Chemical Process Instrumentation
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Lecture - 26
High Vacuum Measurement

Welcome to week 6, lecture 26, in week 5 we have started our discussion on pressure measuring instruments and during week 5 we have talked about measurement of moderate pressure as well as measurement of high pressure. So, in week 6 we will talk about measurement of high vacuum or measurements of very low pressures.

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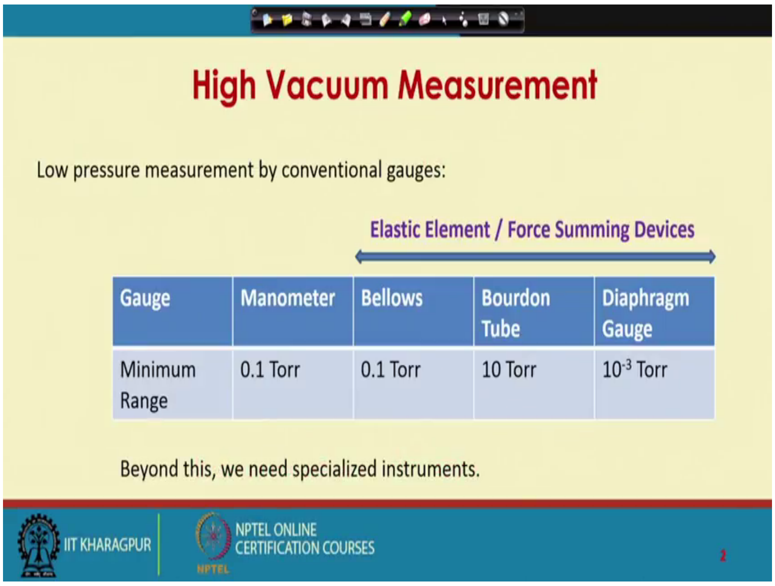

So, now we have talked about bellows, bourdon tubes, diaphragm gauges. If you visit any chemical process industry you will find that lot of pressure gauges are made of bellows, bourdon tubes and diaphragm gauges; one reason may be that most of the operations will take place at moderate pressures. So, bellows, bourdon tubes and diaphragm gauges will find wide application in chemical processes industries as pressure measuring element. These are all elastic elements these are also called force summing device.

Now, bourdon tubes, bellows and diaphragm gauges are primarily meant for measurement of moderate pressures, but they also can be used for measurement of low pressures, but they are not suitable for measurement of very low pressure or high vacuum. Now if you look at indicative range a manometer can measure up to point 1 torr minimum range..

Similarly minimum range, for bellows will be again above 0.1 torr, bourdon tube may be up to 10 torr and diaphragm gauge can go further down up to 10 to the power minus 3 torr. But beyond these we need specialised instruments. So, the purpose of this week is to know about such specialised instruments.

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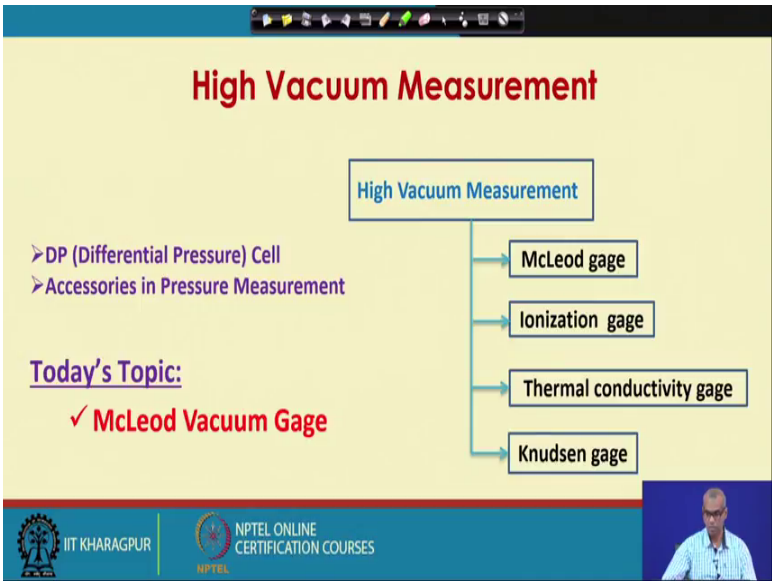

So, for measurement of high vacuum or measurements of very low pressures, we will talk about McLeod gage, Ionization gage, Thermal conductivity gage, Knudsen gage. In addition to that in this week we will also talk about differential pressure cell or DP cell which is an important instrument for the purpose of measurement level measurement etcetera, and we will also talk about few accessories in pressure measurement such as diaphragm seal etcetera.

Now, today's topic is McLeod vacuum gage.

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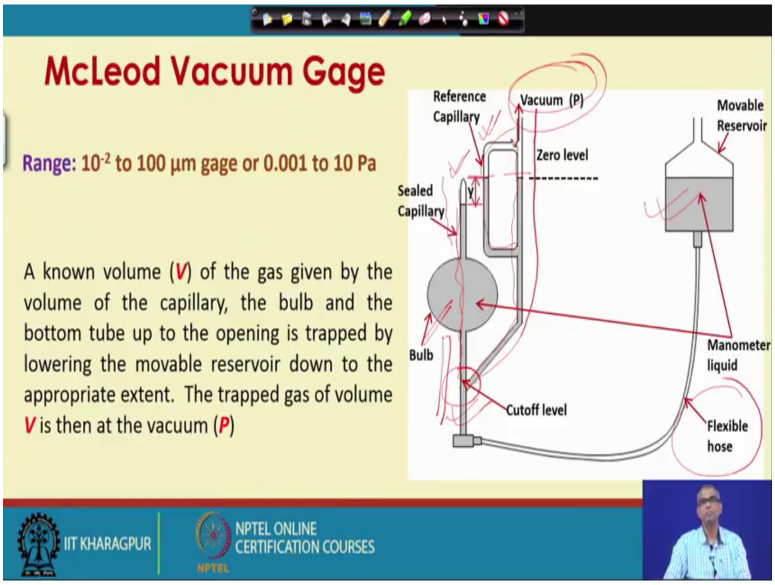

Mcleod vacuum gage is essentially a modified manometer. So, look at the construction of the McLeod gage, this consists of a tube which is sealed at this end, this is a bulb and again a tube is attached. Another tube is connected and the fluid whose pressure I want to measure that vacuum source is attached here. So, there is a reference capillary attached here look at the construction, if there is up fluids such as mercury a manometer liquid is inside the level here and the level here will be same..

Now this tube is connected to a movable reservoir of mercury or the manometer liquid by a flexible tube or flexible hose. Please note that when the mercury level goes down this point the branching point and if this is connected to the vacuum source this entire thing is now exposed to the same vacuum..

So, the McLeod gage works as follows..

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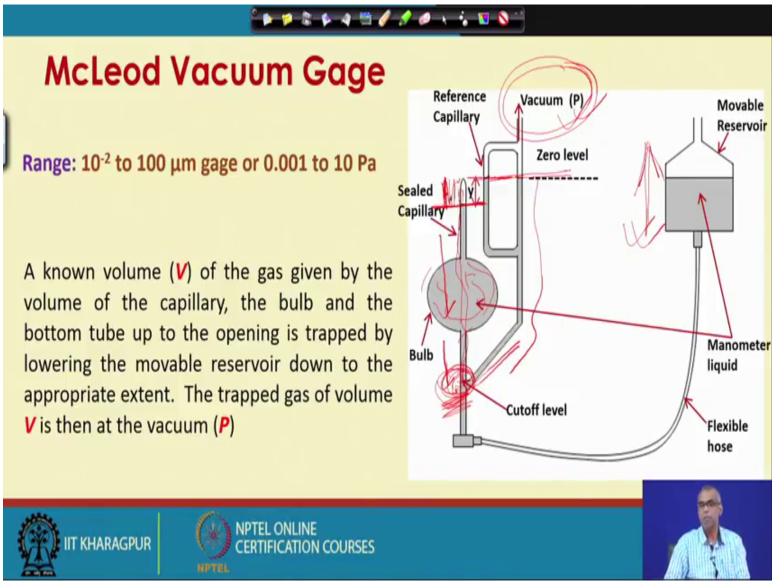

We first adjust this level of the movable reservoir. We bring down the movable reservoir so that the mercury level here goes down and goes down this point let us say it comes here, goes down the branching point. Before that I have connected this to the vacuum source..

Now this entire volume is connected to the this pressure or to the vacuum. Now I raise the movable reservoir and I raised it until the mercury level just comes here, it cuts off this part and just comes here, then I further raise it and stop when the mercury level matches with the 0 level in the capillary. So, there are basically 2 steps; first you bring down the reservoir so that, this goes below the branching point, then it slowly raise it the moment you come here it basically get cut off from this part, and then further you slowly raise it and then you stop, when the mercury level and the reference level matches the 0 mark..

Then the reading is y, which is the length of the fluid trapped in this tube that is my measurement. So, basically what you did is when I raise this sorry when I brought it down the mercury level when below this point. So, I had let us say a gas with this pressure or vacuum, then I slowly raise it and stop when this matches with the 0 mark, what I am basically doing now is I am compressing the same gas. So, the initial volume is this, final volume is this, from these I will be able to calculate the pressure so, let us see how.

The typical range of a McLeod gage is 10 to the power minus 2 to 100 micrometre gage or 0.001 to 10 Pascal. The working principle I will repeat and is as follows, a known volume v of the gas given by the volume of the capillary the bulb, and the bottom tube up to the opening is trapped by lowering the movable reservoir down to the appropriate extent the trapped gas of the volume V is then at the vacuum P this is what we explain.

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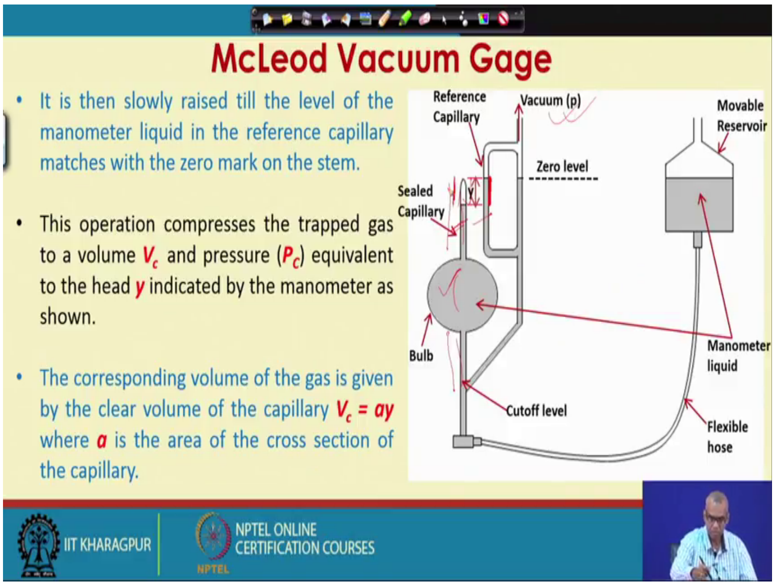

Now, the movable reservoir is slowly raised till the level of the manometer liquid the capillary reference matches with the 0 mark on the stem. This operation compresses the trapped gas to a volume V c and pressure P c equivalent to the head Y indicated by the manometer as shown. So, initially I had the volume of the gas as the volume of this tube, the volume of the bulb as well as the volume of the tube up to this point, and the pressure of that gas was same as the vacuum..

Now when I raise the movable reservoir and come up to this 0 mark here, the volume of the gas in the sealed capillary is y. So, basically I am compressed the gas of the previous volume up to this volume, and the pressure after compression is indicated by the head y. We represent the volume of the compressed gas as V c and the pressure of the compressed gas as P c which is equivalent to the head y head y indicated by the manometer in the figure.

The corresponding volume of the gas is given by the volume of the capillary of V c into a V c equal to a into y where a is area of the cross section of the capillary. If you take if you can take the cross sectional area of this and this same, if it is a then the volume is V c ay or if the cross sectional area of this tube is a this part is y. So, volume V c is ay.

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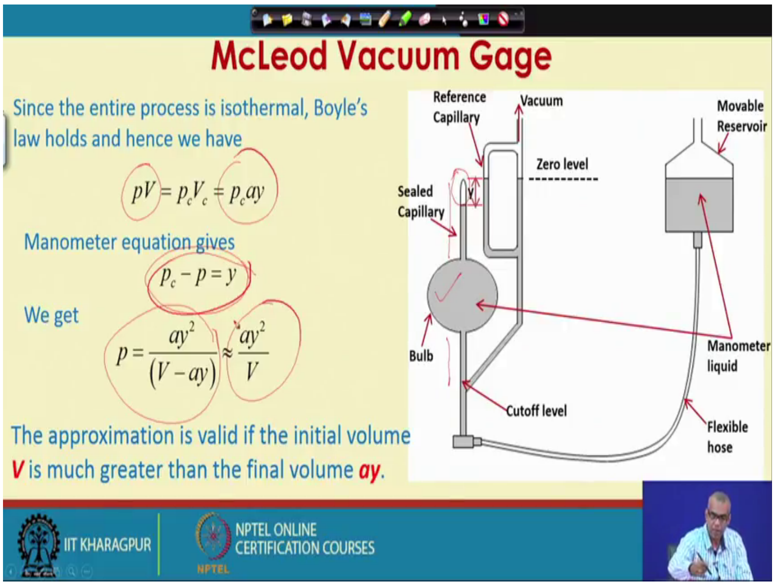

Since the entire process is isothermal Boyles law holds, and hence we can write p 1 v 1 equal to p 2 v 2 relationship. So, if you will write p into v which is the p is pressure before compression v is the volume before compression. So, p V equal to P c into V c V c we know as a into y and from manometer equation we can write as the head is expected as y P c minus P is y. So, you make use of p V equal to pc into ay and P c minus p equal to y you combine these I will get this equation which says p equal to a y square divided by v minus ay.

V is the volume of the gas before compression. So, that consists of volume of this capillary volume of this bulb as well volume of the tube up to this point, and ay represents the volume only for this much. So, v is much much greater than y. So, this can also be approximated as ay square divided by V; the approximation is valid if the initial volume v is much greater than the final volume y which is usually true.

Note one thing in this equation the pressure is expressed as ay square by V or p equal to ay square divided by V minus a into y. Now a y v all represents dimensions of the McLeod gage. So, the pressure is expressed in terms of dimensions of the McLeod gage. So, that is why McLeod gage can measure pressure very accurately..

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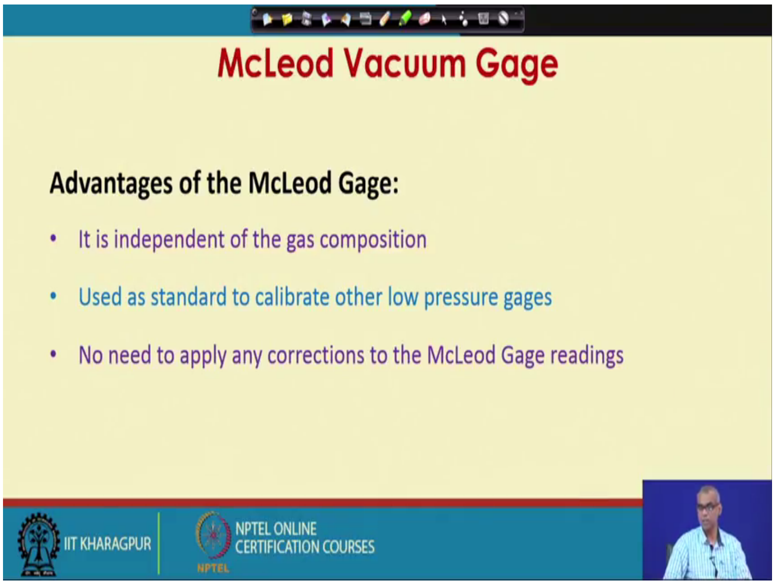

Advantages of the McLeod gage; it is independent of the gage composition sorry it is independent of the gas composition this is the point I was talking about that the pressure is measured in terms of dimensions of the McLeod gage. No property of the gas is present in the equation. So, the measurement is independent of the gas composition. Use as standard to calibrate other low pressures McLeod gage can be used as standard to calibrate other low pressure gages, there is no need to apply any corrections to the McLeod gage readings.

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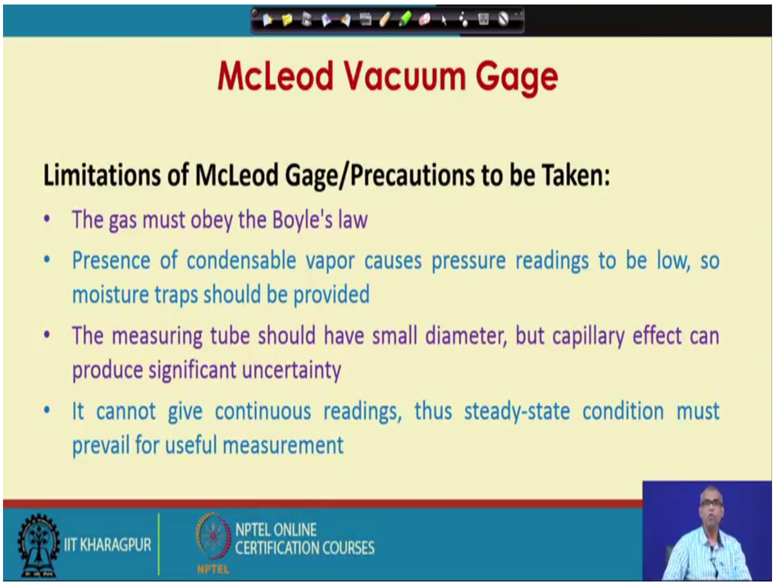

However there are some limitations of McLeod gage or you can also say precautions that are to be taken the gas must obey the Boyles law. Because the key state was product of pressure and volume before compression and after compression are equal which is Boyles law. So, gas must obey Boyles law. Presence of condensable vapor causes pressure readings to be low. So, moisture traps should be provided. So, presence of condensable vapor may cause problems..

The measuring tube should have small diameter, but capillary effect can produce significant uncertainty, if the diameter of the tube is very small. So, the tube diameter should be very small, but it should not be so small that there will be capillary effect to a significant extent. It cannot give continuous reading because operators help is required, operator service is required in (Refer Time: 17:46) for raising the movable reservoir bringing it down so on and so forth. Thus steady state condition must prevail for useful measurement.

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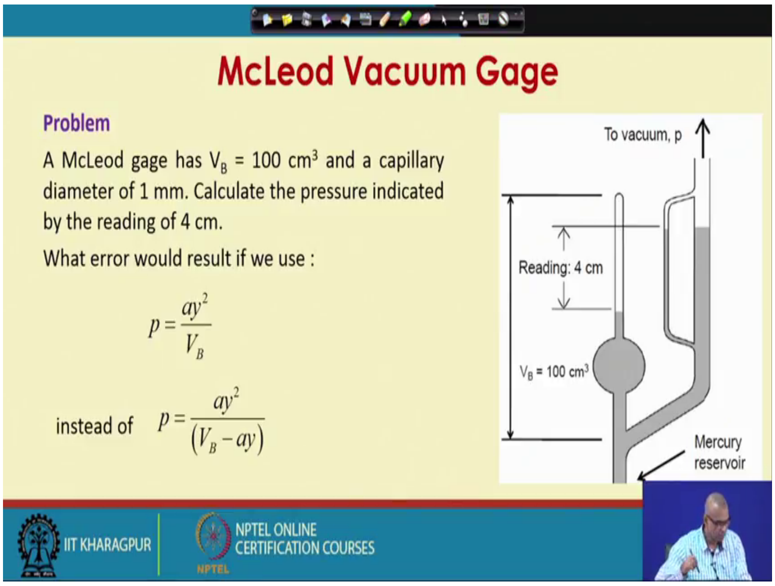

Let us now look at a simple problem for McLeod. Vacuum gage a McLeod gage has volume of bulb as hundred centimetre cube and capillary diameter 1 millimetre. So, this diameter is 1 millimetre, calculate the pressure indicated by the reading of 4 centimetre. So, this is the reading. So, this is the 0 mark in the reference capillary. So, we have this is that y in our previous derivation. So, we can make use of the previous equation that we have derived to calculate p..

So, once again the McLeod gage has V B equal to 100 centimetre cube, and a capillary diameter of 1 millimetre we calculate we want to calculate the pressure indicated by the reading of 4 centimetres, and we also ask that if I use p is equal to ay square by V B instead of p equal to ay square by V B minus ay what error would result, because this is an approximation to this. So, we want to know how much there will be error.

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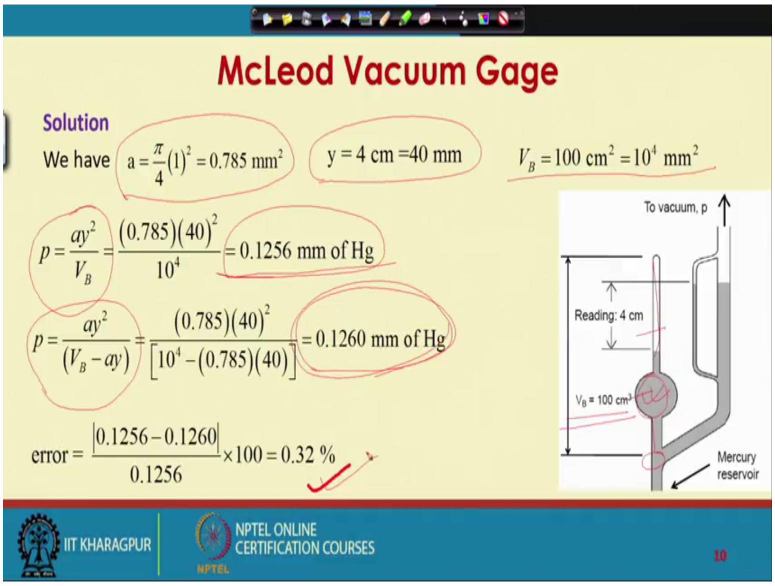

So, to calculate the cross sectional area of the capillary tube from the given diameter make use of pi d square by 4 relationship, and you get a as 0.785 millimetre square, y is given as 4 centimetre. So, 4 millimetre here V B as the diagram shows V B equal to hundred centimetre and that V B is not only about the bulb, but also includes the volume of the capillary volume of the bulb as well as volume of the tube up to this branching point. So, V B includes this volume of the bulb as well as volume of the tube down up to branching point. So, V B equal to v in our previous equation.

So, if I make use of p equal to ay square by V, I get after putting all the values 0.1256 millimetre of mercury. V B is given as 100 centimetres square everything we are talking about millimetre. So, express 100 centimetre square as 10 to the power of 4 millimetre square. Now let us use p equal to ay square by V B minus ay equation again put the all values and you get 0.1260 millimetre of mercury.

So, difference is not much here it is 0.1256 millimetre of mercury given by the approximate equation and given by the original equation it is 0.1260 millimetre of mercury. So, you can find out the error as 0.1256 minus 0.1260 divided by 0.1256 which is 0.32 percent. So, you do not invite much error by that approximation. So, we stop our lecture 26 here.