Chemical Process Instrumentation
Prof. Debasis Sarkar
Department of Chemical Engineering
Indian Institute of Technology, Kharagpur

Lecture – 21
Pressure Measurement: Moderate and High Pressure Measuring Instruments

Welcome to lecture 21. So, this is the first lecture for week 5. We will talk about pressure measuring instruments in this week.

Measurement of pressure is a very common requirement in chemical process industries their process operations which take place at moderate pressures. In fact, we can say that most of the operations will take place at moderate pressures. But there are process operations which will take place at high pressures and their operation which take place at low pressures or vacuum. For example, there are several chemical reactions which takes place at high pressure. For a sensitive material we can carry out a vacuum distillation for separation. So, it happens at low pressures, lower than atmospheric pressure. For multiple effect evaporators the last effect we can operate under vacuum.

So, in a chemical process industry we will be require to measure moderate pressures, high pressures, low pressures, pressures at all levels. So, in this week as well as in the following week we will be talking about several pressure measuring instruments.

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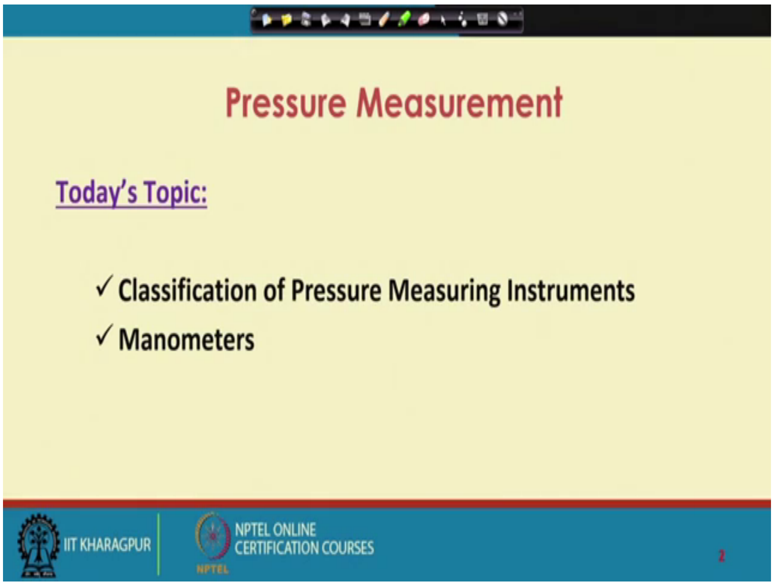

So, today we start our discussion on pressure measuring instruments. So, in today's lecture we will concentrate on classification of various pressure measuring instruments and we will also talk about manometers which are very common pressure measuring instruments, very commonly used in laboratories.

So, before we start talking about pressure measuring instrument let us be familiar with certain terms associated with the pressure measuring instruments. So, will be familiar first with various units of pressures and we will also be familiar with various terminologies such as absolute pressure gauge pressure so and so forth. So, pressure is nothing, but force per unit area.

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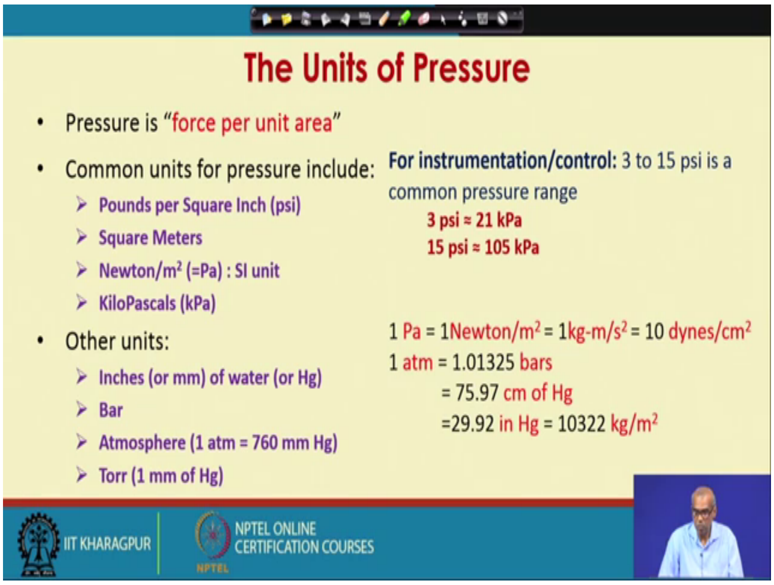

Common units for pressure include pounds per square inch which is briefly known as psi square metre Newton per metre square which is Pascal and SI unit of pressure. You may also have kilo Pascals one Pascal is equal to 1 kilo Pascal is equal to 1000 Pascals.

There are other units such as inches of water or inches of mercury millimetre of water or millimetre of mercury bar atmospheric pressure you know one atmospheric pressure is equal to 760 millimetre of mercury at sea level. Torr is another units of pressure, torr is equal to 1 millimetre of mercury. For instrumentation and control we use pressures in the range of 3 to 15 psi. So, this is used for pneumatic control systems. 3 psi is about 21 kilo Pascal and 15 psi is above 105 kilo Pascal. 1 Pascal is 1 Newton per metre square which is equal to 1 kg metre per Second Square which is equal to 10 dyne per centimetre square. 1 atmosphere is 1.01325 bars is equal to 75.97 centimetre of mercury, commonly say as 76 centimetre of mercury is equal to 29.92 inch of mercury we commonly say 30 inch of mercury which is equal to 10322 kg per metre square. So, please be familiar with these various units of pressures.

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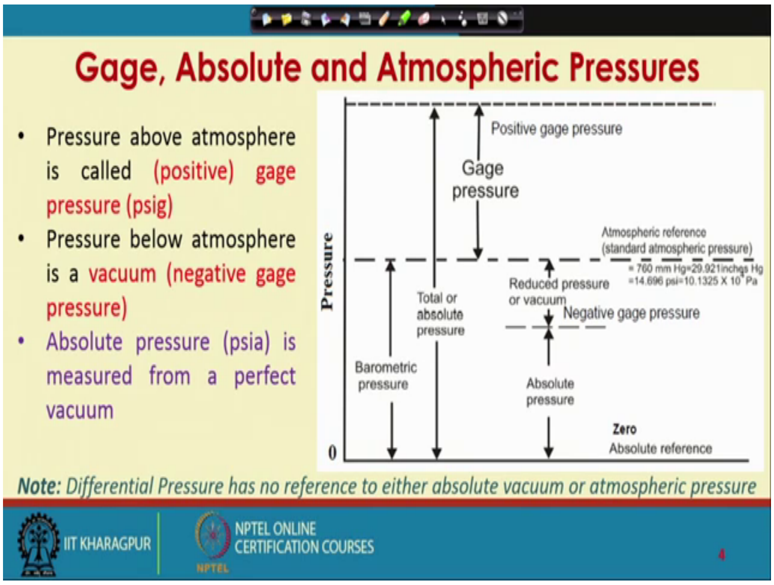

Now, let us define the terms gauge pressure, absolute pressure, atmospheric pressure so on and so forth. Please look at the diagram. Let us say this is the atmospheric reference meaning this is standard atmospheric pressure. So, this pressure is positive gauge pressure equal gauge pressure. So, gauge pressure is above atmospheric pressure below atmospheric pressure is negative gauge pressure or reduced pressure also known as vacuum. If I now consider absolute zero as reference, so this pressure will be my absolute pressure. Note, this pressure is this much gauge pressure, but this much absolute pressure similarly this pressure which is this much vacuum with respect to atmospheric pressure, but this much absolute pressure because now zero is my reference.

So, pressure above atmosphere is called positive or gauge pressure expressed as psi g, pressure below atmosphere is vacuum or negative gauge pressure absolute pressure psi a is measured from a perfect vacuum; that means, zero pressure. Differential pressure which is the difference between two pressure sources has no reference to either absolute vacuum or atmospheric pressure.

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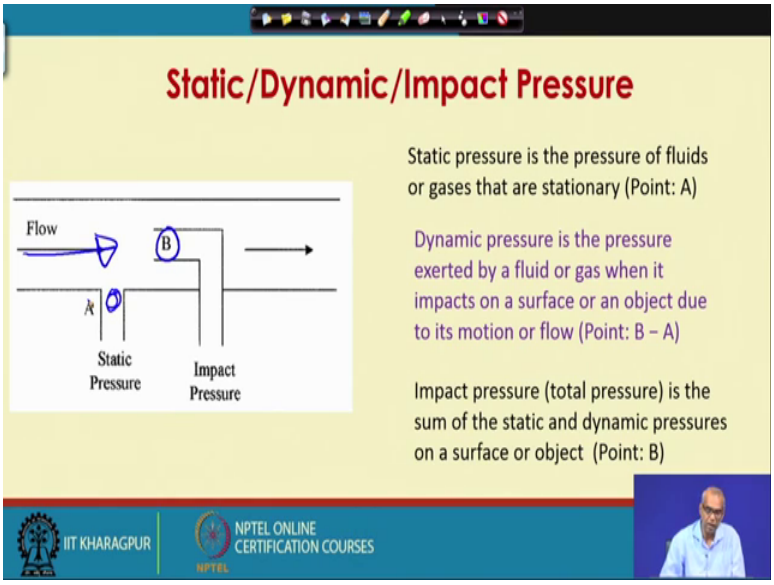

We will also define three more terms known as static pressure, dynamic pressure and impact pressure. Static pressure is the pressure of fluids or gases that are stationary. So, imagine a fluid flowing through this pipe. So, static pressure is the pressure of fluids of gases that are stationary. So, at point A the pressure I measure will be known as static pressure. Dynamic pressure is the pressure exerted by a fluid or gas when it impacts on a surface or an object due to its motion or flow. So, the pressure at point B minus the pressure at point A will be the dynamic pressure.

Impact pressure or the total pressure is the sum of the static and dynamic pressure on a surface or object. So, point B will have the impact pressure or total pressure which involves both static pressure and dynamic pressure.

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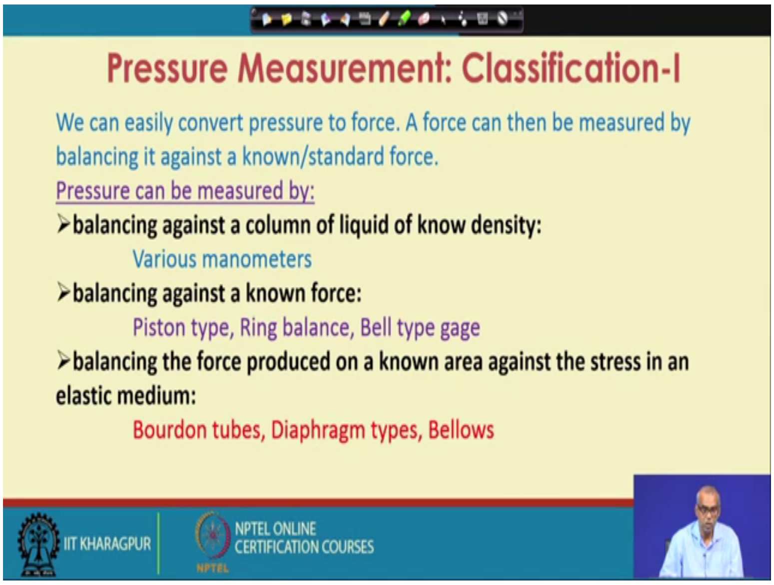

Now, how do we measure pressure? See pressure can be very easily be converted to force because if I allow pressure to act on a surface area on a surface of known area a force will be developed. Now, this force can be measured or compare against unknown force or standard calibrated force. So, that way by measuring a force I can measure pressure. So, one idea of pressure measurement maybe you allow the pressure to act on a surface area whose area we know accurately. So, a force will be developed, now that force can be compared or measure against a known force. Now, since we know the surface area we can find out now, pressure which is force per unit area.

So, pressure can be measured by balancing it against the column of liquid of known density. We have various manometers which are based on this principal. So, in manometers we balance the pressure against the column of liquid of known density. Pressure can also be measured by balancing against a known force. So, pressure measuring instruments such as piston type, ring balance, bell type, gauge are all examples of instruments which use this principle. Pressure can also be measured by balancing the force produced on a known area against the stress in an elastic medium this is an important class of pressure measuring instrument. So, here we balance the pressure or balance the force that is produced on a known area against the stress in an elastic medium. This class of instruments are also known as elastic pressure transducers, examples are bourdon tubes, diaphragm types, pressure gauge bellows. So, this is one possible classification of pressure measuring instruments.

Here we classify pressure measuring instruments based on how they measure pressures. But of course, high vacuum measurement or instruments that are used for measuring very very low pressures or high vacuum will require specialised instruments. So, high vacuum requires specialised instruments.

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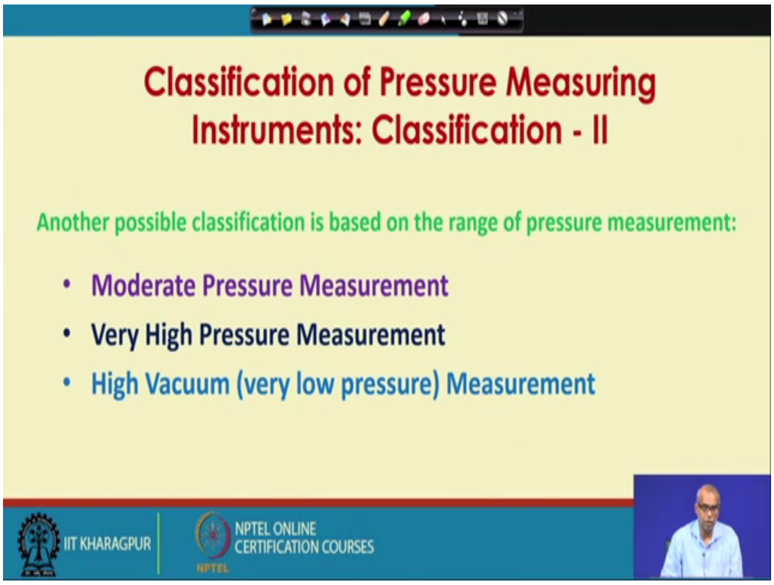

So, that was one possible classification. Another possible classification is based on the range of pressure measurement whether I am measuring high pressures, whether I am measuring low pressure or moderate pressure based on that it is possible to classify various instruments. So, we can classify all pressure measuring instruments based on moderate pressure measurement, very high pressure measurement and high vacuum or very low pressure measurement. So, we can classify all pressure measuring instruments into 3 categories pressure measuring instruments for measurement of moderate pressure, pressure measuring instruments for measurement of very high pressure and pressure measuring instruments for measurement of high vacuum or very low pressures.

In this lecture let us follow this classification. So, we will classify all pressure measuring instruments into three categories moderate pressure measurement, very high pressure measurement and low vacuum or very low pressure measurement.

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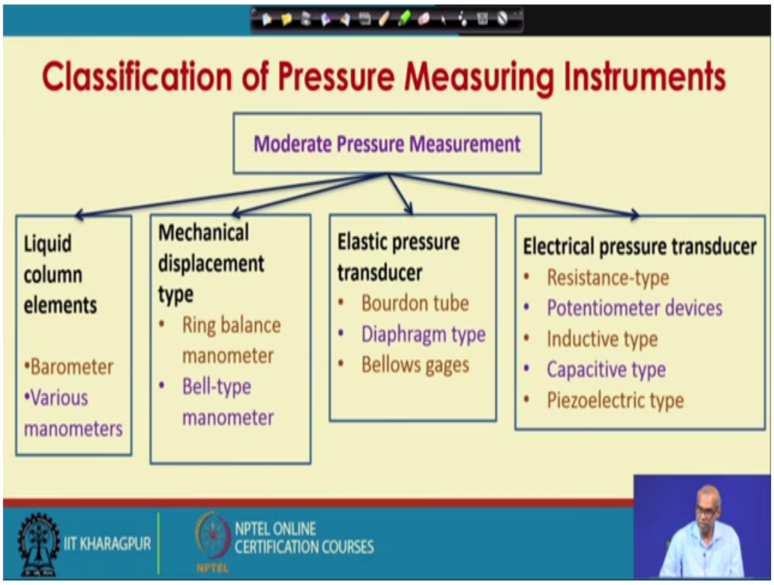

So, let us now look at closely on moderate pressure measurement. So, what are the various pressure measuring instruments that are available under moderate pressure measurements? Most of the chemical process operations happen at moderate pressure measurement, most of the chemical process operation occurs at moderate pressures. So, there must be various pressure measuring instruments which were able to measure moderate pressure. So, again there are various classifications based on the principle on which they work we called liquid column elements examples are barometers and various manometers mechanical displacement type, ring balance manometer or bell type manometer. So, this is essentially pressure measurement by balancing the force by balancing it against the known force.

Elastic pressure transducer. So, the force developed in the pressure measuring instrument is balanced by the space developed in the elastic medium. So, elastic pressure transducers such as bourdon tube diaphragm type bellows gauges and electrical pressure transducer, resistance type, potentiometer, devices inductive type, capacitive type piezoelectric types. So, these are various instruments under moderate pressure measuring instruments. So, liquid column elements examples barometers, various manometers, mechanical displacement or the instruments that balances force arraying balance manometer bell type manometers. Elastic pressure transducer bourdon tube diaphragm type bellows gauges and electrical pressure transducers resistance type, potentiometer devices, inductive type, capacitive type and piezoelectric type. Some of these electrical pressure transducers we have talked about when I discussed transducer elements.

Apart from these we will talk about these pressure measuring instruments, apart from this only talk about ring balance manometer or bell type manometer we will also talk about an instrument known as dead weight tester for piston type pressure gauge which is also used for calibration of various pressure measuring instruments.

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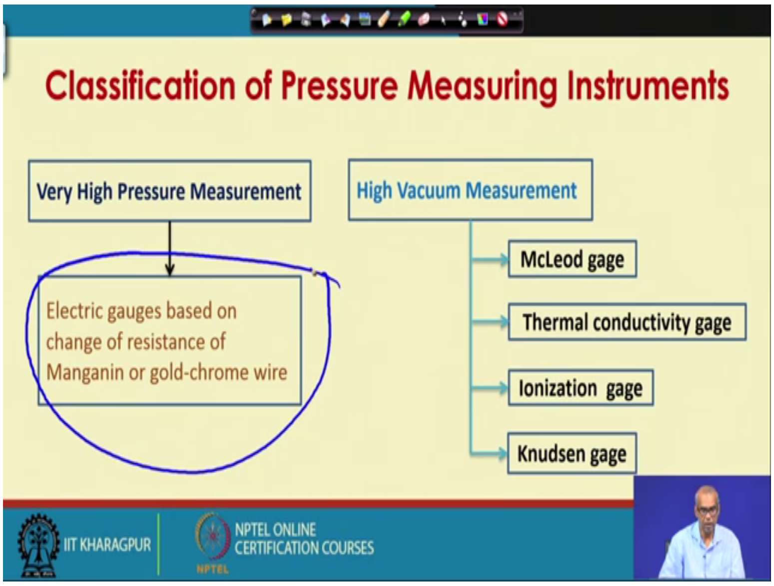

So, that was moderate pressure measuring instruments, very high pressure measurements. Very high pressure measurements is done by electric gauges based on change of resistance of manganin or gold chrome wire. Very high vacuum measurement or very low pressure measurement will discuss wire, very high vacuum measurement or very low pressure measurement we will discuss instruments known as McLeod gage, Thermal conductivity gage, Ionization gage and Knudsen gage. So, in this week and the following week we will be talking about all these various pressure measuring instruments.

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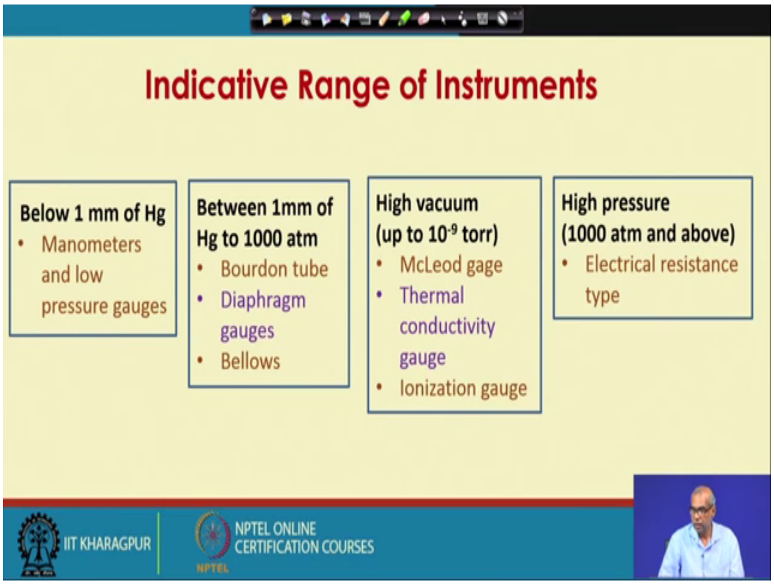

Now, let us talk about some indicative range of instruments. So, we want to know what are the ranges of pressures over which I will use say monometer, what are the ranges of pressures over which I will use bourdon tubes and so on and so forth. Now, the numbers that are going to present are some indicative rangers. For example, below 1 millimetre of mercury we use manometers or low pressure measuring instruments. Between 1 millimetre of mercury to 1000 atmosphere we use elastic pressure transducers such as bourdon tube, diaphragm gauges, bellows etc. For measurement of high vacuum or very low as low as up to 10 to the power minus millimetre of mercury or 10 to the power minus torr we use high vacuum measuring instruments such as McLeod gauge, thermal conductivity gauge ionization gauge etc. For high pressure measurements such as 1000 atmosphere and above we use electrical resistance type.

This electrical resistance type depend on the principle that at high pressure there will be changes in the resistance, this one. So, electrical gauges based on change of resistance of manganin or gold chrome wire.

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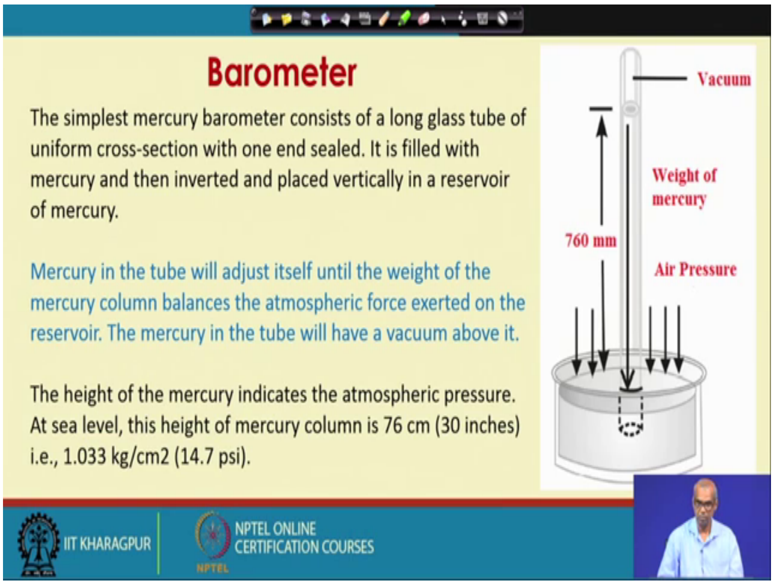

So now, let us talk about moderate pressure measurements. So, we start our discussion with barometer. You are all familiar with barometer since your school days, it is a simple instrument which measures atmospheric pressure. So, the simplest mercury barometer consists of a long glass tube of uniform cross section with one end sealed. So, tube with uniform cross section and one end is sealed other end is open. This tube is filled with mercury and then inverted and placed vertically in a reservoir of mercury. So, this is the reservoir of mercury.

Mercury in the tube will adjust itself until the weight of the mercury column balances the atmospheric force exerted on the reservoir, the mercury in the tube will have a vacuum above it. So, the weight of the mercury column has balanced the atmospheric pressure or atmospheric force exerted on the mercury level in the reservoir.

The height of the mercury indicates the atmospheric pressure. At sea level this height of mercury column is 76 centimetre or 30 inches of mercury, that is 1.33 kg per centimetre square or 14.7 pounds per square inch.

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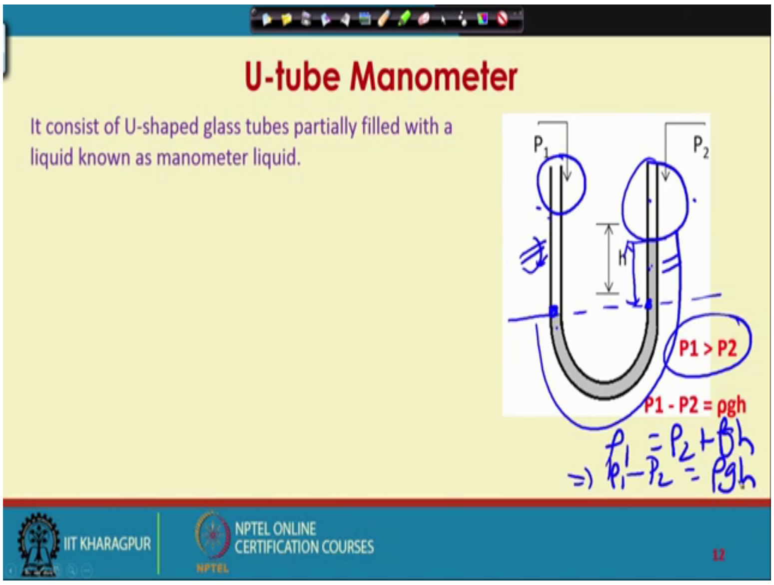

Next, let us talk about U-tube manometer it consists of U shaped glass tubes partially filled with a liquid known as manometer liquid. So, U-tube manometer is U shaped glass tube and this is partially filled with a liquid known as manometer liquid, mercury is a very common manometer liquid.

Now, these are known as two limbs of the manometer. So, this is one limb this is another limb. If both the limbs are connected to the same pressure source the level of mercury in both the limbs will be same, but if these two limbs are connected to two different pressure sources, level of mercury in both the levels will be different. In the diagram pressure P 1 is greater than pressure P 2. So, the mercury level in this limb is pushed down compared to this limb. Now, this difference between the mercury level in this limb and this limb which is shown here by h is the measure of difference of pressures between this limb and the other limb. So, if you make a balance if you right a balance. So, take this two points, so here the pressure is P 1 if I neglect this column it may be filled with air, here the pressure will be P 2 plus the pressure due to this column that is h which can be considered as rho g h which is density of the mercury times acceleration due to gravity times h. So, P 1 equal to P 2 plus rho g h, which gives you P 1 minus P 2 equal to rho g h.

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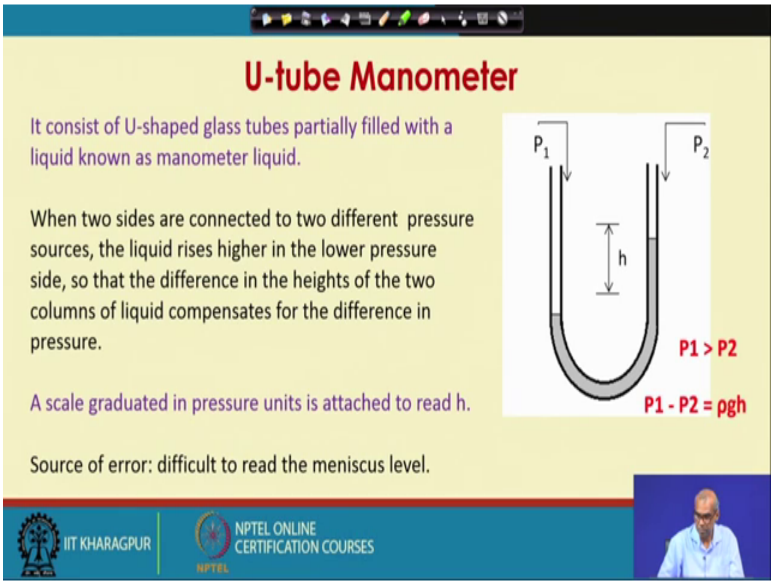

So, when two sides are connected to two different pressure sources the liquid rises higher in the lower pressure side so that the difference in the heights of the two columns of liquid compensates for the difference in pressure. A scale graduated in pressure units is attached to read h. So, a scale graduated in pressure units will be attached from which you can read the h. It may be difficult to read the meniscus level of mercury so that may bring in some error in the measurement.

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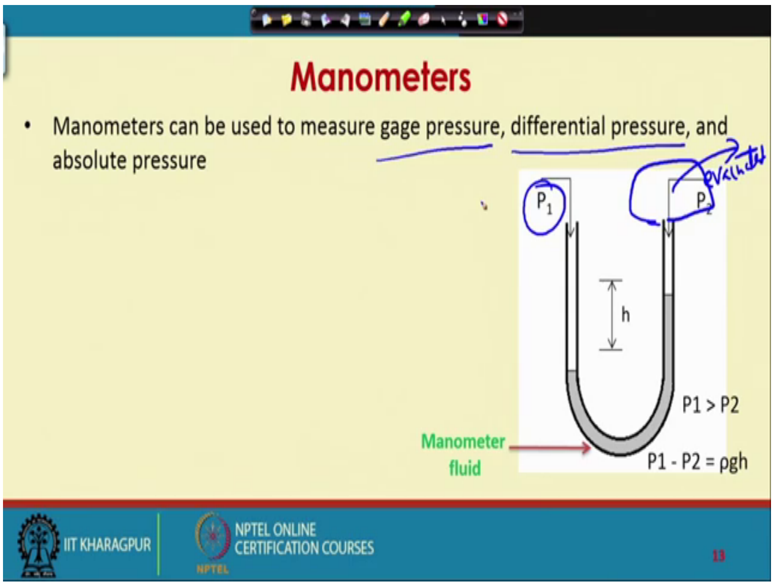

Manometer can be used to measure gauge pressure differential pressure as well as absolute pressure. If both the limbs are connected to two different pressure sources such as P 1 and P 2 this is measuring differential pressure. If one limb is open to atmosphere and another limb is connected to the pressure source I am measuring gauge pressure and if on limb is connected to vacuum, this is let us see this is connected to a sealed chamber and I completely evacuate it, evacuate, then I am measuring absolute pressure.

So, manometer can be used to measure gauge pressure differential pressure as well as absolute pressure, when you measure gauge pressure one end is connected to the pressure source the other limb is open to atmosphere when you are measuring differential pressure both the limbs are connected to two different pressure sources and when you are measuring absolute pressure one end is completely evacuated and sealed and the other end is connected to the pressure source we are measuring. So, that way you can measure gauge pressure differential pressure as well as absolute pressure.

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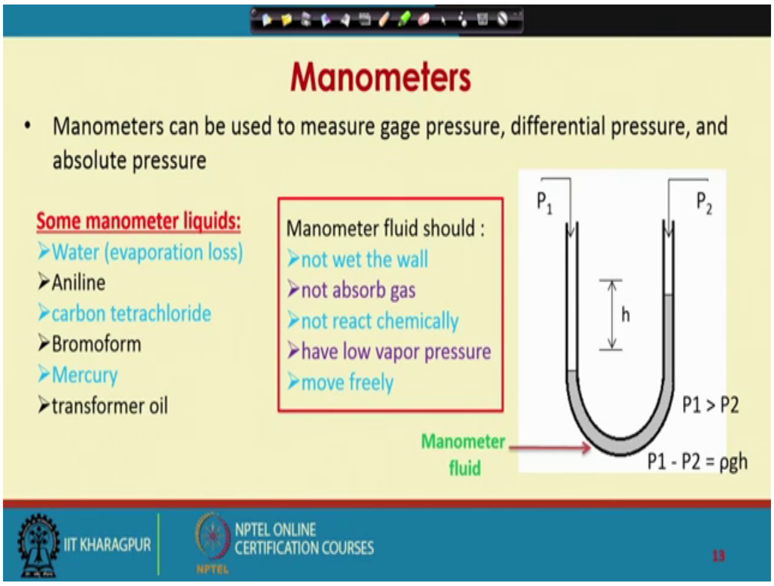

So now, there should be certain desirable properties of manometer liquid. Manometer liquid must not wet the wall monometer liquid must not absorb gas or it must not react chemically with the fluid whose pressure I am measuring. Manometer liquid or manometer liquid should have low vapour pressures if we use a liquid with high vapour pressure there will be loss of liquid and there will be error manometer liquid should move freely. Some common manometer liquids are water, but you have to remember that there will be evaporation loss aniline, carbon tetrachloride, bromoform, mercury, transformer oil. So, these are some common manometer liquids.

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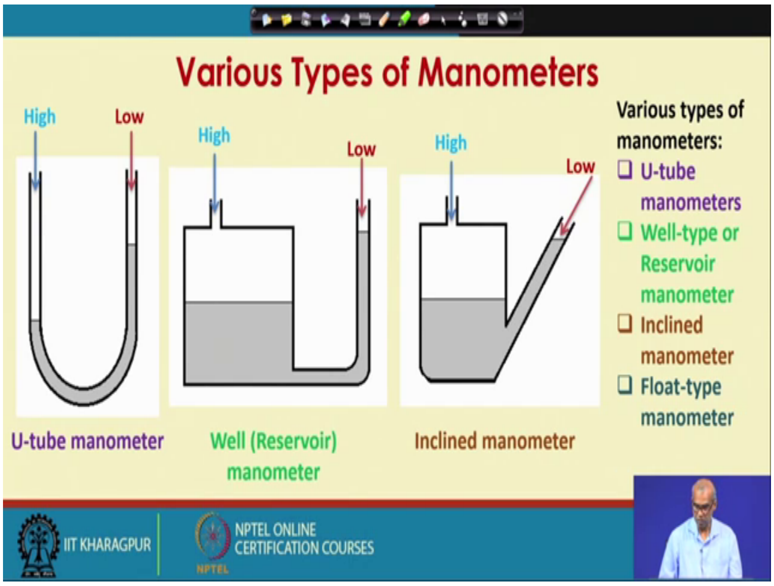

Let us now talk about various types of manometers. Various types of manometers are U-tube manometers we just talked about U-tube manometers then well-type or reservoir manometer which is a modified manometer which is a modified U-tube manometer, then we have inclined manometer and then you also have float-type manometer.

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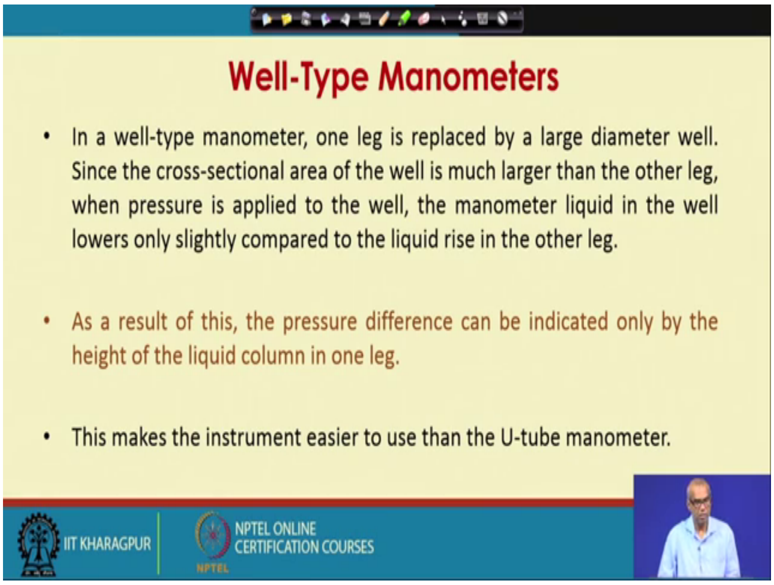

Well-type manometers, in well-type manometer one leg is replaced by large diameter well. Since the cross sectional area of the well is much larger than the other leg when pressure is applied to the well the monometer liquid in the well lowers only slightly compared to the liquid rise in the other leg. So, what we do is in a well-type manometer one leg is replaced by a large diameter well. Since the cross sectional area of the well is much larger than the other leg when pressure is applied to the well the monometer liquid in the well lowers only slightly compared to the liquid rise in the other leg. As a result of this the pressure difference can be indicated only by the height of the liquid column in one leg. So, you do not have to measure the liquid level in both the legs you can measure the liquid level in only one leg because the change in the mercury level in the well which has a large diameter is very very low this makes the instrument easier to use then the U-tube manometer.

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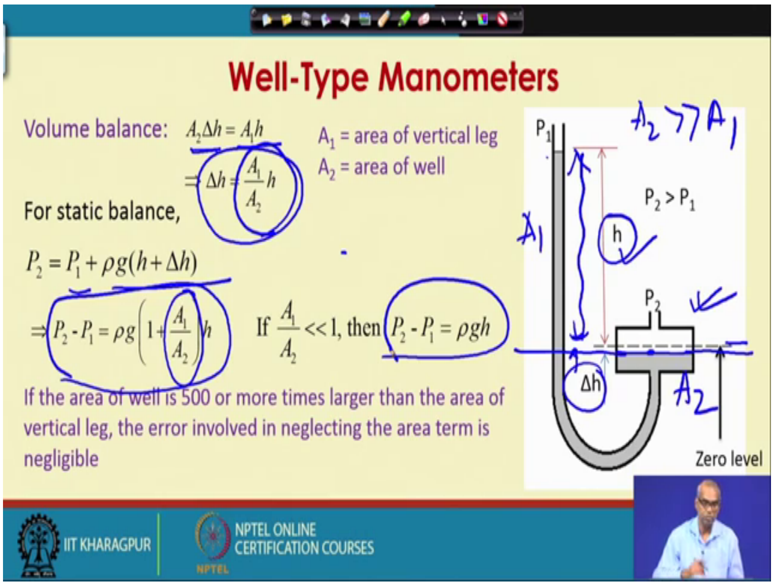

So, let us look at some calculations. So, this is the well time monometer this is the well it has large diameter. Let us say this is the cross sectional area of the well at two this is the cross sectional area of A 1 and A 2 is much much greater than A 1.

Now, when this two links are connected to different pressure sources the level of the mercury in well goes down by a very small amount let us say delta h and the level of the mercury in the low diameter leg increases much and let us this reading be h. So, initially this was the zero level. So, the change in the mercury level in the well has gone down only by small amount delta h and the change in the mercury level in the vertical leg is h and P 2 is better than P 1.

So, the amount of mercury that has been pushed down in the well has only gone up in the vertical leg. So, I can write A 2 times delta h which is the volume of the mercury that has gone down in the well is equal to A 1 h which is the amount of mercury that is contained in this length from that I can rearrange delta h equal to A 1 by A 2 into h. For static balance we will write P 2 is equal to P 1, so P 2 is equal to P 1 plus rho g into h plus delta h. So, make a balance on these line.

So, here the pressure is P 2 and here the pressure is P 1, pressure is P 1 plus pressure due to this mercury level plus pressure due to this delta h. So, P 2 equal to P 1 plus rho g into h plus delta h. If you now, put delta h equal to A 1 by A 2 into h I get P 2 minus P 1 equal to rho g into one plus A 1 by 2 into h. Now, if A 1 by A 2 is much much less than 1 because A 2 is much much greater than A 1 then I can neglect this and then P 2 minus P 1 can be written as P 2 minus P 1 equal to rho g into h. If the area of the well is 500 or more times larger than the area of the vertical leg the error involved in neglecting the area term is negligible.

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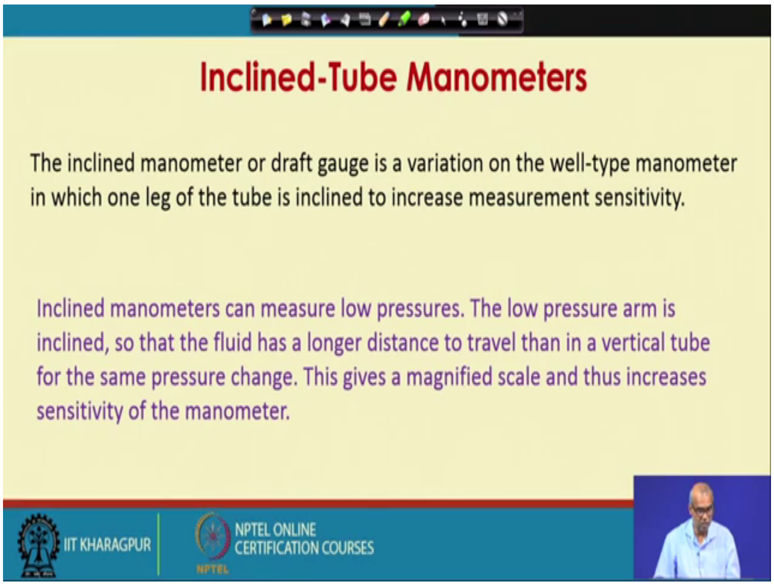

Next, let us briefly talk about inclined tube manometer. The inclined monometer or draft gauge is a variation on the well-type manometer in which one leg of the tube is inclined to increase measurement sensitivity. Inclined manometers can measure low pressures the low pressure arm is inclined so that the fluid has a longer distance to travel then in a vertical tube for the same pressure change. This gives a magnified scale and thus increases sensitivity of the manometer.

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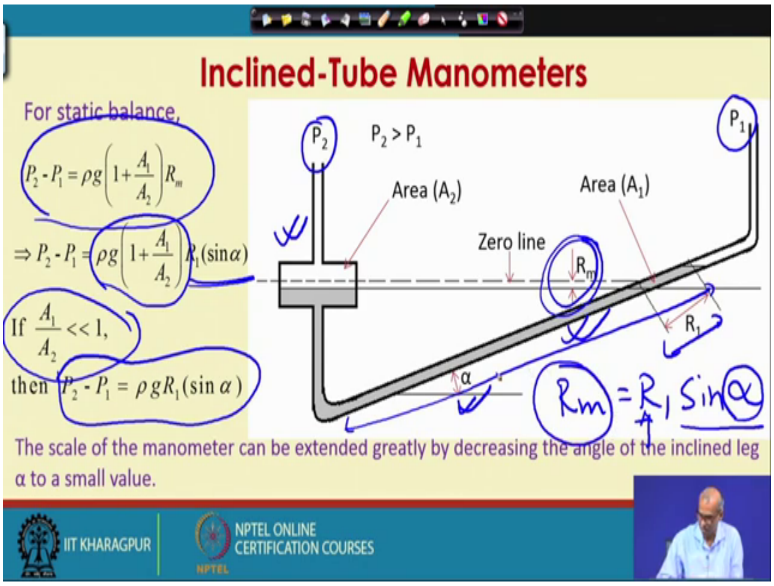

So, this is inclined manometer you have the well and the other leg is inclined. So, what happens is mercury travels a long distance in this arm. So, when the limbs are connected to two different pressure sources mercury level goes down here only by this amount say R m. But since this is inclined this much will be the increase in the length of mercury in the tube and the relationship between R m and R 1 is R m equal to R 1 sin alpha.

So, now, again I can write the balance equation for static balance P 2 minus P 1 equal to rho g into 1 plus A 1 by A 2 into R m this follows straight from the discussions on well-type manometer. R m is equal to R 1 sin alpha, so P 2 minus P 1 equal rho g into 1 plus A 1 by A 2 into R 1 sin alpha, if A 2 is much much greater than A 1 then A 1 by A 2 will be much much less than 1. So, in that case P 2 minus P 1 will be equal to rho g R 1 sin alpha.

The scale of the manometer can be extended greatly by decreasing the angle of the inclined leg alpha to a small value. This comes from the relationship R m equal to R 1 sin alpha. If you make alpha small sin alpha will be small, so we have to increase our 1, so that R 1 into sin alpha matches with R m. So, by decreasing the value of alpha I can increase the sensitivity further.

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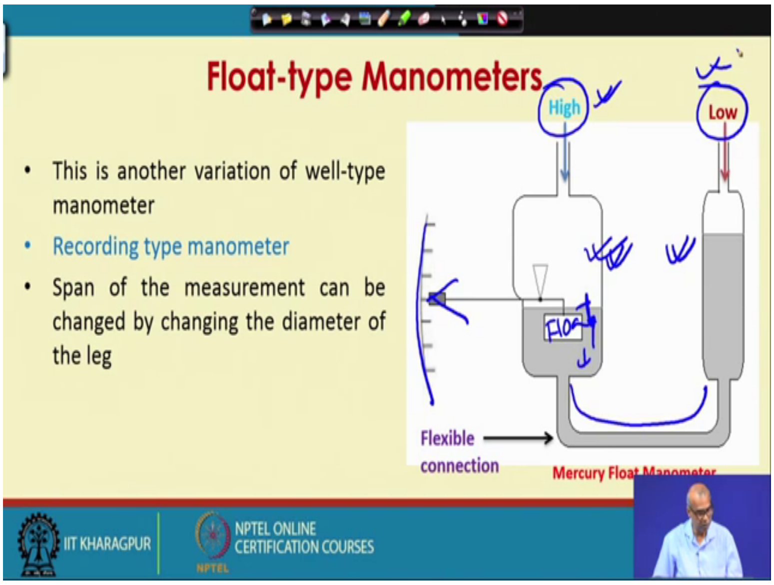

And finally, let us talk about float type manometer. This is another variation of well-type manometer this can also be used as a recording type manometer this works as follows do you have this two legs of the manometer. These two are connected by a flexible connection. Now, the diameter of this leg is higher and you can place a float inside this, as the mercury level here goes up or comes down depending on these two different pressures the float goes up or comes down. This moment of the float can be used to move a pointer against this scale which can be directly calibrated in units of pressure so that you can measure the difference between these two pressures. So, that way this mercury float manometer can be used to measure differential pressure.

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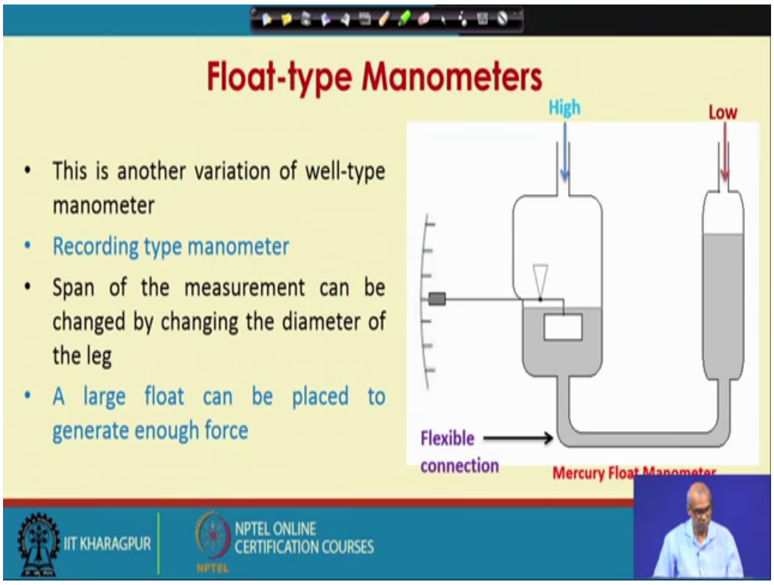

So, the span of the measurement can be changed by changing the diameter of the leg. A large float can be placed to generate enough force so that the pointer and scale movement is possible.

So, we stop our lecture 21 here.