Chemical Process Instrumentation

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Lecture – 55
Miscellaneous Measurements: Composition (Contd.)

Welcome to lecture 55. This week we are talking about Miscellaneous Measurements. In this lecture, we will talk about measurement of density and measurement of pH. We are all familiar with these 2 terms. Density is nothing but mass per unit volume, and pH represents hydrogen ion concentrations. It is a measure of hydrogen ion concentrations. Density is mass per unit volume so, if you know the value, if you take a particular volume of the liquid, and if you know the mass of this liquid you can easily measure the density.

We have also talked about pressure measurements, we are familiar with various pressure measuring instruments, think of a say liquid column of length l of h or of say height h, a liquid column of height h. The pressure at the bottom of the liquid will be P equal to rho g h so, density of the liquid multiplied by g multiplied by height of the liquid which is h. So, if I measure the pressure, I can relate the pressure with the density, because the pressure P is P equal to rho g h.

So, P is proportional to the density of the liquid. So, that can we want way of measuring density. And pH can we measure? Usually by 2 principles one is we can make use of chemical indicators you all know litmus papers. So, one can have an indication of the pH using say litmus paper for such chemical indicators. Of course, the error will be more there, it may be some approximate value in may not be always accurate values. We also have pH meters which makes use of 2 electrodes, and the potential difference that is developed between these 2 electrodes and this potential difference is related to the pH.

So, commercially available pH meter so, works on this principle. So, we will quickly took look at some measurements of densities and pH in this lecture.

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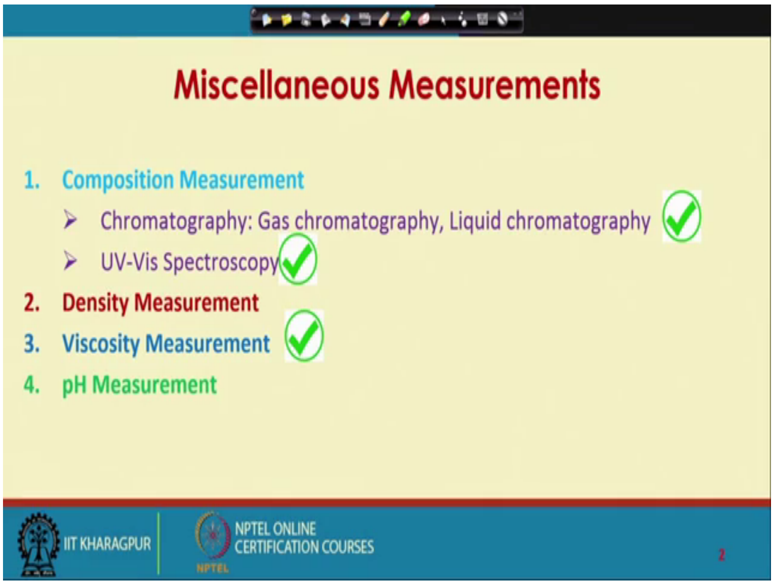

So, we have talked about composition measurement, viscosity measurement so, let us talk about density measurement and pH measurement, and first we talked about density measurement.

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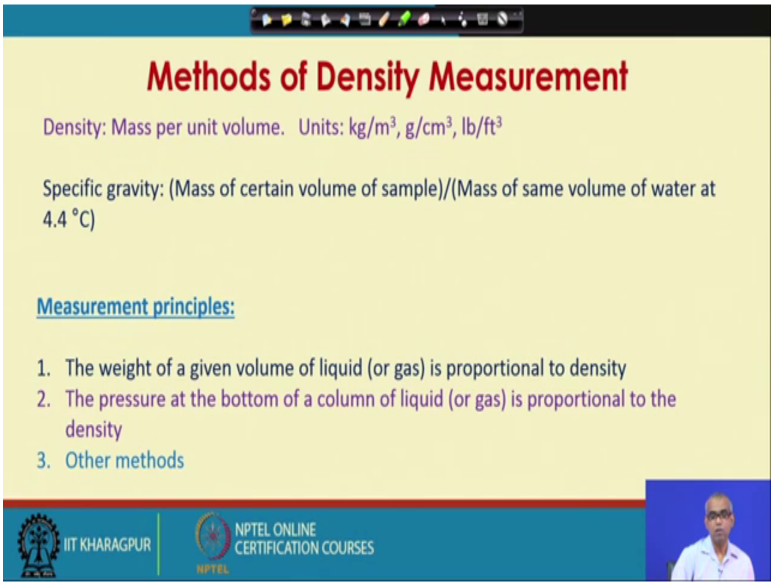

So, as we discussed density is nothing but mass per unit volume. So, typical university kg per meter cube gram per centimeter cube pound per feeted cube; there is another term closely associated density known as specific gravity, which is mass of certain volume of sample divided by mass of same volume of water at 4.4 degree Celsius. The measurement principles for density may be the weight of a given volume of liquid or gas is proportional to density.

The pressure at the bottom of a column of liquid or gas is proportional to the density, and there are some other measures also which can be used to measure density, such that we will talk about coriolis mass flow meter which have already talk about when talking about the flow measurement the coriolis mass flow meter the coriolis mass flow meter can also be used for measurement of liquid density.

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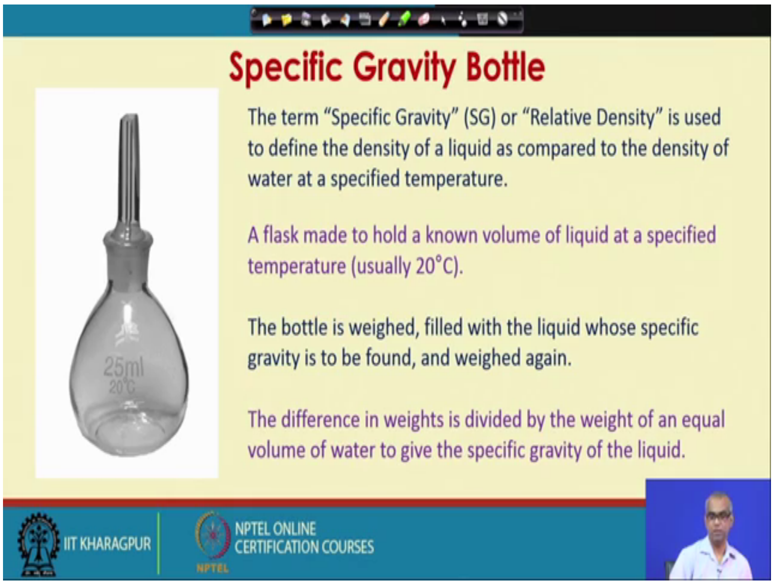

You are all familiar with specific gravity bottles. You have you must have done this experiment during your school days. The term specific gravity or relative density is used to define the density of a liquid as compared to the density of the water at a specified temperature. A flask made to hold and known volume of liquid at a specified temperature is very 20 degree Celsius. The bottle is weighted filled with the liquid whose specific gravity is to be found and weighted again. So, first take the weight of the empty bottle, fill the bottle with the liquid is specific gravity needs to be measured, and then again take the weight of the liquid filled bottle.

The difference in weights is divided by the weight of an equal volume of water to give the specific gravity of the liquid.

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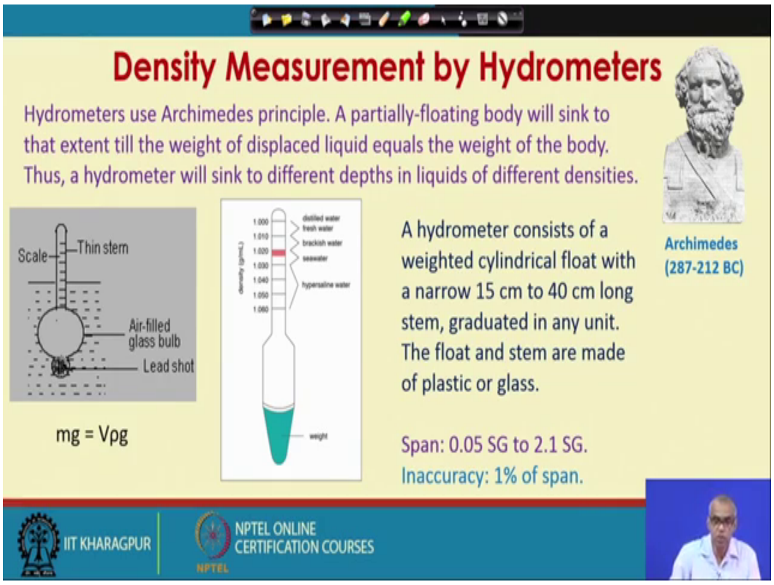

Let us now talk about density measurement by hydrometers. Hydrometers use Archimedes principle, Archimedes principle also you are familiar with from your school days. A partially floating body will sink to that explained till the weight of displays liquid equals the weight of the body.

I repeat, a partially floating body will sink to that extent till the weight of displays liquid equals the weight of the body, does a hydrometer will sink to different depths in liquids of different densities? This is a schematic of hydrometer so, it has some weights here which are let us sorts as shown here, and this is air filled glass bulb.

You have the stem here, and there is a graduated scale eastern the stem. Now, if I dip this hydrometer into a full of liquid depending on the density of the liquid it will sink to a particular depth. So, when this hydrometer is depth in say liquid one, it can sink to it can sink say up to one particular depth, but if I know take this hydrometer and put it some other liquid with different density it will sink to some other depth.

So, this scale can be used to indicate the density. So, we can perform proper calibration, we can perform calibration using liquid some known density, and can note up to what depth this hydrometer sinks. And then can use the hydrometer to find out the density of unknown liquid.

Like here if you look at the scale, the different densities in gram per ml is indicated on this scale. So, they all corresponding to different liquids, density gram per densities represented in gram per ml; so when it when it is one it is distilled water one point 0 to 0 brackish water so on and so forth. So, basically a hydrometer consists of a weighted cylindrical float with an arrow 15 centimeter to 14-centimeter-long stem graduated in any unit.

The float and steam are made of plastics or glass so, from the scale; that is, they are on the stem of the hydrometer, you can measure the density of the liquid. This equation tells you the mass m g which is mass of the hydrometer is equal to the mass of the liquid that is displaced.

So, mass of the hydrometer is mg and V is the liquid that is displaced. So, V into rho into g is the mass of the liquid that is displaced. So, this equation tells you that this V into rho will be different for different liquid. Because m g is fixed so, when different liquids, I am take if I take different liquids this is V into rho will be different. So, so this is basically this rho will be different.

So, this is rho is since this is rho is different, since this rho is different, it has to sink to different depths. So, let me clarify this 0.1 more time. Mg represents the mass of the hydrometer which is fixed. Now when you depict into a liquid of density rho, it displaces a volume of water which is b vol volume of the liquid is V that is displaced.

So, n g has to be equal to V into rho into g. So, if I put it into different liquid now, this has to sink to different depths. So, from the scale that is attached to this stem can be used to indicate densities. The span that can be covered is 0.05 to 2.1 specific gravity.

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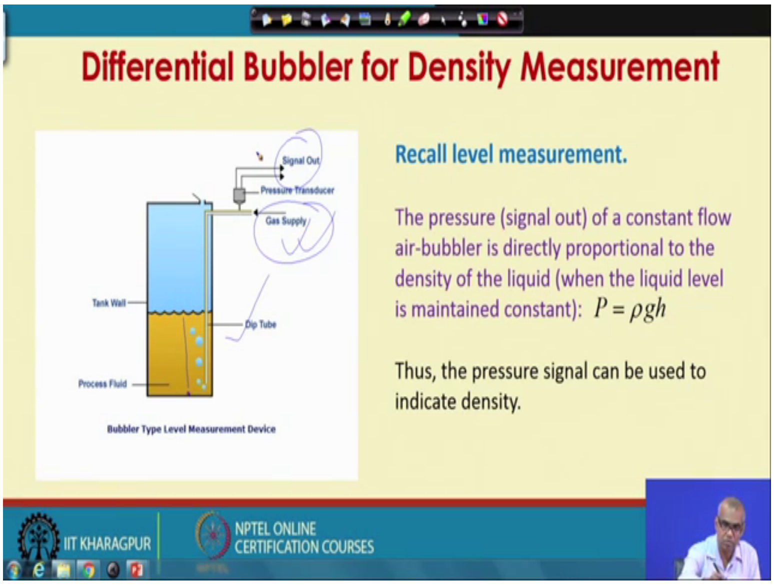

Next let us talk about differential bubbler for density measurement. First let us talk about level measurement, let us recall the level measurement. If you remember we have talked about bubbler type level measuring device which is nothing but consists of dip tube, and then are regulated gas supply is there. So, gas is supplied let us say air or nitrogen is supplied through this dip tube to change the flow rate until you see the bubbler just escapes from the tip of the dip tube.

At this point, the pressure here and the pressure exerted by the depth of the liquid here at the level were the dip tube is there is same so, P equal to rho g h. So, by measuring pressure I should be able to measure density so, the pressure which is signal out here of a constant flow air bubbler is directly proportional to the density of the liquid when the liquid level is maintained constant. So, P equal to rho g h does the pressure signal can be used to indicate density.

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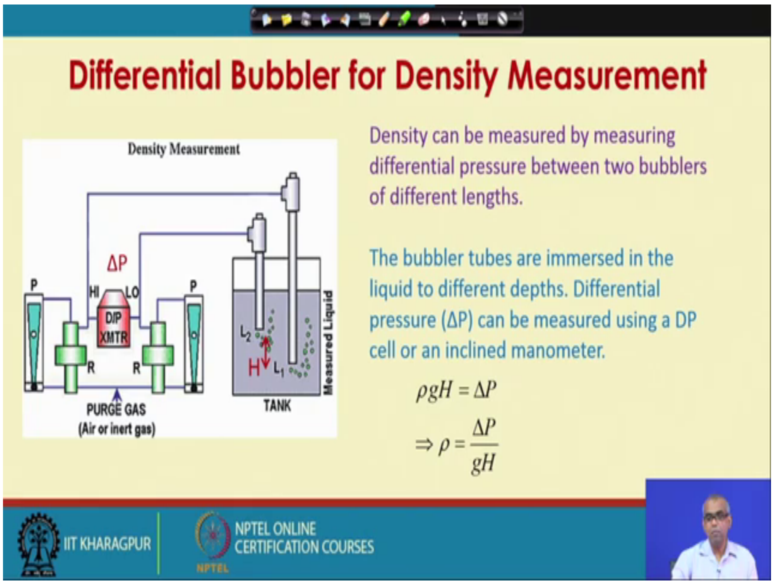

Differential bubbler for density measurement, better way to measure density will be you make use of 2 bubbler tubes.

See here when I say P equal to rho g h, you consider the pressure here as rho g h. So, if the tank is open to atmosphere, I am not considering any fluctuation at atmospheric pressure. But this will cause no problem if I consider, if I take 2 bubbler tubes and measure the differential measure.

So, I basically do the same experiment with 2 bubbler tubes. Density can be measured by measuring differential pressures between 2 bubbles of differential lengths. The bubbler tubes are immersed in the liquid to different depth differential pressure can be measured using a d P cell or an inclined manometer. So, delta P equal to rho g h. So, what you do you do is, I take 2 dip, I take 2 bubbler tubes, this length is h.

So, let us say air passes through this bubbler tube using a regulated flow, the air passes through these bubbler tube in a regulated flow, and you maintain the flow rate such that the bubble just escapes at the end of the bubbler tube. So, at this stage the pressure here at the pressure due to flow is same, pressure here, pressure here and the pressure here are same due to air corresponding air flows.

The delta pressure delta P can also be measured using say a d P cell differential pressure cells or using an inclined manometer, and then can relate P equal to rho g h from that you can calculate rho or the density of the liquid.

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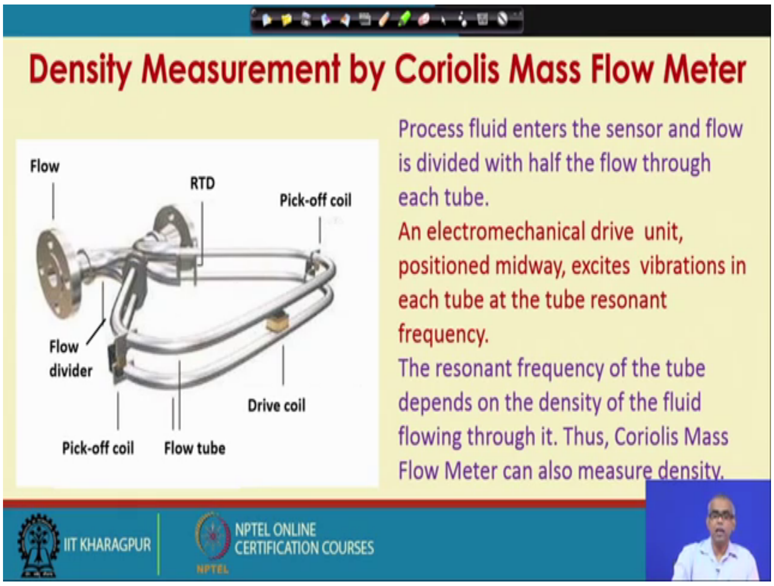

Density can also be measured by coriolis mass flow meter. Process fluid enters the sensor and flow is divided with half the flow through which tube we have talked about coriolis mass flow meter look at the coriolis mass flow meter here. The process fluid enters the sensor and flow is divided with half the flow through institute. So, you have a flow divider, and the flow is divided with half the flow through each tube and electromechanical drive unit position midway excites vibrations in each tube at the tube resonant frequency.

The resonant frequency of the tube depends on the density of the fluid flowing through it, does coriolis mass flow meter can also measured density. So, process fluid enters the sensor and flow is divided with half of the flow through each tube, and electromechanical drive unit position midway, excites vibrations in each tube at the tube resonant frequency. The resonant frequency of the tube depends on the density of the fluid flowing through it, does coriolis mass flow meter can also measure density.

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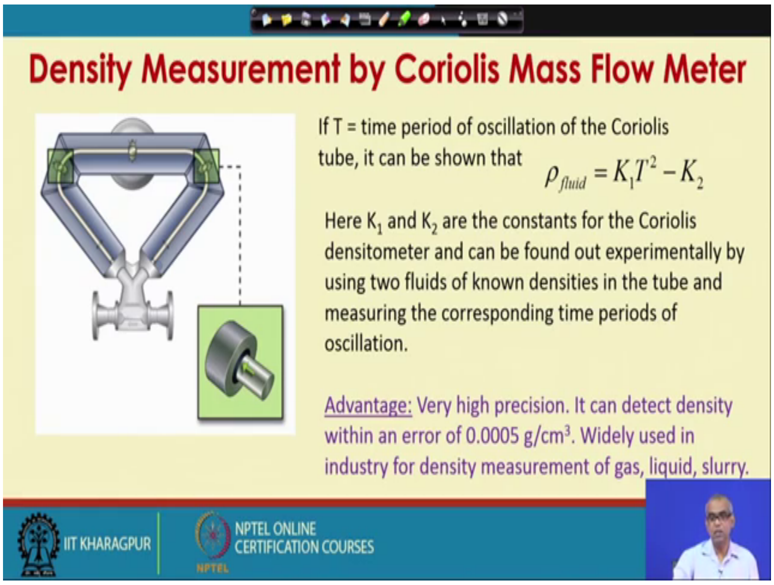

If t is the time period a oscillations of the coriolis tube, it is possible to show that density of the fluid is related to the time period of oscillation of the coriolis tube as given by this expression.

Density of the fluid equal to K 1 t square minus K 2, where K 1 and K 2 are the constants for the particular coriolis densitometer. Densitometer is an instrument which can be used for density measurement. So, here the coriolis mass flow rate is a densitometer. Now the constants K 1 and K 2 can be found out experimentally by using 2 fluids have known densities in the tube, and measuring the corresponding time periods of oscillations.

So, you take 2 liquids of non-densities and perform the experiment using coriolis mass flow meter. So, find out the time period of oscillation for liquid one, find out the time of oscillation for liquid 2. Put in these equations you will have 2 equations, 2 unknowns you can find out K 1 and K 2.

Once K 1 and K 2 is known, then for any unknown sample whose density is to be found out, you can make use of the coriolis mass flow meter. So, simply by measuring, the time period of oscillations, you can now find out the density of the liquid once K 1 and K 2. Unknown coriolis mass flow meter has very high precision; it can be take density within an error of 0.005 gram per centimeter cube widely used in industry for density measurement of gas liquid and slurry.

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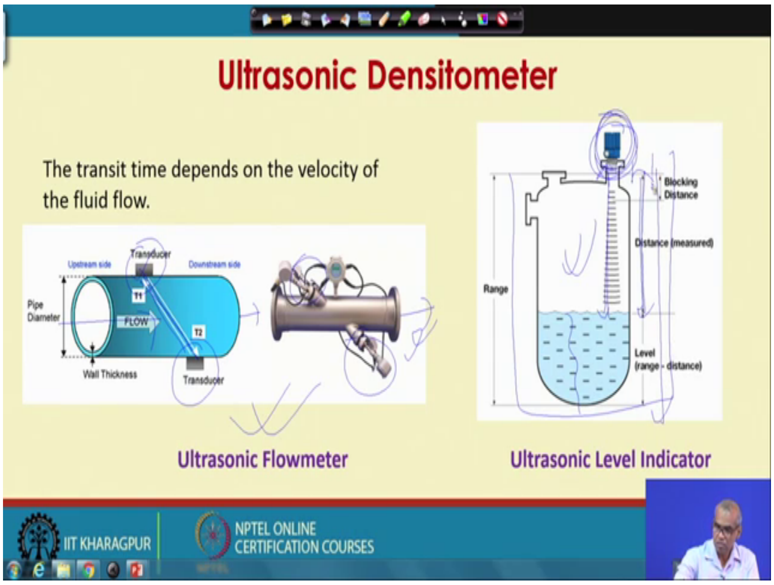

Ultrasonic densitometer so, here density measurement is done using ultrasound waves.

Ultrasound can also used for measurement of flow as well as measurement of liquid level. What you see here is a schematic and also a real image of an ultrasonic flow meter. So, the basic principle is very simple, you have a transducer here, you have a transduction here. So, ultrasound can be say imitated from here, and this can be received here.

So, in this flow is passing in this direction, the time the transit time depends on the velocity of the fluid flow. So, basically find out the time the ultrasound takes to cover this distance, and from that it is possible to compute the velocity of the fluid flow. In the real image, you can see the ultrasonic transducers are located across the tube, through which there is a flow. Similarly, there is ultrasonic level indicator so, you have the liquid in this tank you have to the ultrasonic transducer.

So, here the ultrasonic this of this is this is this generates ultrasound, as well as remote, as well as receives it. So, you generate ultrasound. So, ultrasound comes gets reflected from here goes back and that time is noted down

So, if I know the velocity of the ultrasound in this medium, which in this particular case may be here may be and above the liquid. I know the distance it has covered so, I can find out this height. So, this tank dimension is known, the point where this ultrasound indicated is mounted into an ultrasound transducer is mounted that is also known.

So, this height is fixed, this height is fixed so, as the liquid level changes, this height changes, in other words this height changes. So, if I know this height, I can always know this height because some of them is nothing but this.

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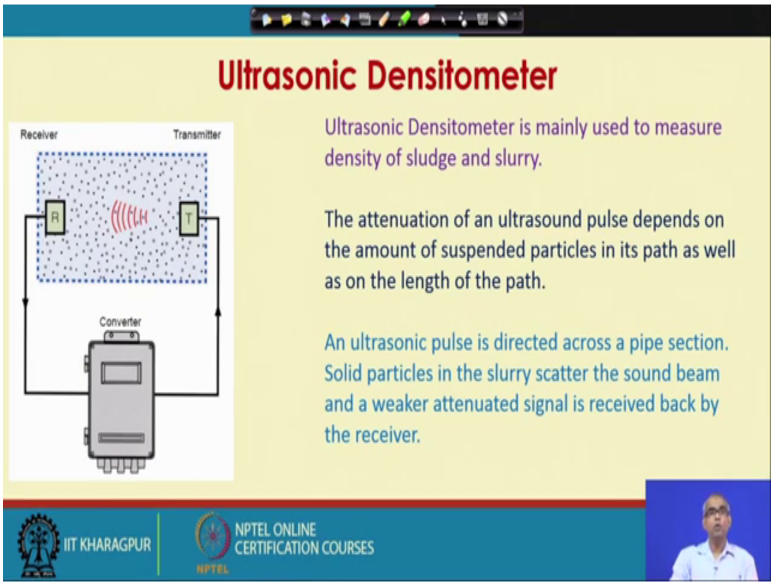

Now, how do use ultrasound to measure density? The ultrasonic densitometer is mainly used to measure density of sludge and slurry.

The attenuation of an ultrasound pulse depends on the amount of suspended particles in it is path as well as on the length of the path. And ultrasonic pulse is directed across a pipe section, solid particles in the slurry scattered the ultrasound beam and a weaker attenuated signal is received back by the receiver. So, here imagine that this is a part of the liquid flowing through the active. So, there are suspended particles in the liquid. So, this is slurry or sludge for which ultrasonic densitometer is commonly used.

So, slurry is flowing through a tube, you have an ultrasound transmitter you have an ultrasound receiver. So, you generate ultrasound using the transmitter. So, ultrasound travels and it is received by the receiver, as the ultrasound travels, the intensity decreases because it interacts with the particles that are present in the sludge or the slurry.

So, week in weaker attenuated signal is received by the receiver. These attenuation depends on the density of the slurry or sludge so, by measuring the difference of these intensities, or by measuring the attenuation of this dens of this intensity of the sound wave of the ultrasound, I can find out the density, because the degree to which it will be attenuated depends on the density of the slurry or sludge.

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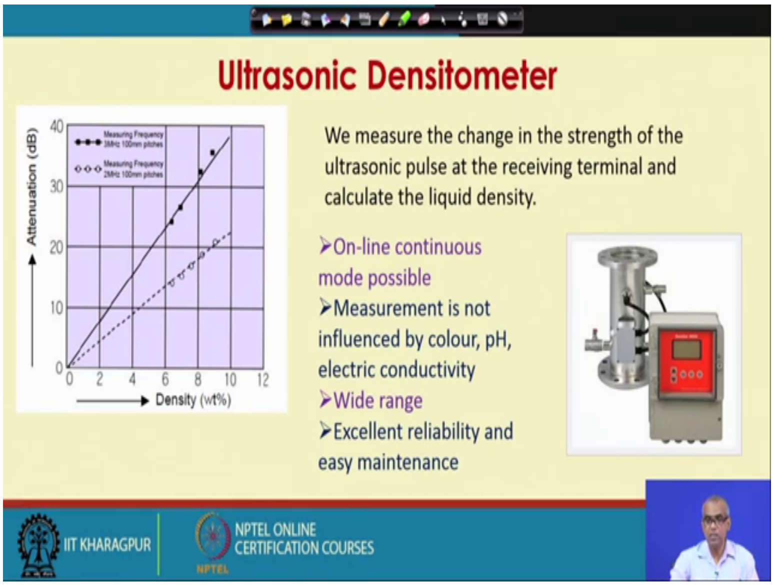

So, measure the change in this strength of the ultrasound pulse at the receiving terminal and calculate the liquid density so, such plots can be obtained. Attenuation versus density if we plot we will get straight lines. We measure the change in the strength of the ultrasonic pulse at the receiving terminal and calculate the liquid density.

Note that this and this plots corresponds to corresponds to different frequency, ultrasound of different frequency. So, this is for 2 megahertz, this is for 3 megahertz frequency. Online continuous mode is possible, measurement is not influenced by color pH or electrical conductivity, it has wide range it has excellent reliability and easy maintenance. So, this is a real example or real image of ultrasonic densitometer, you can see the transmitters and receivers are connected across the tube through which the flow will be there.

So, next let us talk about pH measurement, pH is the measure of the acidity or alkalinity of a solution.

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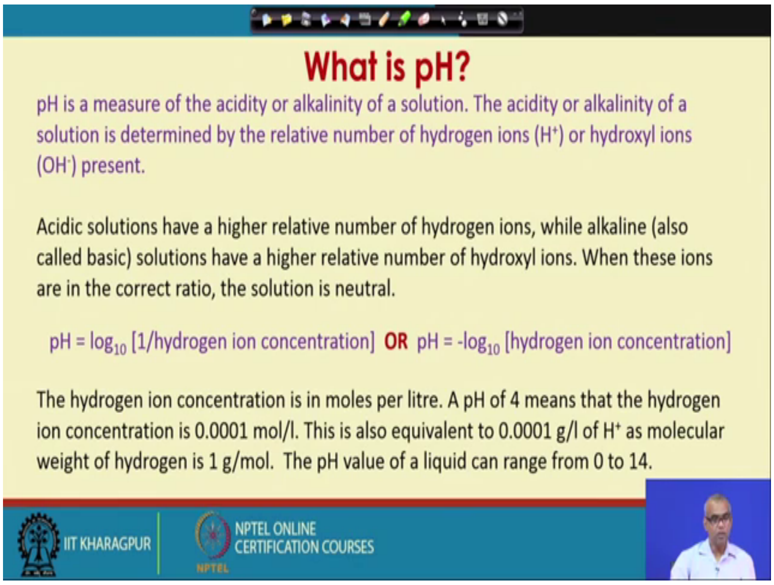

The acidity or alkalinity of a solution is determined by the relative member of hydrogen ions or hydroxyl ions present. Acidic solutions have a higher relative number of hydrogen ions well alkaline or basic solutions have a higher relative number of hydroxyl ions. When these ions are in the correct ratio the solution is neutral. You are familiar with this expression of pH, pH equal to log 10, 1 by hydrogen ion concentration or pH equal to minus log 10 hydrogen ion concentration both are same. The hydrogen and concentration is in moles per liter. So, a pH of 4 will mean that the hydrogen ion concentration is 10 to the power minus 4 moles per liter or 0.0001 mole per liter.

This is also equivalent to 0.0001 gram per liter of hydrogen ion, as molecular weight of hydrogen is one gram per mole. The pH value of a liquid can range from 0 to 14.

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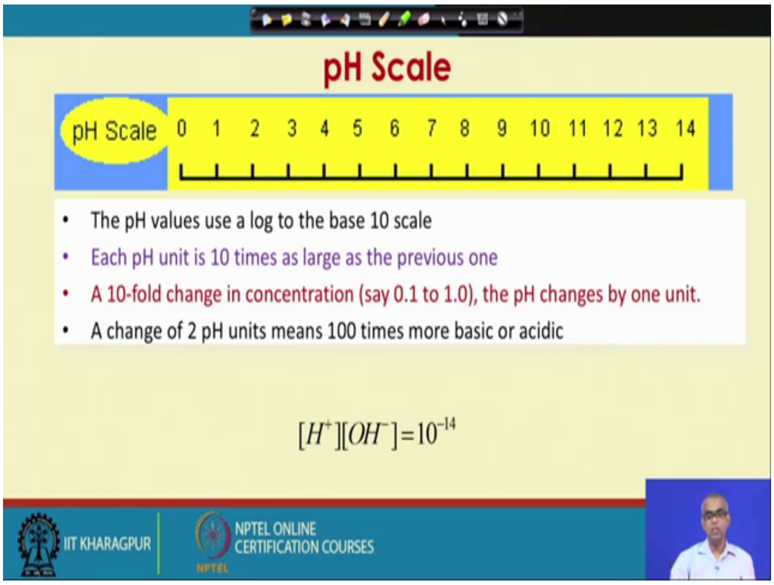

So, this is the scale 0 to 14, 7 is neutral 0 to 6 is acidic 8, 14 is basic the pH values use a log to the base 10 scale. So, each pH unit is 10 times as large as the previous one. At tenfold change in concentration say 0.1 to 1 the pH changes by 1 unit. So, when there is a change in concentration by tenfold, pH will change by 1 unit, this is because this log to the base 10 scale.

A change of 2 pH units will mean 10 into 10 times that is 100 times more basic or acidic. You also know that the product of hydrogen ion concentration and hydro hydroxyl ion concentration is 10 to the power minus 14.

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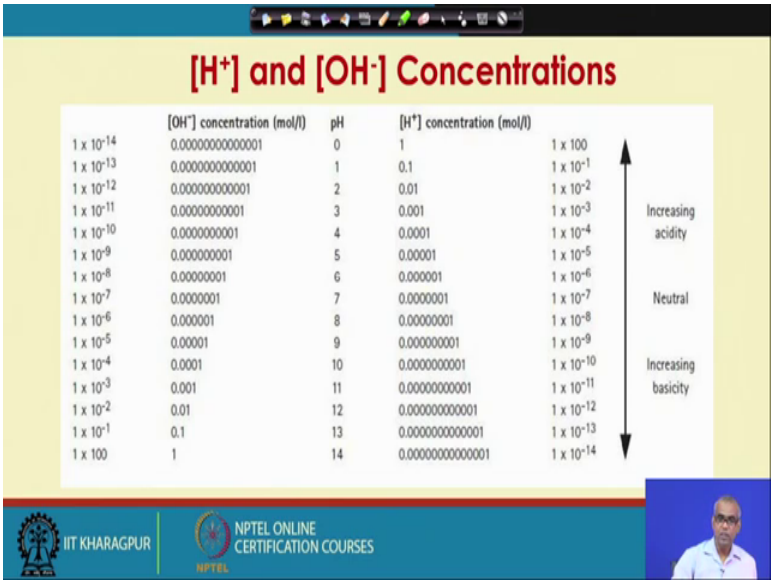

So, this basically tells how the hydrogen ion concentration and the hydroxyl ion concentrations related. So, look at this it is product of these 2 are always 10 to the power minus 14.

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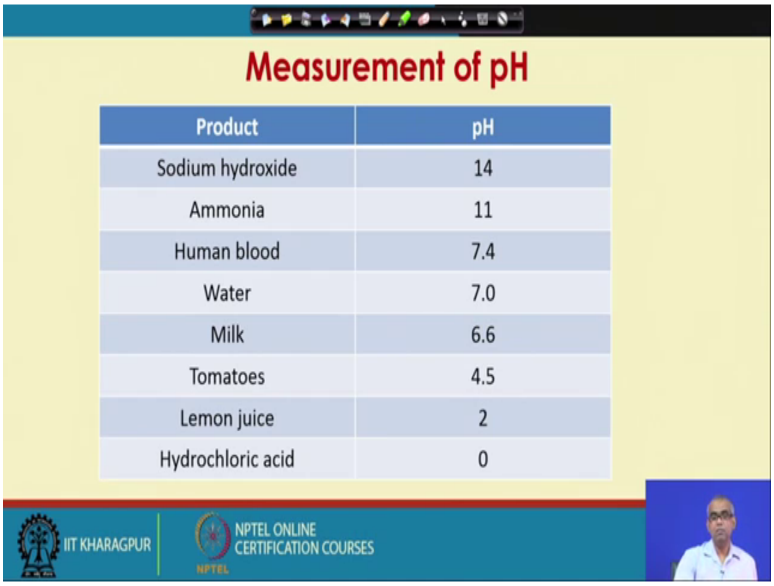

Here we show pH of some typical products sodium hydroxide being a highly alkaline or basic pH 14, ammonia maybe around 11 human blood is 7.4 pH. So, slightly basic water pure water is exactly neutral. So, 7 pH milk is slightly acidic 6.6, tomatoes 4.5, lemon juice 2, hydrochloric acid extremely acidic.

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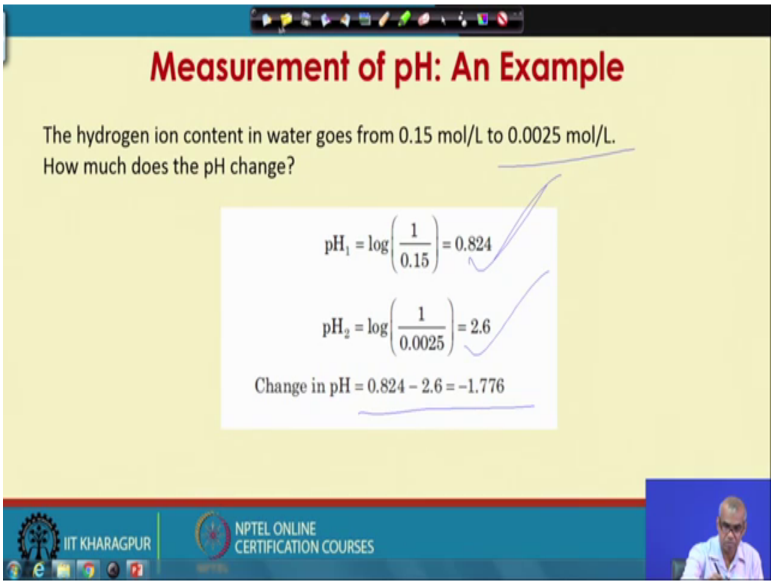

The hydrogen ion concentration in water let us say goes from 0.15 moles per liter to 0.0025 mole per liter. So, how much does the pH change? Let us do a simple example, this can be easily found out as, what is the pH when the concentration was 0.1 moles per liter? So, it is minus log 0.15 or log 1 by 0.15 which is 0.8 to 4. Again, when it is 0.0025 mole per liter, the pH is 2.6. So, the change in pH will be 0.824 minus 2.6 is minus 1.766. So, simply makes use of the formula for pH.

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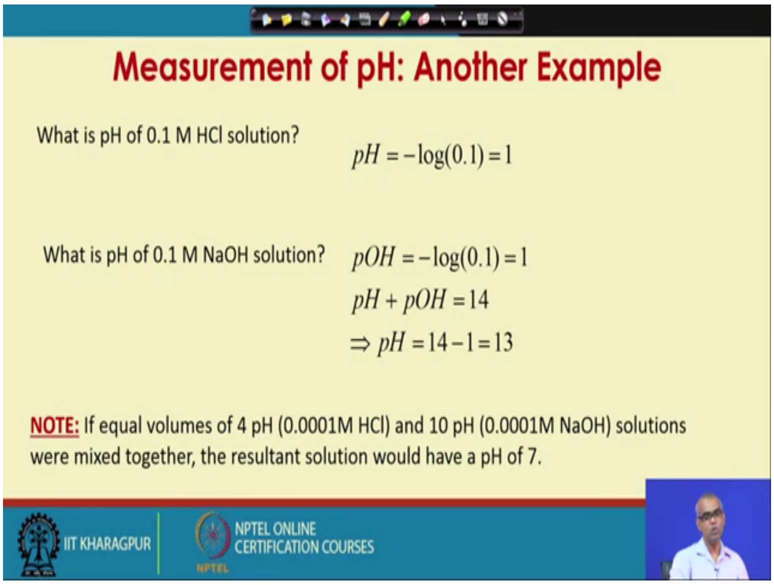

Let us take another example, what is the pH of 0.1 molar hydrochloric solution?

0.1 molar so, pH equal to minus log 0.1 is 1 what about pH of 0.1 molar sodium hydroxide solution. So, pOH is minus log 0.1 is 1, but you know that pH plus pOH equal to 14; that means, hydrogen of product or hydrogen and concentration and oxygen concentration is 10 to the power minus 14. So, this relation must hold true so, if I know pOH equal to 1, I know pH equal to 13. Note if equal volumes of 4 pH; that means, 0.0001 molar HCl and 10 pH, there is 0.0001 molar in which solutions where mixed together the result and solution would have been pH of 7, because there any true lies perfectly.

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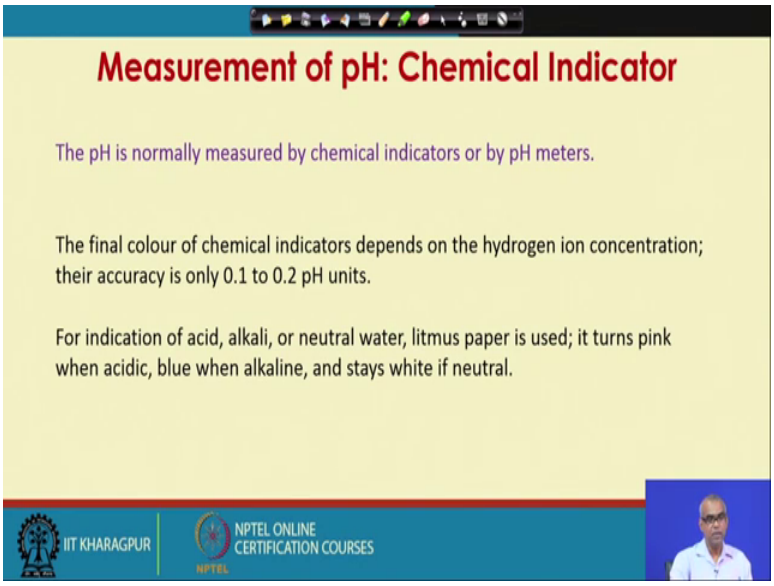

Measurement of pH the pH is normally measured by chemical indicators or by pH meters. The final color of chemical indicators depends on the hydrogen and concentrations. So, that is the principle by which chemical indicators such as litmus papers measures the pH. Away their accuracy is only 0.1 to 0.2 pH units. For indication of acid alkali or neutral water litmus paper is used, it turns pink and acidic blue and alkaline and stays white if neutral.

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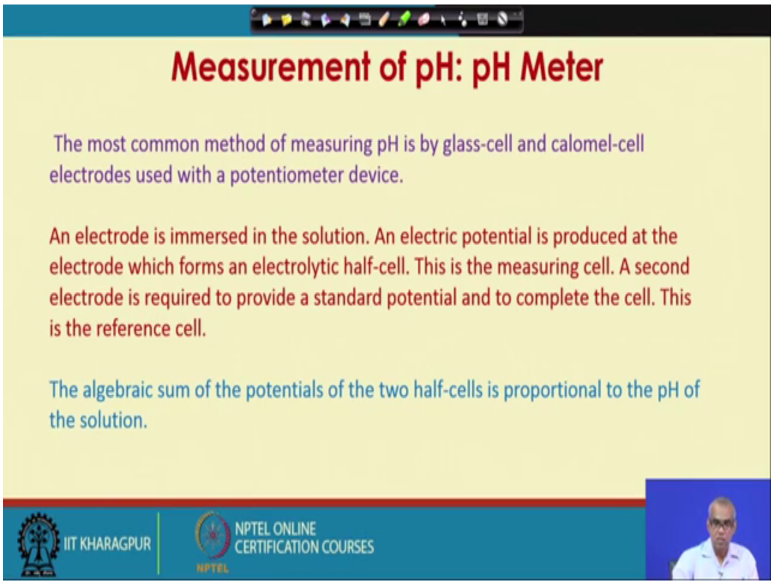

So, most accepted well accepted method of pH measurements in laboratory and industry is by pH meter. The most common method of measuring pH is by glass cell and calomel cell electrodes used with a potentiometer device. And electrode is immersed in the solution, and electric potential is produced at the electrode which forms and electrolytic half-cell.

This is the measuring cell, a second electrode is required to provide a standard potential and to complete the cell this is the reference cell.

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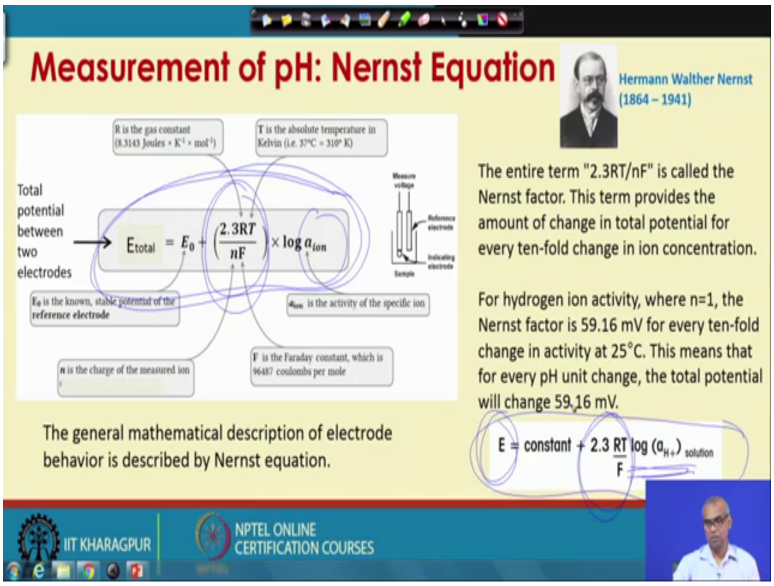

The algebraic sum of the potentials of the 2 half cells is proportional to the pH of the solution. This is basically based on Nernst equation, which is E equal to E 0 plus 2.3 RT by nF into log activity of sad vagina. So, E total is the total potential between 2 electrodes, you take 2 electrodes, this equation tells you the potential that is formed between 2 electrodes.

So, if that is I have in measuring electrode I have a reference electrode. So, the potential that is formed between these 2 electrodes, E equal to E 0 plus 2.3 RT by nF into log hydrogen and concentration ion relevant ion concentrations. E 0 is the stable potential of the reference electrode so, it will be normally known. This is the activity of the specific ion concentration for hydrogen cells is hydrogen and concentrations. R is the gas constant, t is the absolute temperature, n is the charge of the measured ion and f is the faraday's constant which is 96487 columns per mole.

The term 2 point 2.3 RT by nF is called the Nernst factor. This is known as Nernst factor. This term provides the amount of change in total potential, for every 10-fold change in ion concentration. For hydrogen ion activity where n equal to 1, the Nernst factor is 59.16 milli volt for every 10-fold change in activity at 25 degree Celsius. This means that for every pH unit change, the total potential will change 59.16 milli volt. So, for n equal to 1, and hydrogen ion we can write the Nernst equation as E equal to constant plus 2.3 RT by f log of hydrogen and activity.

So, this is nothing but a measure of pH this part, ok. So, you see that by measuring the potential between these 2 electrodes, I can measure the pH. All so, another thing please note that the Nernst factor is temperature dependent. So, whenever you measure pH using a commercially available pH meter, we also indicate temperature, because the Nernst factor has a temperature dependency unit.

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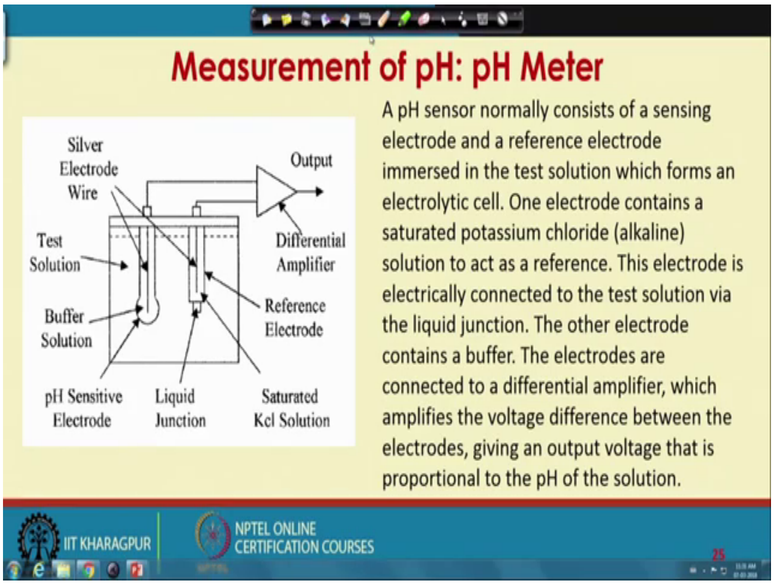

So, this schematically represents a pH meter so, we have a reference electrode and you have the measuring electrode pH sensor normally consists of a sensing electrode and a reference electrode immersed in the test solutions which forms and electrolytic cell. One electrode contains a saturated potassium chloride or alkaline solution to act as a reference.

This electrode is electrically connected to the test solution why are the liquid junction. The other electrode contains the buffer the electrodes are connected to a differential amplifier which amplifier is the voltage, between voltage difference, between the electrodes giving an output voltage that is proportional to the pH of the solution. So, according to Nernst equation, the output which is millivolt the potential difference is proportional to the pH of the liquid that is taken here.

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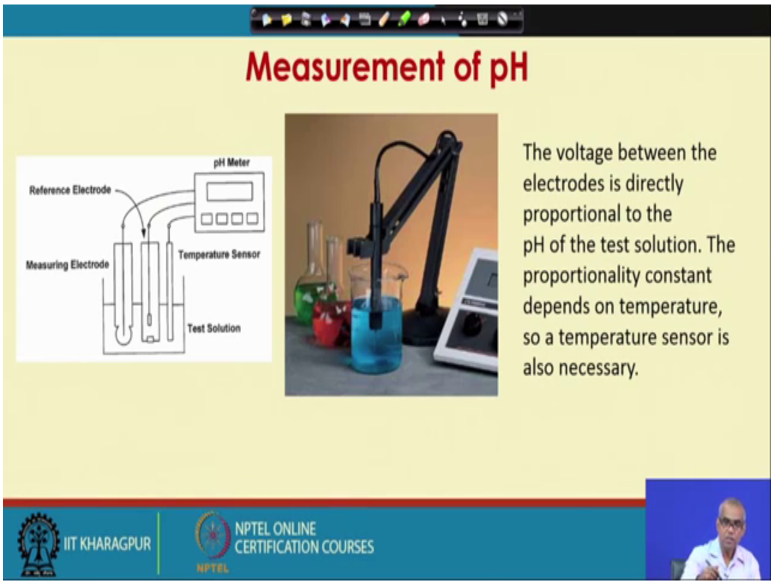

So, this is how commercially available pH meter looks like. Here you basically have the combined electrodes; that means, both the reference electrode and measuring electrodes are there inside it as shown here, it also has a temperature indicator. The voltage between the electrodes is directly proportional to the pH of the test solution. The proportionality constant depends on temperature because of that the non-specter temperature dependency. So, a temperature sensor is also necessary, and provided with all commercially available pH meters.

So, with this we conclude week 11 and our discussion on density and pH meter.