the thin open tube is dipped into the liquid.

So, we can see now at what point the liquid level is and that will give an approximate understanding about the liquid level in the cryogen. The following video demonstrates this technique for liquid nitrogen. So, this video will make it absolutely clear for the dipstick technique works.

So, let us have a look at this video which shows the working of the dipstick which is normally used in a lab atmosphere. So, what you see here is a a container of around 1.5 liter of liquid nitrogen and what you see in this my student hand is a dipstick which is just a hollow tube of a small diameter are having for around let say 2 meter or a 1 meter or 2 feet kind of a length. And what is important it is a get small hole and now let us insert this tube or the dipstick in this liquid level or to measure the liquid level of this container. So, around 1.5 liter and you get a small containers and you see as he has dipped is and suddenly you can see that the boil off started occurring all right.

So, you can see a very important thing that as soon as it touches liquid level the boil off starts coming out this tube which is basically because of the heat, because the boil off that occurs as soon as this touches and now I can take it out and I can see corresponding outside how much liquid is there in this container all right.

So, you can measure you can measure using a simple scale and corresponding you know that you know vertical height of this means 1.5 liter and therefore, this will this much of height will be something like that. So, if I I can also see approximately how much liquid there. So, one can see that this much amount of liquid from bottom is going to be there. Let say around .75 fifty percent is going to be there and this is the way a dipstick would function so very approximate indication of liquid nitrogen level.

So, having seen the video now; let us go to the next gauge which is called hydrostatic gauge.

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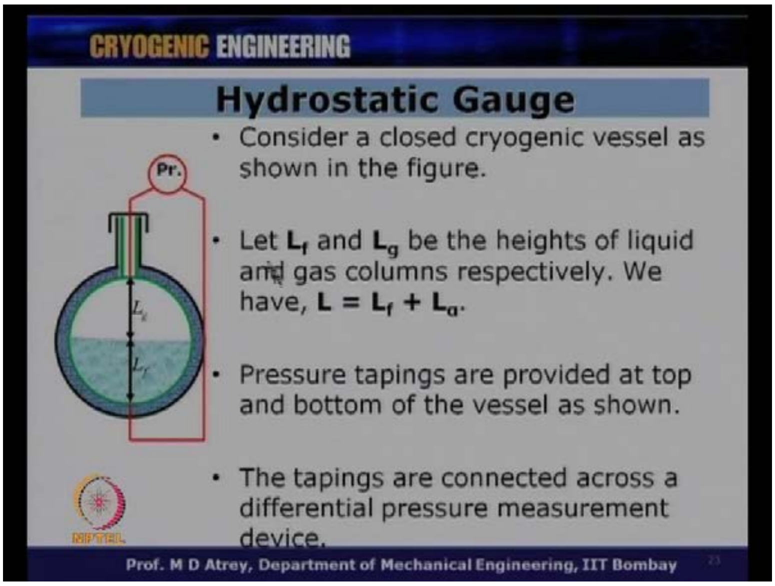

Consider a close cryogenic vessel as shown in the figure. So, this is the liquid level and the sensor is going to be dipped in these and it will monitor at what point at what is the level of this liquid is.

Let l f and l g are be the heights of liquid and gas columns. We have got a liquid level over here you got a gas level over here because this is the gas in these which are the boil off of this liquid basically and you can see that you got a l f and l g are the heights of the liquid and gas column respectively and we have l is equal to l f plus l g simple.

Pressure tapings are provided at top and bottom of the vessel as shown. So, these there are two pressure tapings here and here and this pressure tapings are now connected to a pressure gauge. Also tapings are connected across a differential pressure measurement device as shown over here all right.

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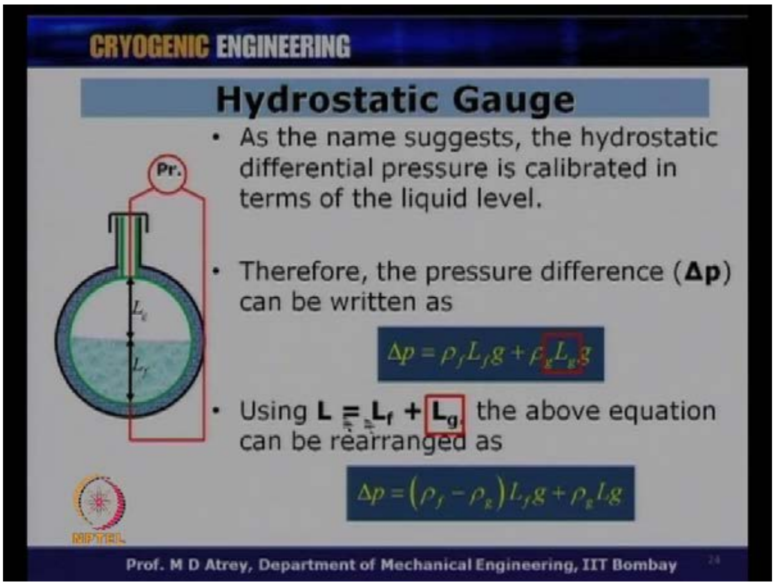

(( )) as the name suggests now the hydrostatic name, the hydrostatic differential pressure is calibrated in terms of liquid level. Therefore, the pressure difference delta p can be written. Now, this is the pressure gauge basically and this pressure is going to actually show a delta p pressure difference at this point and this point which actually is indicative of the level all right.

So, the pressure differential delta p can be written now in terms of l f and l g l p is equal to rho l g for gas and rho l g for so rho f l f g which is this column this vertical pressure plus. So, the pressure at this point actually at this point is equal to rho f l f g plus rho g l g G at this point while the pressure at this point going to be atmosphere.

So, the pressure difference is actually going to measure the pressure at this point which is the function of l f and l g all right. So, pressure difference therefore, is actually going to see the pressure difference at this point and at this point and delta p. Therefore, will be rho f l f g plus rho g l g g using l is equal to l f plus l g which is what we know. The above equation can be rearranged as, so I am just replacing this l g as l minus l f and put it this equation and this. Manipulate the terms what you get ultimately is delta p is equal to rho f minus rho g l f g plus rho g l into g all right.

By putting this value of l g as l minus l f here you get these:

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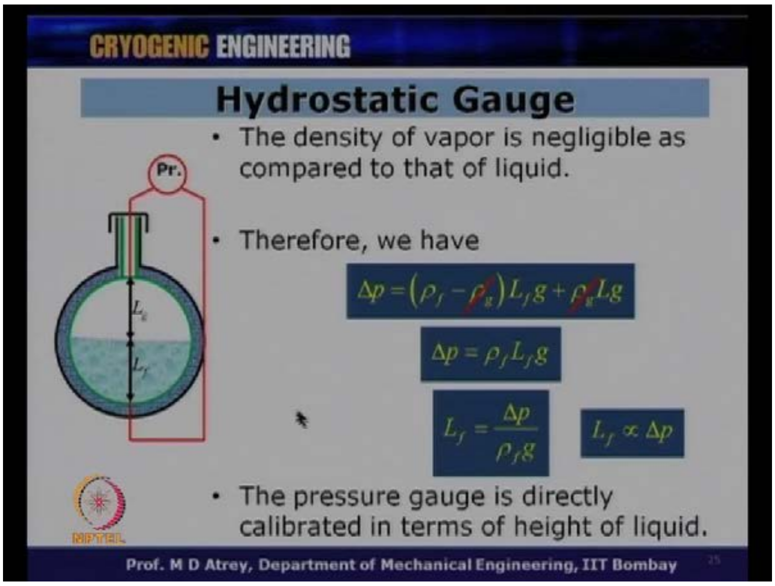

The density of vapor is negligible as compared to that of liquid. So, in the equation what we found; we got a term called rho f minus rho g and you can see that rho g is going to be very small as compared to rho f. Therefore, what we can write is this equation what we have delta p is equal to rho f minus rho g L f g plus rho g L g L g and we just said that the density of vapor which is rho g is going to be very small as compared rho f.

So, rho f minus rho g can be written as rho f only and this can be neglected of this term. So, by this assumption that rho g is very small as compared to rho f you can get delta p is equal to rho f L f g and therefore, we can write L f is equal to which is this height the liquid level height is equal to delta p upon rho f g rho f g is constant and therefore, we can say that l f is directly proportional to delta p.

So, whatever delta p is shown here at this point which can be calibrated straight away in terms of L f. So, when you got a hundred percent L f you got some delta p you got a fifty percent you got something and you can have a calibration function fed to this pressure gauge and L can compute whatever pressure difference is shown here. Correspondingly L can compute this pressure difference as a function of height over here all right.

The pressure gauge is directly calibrated in terms of height of the liquid.

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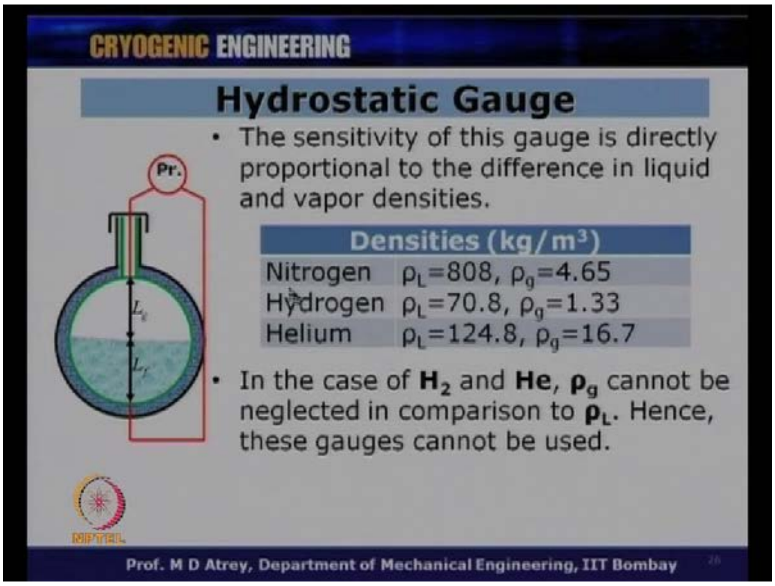

The sensitivity of the gauge is directly proportional to the difference in the liquid and vapor densities which we just saw rho f minus rho g. If we could neglect that then that is possible. If we cannot neglect this then it is not possible and just wanted to compare with this is the different fluids. So, we got a densities here for nitrogen you got a rho l is equal to eight 0 eight while that is rho f we talking about and rho g is 4.65.

So, if we say rho l minus rho g for nitrogen all right rho g is very small as compared to rho l and therefore, 1 can neglect for nitrogen rho g as compared to rho l. But, for hydrogen or helium the liquid density itself is very small. While in case of nitrogen the liquid density is very very high. So, because the liquid levels are liquid densities are very low values rho l is equal to just 70 rho l is just 124. So, in front of these your rho g cannot be neglected all right.

So, rho l minus rho g becomes a parameter it is important parameter and therefore, for hydrogen and helium because of the low density of liquid hydrogen and liquid helium you cannot use such technique. Hydrostatic gauge cannot be used because I cant neglect rho g in front of rho l.

In the case of hydrogen and helium rho g cannot be neglected in comparison to rho l. So, this assumption what we had was rho g is very very small as compared to rho l does not hold good for hydrogen and helium hence these gauges cannot be used for hydrogen and helium but, of course, they can be used for nitrogen.

Then we go to next kind of a gauge which is electrical resistance gauge and this gauge is movable actually. So, let us see how it works.

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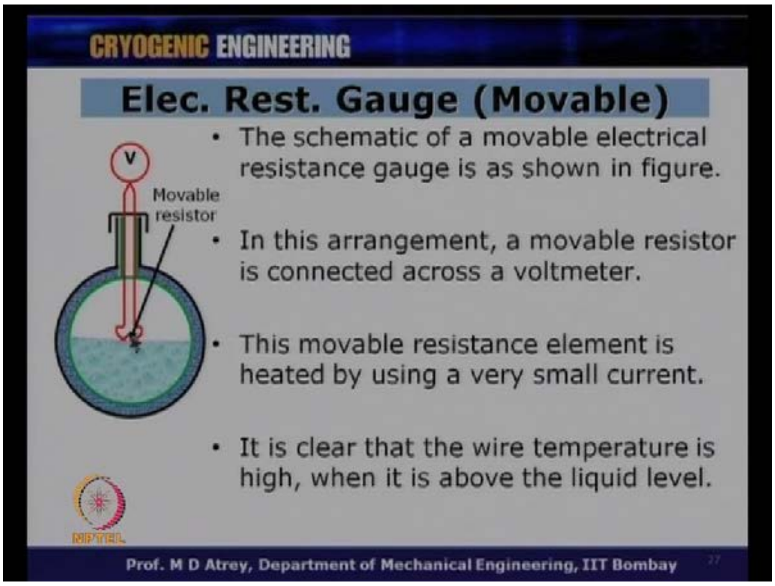

So, the schematic of a movable electrical resistance gauge is as shown in the figure and here you can see that the movable gauge here in this arrangement a movable resistor is connected across the voltmeter.

So, you can see you got a movable resistor you can go up and down again you got a liquid level at this point and you got a boil off gas in this region. So, you can you can push this sensor down and you can see what happens at the interface when the sensor enters from the gaseous region and enters the liquid region.

This the the movable sensor element is heated by using a very small current. So, what I do; I just heat it small before I want to measure the the level just heat it. Therefore, the temperature of the sensor increases because it gets heated by I square r value all right.

And now, there the heat transfer because this heated surface and heat transfer from this resistor to the gas or resistance to the liquid depending on the verities all right. It is clear that the wire temperature is high when it is above the liquid level. So, when it is in the gaseous region you got a heat transfer by convection to the gas here and these heat transfer is going to very very less as compared as compared to when it is in the liquid state all right.

So, temperature in this case is going to be very high where the temperature in this case is going to be very low if you move these at a particular point. This is sudden chain change of temperature that will happen and therefore, voltage chain will occur and therefore, from that you will come to know that the level lies at this point. So, if you take it up and start coming down at a particular point because the heat transfer characteristic in the gas and heat transfer characteristic in the liquid there is going to be some temperature change which is going to be shown as a change in value of v. Therefore, it gets calibrated with the movement of this sensor at what point it happens and that will indicate indirectly the level of the cryogen.

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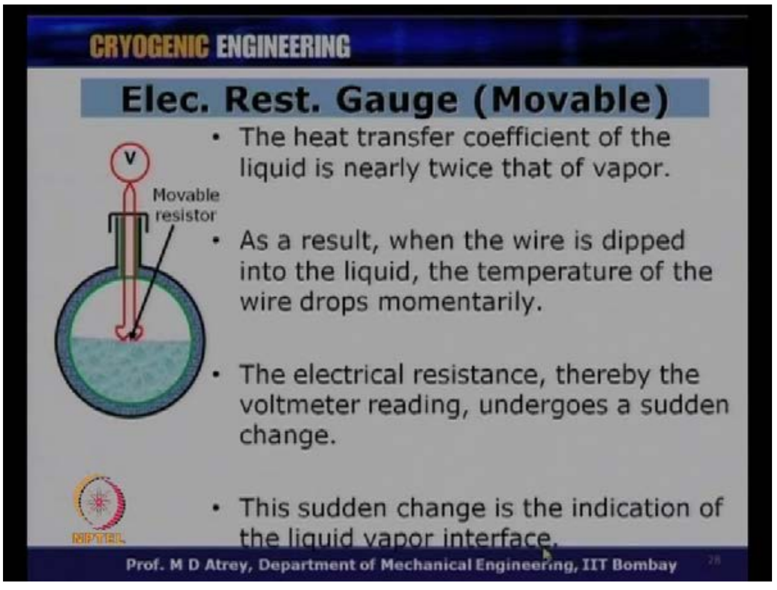

The heat transfer coefficient of the liquid is nearly twice that of vapor and therefore, there will good heat transfer in the liquid and therefore, temperature will be low in this case while the temperature will be higher in this case all right.

As a result, when the wire is dipped into the liquid the temperature of the wire drops momentarily and therefore, this is the change of resistance that will occur change of voltage that will occur which can be monitor as a level indicator. The electrical resistance thereby the voltmeter reading undergoes a sudden change which is actually calibrated. This sudden change is the indication of the liquid vapor interface. So, this is what constitutes in a movable electrical resistance gauge.

Now, let us see electrical resistance gauge when it is immovable. That means there is no movement happening of the sensors as what we did earlier.

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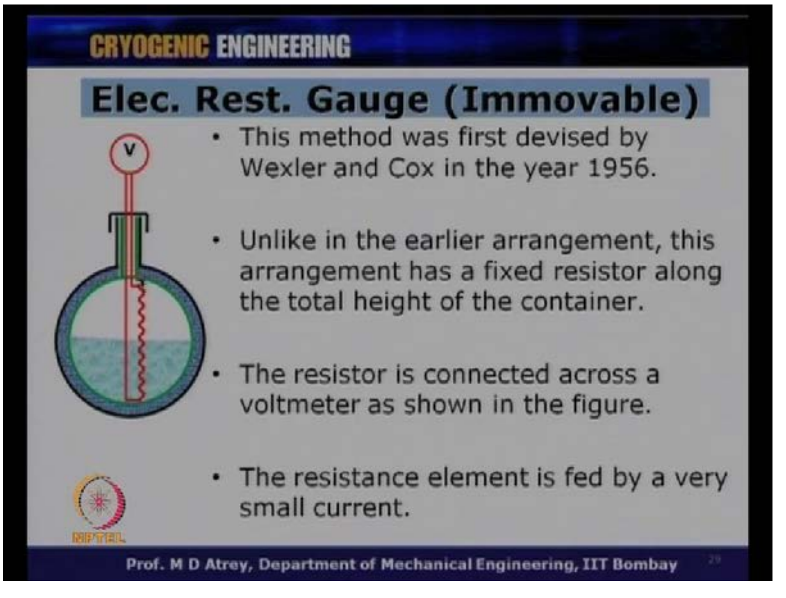

This method was first devised by waxier and cox in the year 1956 unlike in the earlier arrangement. His arrangement has a fixed resistor along the total height of the container.

So, what you see here a fixed resistor. So, you can see in the earlier case I had a resistor only up to this and I will go up and down or I will move the electrical resistance while here I have got a resistance coming down from the hundred percent liquid to the 0 percent liquid and this is resistor running from top to bottom and ultimately it is connected to some voltmeter all right.

And if I want to measure the liquid level; now I do not have to move this up and down because it is occupying the entire space entire, the vertical space in the container the resistor is connected across a voltmeter as shown in the figure. The resistance element is fed by a very small current if I want to measure the liquid level. Now, I just press a button here which will pass a current a very small current through this circuit. So, there is a circuit over here and therefore, there is a effective resistance of this circuit which is what is indicated by the voltage here.

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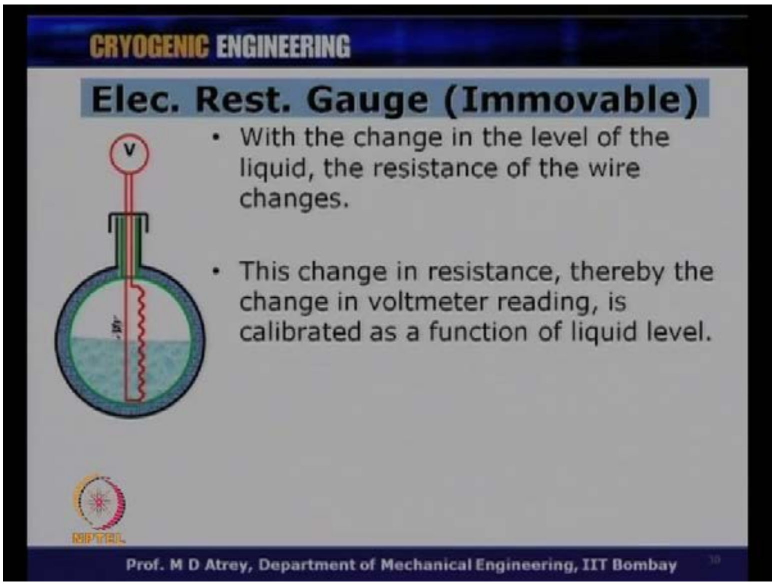

With the change in the level of the liquid the resistance of the wire changes. So, as we know that this much part is in the vapor region; this much part is in the liquid level. So, depending on how much part is going to be in the gaseous region and how much part is going to be in the liquid region; you got a heat transfer which is what we just have seen.

So, the temperatures will be different at this point and correspondingly the resistance of the voltage shown will indicate at what point this liquid level (( )). How much part is dipped in liquid how much part is there in gas that is can be calibrated and indirectly the voltage shown at this point will be representative of what is cryogen level over existence over here.

So, with the change in the level of the liquid; the resistance of the wire changes. This change in resistance, now this changes in resistance thereby the change in voltmeter reading is calibrated as a function of liquid level. So, here I have got an immovable unit and as soon as the liquid level changes the voltage will show that change.

Now, what is a difference you got a immovable unit and therefore, this unit is always dipped over here and which will also causes some losses in a system because this will have some conductive losses brought it from 300 Kelvin down and then of course, your dipping an outside foreign body in the liquid which will cause some extra boil off. Not only that it is getting some conduction heat from outside in addition and therefore, such sensors actually are producing continues boil off at the advantage of being immovable. We do not have to move the sensor in these cases.

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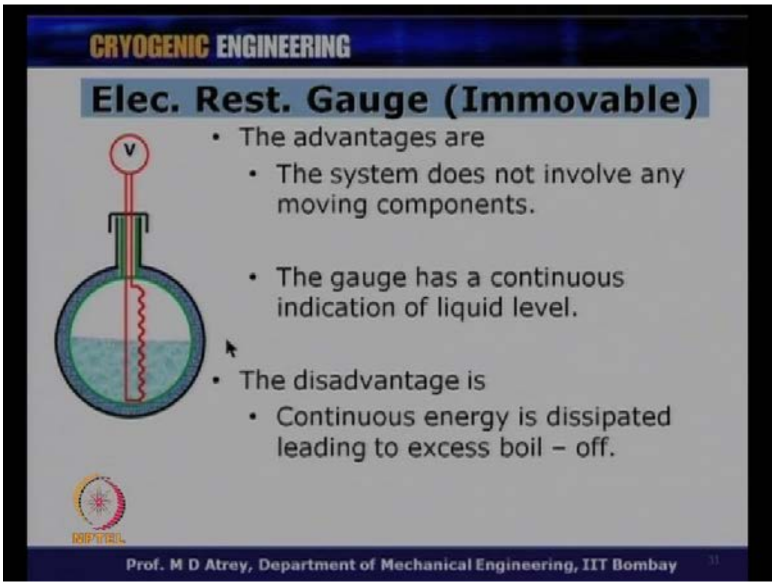

The advantage of such sensor therefore, if the system does not involve any moving component; so I do not have to worry about any extra mechanism of how to move this sensor up and down. So, system becomes simple in this case. The gauge has a continuous indication of liquid level. So, because the gauges always dipped over here, 1 can have a continues display of the liquid level also is one or two.

The disadvantage is continuous energy is dissipated leading to excess boil off so because system is actually all the time dipped in liquid helium. In the earlier case it was not and it will also doing some conduction happening across it. Therefore, it will cause some extra boil off. So continuous energy is dissipated leading to excess boil off. This is the disadvantages of such a system.

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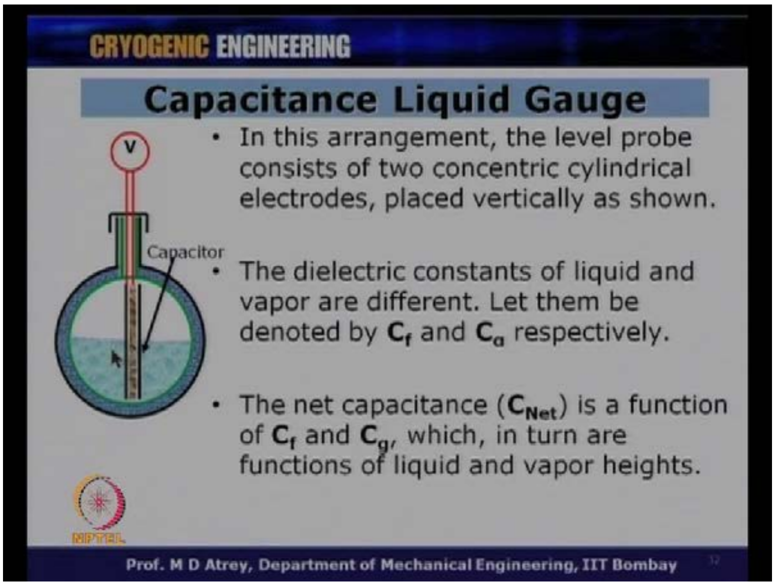

In the similar way, now you can have various other gauges working on similar principle. For example, we have got a capacitance liquid gauge again, you got a capacitance over here in gaseous region and capacitance exits in the liquid level and again they can be actually calibrated to indicate the level.

In this arrangement the level probe consists of 2 concentric cylindrical electrodes as what we see here placed vertically as shown the dielectric constants of liquid and vapor are different you know that dielectric constant for gas is C g dielectric constant for the liquid is c f and this is going to be different for gas and different for the liquid. Let them be denoted by the C f and c g respectively.

The net capacitance C net is a function of C f and C g which in turn are function of liquid and vapor heights so depending on what is my l v is what is my l g is corresponding to that we have got a C f and C g and therefore, you got a C net net capacitance. And therefore, I can have net capacitance calibrated with the level over here with c f actually over here.

So, net capacitance can be calibrated as level indicator. It will indicate the level directly depending on the calibration.

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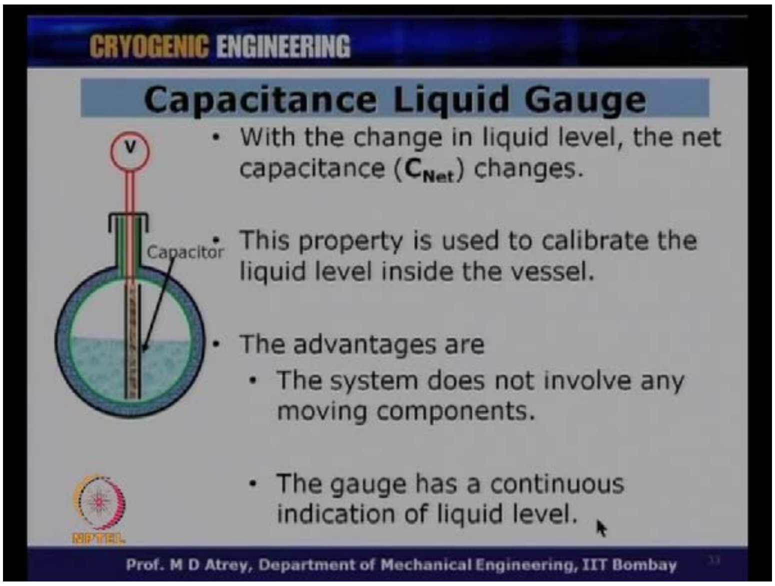

With the change in the liquid level; the net capacitance changes this property is used to calibrate the liquid level inside the vessel. So, capacitance liquid level also actually is going to be dipped all the time. So, it is also going to bring some dissipative energies energy over here. But, then this is what the principle of the capacitance liquid gauge will be.

The advantages are again the system does not involve a moving component. The gauge has a continuous indication of liquid level and disadvantage is again it will bring in some extra load on a system.

Going to the next type of liquid level gauge is thermodynamic liquid gauge.

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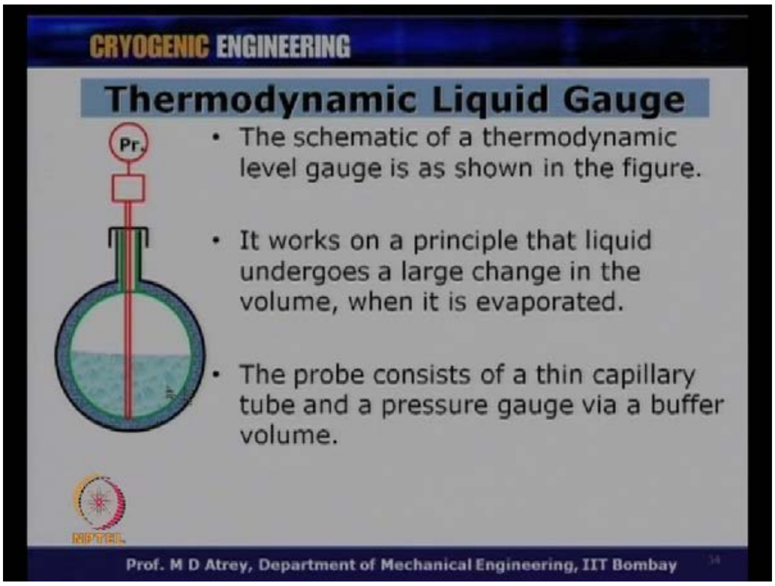

The schematic of a thermodynamic level gauge is as shown in the figure. It works on a principle that so you can see the gauge over here. So, what you can see is here is a capillary running from top to bottom some kind of dead space over here where the gas is stored and you got a pressure indicator at this point.

So, it works on a principle that liquid undergoes a large change in the volume when it is evaporated all right. So, this is the principle on it works. So, when the gas becomes liquid there is the large change in the volume happens. For example, when the condensation happen, the volume decreases the gas will occupy all the volume the liquid undergoes a large change in volume when it is evaporated.

So, when liquid becomes gas or gas becomes liquid there is a huge change in volume and there the therefore, the pressures all right. So, this is the indicative of the level that is the principle they want to use.

The probe consists of a thin capillary tube which is hallow kind of a thing and a pressure gauge via a buffer volume. So, you have got a buffer volume you have got a buffer volume connected to capillary tube and then top you got a pressure gauge.

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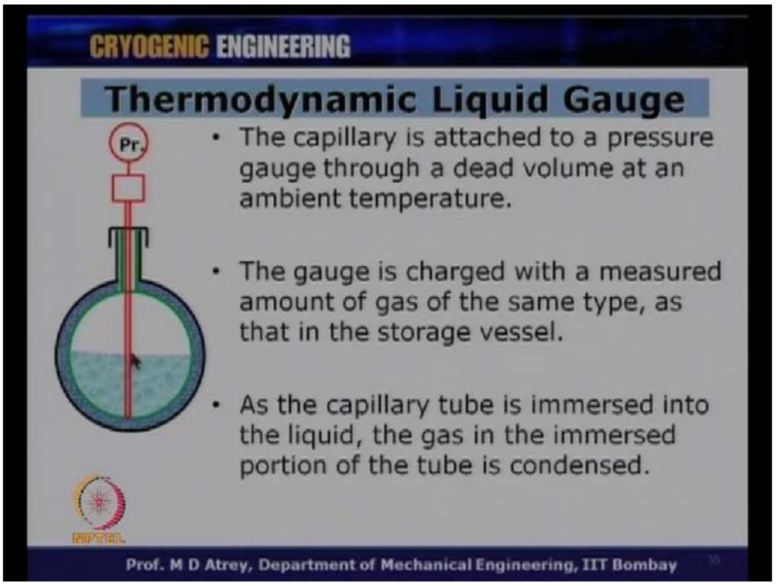

The capillary is attached to a pressure gauge through a dead volume at an ambient temperature. So, you have got a dead volume which is a ambient temperature the gauge is charged with a measured amount of gas of the same type as that of the storage vessel. If you want to measure liquid nitrogen or liquid helium; you will charge in nitrogen or helium gas respectively depending on what fluid you have. If you have nitrogen, you in charge nitrogen gas, if you got helium you will charge helium gas.

So, the same gas will be there in this capillary tube and staying in this dead volume or volume at room temperature at ambient temperature as the capillary tube is immersed into the liquid. Now, you got a capillary tube. Some part of the capillary tube is is in the gaseous phase sorry in the gaseous part of the boil off gas is stored while the other part of this capillary tube is dipped in liquid.

So, the gas that is going to be in the liquid region is going to get condensed because it has got a boiling point just above these and therefore, this gas will get condensed while this gas will remains the gaseous phase because the temperature of this the gas around is going to be more than its boiling point. If I got a nitrogen gas over here, the nitrogen gas and the outside temperature is going to be 77 Kelvin. So, nitrogen gas in this height depending on how much portion of this capillary is below or easy in this liquid region this gas would condensed and accordingly there will pressure in this happening and this is the principle.

So, as the capillary tube is immersed into the liquid; the gas in the immersed portion of the tube is condensed all right. So, these gas in the capillary tube which is immersed in the liquid we will get condensed and therefore, this is the change of volume happen.

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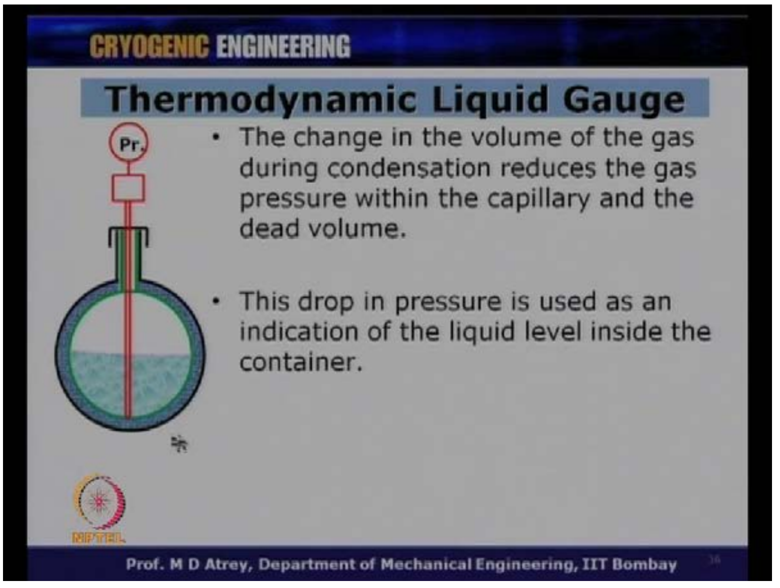

The change in the volume of the gas during condensation reduces the gas pressure. So, as soon as the condensation will occur your pressure will decrease and therefore, this pressure can indicate how much condensation has occurred and how much condensation occurs will depend on how much part of this capillary is below the liquid level.

So, depending on the gas which is below the liquid level that will condense and depending on that the pressure would change and therefore, this pressure can directly calibrated as a function of liquid level all right.

So, the change in the volume of the gas during condensation reduces the gas pressure within the capillary and the dead volume. This drop in pressure is used as an indication of the liquid level inside the container.

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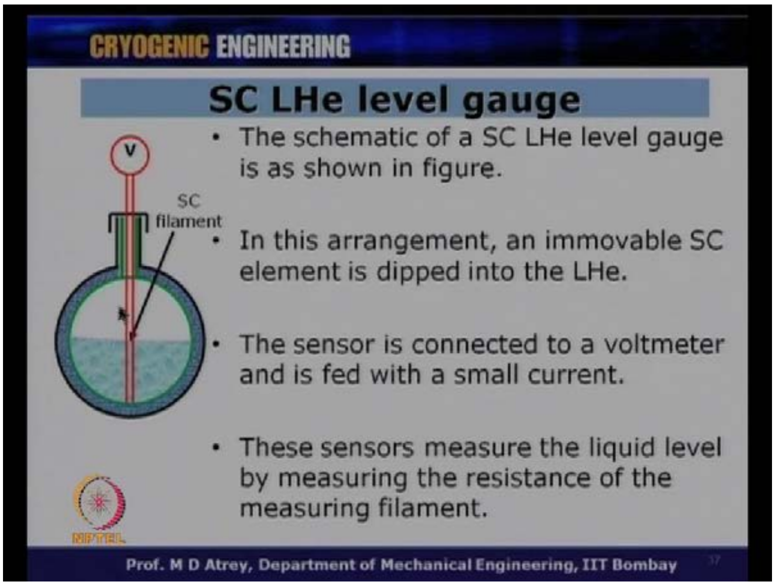

So, there is the direct calibration between the drop in pressure and the liquid developed here. So, this is the way the thermodynamic liquid gauge would work.

Similarly, we got one more level gauge which is normally will be used for liquid helium only. So, we got a superconducting liquid helium level gauge because it it has got a superconducting wire. It uses some superconducting material. Now, it is going to little costlier as compared to the other gauges but, it is normally preferred because more accurate and simple.

So, this schematic of a superconducting liquid helium level gauge is as shown in this arrangement an immovable superconducting element is dipped in the liquid helium. So, you can see the element of there is the material which becomes superconducting at liquid helium temperature and whatever part is dipped below in the liquid helium will turn superconducting and whatever part is above the liquid helium in the gaseous region, it will not be superconducting; it will normal.

And therefore, depending on whatever part is immersed; voltage will vary all right. This is the principle on which superconducting liquid helium level gauge would work. The sensor is connected to a voltmeter and is fed with a small current, some small current. There is a circuit over here and small, some small current is fed through these sensors. Measure the liquid level by measuring the resistance of the measuring filament.

So, you have got the measuring filament running from top to bottom and the resistance or when I flows to this, the current flows to this. You got a some resistance across this which will what will indicated by the voltage.

Now, depending on the how much part is below the liquid level because this much part which is below the liquid level is going to be superconducting and therefore, the resistance in this region is 0. So, whatever voltage is shown will be going to be corresponding to the resistance offered by the material which the normal stage.

The superconducting state will show 0 resistance and this is what can be calibrated as a function of level as far as working of a superconducting liquid helium level gauge is considered. This superconducting filament is housed inside a Teflon protective tube, the portion of filament in liquid remains in the superconducting state and exhibits 0 resistance all right. So, this much part will show 0 resistance.

Therefore, the resulting voltage along the sensor filament is proportional to the length of filament above the liquid helium. So, whatever resistance is offered actually is offered by this normal material d all right.

So, this can be therefore, calibrated accordingly to show the liquid cryogen level; it is a very important type of level gauge which is used in helium containers.

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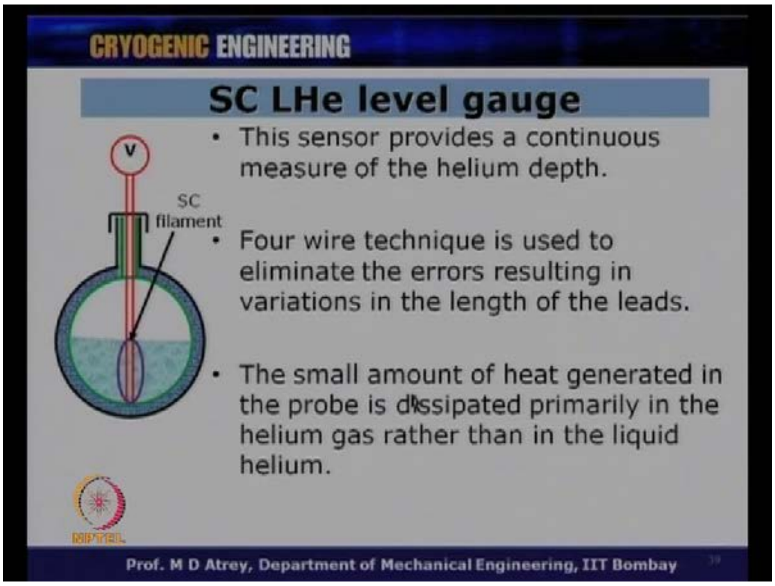

This sensor provides a continuous measure of the helium. Again, you can press a button when you want to measure, current is passed and accordingly voltage can be seen and this can be calibrated in terms of the liquid level.

Four wire technique is used to eliminate the errors resulting in variations in the length of the leads. The small amount of heat generated in the probe is dissipated primarily in the helium gas rather than in the liquid. So, when you pass the current through it the heating is going to happen only in this part because this is superconducting part and therefore, there is no extra heating that is there. There is no high sphere are associated with this solution.

Whatever high sphere are happens is only in the gaseous in the boil off region region only. So, the heat dissipation in this case amounts to only the part which is in the gaseous phase which is in the boil off which see the boil off gas not for the part which is dipped in the in the cryogen.

So the summery of the lecture therefore, is

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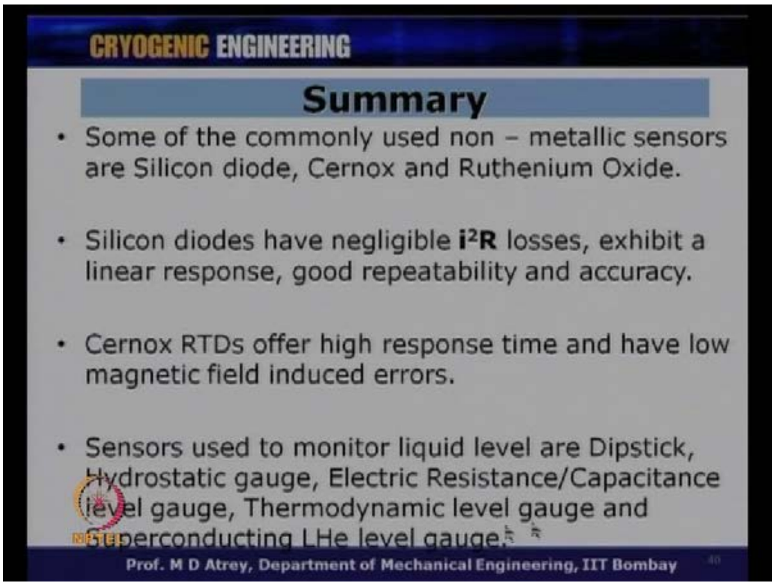

Some of the commonly used non-metallic sensors are silicon diode cernox and ruthenium oxide. Silicon diodes have negligible I square r losses, exhibit a linear response good repeatability and accuracy. The I is in micro amps and therefore, the losses are minimum for this non-metallic sensors.

The cernox RTD’s offer high response time and have low magnetic field induced errors. So, whenever you got a magnetic field environment, cernox are most preferred sensors. Sensors used to monitor liquid level are dipstick hydrostatic gauges electric resistance or capacitance liquid level gauge, thermodynamic level gauge and superconducting liquid helium level gauge.

So we have seen the working of all this sensors and they work for the way you want. For example, dipstick works for an giving an approximate indication of the level for nitrogen while superconducting will be used for liquid helium level and other could be used for nitrogen, neon, hydrogen etc.

Thank you very much.

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