Chemical Process Instrumentation
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Lecture – 34
Temperature Measurement (Contd.)

Welcome to lecture 34. We are talking about temperature measuring instruments. In our previous lecture, we have started our discussion on liquid expansion thermometers. And specifically we talked about liquid-in-glass thermometer. We will talk about the other variants in today's class, which is liquid-in-metal thermometers.

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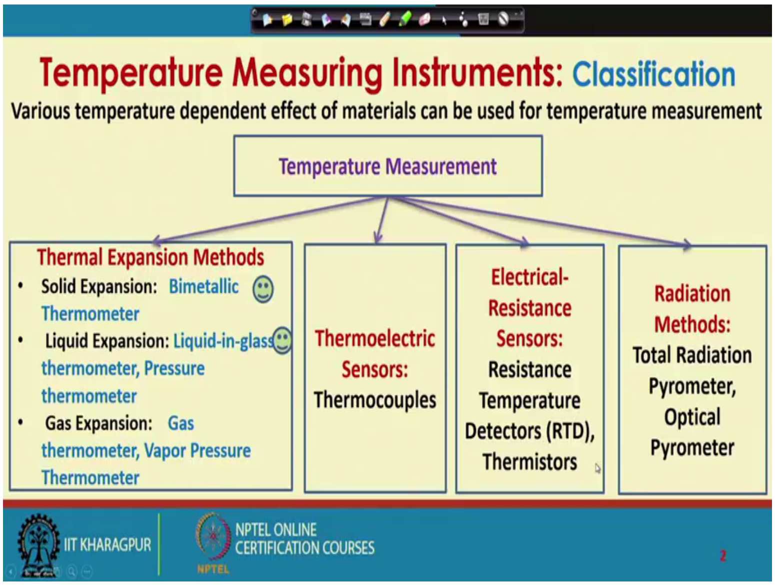

So, let us look at our classification. We have talked about bimetallic thermometers, which is based on the solid expansion. And we are currently talking about liquid expansion thermometers; liquid-in-glass thermometers we have covered in previous lecture.

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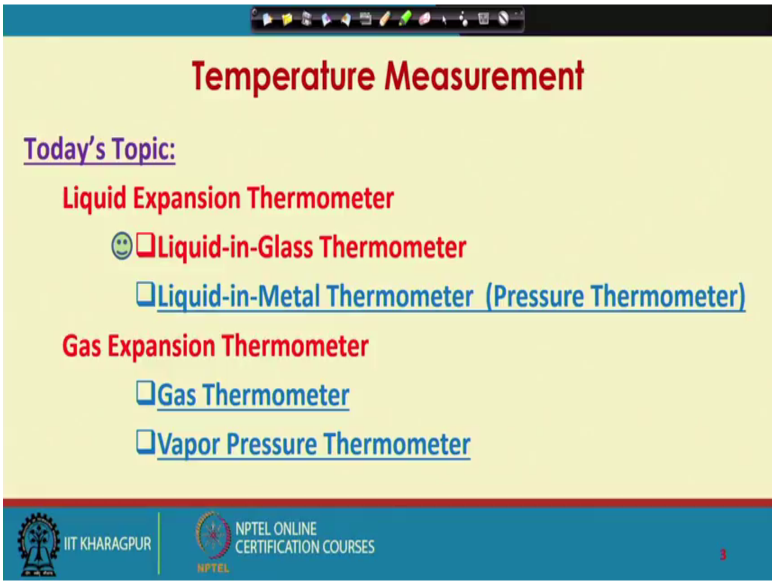

So, today will talk about liquid-in-metal thermometer also known as pressure thermometer. We will also talk about gas expansion thermometers, and under which we will talk about gas thermometer, constant volume gas thermometer and vapor pressure thermometer so that will complete our discussion on temperature measuring instruments based on thermal expansion methods.

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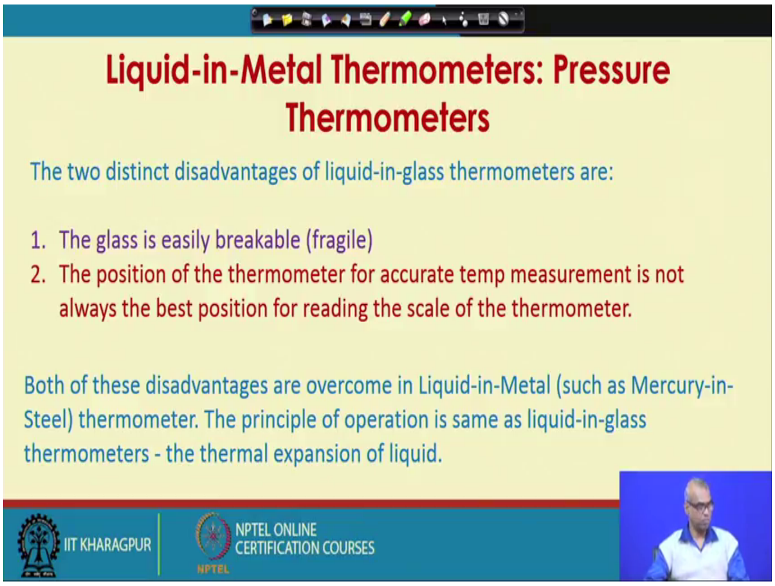

So, let us start with liquid-in-metal thermometers. The principle of operation is very much similar to liquid-in-glass thermometers. Liquid-in-metal thermometers are also known as pressure thermometers. There are two distinct disadvantage of liquid-in-glass thermometers. The glass is easily breakable, and the position of the thermometer for the accurate temperature measurement is not always the best position for reading the scale of the thermometer. We have seen how to read the scale to avoid parallax error in previous lecture. Both of these disadvantages are overcome in liquid-in-metal thermometer such as say mercury in steel thermometer the principle of operation is same as liquid-in-glass thermometers the thermal expansion of liquid.

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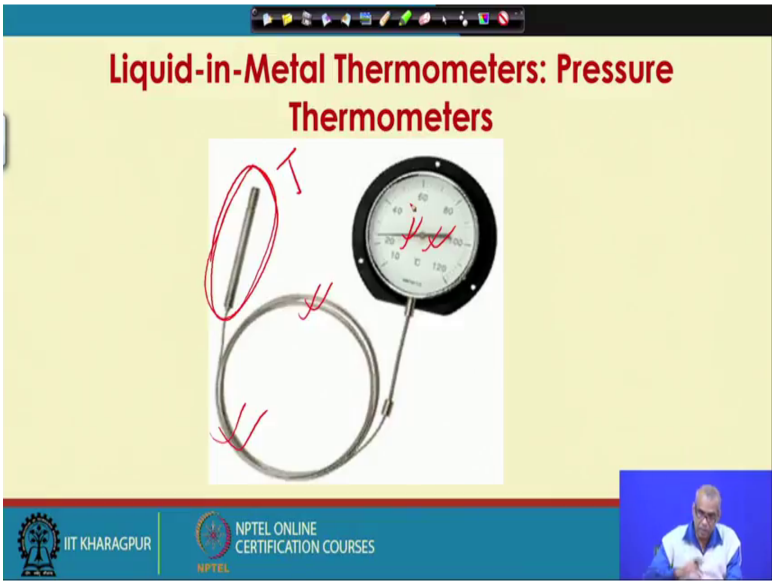

This is an image of liquid-in-metal thermometer. Consist of a bulb and then a tube is attached to the bulb, the tube may be flexible. And the other end of the tube is connected to a pressure sensitive element. The pressure sensitive element can be a bourdon tube may be a C type bourdon tube, or a spiral bourdon tube or a diaphragm gauge. So, commonly it is either a bourdon tube or a diaphragm gauge. Now, this pointer and scale is attached to the tip of the bourdon tube. We see the pressure spring the bourdon. So, the you way it works is we will put this bulb into the medium whose temperature we are going to measure. This bulb, this capillary tube and the bourdon tube are all filled with acciling liquid such as an oil or a glycerin.

Now, when this bulb is put into the medium whose temperature I am measuring, the bulb will receive thermal energy, the liquid will undergo a restricted thermal expansion, a pressure will be developed, that pressure will be transmitted through this capillary to the bourdon tube. Now, it is same as applying pressure to a bourdon tube, so there will be deflection of the tip of the bourdon tube. The tip deflection will depend on the amount of pressure that is build up, and the amount of pressure will depend on temperature of the medium. So, the tip deflection is used to move this pointer against this scale. And the scale can be directly calibrated in terms of temperature units from which you can get direct reading of the temperature.

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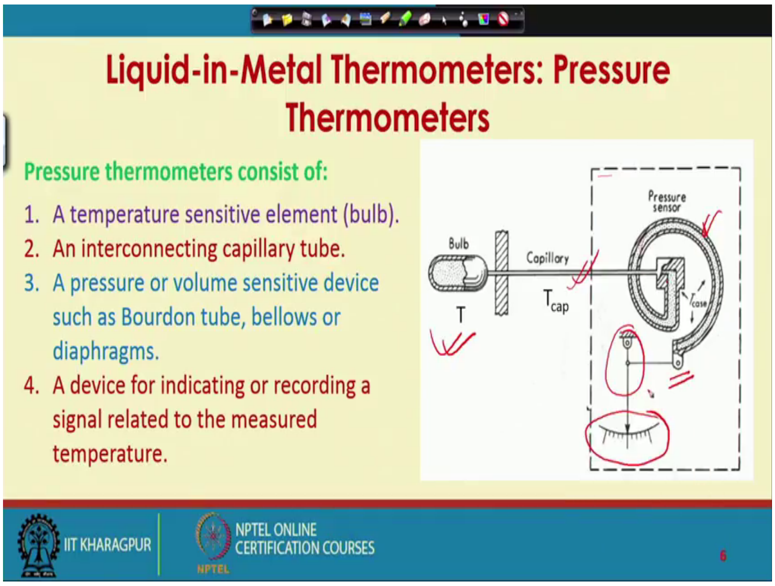

So, pressure thermometers or liquid-in-metal thermometers consist of a temperature sensitive bulb - this is the sensitive element, an interconnecting capillary tube, a pressure or volume sensitive device such as bourdon tube bellows or diaphragm a device for indicating or recording a signal related to the measured temperature. So, once again you have the bulb. So, bulb is receiving this thermal energy, you have this capillary. The other end of the capillary a bourdon tube is attached.

So, this is the spiral bourdon tube. One end of bourdon tube is fixed, so there will be deflection of the other end to these bourdon, to this tip of the bourdon tube a pointer is attached which deflects against this scale and you can get the reading directly after suitable calibration. Please note that the bulb is put to the medium whose temperature I am going to measure, this capillary is exposed to the surrounding temperature also. This center part is put within the case and the pressure spring or the bourdon tube is subjected to the temperature of the case.

Now, as we just discussed that is bulb will receive thermal energy from the medium and a pressure will be developed. But this capillary and this case, they have different temperatures and these temperatures can also cause the change in volume of this capillary or this pressure spring. So, there will be some error due to ambient temperature and we need to compensate for this error.

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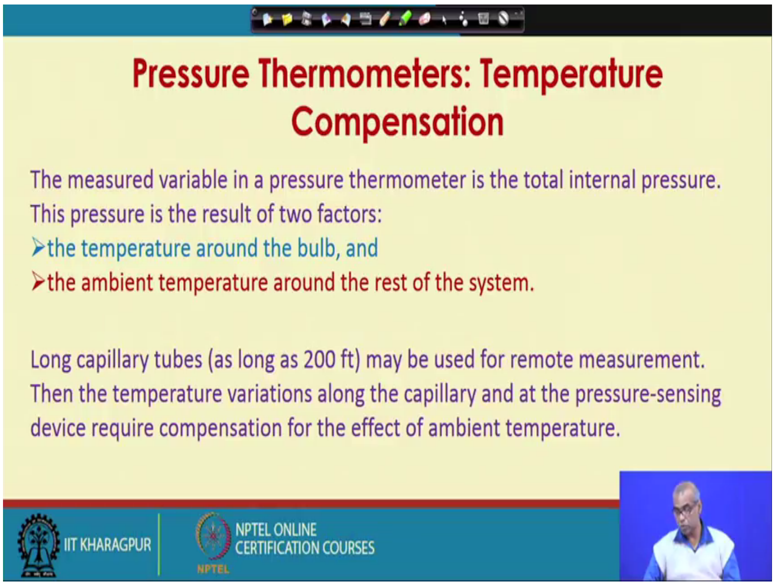

So, how this temperature compensation can be achieved? The measures variable in a pressure thermometer is the total internal pressure. This pressure is the result of two factors - the temperature around the bulb and the ambient temperature around the rest of the system that means ambient temperature around the capillary ambient temperature around the pressure spring or bourdon tube. But we basically want then the pressure we have function of temperature around the bulb alone, so that I can get correct reading of the medium, but the pressure build up depends both on the temperature of the medium which is the temperature around the bulb and the ambient temperature around the capillary as well as the pressure spring.

Long capillary tubes as long as 200 feet may be used for remote measurement. Then the temperature variations along the capillary and the pressure-sensing device will be significant and it will require compensation for the effect of ambient temperature.

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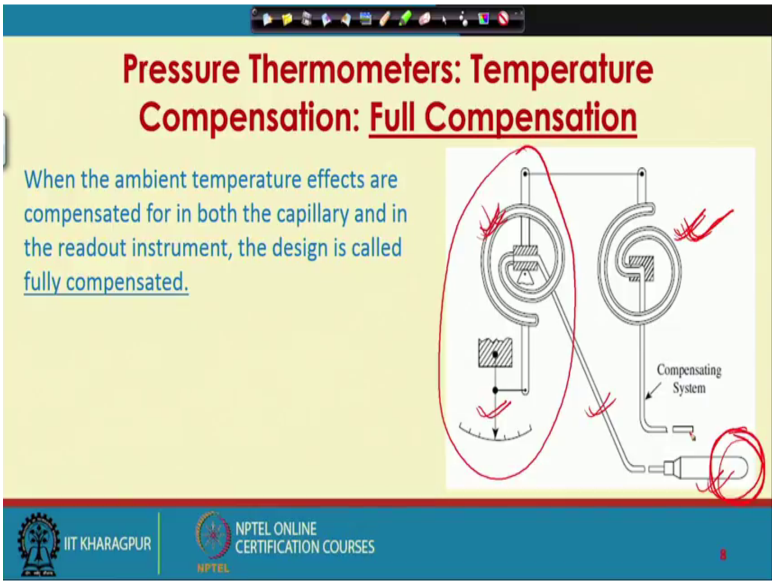

Now, there are two types of compensation, full compensation and case compensation. When the ambient temperature effect are compensated for both the capillary the readout instrument that means, the bourdon tubes, the pointer scale that part of the instrument, the design is called fully compensated. So, for fully compensation, for fully compensated design, the effect of ambient temperature effects are compensated for the capillary as well as the bourdon tube and the associated elements.

So, how do you do it? So, this is the measuring element. You have this bulb, the capillary tube, and this is the pressure spring or bourdon tube. Now, I take an exactly identical system or exactly identical element and connect them as shown. So, I basically have two pressure thermometers, and they are connected in opposition. This one I call compensating system, and this is exposed to the surrounding medium only it is not exposed to the medium whose temperature I am measuring. So, this exposed to the surrounding only.

So, the pressure that is build up here is based on effect of ambient temperature only. The pressure that is build up here based on the medium temperature as well as the ambient temperature. Now, since this and this are connected in opposition, the pointer deflection will be based on the effect medium temperature only, effect of ambient temperature will be cancelled out.

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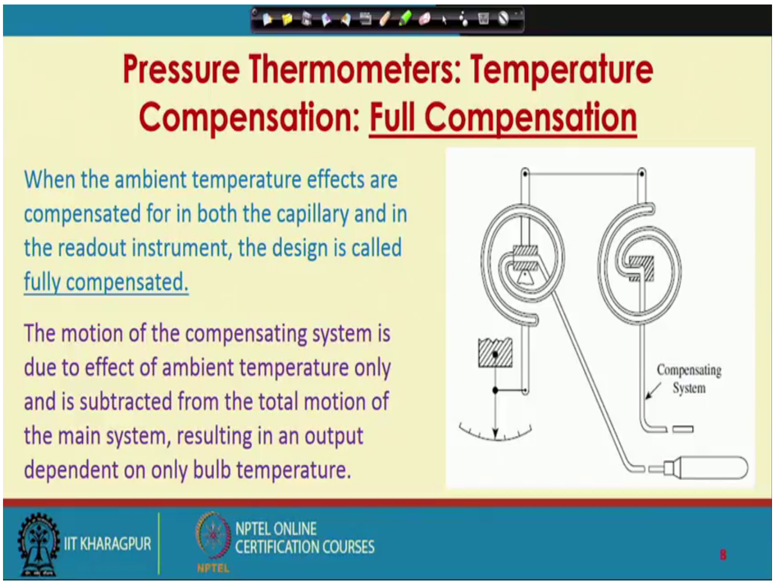

The motion of the compensating system is due to effect of ambient temperature only and is subtracted from the total motion of the main system, resulting in an output dependent on only bulb temperature.

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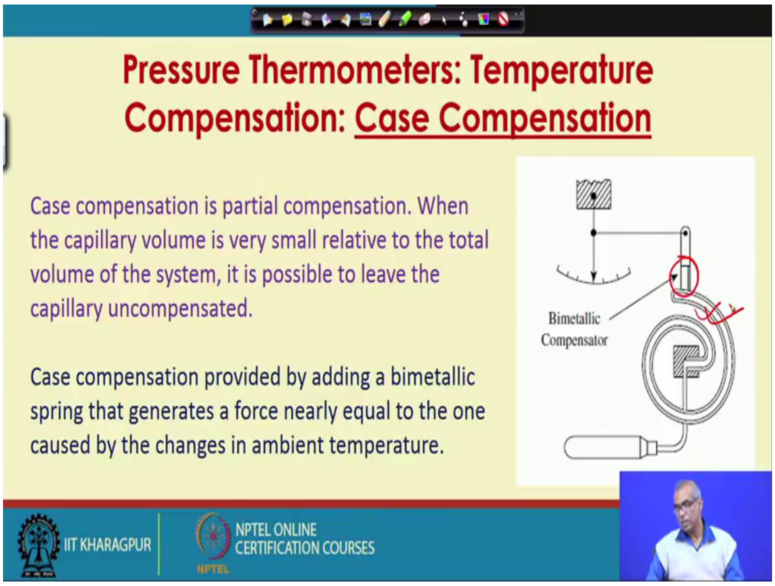

Case compensation is partial compensation. When the capillary volume is very small relative to total volume of the system, it is possible to leave the capillary uncompensated. So, you compensate only for the pressure element, there is no need for capillary compensation; in case of full compensation, you compensate for capillary as well as for pressure spring; but in case of case compensation, you compensate only for the pressure spring namely the bourdon tube. And the capillary compensation is not required or is not achieved here. The capillary compensation may not be required, when the volume of the capillary is small compared to the total volume of the system that means, the length of the capillary not very large.

So, what do you do in case compensation is we take the help of a bimetal. A suitably designed bimetallic strip is attached to the pressure element. Case compensation is provided by adding a bimetallic spring that generates the force nearly equal to the one cause by the changes in ambient temperature. So, we have attached a bimetallic spring here. You know that bimetal will also undergo thermal deflection; bimetal will show deflection upon changes in temperature. Now, this bimetallic spring is so designed that the deflection in the bimetallic spring is equal and opposite to the additional deflection caused in this pressure element due to change in ambient temperature. Then it is possible to compensate for the effect of ambient temperature in the pressure spring, and this is how case compensation is achieved.

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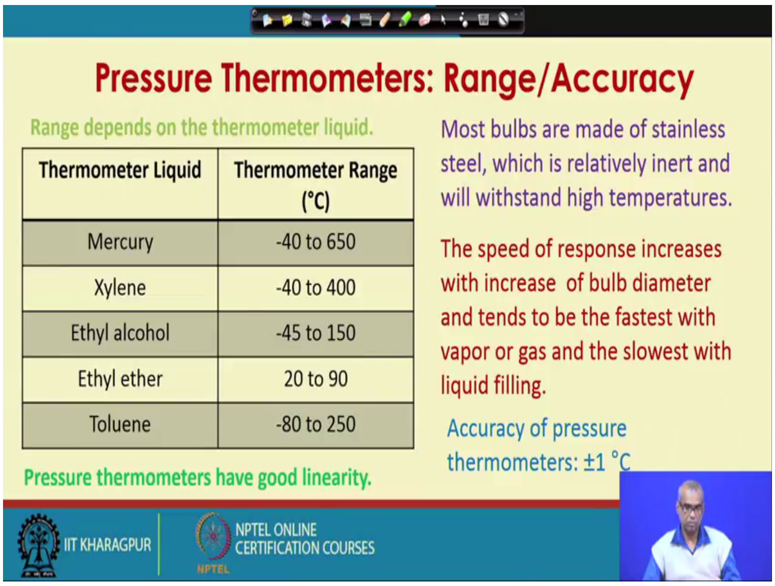

So, here are some of the thermometer liquids using pressure thermometer, mercury, xylene, ethyl alcohol, ethyl ether, toluene. The temperature ranges are indicated mercury thermometer can be used from minus 40 to 650 degree Celsius; xylene minus 40 to 400 degree Celsius and so and so forth. Note that when we want to use mercury for as I have

650 degree Celsius, you need to increase the pressure inside the thermometer bulb that means, the mercury filling will be done at higher pressure, so that the boiling point of the mercury increases.

So, the range can be extended beyond the normal boiling point only by filling the liquid at higher pressures. Most bulbs are made of stainless steels, which is relatively inert, and will withstand high temperatures. The speed of response increases with increases of bulb diameter, and tends to be the fastest bulb diameter and tends to be the fastest with vapor or gas and the slowest with liquid filling. So, later on we will talk about gas-filled thermometer or vapor filled thermometer, now we are talking about liquid filled thermometers. The speed of the response of vapor or gas-filled thermometer is more than compared to liquid filled thermometers. Accuracy of liquid filled pressure thermometers is around plus minus 1 degree Celsius.

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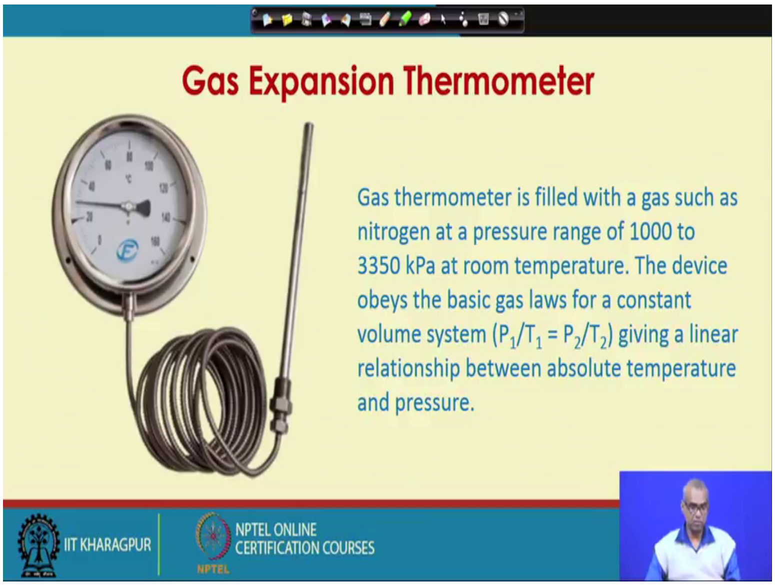

Now, let us talk about gas expansion thermometer. So, looks very much similar to liquid-in-metal thermometer the difference being instead of liquid filling we now have a suitable gas filling often times nitrogen is used. So, gas thermometer is filled with a gas such as nitrogen at a pressure range of 1000 to 3,350 kilo pascal at room temperature. The device obeys the basic gas laws for a constant volume system that is P by T is constant at a constant volume or P 1 by T 1 equal to P 2 by T 2, and this gives a linear relationship between absolute temperature and pressure. So, basic principle is that pressure divided by temperature absolute temperature is constant for volume being constant.

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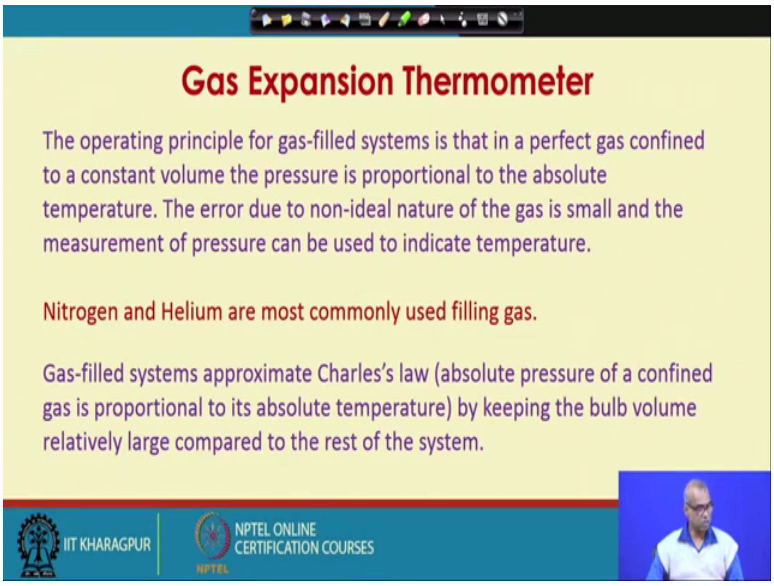

The operating principle for gas-filled systems is that in a perfect gas confined to a constant volume the pressure is proportional to the absolute temperature. The error due to non ideal nature of the gas is small, and the measurement of pressure can be used to indicate temperature. Nitrogen and helium are most commonly used filling gas. Gas-filled system approximate Charles's law absolute pressure of a confined gas is proportional to its absolute temperature by keeping the bulb volume relatively large compared to the rest of the system.

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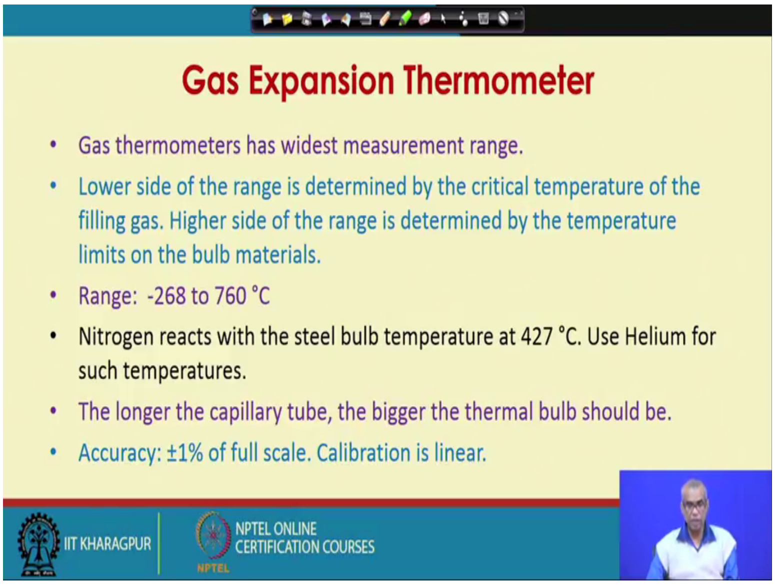

Gas thermometers has widest measurement range. The lower side of the range is determined by the critical temperature of the filling gas Higher side of the range is determined by the temperature limits on the bulb materials. You cannot exceed the temperature at which the bulb material will melt. Typical range is minus 268 to 760 degree Celsius. Nitrogen reacts with the steel bulb at a temperature of 427 degree Celsius. So, use helium for temperature of 427 degree Celsius or higher. The longer the capillary tube, the bigger the thermal bulb should be. Accuracy is about plus minus 1 percent of full scale. Calibration is linear.

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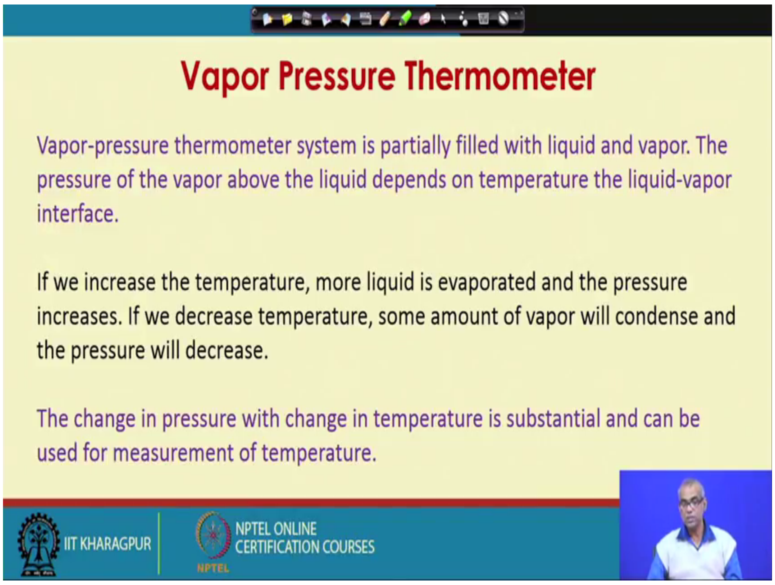

Now, let us talk about vapor pressure thermometer. Vapor pressure thermometer system is partially filled with liquid and vapor. The pressure of the vapor above the liquid depends on temperature of the liquid-vapor interface. So, vapor pressure thermometers is also similar to liquid or gas-filled thermometers, but there is some difference. In case of vapor pressure thermometer, the system is partially filled with liquid and vapor. The pressure of the vapor above the liquid depends on temperature at the liquid-vapor interface.

If we increase the temperature, more liquid is evaporated and the pressure increases. If we decrease temperature, some amount of vapor will condense and the pressure will decrease. The change in pressure with change in temperature is substantial and can be used for measurement of temperature. So, the basic principle that is used is that you take a volatile liquid, and the pressure will change with change in temperature, because the liquid-vapor equilibrium is a function of temperature at the liquid-vapor interface only.

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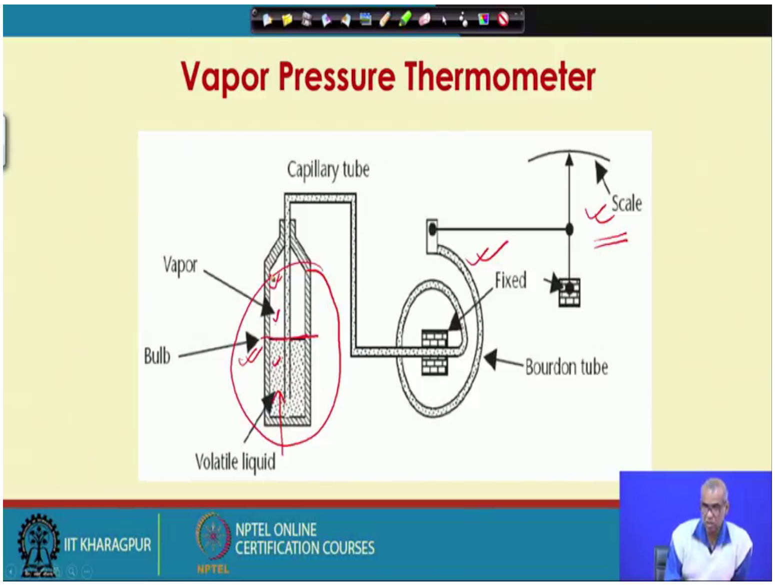

So, this is the schematic of vapor pressure thermometer. We have the bulb; inside, we have taken a volatile liquid, and you have the liquid and vapor interface in the bulb. If temperature increases, some amount of liquid will be evaporated, so the pressure will increase. So, the increase pressure will show increase deflection in the pressure spring which will led by this pointer and scale. If temperature is decreased, some amount of vapor will condense and the pressure will fall, so that will also indicated by movement of this pointer against this scale. So, it is the temperature that governs this vapor liquid equilibrium.

So, vapor pressure being a function of temperature at the liquid-vapor interface, we can measure the pressure to indicate the temperature at the liquid-vapor interface. So, you must put the bulb in the medium whose temperature we are measuring and ensure that the liquid-vapor interface exist within the bulb for the vapor pressure thermometer to wok correctly.

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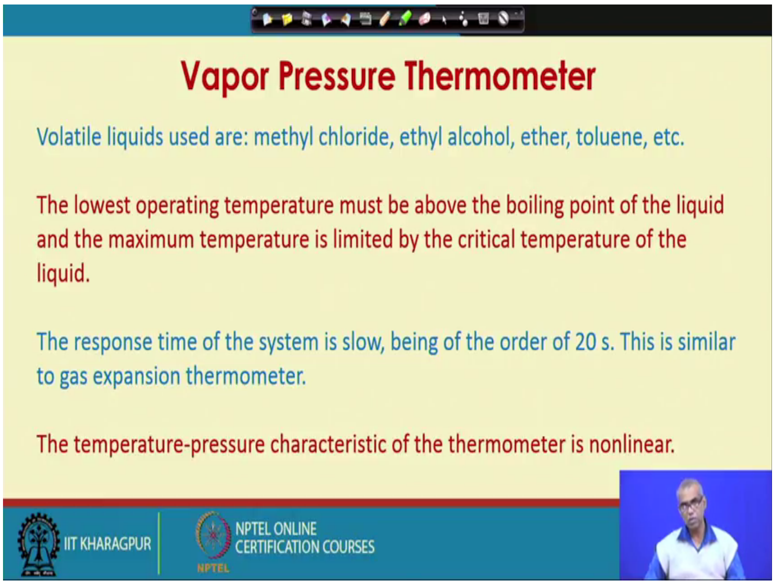

Volatile liquid used are methyl chloride, ethyl alcohol, ether, toluene etcetera. The lowest operating temperature must be above the boiling point of the liquid and the maximum temperature is limited by the critical temperature of the liquid. So, lowest operating temperature must be above the boiling point of the liquid otherwise there would not be any vapor liquid interface in the bulb. And the maximum temperature is limited by the critical temperature of the liquid. The response time of the system is slow, being of the order of 20 second. And this is similar to gas expansion thermometer. The temperature-pressure characteristic of the thermometer is non-linear. So, the calibration will be non-linear.

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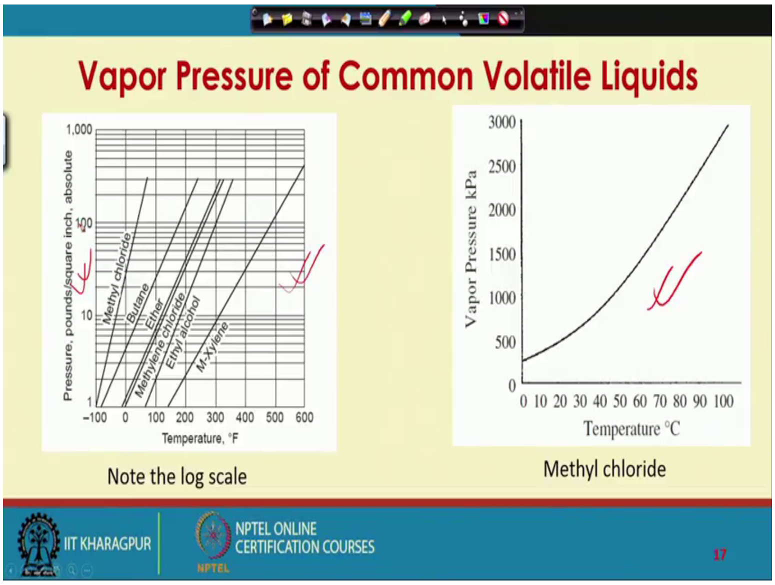

So, this a typical vapor pressure versus temperature relationship for methyl chloride. And here the temperature vapor pressure relationships are given for a set of volatile liquids such as methyl chloride, butane, ether, methylene chloride, ethyl alcohol etcetera. Note that this scale is logarithmic scale and that is why the plots look linear; otherwise the relationship is non-linear.

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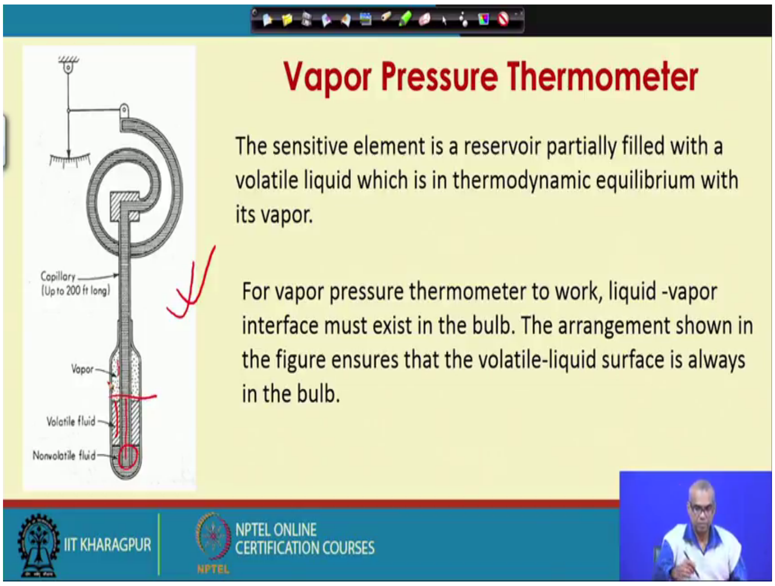

The sensitive element is a reservoir partially filled with a volatile liquid, which is in thermodynamic equilibrium with its vapor. This is for a vapor pressure thermometer. For vapor pressure thermometer to work, liquid-vapor interface must exist in the bulb. The arrangement shown in the figure ensures that the volatile liquid surface is always in the bulb. You note that we take a nonvolatile fluid here and we take a volatile fluid. So, you have this interface between volatile liquid and the vapor.

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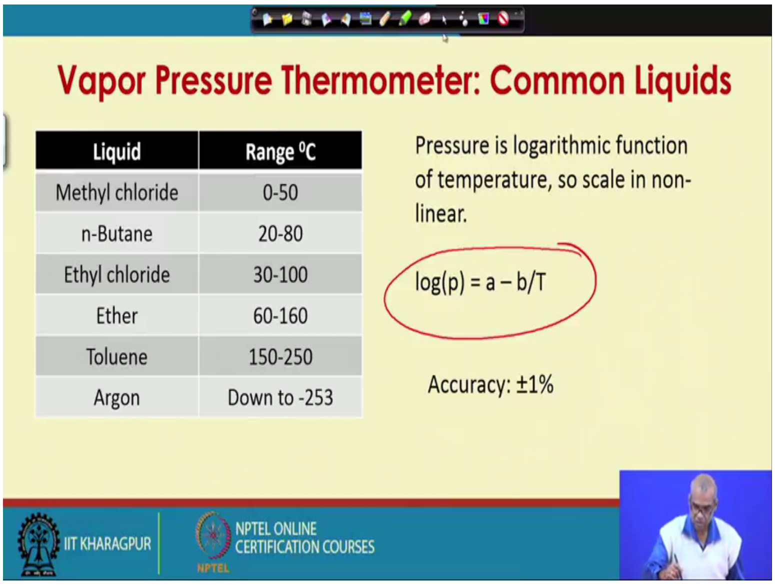

Here are some of the liquids in the vapor pressure thermometer along with the ranges. Note that the ranges are not very high on the higher side. Pressure is the logarithmic function of temperature, so the scale is non-linear. A typical relationship of vapor pressure with temperature is log P equal to a minus b by T. So, a non-linear relationship is indicated and a calibration curve will be non-linear. Accuracy is about plus minus 1 percent.

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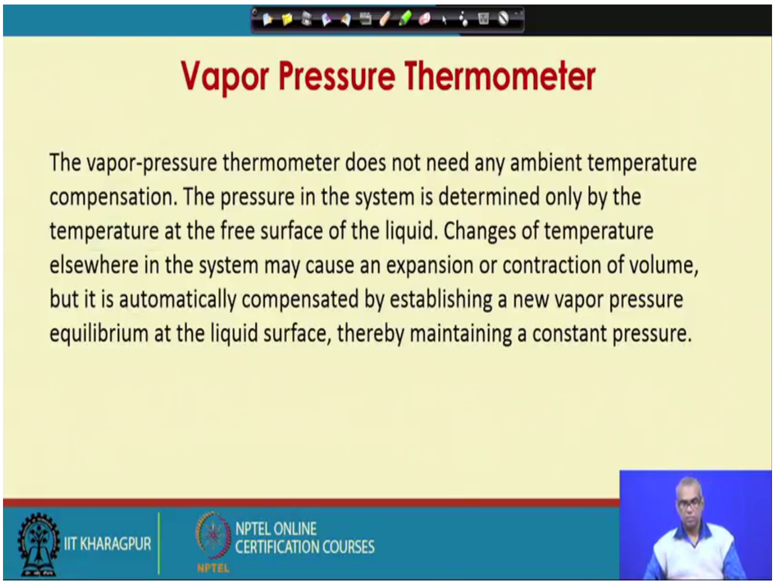

The vapor pressure thermometer does not need any ambient temperature compensation. This is a very important aspect of vapor pressure thermometer. The pressure in the system is determined only by the temperature at the free surface of the liquid. So, the vapor-pressure is governed only by the temperature at the liquid-vapor interface. Changes of temperature elsewhere in the system may cause an expansion or contraction of volume, but it is automatically compensated by establishing a new vapor pressure equilibrium at the liquid surface, thereby maintaining a constant pressure.

So, we will stop our discussion on liquid expansion thermometers here.