Experimental Methods in Fluid Mechanics
Professor Pranab Kumar Mondal
Department of Mechanical Engineering
Indian Institute of Technology Guwahati
Lecture 13
The McLeod gauge, The Pirani gauge, The Ionization gauge Contd.

Good afternoon, I welcome you to this session of Experimental Methods in Fluid Mechanics.

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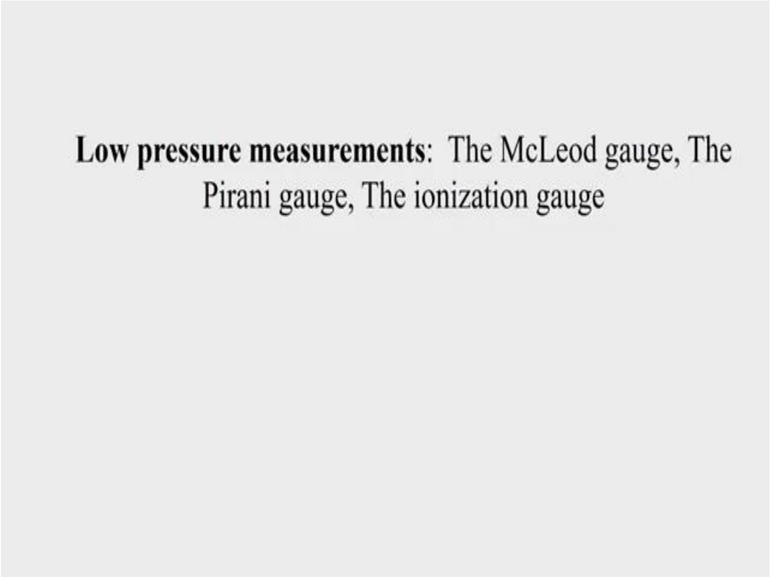

And today in continuation of my last lecture on low pressure measurements, we will discuss today the operational principle of the Pirani gauge and the Ionization gauge. And then finally, we will walk out to a numerical problem on the McLeod gauge and how we can measure the very low pressure that is what we have discussed. So today, we will discuss about the operational principle of it of the Pirani gauge.

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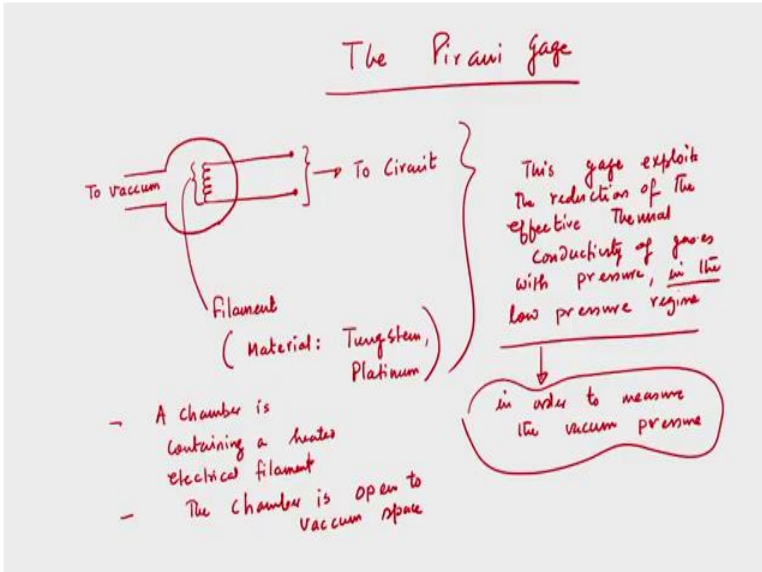

So, we are writing the Pirani gauge. So, this is also used to measure a very low pressure. And now we will see with a schematic depiction that how we can measure low pressure and if you would like to measure low pressure using this instrument, what are the steps we need to follow and, of course, what are the precautions we need to consider while using this device. So, now, I will draw a schematic diagram then perhaps from the schematic diagram, rather, perhaps the schematic diagram will help us to understand the operational principle of this instrument in a better way. So now, I will draw a schematic depiction of the Pirani gauge.

So, this is a schematic depiction of Pirani gauge that it is having a chamber, the chamber is not closed one, it is open and one side of the chamber is you know open to the vacuum that is low pressure that is what we would like to measure it and one filament that is there inside the chamber and the you know two ends of the filament which are connected to a circuit and the filament material is tungsten or many a time we are using platinum as the filament material.

Now so, this is a typical diagram, a typical depiction of Pirani gauge. Now, this Pirani gauge is used to measure low pressure and while we are using low pressure using this device, it exploits reduction in the, you know, effective thermal conductivity of the you know gas which is at a low pressure. So, I can write that that this gauge exploits the reduction of the effective thermal conductivity of gas or gases with pressure in particular in the low pressure region.

So, effective conductivity of the gas will be reduce, we will see how and then if the effective conductivity of the gas is reduced, then how can we measure pressure because the conductivity will reduce with pressure in particular in the low pressure region, in the low pressure region, because I am using this sentence in the low pressure reason, because at a high percent the change in thermal conductivity with a change in pressure may not be you know captured correctly, so we may not come up with a you know correct measurement of the pressure that is what we are going to measure.

Now this low pressure basically, in the low pressure region that means in order to measure the vacuum pressure that means in order to measure the vacuum pressure. So that is our objective is because a very low pressure that is what we are trying to measure using this gauge. So, the conductivity of the gas very low pressure region will be such that we can measure it that is the objective is.

Now, what we can see from the schematic let me write again, from a schematically see that a chamber we have and this chamber is containing a heated electrical filament. So, a chamber which is containing a heated electrical filament and chamber is open to a vacuum space. So this is, and the chamber is open to vacuum space that is clearly seen from the schematic itself. So, now the filament is connected to the circuit and that is elliptical filament.

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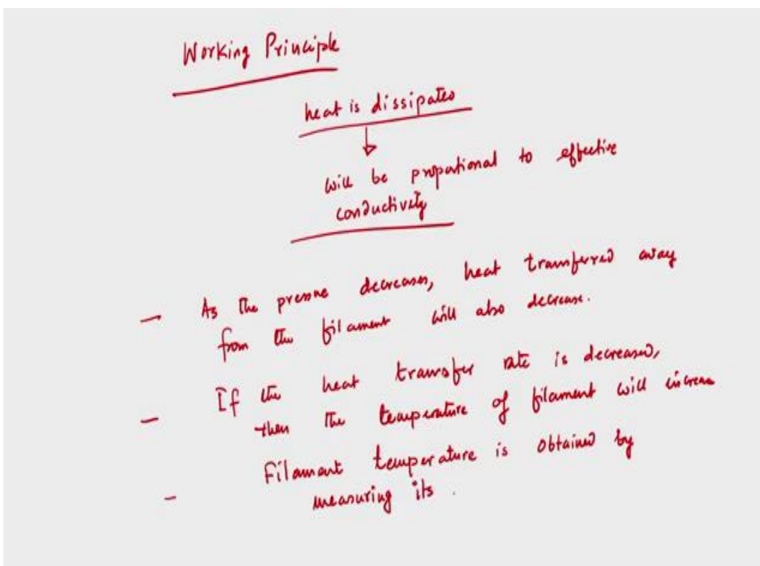

Now, I am writing next that heat dissipated rather through the filament, heat is dissipated and this heat which is dissipated is rather will be that is what we need to calibrate will be proportional to thermal conductivity or effective conductivity. So, if we now connect the filament that is with a electrical circuit, whenever current is passing through the filament then heat will be dissipated because of the electrical bulb, now that will be converted to the heat and that heat will be, heat is dissipated and that dissipated heat which will be proportional to the effective conductivity.

Now, as the pressure decreases, heat transferred away from the filament will also decrease. So, this is now we are writing the operational principle or working principle, I can write the working principle. So, heat is dissipated that dissipated heat will be proportional to the effective productivity, now, as the pressure decreases, then the heat transferred from the filament because the dissipated heat will be transferred from the filament to the gas and that will decrease if the pressure decreases.

Now, if the heat transfer rate is decreased, then it is common that the filament temperature will increase, then filament temperature increases then the temperature of filament will increase and this filament temperature need to measure. So, that means, if I allow current to pass the filament, there will be electrical work that will be converted to the heat, heat will be dissipated, the dissipated heat will be proportional to the effective conductivity.

And the moment when heat dissipation starts, the heat will be transferred away from the filament and that will be taken by the gas. Now, if the gas pressure becomes less, then that transferred heat, the amount of heat being transferred will also be you know lesser and in a way that means there is no medium to take the heat away from the filament which will eventually results in an increment of filament's temperature.

Now, if the temperature of the filament increase, then we need to measure it and that will essentially gives us an indication of the pressure which is being reduced, I mean that is a change in pressure. So, this filament temperature is measured by measuring is obtained, I can say measured I can say obtained by measuring its resistance in a bridge circuit. If we can measure the temperature, rise in temperature of the filament using a bridge circuit, which is connected to bridge circuit that is what we have shown in the schematic.

Then by knowing the change in temperature of the filament we can correlate that what is the pressure, I mean change in pressure and that too in the low pressure region that is what is the operational working principle of this gauge, the Pirani gauge. So, essentially a change in temperature of the filament which is recorded by the bridge circuit will gives us an information about the change in pressure inside the chamber and that too in the low-pressure region and by how we can measure a very low pressure.

One important thing that should be mentioned in this context that, since you are going to measure pressure or a change in pressure, gauge pressure of course, and that is very less. So, the measurement is based on the indirect measurement of the pressure that is the change in pressure inside the chamber is obtained indirectly because of change in the filament temperature and that is recorded by the bridge circuit.

So, we need to mention that the environmental temperature effect may sometimes leads to you know error in the results which you are getting from this gauge. So, that is what now I should tell you but I will write that environmental temperature effect on this measurement may trigger error in the results so that aspects should be taken into account.

And I am not going to discuss in detail how we can take care of that effect. But normally what is done, similar kind of two chambers are connected in series; one is open other is closed and to nullify the effect that might affect the measurement of the low pressure using this device. Now, from this discussion, we can see that Pirani gauges require calibration, I mean that is very important.

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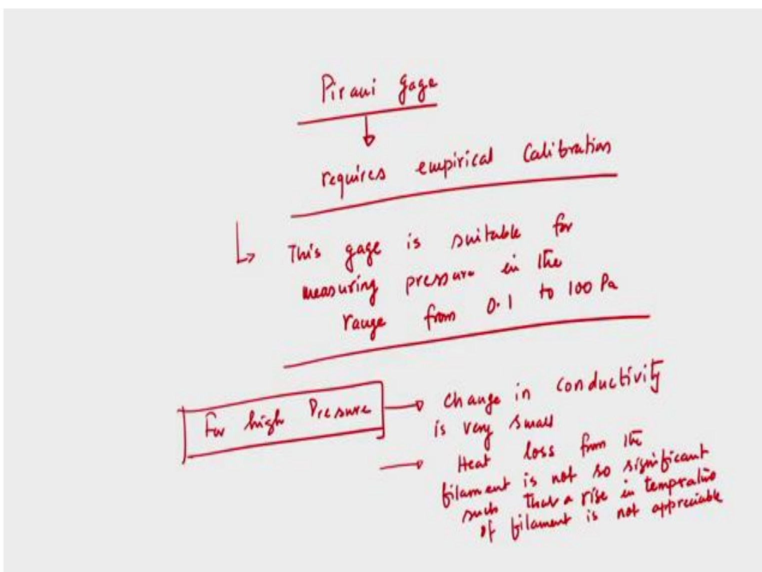

So that means, this Pirani gauge, this gauge requires empirical calibration. So, without calibration we cannot measure because that is what I have discussed now that by with a change in temperature of the filament, we can measure a change in pressure inside the chamber. So, that issue requires empirical calibration rather Pirani gauge requires empirical calibration and this gauge is suitable for measuring a very low pressure, and this gauge is suitable for measuring pressure in the range from 0.1 to 100 Pascal.

So, this gauge is suitable for measuring pressure in the range from 0.1 to 100 Pascal and that requires empirical calibration. While we are discussing about the working principle of this gauge we also should discuss about the limitation and what are the possible sources of error which, if we do not take care all those, we may finally arrive at with the wrong prediction.

So, now, a question which may arise that is this gauge not applicable for the high pressure. Why you cannot measure high pressure using this gauge? Because this of course, this is obvious that this gauge is you know pertinent to measure a very low pressure which is that is in the range of 0.1 to 100 Pascal, but cannot we measure a relatively high pressure using this gauge? If we cannot, why we cannot? So, I would like to discuss a few points for that aspect.

Say, what will happen for high pressure? So, for high pressure we have understood that essentially a change in conductivity of the gas, thermal conductivity that each important to measure the change in pressure and that too in the low pressure region because if the conductivity of the gas is very less, then perhaps we cannot measure, I mean the rise in temperatures of the heater of the filament will increase and if that increase, then we can measure the temperature by a bridge circuit and from there we can correlate through the empirical relationship calibration what will be the pressure in the low pressure region.

Now for low high pressure you know the change in conductivity is very small. So for high pressure, change in conductivity is very small. And if the change in conductivity is very small because essentially a change in conductivity rather reduction in thermal conductivity with gas that is the key theme of measuring low pressure using this gauge. Now, if that is the case then heat loss from the filament is not so significant such that rise in temperature of the filament such that rise in temperature of filament is not appreciable.

So, this is very important that because of the conductivity change of the gas it is really less, then perhaps the heat lost from the filament is not significant. So, because there should not be no any heat transferred by the gas so conductivity is very less. So, the rise in temperature of the filament is not appreciable that will be measured captured by bridge circuit so that we can measure the pressure.

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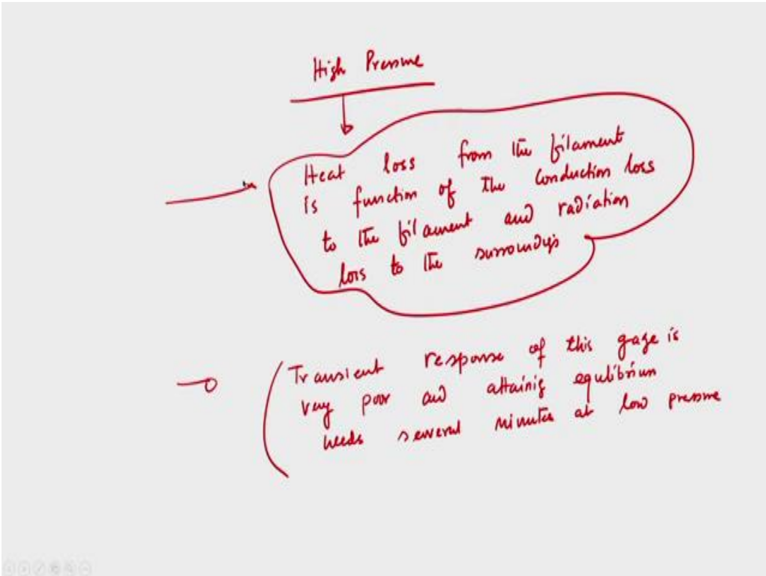

So the high pressure issue high pressure, so heat loss from the filament is function of the conduction loss, heat loss from the filament is function of the conduction loss to the filament and radiation loss to the surroundings. So, this is the issue that heat loss from the filament is function of the conduction loss to the filament and radiation loss to the surroundings that means for the high pressure the change in conductivity is very less right change in conduction is very less very small.

And since the heat loss from the filament in that case becomes function of the conduction loss and also up to the filament and also radiation loss to surroundings. So, that means, for the high pressure we cannot measure because for the high pressure which that means this is very important to know that there will be a significant change in the conduct, you know conductivity thermal conductivity of the gasses, otherwise we cannot measure low pressure using this device.

And for the high pressure this conductivity of the gas is not so significant that we can measure the change in pressure using indirectly by measuring the temperature of the filament, in that case temperature of the filament will not mean that, there will not be an appreciable change in the temperature of the filament. So that we can record using bridge circuit effectively, we will not be able to capture the change in pressure correctly. So this is what is the restriction of this device.

And another important is that the transient response of this device is very poor, because this we should know that you know transient response of this gauge is very poor and attaining equilibrium needs several minutes at low pressure. So, this is another important point that I would like to discuss that the transient response of this gauge is very poor because if you need to attain equilibrium which requires several, I mean several minutes at the low pressure.

So, it cannot give us a transient response that means, if we would like to measure a change in pressure, so measurement of a change in pressure, transient measurement of a change in pressure is not, this gauge is not appropriate for the transient measurement of a change in pressure because the working principle by which the gauge works, which requires several minutes time to reach at the equilibrium at low pressure.

Otherwise, we will not get the correct result, it will continuously fluctuate. So, these are the restrictions, limitations of this gauge. And typically this gauge is used to measure a pressure which is that is what I said that from 0.1 to 100 Pascal. And again I am telling, whoever will be using this gauge to measure low pressure, of course, in the region of low pressure he or she needs to use this very cautiously. And not only that, because we need to measure everything correctly otherwise, we will not get the result correct, we will not get the perfect results.

So with this, we have discussed about two gauges which are used to measure low pressure; first one I have discussed in my last lecture that is the McLeod gauge and today I have discussed about the Pirani gauge, and both these gauges are used to measure low pressure. And we have discussed about their working principle, also we have discussed about their, you know, about the limitations, about the restrictions of using this device in measuring pressure.

Now, today we work out on your vehicle problem on the McLeod gauge that is what we have discussed in the last lecture. Now, McLeod gauge if you can recall that you have used, you have seen that this gauge is also used to measure a very low pressure, I mean in the region of low pressure that is what we have discussed. And this McLeod gauge again if you can recall that the reading in the capillary tube, if you can recall that is what we have discussed clearly.

That we can have the moment of the rather reservoir and by having moment of the reservoir we can bring, we can alter the level of the mercury in the capillary and reference capillary. And by taking by allowing the vacuum pressure, very low pressure into the system then again if we try to bring the reservoir in its original position then we can measure the low pressure. Now, today we will work out one numerical problem and for that and let me write the problem statement then we will see how we can work.

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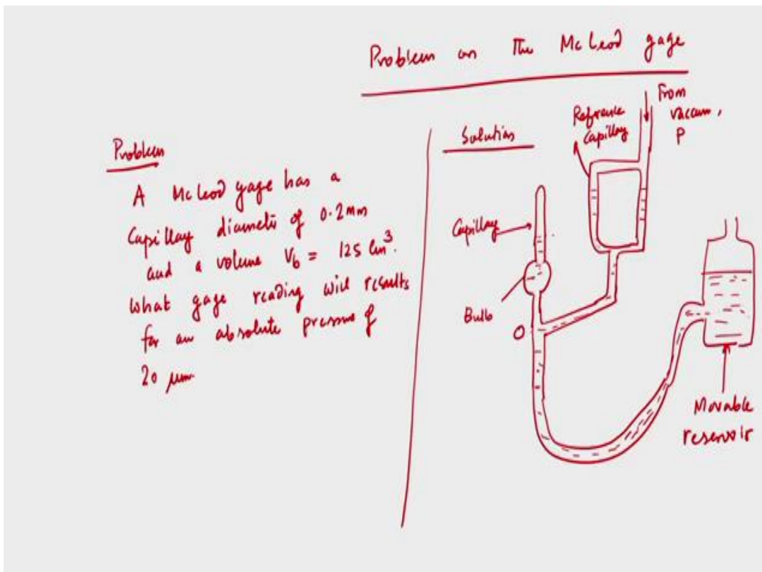

So the problem on the McLeod gauge. So, I am writing one numerical problem, a McLeod gauge has capillary diameter of 0.2 millimeter and a volume that is bulb volume, volume V b is equal to 125 centimeter cube. Now question is, what gauge reading will result for an absolute pressure of 20 micron. So, a McLeod gauge has a capillary diameter 0.2 millimeter and a volume V b that is the bulb volume. If we try to recall the schematic of the McLeod gauge, then this V b is the bulb volume 125 meter cube, then we need to calculate what gauge reading will result for an absolute pressure of 20 micron, results for an absolute pressure of 20 micron.

So this is the question, now we have to solve this problem. So, now we will try to solve, but for that at least it would be nice if we try to just recall the schematic of the gauge and it will help us to understand the problem in a better way. So now, we have seen that we have this small capillary then we have kind of thing and then just I am trying to draw the schematic. This is not again at per scale, and this is from vacuum and this is P and this is the close end capillary that is now and sat this is the mercury and this is connected to one movable reservoir.

So, this is movable reservoir and this is bulb, this is capillary and this is reference capillary, and this is opening O, if I can recall. Now, this is what we have discussed in the last class that they are personal, the working principle of this McLeod gauge. Now the problem is very easy, now if you would like to solve this problem.

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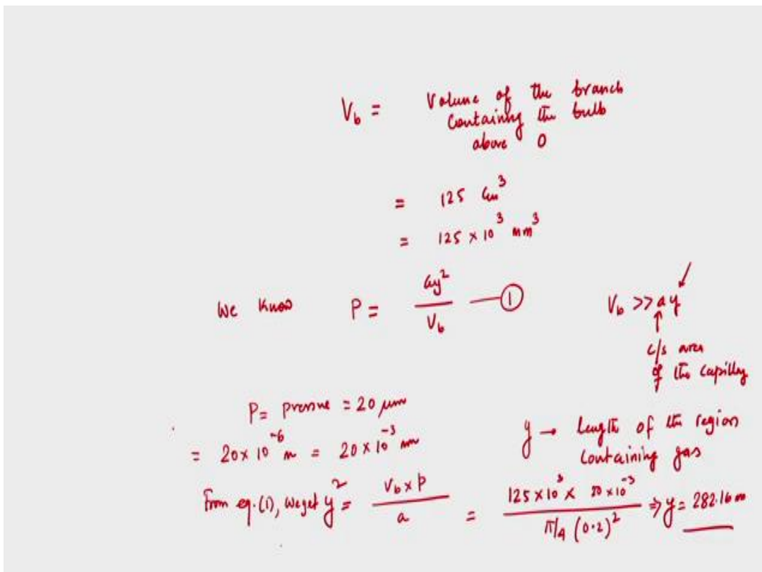

For this problem, the volume V b, the V b essentially if you can recall the V b essentially, the volume of the branch containing the bulb that is what we have discussed in my last lecture, this is the volume of the branch containing the bulb above O. So, volume of the branch containing the bulb above O, so this is the V b. So, that means there are two different branches; one is with the capillary, other is connected to the reference capillary. Now, V b is the volume of the branch which contains so that containing the bulb above O.

Now, V b is given that is 125 centimeter cube and that is 125 into 10 power cube millimeter cube. Now, we know from our previous lectures I mean from my previous lecture we know that the pressure P is a y square by V b. And to arrive at that expression we have assumed that the V b that is if you can recall, we have discussed that the V b is much smaller than a y that is the length of the mercury continuing in the capillary that is a y that is a is a cross section area that pains V b is much larger than a y, a is the cross section area of the capillary, and y is the capillary distance that is what we would like to measure right, y is the capillary distance.

Length of the region contained the gas, length of the region containing gas is y. So now, that is what we have to measure, I mean y we need to measure. So, y is the length is very important, y is the length of the region containing gas above the, that is what in the capillary. Now if and that relationship we have derived. Now, we need to know if we look at the question that what gauge reading will it results for an absolute pressure of 20 micron that means, P is given that pressure of 20 micron that 20 into 10 power minus 6 meter and 20 into 10 power minus 3 millimeter.

So now, y we can directly get from this expression 1. So, from equation 1 we get y square is equal to V b into P divide by a. So, we can calculate 125 into 10 cube that is a V b and P that is the absolute pressure of 20 micron. Now, long back I told that these gauges are also many a times we can use, if you can recall that when I have discussed about the pressure measurement that how we can measure absolute pressure, gauge pressure we have defined.

And then we have discussed that we are many a times we are using this kind of you know, this aneroid barometer right, this aneroid barometer is advantage is that we have discussed that the measurement of the gauge pressure, which is sometimes I mean the absolute measurement is directly related to the measurement of gauge pressure that is what we have discussed now.

This is 125 into 10 cube into that is P is equal to 20. 20 into 10 power cube that is what we have written, 20 into 10 power minus 3 divided by a, a that is Pi buy 4 into 0.2 square because, it is given that 0.2 millimeter is the diameter of the capillary. So if I calculate it, we will get y is equal to 282.16 millimeter, so this is the gauge reading for an absolute pressure of 20 micron that is the beauty of this kind of gauges that I would like to measure absolute pressure I mean we can. So, for the measurement of 20 absolute pressure the gauge reading will be 286.16 millimeters.

So, now, if we know the gauge reading, from there again we can calculate what will be the absolute pressure that is what we have, we can measure using this kind of McLeod gauge. So, today to summarize, today we have discussed about another one type of you know low pressure measuring gauge that is the Pirani gauge. We have discussed about the working principle of the Pirani gauge.

Also discussed about the limitation of this gauge and also finally we have discussed about that if someone would like to use this gauge to measure pressure, which is in the region of low pressure then he or she should take special care while measuring the reading from the, to measure the temperature of the temperature change, since the change in temperature will directly give us the change in pressure within the chamber.

And finally, we have discussed rather we have solved one numerical problem on McLeod gauge from there that is we have seen how we can measure the absolute pressure in terms of measuring the length of the region containing the gas. So, this I stop my discussing today and we will continue our discussion in next class. Thank you.