Industrial Instrumentation
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Lecture - 20
pH and Viscosity Measurement

Welcome to the lesson 20 of Industrial Instrumentation. In this lesson, we will discuss basically the analytical instrumentation. We will find that the two most important physical, I mean process parameters are pH and viscosity and as you know, the pH is very much necessary for many industrial application as well as bio-reaction and biomedical applications. Because, in some applications we will find that we have to monitor the pH of the blood and in some bio-reactions, bio-reactions, we have to purposefully make a particular pH value to have a good growth and there are numerous applications of measurements of pH in chemical industries. So, keeping all this in mind, in this particular lesson, we will discuss pH and viscosity measurements and different techniques of the viscosity measurements, pH particular probe and pH amplifier what are the, should be the typical characteristics of the pH amplifier, the, all these things will be discussed in this particular lesson.

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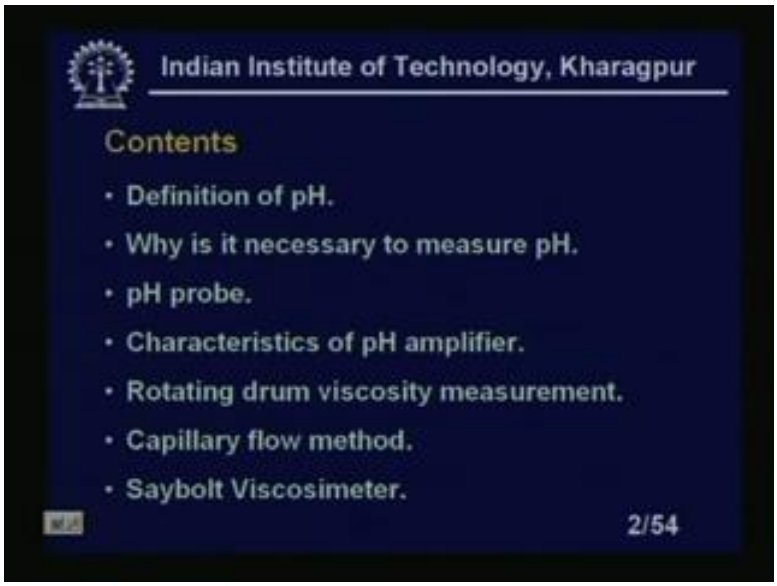

Contents are: the definition of pH, why is it necessary to measure pH, pH probe, characteristics of pH amplifier. Now, viscosity measurements - basically we will discuss two types of viscosity measurements. One is capillary method, another is rotating drum method and some industrial viscosity meter or viscosimeter. In industry it is called the viscosimeter. So, rotating drum viscosity measurements, then we will discuss the capillary flow method. Also we discuss industrial viscosimeter; it is called Saybolt viscosimeter, right?

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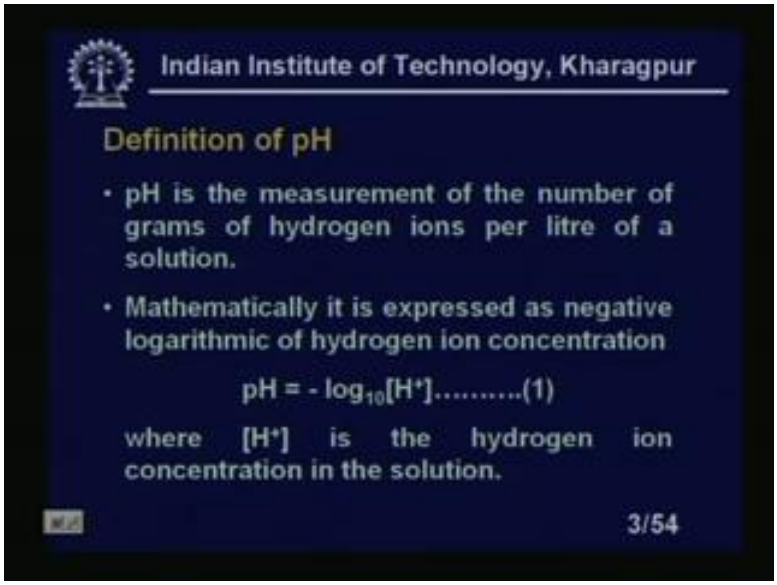

So, definition of pH you see, pH is the measurement of the number of grams of hydrogen ions per liter of solution, right? Mathematically it is expressed as negative logarithmic of hydrogen ion concentration, right? Mathematically can be expressed like this - pH equal to minus log base 10 of hydrogen ion concentration. This is equation number 1, where H plus is the hydrogen ion concentration in the solution.

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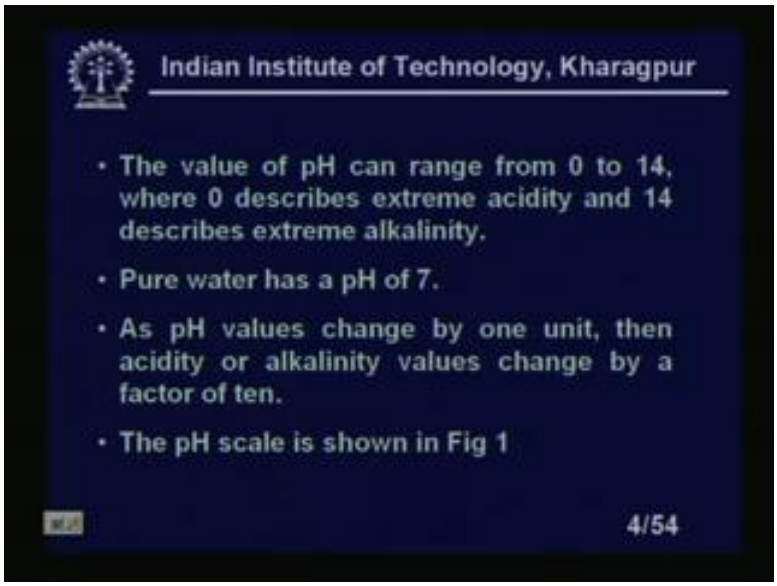

The value of pH can range from 0 to 14, where 0 describes the extreme acidity and 14 describes the extreme alkalinity, right? So, 0 describes the extreme acidity and 14 describes the extreme alkalinity. This is the range of pH. Either it will be 0 to 14 and if it is neutral, neither acidic nor alkaline, then in that case the pH will be 7 like distilled water has a pH, supposed to have a pH of 7. Now, pure water or distilled water has a pH of 7. As pH values change by 1 unit, then the acidity or alkalinity values change by a factor of 10. The pH scale is shown in Figure 1, you see.

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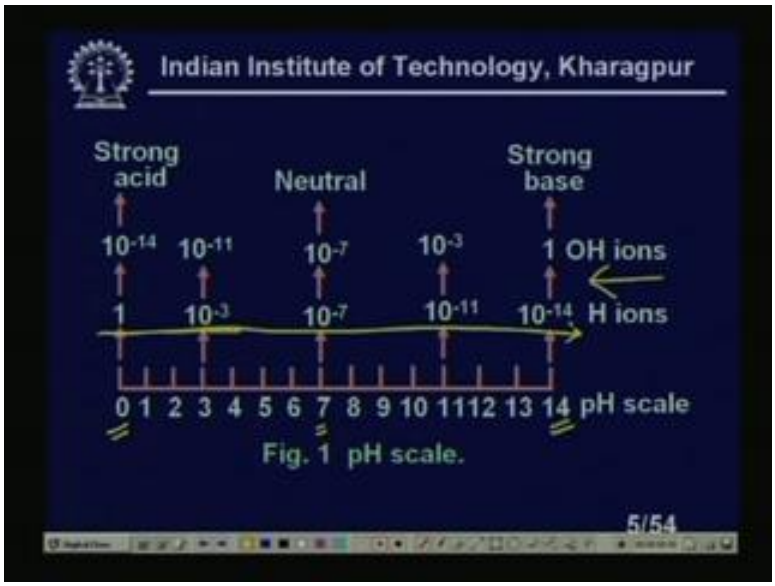

Next figure we will find, this is the pH scale we have seen. You see here, so this is, you see zero strong acid and this is a strong base. Base and alkali, as you know it is same thing and pH 7 is neutral, as I told you the distilled water. Strong acid like your, our acids are, I mean inorganic acids are very, very strong acid. In that case pH will be very close to 0, if it is not zero, right? In, similarly alkaline like, I mean any alkalis like sodium hydroxide and other types of solutions will give you a very strong base and as I told you distilled water should have a pH of 7.

Here in this scale you see here, in this scale we will show you the hydrogen ions. It starts from 1 into 10 to the power minus 4 and in this end we are showing the -OH ions. When the -OH ions are strong, we will call it strong acid. When the hydrogen ions are strong we were calling it, sorry and it is other way. When the ions are becoming weak, then it is becoming the strong acid. When H ions are strong in this way, because it is decreasing in this directions, it is say strong acid, right? So, it is 1 here, so it is 10 to the power minus 14 here.

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Now, why is the pH measurement is important? That is in the initial stage I told you once and let us, let me discuss this in details. Measurement of pH of a solution is necessary to judge whether the liquid is acidic, alkaline or neutral, right? It is necessary in many applications, because in some environments we will find that the, we have to make those environments neutral. So that tap water, suppose the drinking water it should be neutral; so, in that case it should be neither acidic nor alkaline, right? In some reactions like, suppose in the bio-reaction it will be slightly alkaline, so there also the measurement of pH is necessary.

In biomedical applications we will find that the measurement of pH is necessary, because we, we can monitor, by monitoring the pH we can tell some of the particular diseases also. The application areas are food, beverage industry, aquarium, agriculture and gardening and colour photography, etc. There are numerous applications, even more applications like the industrial application as I told you earlier.

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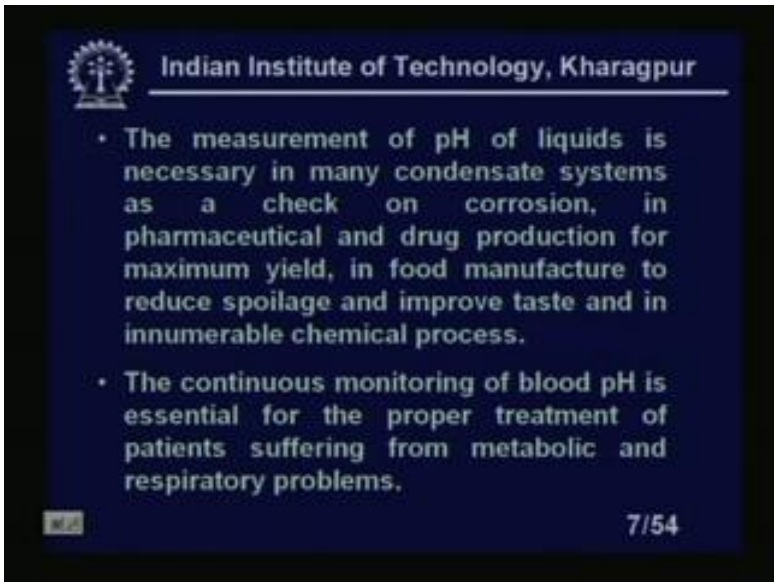

The measurement of pH of liquid is necessary in many condensate systems as a check on corrosion, in pharmaceuticals and drug production for maximum yield, as I told you in the bio-reactors we always make, I mean suppose the yeast culture, say always make the pH slightly alkaline, right? So, that type of situations we call it, I mean the measurement of pH is also necessary. In food manufacture, because we have seen that if you make it slightly alkaline, so we will find the growth will be better, right? So, that reason measurement of pH, continuous monitoring of pH is necessary for any bio-reactions.

In food manufacture to reduce the spoilage and improves the taste and in innumerable chemical processes, you will find the applications of measurement of pH. The continuous monitoring of blood pH is essential for the proper treatment of the patients suffering from metabolic and respiratory problems, because you know, the blood has a pH. It is, I mean varies 7.35 to 7.4 that is 7.35 to 7.5. So, if this is for a normal healthy person, now if this, if this goes out of this range that means the patient has some problems. We can monitor those and appropriate actions can be taken, appropriate drugs to be given to the particular patient, so that the pH value comes to the actual, normal healthy person's range of 7.35 to 7.4 or 7.5.

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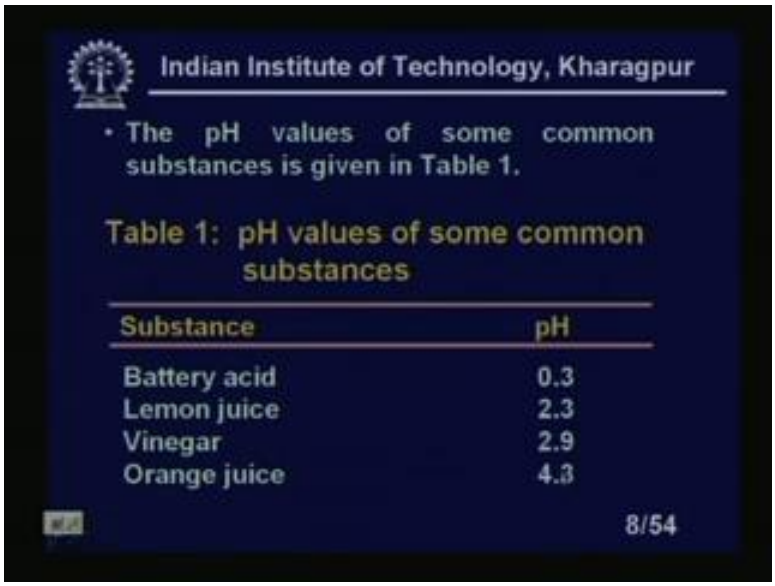

The pH values of some common substances are given in Table 1; let us look at. You see, this is the pH, the values of some common substances. Battery acid which is supposed to be a very strong acid, sulphuric acid, you see it is almost close to 0, .3, very strong acid. Lemon juice – 2.3, because these are all organic acid, is not it? Vinegar – 2.9, orange juice, organic acid – 4.3. So, more and more, you see it is increasing in value of pH, right?

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Then we have boric acid - 5, corn - 6.2, milk – 6.7, slightly acidic that means, distilled water 7.0. Now, it is, if it goes, crosses zero, then you will find, crosses 7 that means it has become acidic, I mean alkaline. Blood – 7.5; as I told you, its range lies from 7.35 to 7.4 or 7.5. So, we have given the value 7.5, right? Sea water is alkaline; it is 8, baking soda – 8.4, milk of magnesia – 10.3, ammonia – 11.4. It is quite highly alkaline, you can say. Bleach is even higher; it is 12.6, right? This is the range of the pH values for different commonly used substances.

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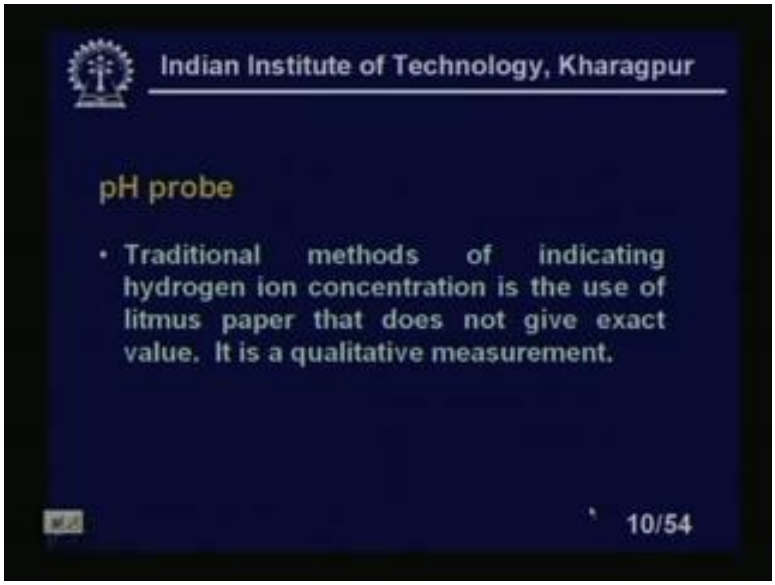

Now, pH probe – the, because pH is, is usually you see that is the, you need a probe and details of the probe needs to be, I mean to be discussed. The traditional method of indicating hydrogen ion concentration is the use of litmus paper. This we have seen in the chemistry laboratory. The people use the litmus paper to know whether the solution is acidic or alkaline, but this, this method is very much qualitative method of measurement. It will not give you how much, how much strong the, it is acidic or how much strong is, I mean it is alkaline.

So, some measurement is necessary, but litmus paper, obviously people are using over the years, over the decades and it gives actually some indications whether the pH value

is, either the liquid is, either I mean acidic or alkaline. So, traditional method of indicating hydrogen ion concentration is the use of litmus paper. That does not give exact value. It is qualitative measurement, as I told you earlier. So, we need some quantitative measurements, which will give you the exact value of the pH.

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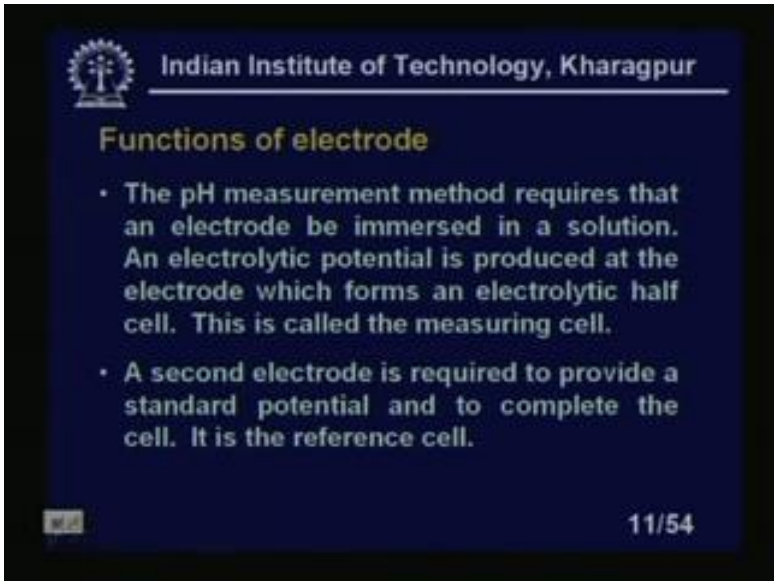

Functions of the electrode - what is the function of this electrode? The pH measurement method requires that an electrode be immersed in a solution, obviously. An electrolytic potential is produced or developed at the electrode which forms an electrolyte, electrolytic half cell. This is called the measuring cell. There are two cells, we will find. One is reference cell, another is measuring cell, right? Now, each of the cells we are calling it half cell. There are combined pH probe also that will be discussed later on. Now, we will first discuss the measuring cells and reference cells. What is the content of this? A second electrode is required to provide a standard potential and to complete the cell. It is the reference cell, right?

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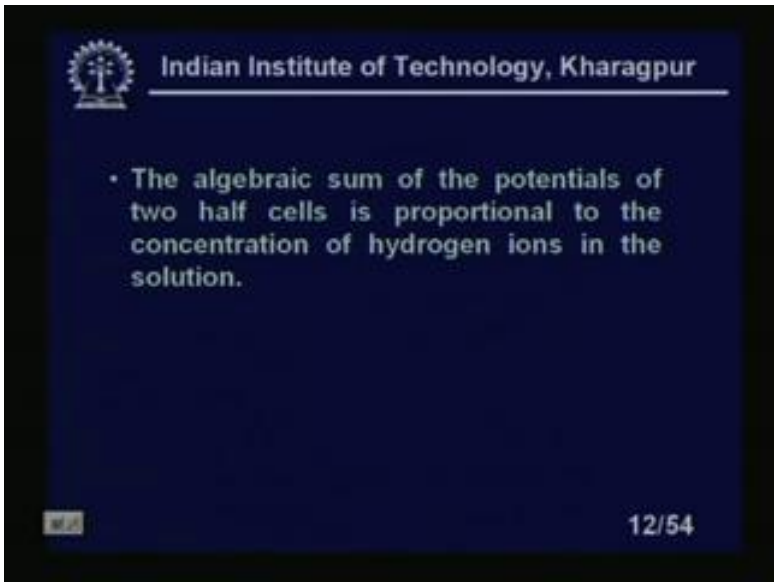

The algebraic sum of the potentials of the two half cells is proportional to the concentration of the hydrogen ions in the solution; actually we want that. The two voltages will be algebraically, I mean added and we will get the value of the pH, right? The measuring glass electrode is shown in Figure 2. So, we will show you the figure. You see, the glass electrode, we will first discuss about the glass electrode, then we will go to the figure. It operates on the principle that a potential is observed between two solutions of different hydrogen ion concentrations when they are separated by a thin glass valve, wall this should be, I am sorry, it should be a wall, wall.

This potential is function of two concentrations. A buffer solution is contained in the permanently sealed glass electrode which is surrounded by the solution whose pH is being measured, right? A buffer solution has a constant hydrogen ion concentration and the potential at the electrode therefore depends on the hydrogen ion concentration of the measured solution. You see this is our measuring glass electrode.

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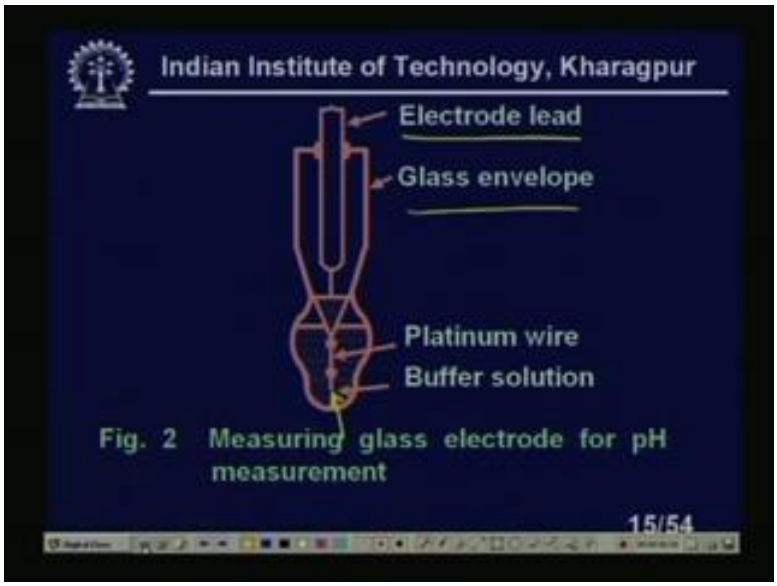

You see here, everything is very much clear. You can see it is the electrode lead. This is the glass envelope. We have a platinum wire and we have a buffer solution here, right? We have a buffer solution here for pH measurements.

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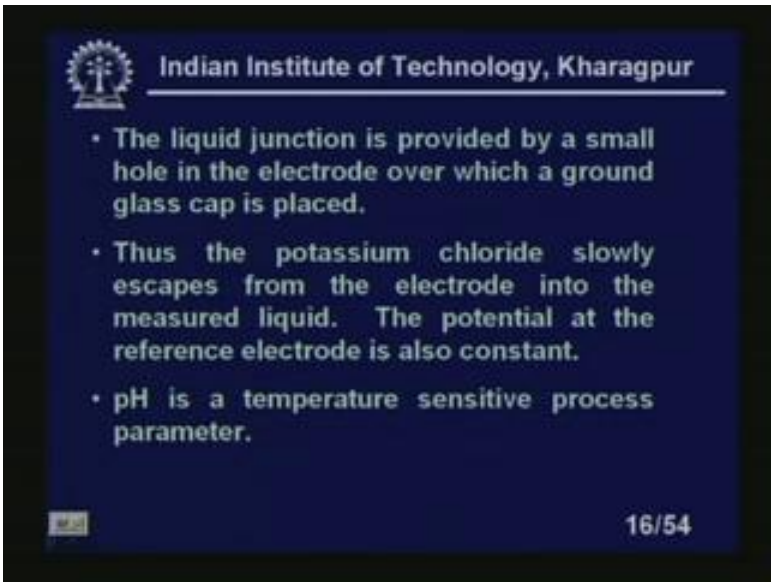

Now, the liquid junction is provided by a small hole in the electrode over which a ground glass cap is placed. Thus the potassium chloride slowly escapes from the electrode into

the measured liquid and the potential at the reference electrode is also a constant. pH is a temperature sensitive process, I mean process parameter. So it, you must compensate for any changes, because if the temperature changes, pH value also will change. So, the output voltage of the meter also will change, so that you must make some compensation for this temperature change.

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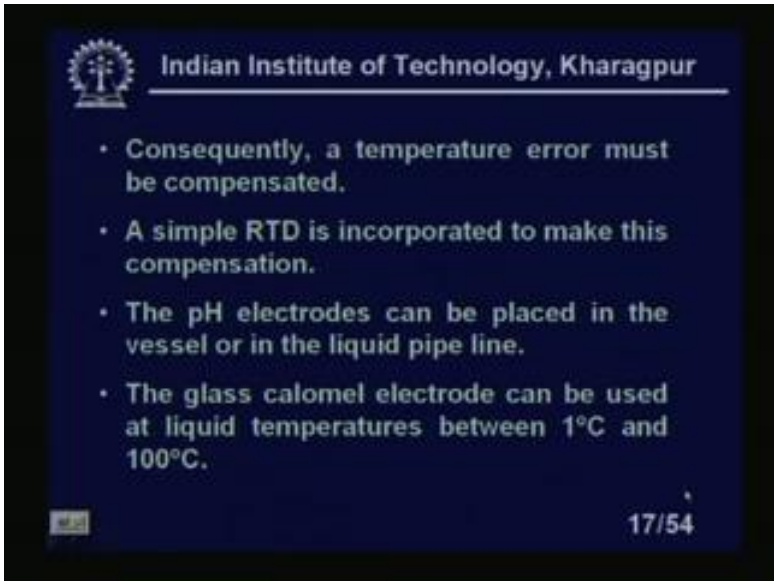

Consequently, a temperature error must be compensated, any temperature error must be compensated. A simple RTD is incorporated to make this compensation. The pH electrode can be placed in the vessel or in the liquid pipe line. Either it can be placed in the vessel in which we have to take the sample of the liquid or in the liquid pipe line where the liquid is flowing that can be also be used to make the measurement, right? The glass calomel electrode can be used as it, at liquid temperature between 1 degree centigrade and 100 degree centigrade.

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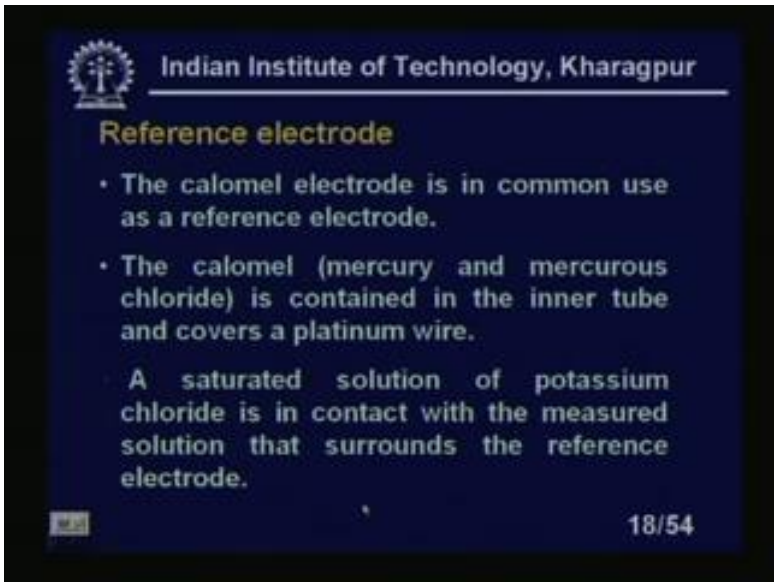

You see, the reference electrode; the calomel electrode is in common used as a reference electrode. The calomel is mercury and mercurous chloride is contained in the inner tube and covers a platinum wire. A saturated solution of potassium chloride is in contact with the measured solution that surrounds the reference electrode.

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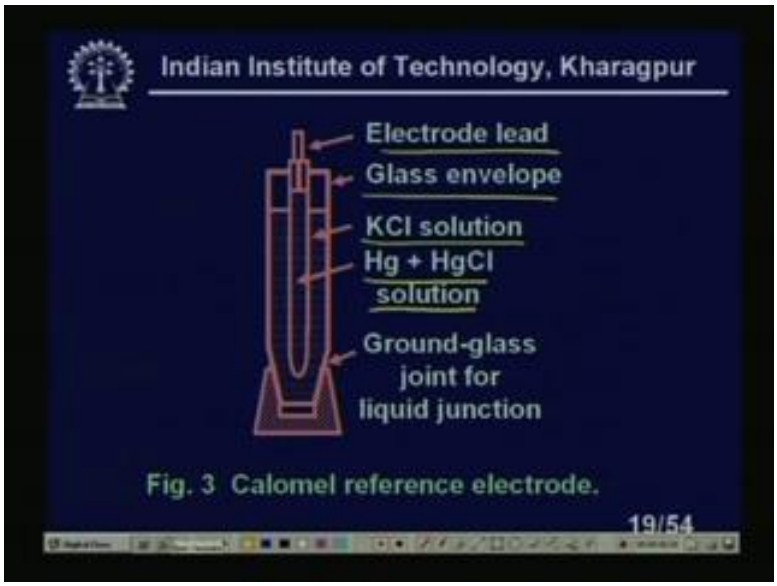

You see, this is the calomel reference electrode. We have a ground glass joint here. This is put on some solution, so that the, it should remain, I mean it should not dry up. We have a, you see Hg and HgCl solution and this is the glass envelope and this electrode lead is coming and this is the KCl solution, right?

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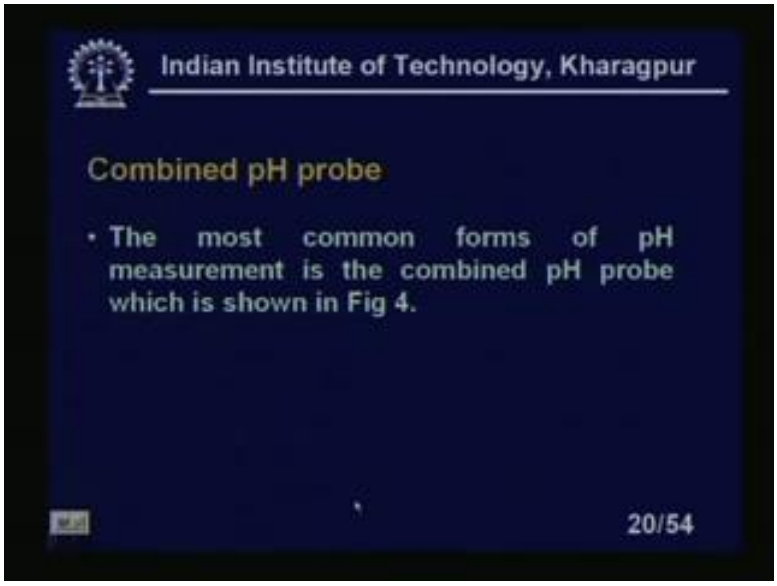

Now combined pH probe, because you see, using two probes it is, obviously it is problematic in many cases. So, we want something very handy. So that type of electrode is the combined electrode. So, we will find most of the application nowadays, I mean in fact in our country Phillips is making that type of probe that which have, but other companies are also making. Those are separate electrode, two separate electrodes we have to put, otherwise you can have a one combined electrode that means both reference electrodes and the measuring electrodes are in the same system. It is very handy, it is very useful and ease of measurement will be, also be there. The most common forms of pH measurement is the combined pH probe which is shown in Figure 4.

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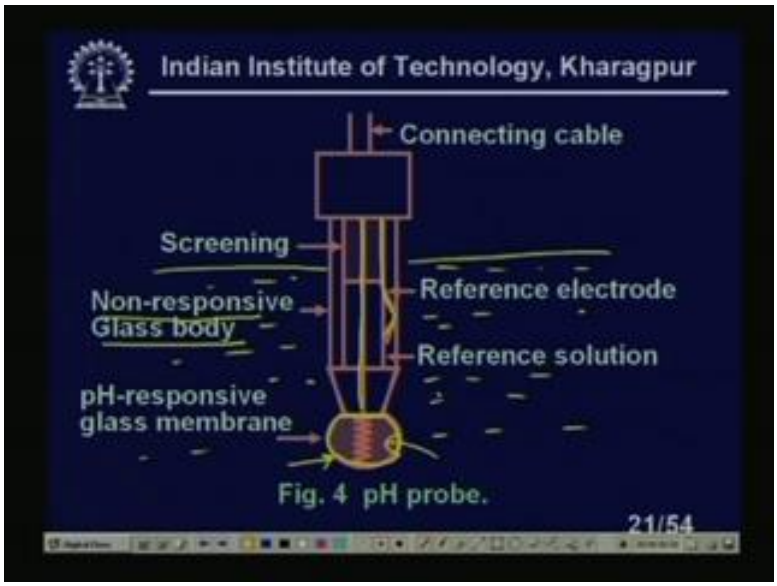

You see, we will show the figure. This is you see the combined electrode, right? You see it is a connecting cable and you see here it has pH sensitive glass membranes. This is not responsive to glass body. You see, this is the non-responsive glass body. We have written here non-responsive glass, glass body, right? So there will, there is no interactions with the, if we, even if we have a liquid up to this, suppose we have a liquid up to this in which, suppose in a beaker we put this, in a beaker we put this electrode, so obviously what will happen?

You will find that this will not act, but this is the pH sensitive, you see this glass is pH sensitive, right? It will react with the, so liquid, it will react with the liquid outside, right, so that, because it is filled with the reference solution, so I will get the measurements and here you see in this case, the reference cell, this is the reference electrode and it is put on the reference solution, right? This is the, this is totally separate. This unit is totally closed. It is not, so only the electrodes are coming out. You see the, here, here the electrodes are that, this lines is going out. Similarly these lines also.

This is the reference electrode line. This will be going out. This is the combined electrode. We will see mostly this is the thing people are now using. This is the same

thing, excuse me, we will find here that there is also reference electrode. The reference solutions like KCl solutions are there, potassium chloride solution and you see, this is all measuring electrode. The same thing is there that platinum bottom or you have, we have seen in the separated electrode, it is already there but it is combining too, combining bond system.

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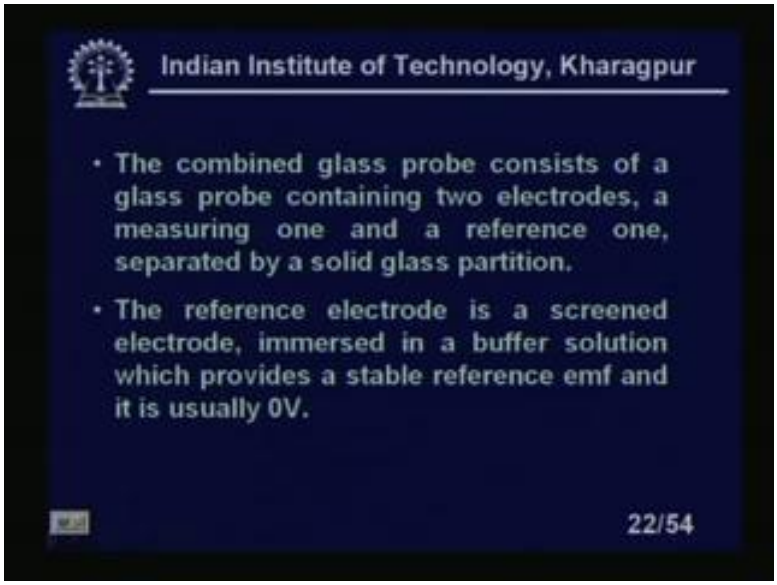

The combined glass probe consists of a glass probe containing two electrodes, a measuring one and a reference one, separated by a solid glass partition. The reference electrode is a screened electrode, immersed in a buffer solution which provides a stable reference emf and it is usually zero volt, right? Reference electrode is a screened electrode, immersed in a buffer solution which provides a stable reference emf and it is usually zero volt. Let us look at again.

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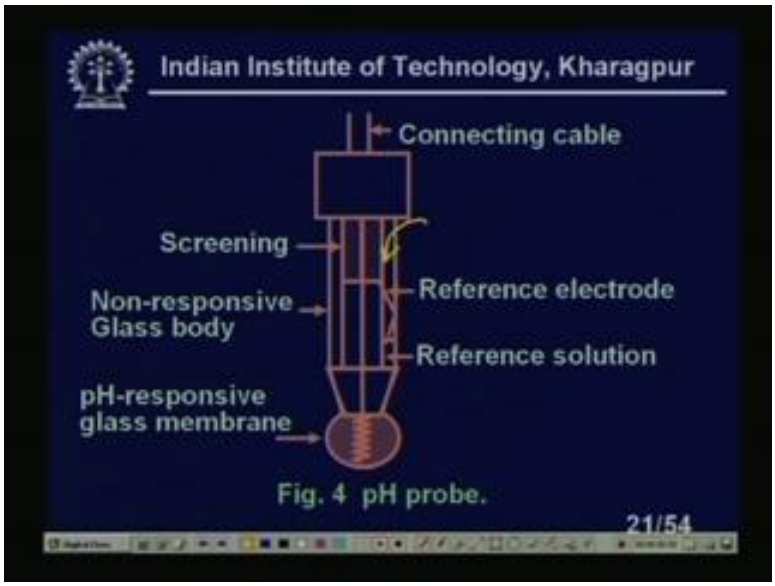

You see here, there is a buffer solution here. You can put this is a buffer solution. This is filled up with a solution, sorry, you see there, here we have a solution, right that is a buffer, I mean solution, right? So, there is a reference electrode, fine. So, reference electrode is a screened electrode and immersed in a buffer solution which provides a stable reference emf and it is usually zero volt, right? No problem, fine.

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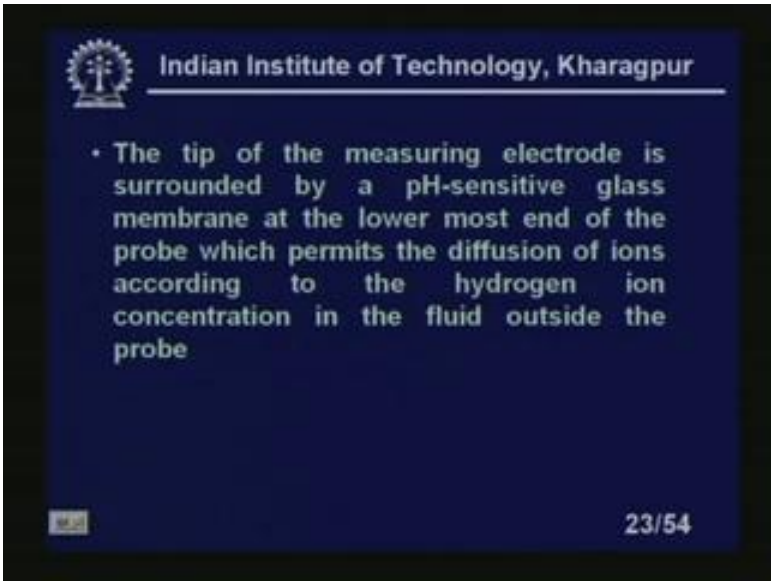

The tip of the measuring electrode is surrounded by a pH sensitive glass. Again let us go back. We can see, it will be more clear.

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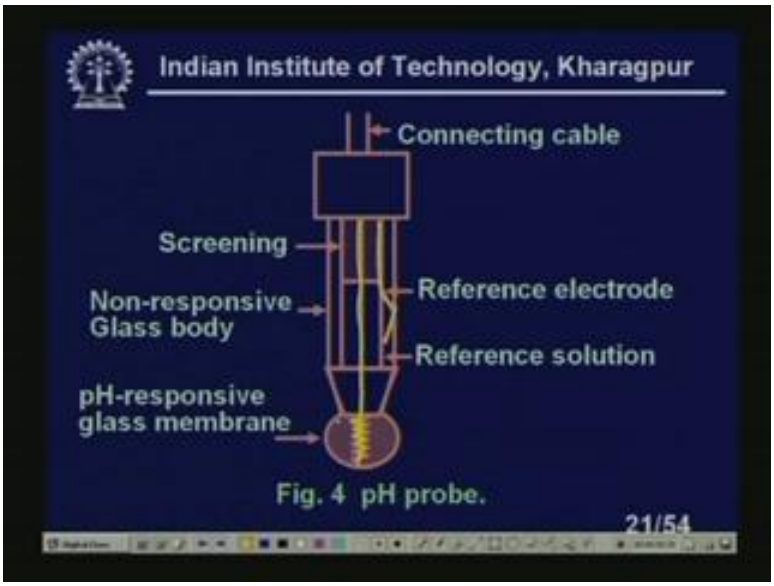

You see, this is the tip of the electrode, this is the measuring electrode. This is the reference electrode. Let me again go back again like this one. So, this is our measuring electrode. It is coming here. This is all those platinum business. Here, here you can see here this is the reference electrode. This you see, is surrounded by a pH sensitive glass membrane, clear?

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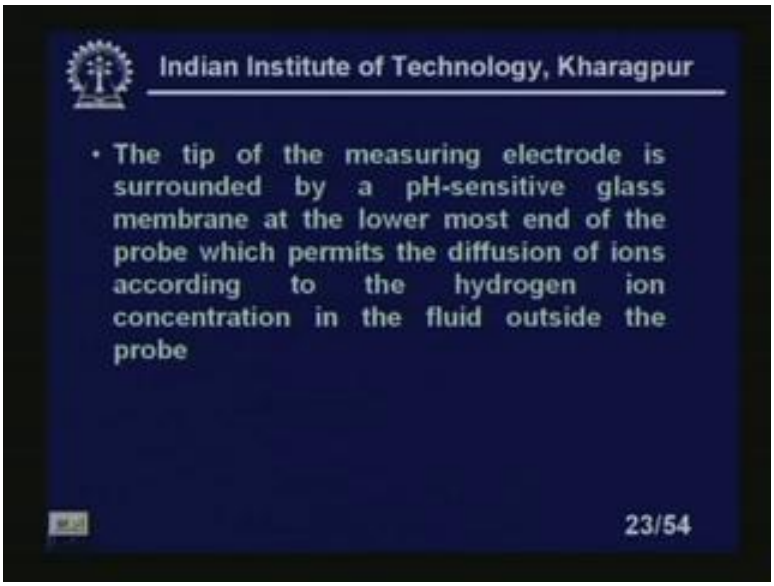

The tip of the measuring electrode is surrounded by a pH sensitive glass membrane at the lower most end of the probe which permits the diffusion of ions according to the hydrogen ion concentration in the fluid outside the probe, clear? Outside the probe we have some liquids, right?

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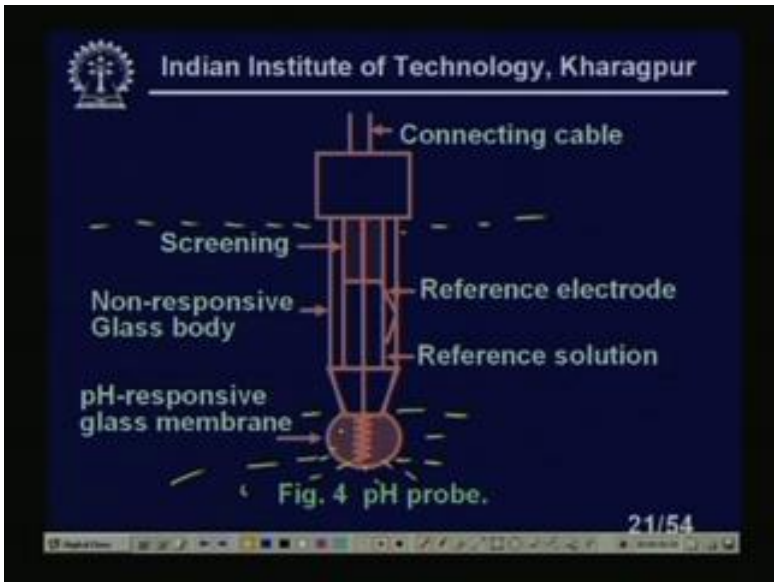

Right, you see, outside the liquids. So, what will happen you see here? So, we have a liquid here. Obviously, as I told you here I have a liquid, but there will be no reactions. Liquid, this liquid cannot go inside. Here you will see there is a diffusion of the hydrogen ions. So, it will react with the, these probes, we will get some output, clear?

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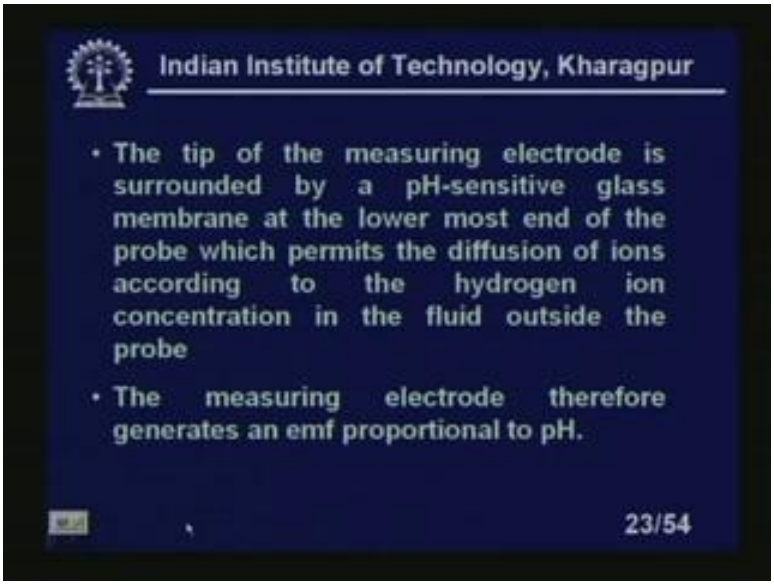

So, tip of the measuring electrode is surrounded by the pH sensitive glass membrane at the lower most end of the probe and which permits the diffusions of ions according to the hydrogen ion concentrations in the fluid outside the probe. Actually there should be a full stop here, anyway. The measuring electrode therefore generates an emf proportional to pH, because other thing is constant. So, because it is electrical circuit I need at least two lead that is the reason reference electrode is also necessary, right? So, measuring electrode therefore generates an emf which is proportional to the pH of the liquid in which that measuring electrode has or measuring tip has been inserted, clear? Because, the measuring tip is to be inserted there, so that I will get some emf which is proportional to the pH of that solution and the reference electrode, so we got two terminals, we will get a voltage that is measured and that will be converted to the current later on.

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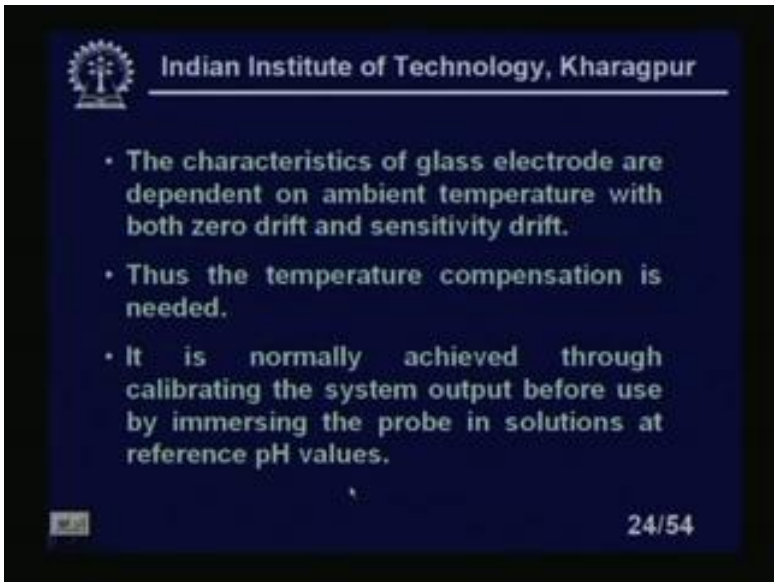

The characteristics of glass electrode are dependent on the ambient temperatures with both zero drift and sensitivity drift. This already we have discussed. Because it is sensitive to the temperature, so we have to take proper care by RTD or any other temperature sensitive devices to make the correction. Thus the temperate compensation is needed. It is normally achieved through calibrating the system output before use by immersing the probe in solution at a reference pH values, right?

That is the very interesting thing, because I can have a reference pH value. Suppose if, I mean solutions of known pH I will put, insert, so I can make necessary corrections or I can have a temperature compensation scheme also by which I can make the correction, right? This is some analytical, I mean that means we have some because normal, I know that it is, pH is suppose 4, now it is coming 4.2. Accordingly I can make the corrections, because this 4.2 into the some temperature, temperate change, so that can be corrected for any unknown measuring value of the pH, right?

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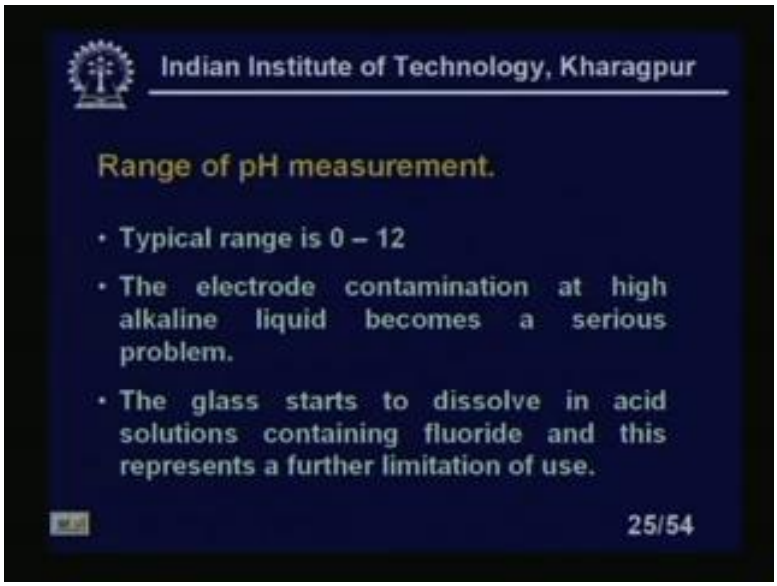

Now, range of pH measurements you see, the typical range, I mean for measurement is 0 to 12, because it cannot read, it is very difficult to measure beyond 12. It will become so much of alkaline, it is very difficult. The electrode contaminations at high alkaline liquid become a serious problem. Electrode can be contaminated at high alkaline liquid and becomes a serious problem. The glass starts to dissolve in acid solution containing fluoride and this represents a further limitation of the …. use. That is for the lower range. Even though I am saying 0, but we cannot measure the pH value of zero, which is very difficult, right? It is highly acidic.

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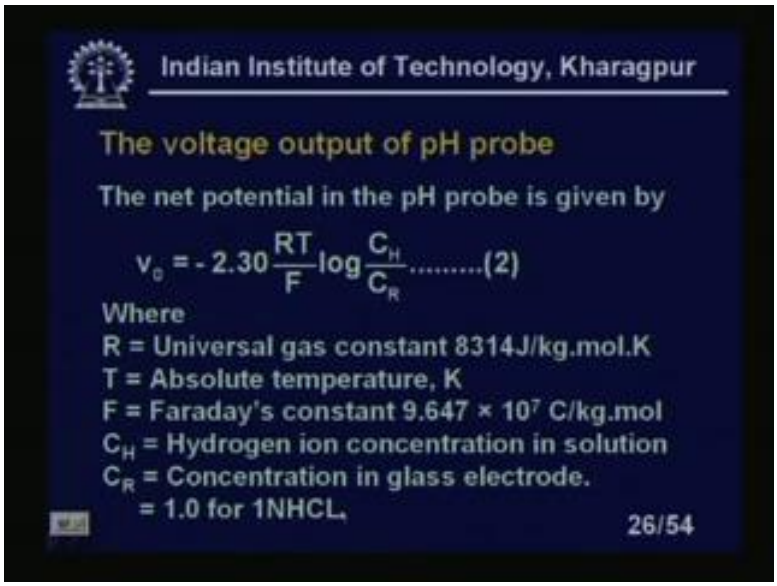

The voltage output of the pH probe you see, because we will get a voltage, the net potential in the pH probe is given by this expressions, right? V naught equal to minus 2.30 RT by F log of C H by C R, equation number 2, where R is the universal gas constant which is 8314 joule per kg per mole per Kelvin, T is the absolute temperature in Kelvin, F is the Faraday's constant; it is 9.67, 9.647 into 10 to the power 7 coulomb per kg mole and C H is the hydrogen ion concentration in solution and C R is the concentration in glass electrode. So, this will cancel, I mean these two units will be cancelled out and that is not, that is the reason it is not mentioned, right? So, we will get that voltage output. If I plug in all the values I will get, which is 1.0 for 1 normal HCL.

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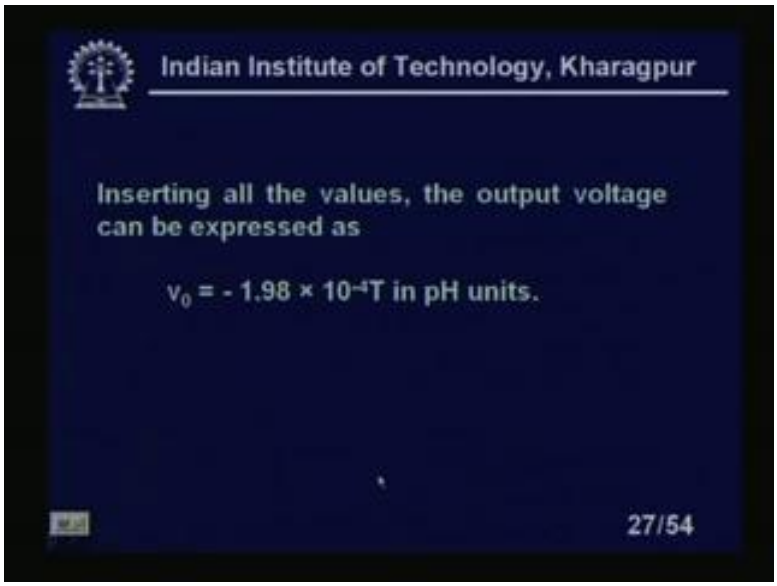

Inserting all the values, the output voltage can be expressed as V naught equal to minus 1.98 into 10 to the power minus 4 T in pH units. So, pH units we can see is very small, right? It is sensitive to temperature, so that is the reason T unit is there. Now pH amplifier, you see the pH amplifier should have very typical characteristics. The pH, since we have glass electrodes, we can consider as a voltage source. It is like this one you see that we can consider as a voltage source.

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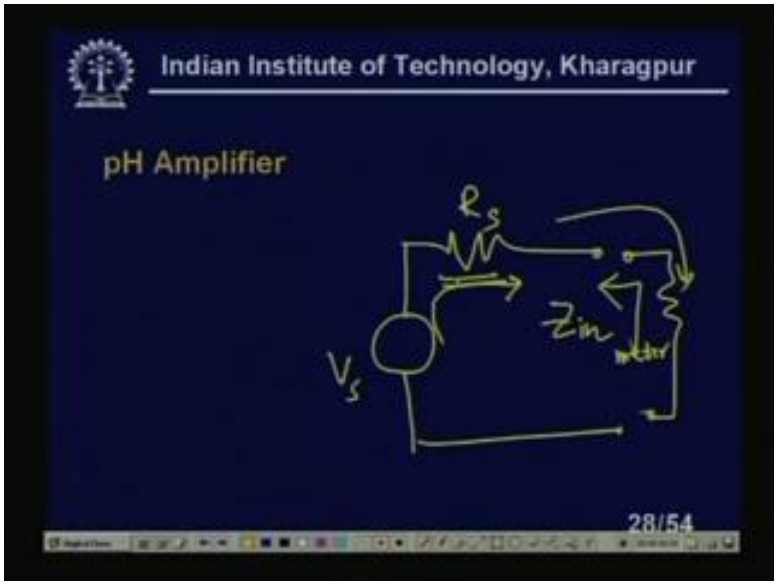

That means I have a voltage source and with a high source impedance, right? So, any current, if I try to draw some current through this circuit, because when we measure with this resistance by some meter, it has some input impedance, is not it? So, a current will start to flow if you connect this one. Suppose this is a meter, then what will happen? There will be a large drop across this. So, I won't get the proper measurements. So, the pH amplifier should have the basic characteristics of the pH amplifier that it should, first of all it is a DC amplifier and amplifier means actually it is amplifying and also the, measuring the voltage output of the pH probe which is coming from the reference and the measuring electrode. Because measuring electrode is one point measuring, I mean two electrodes are there. If I have to take separately, two electrodes are there, so this voltage is to be measured between this point and this point, right?

If it is combined also it is same thing, because this is also two separate and two, as I have seen the two electrode leads are coming out even in the combined electrodes. So I have, we have to measure these two, this voltage between these two electrodes and since we have a glass, so it is, I mean source impedance of this, this we can consider as a voltage source and because of it, the glass, it has a very high internal source resistance, right? That is the reason we cannot get any voltage. You see, this is very common. You see those, we are most familiar with the our dry cell batteries, because I am giving the examples of dry cell batteries because it is almost all of us we have seen that when the dry cell is almost dead, you can see almost, suppose it is, it is supposed to be for normal healthy dry cell it is 1.5.

Now after use over the, suppose days and months we will find the dry cell voltage drop, but we will look at, very interestingly that is the voltage does not drop much and supposedly if you want to draw some current, you will find that you are not getting any current. The reason is due to chemical reactions inside, the dry cells internal impedance has increased so much that you cannot draw any current from that source, right, that is the voltage source, is not it? A dry cell is a, is a voltage source of 1.5 volt.

Now, initially this resistance is so small that is you cannot measure a current. You cannot measure a short circuit current. It will be very high, right? But, as the time goes there is a chemical reaction and we will find this internal impedance initially it is very, very small and initially, after use you will find this voltage, this internal resistance is getting increased. At some level we will find that you cannot take out any current from that voltage source, right, because internal impedance is so high. Similar the case, in the case I mean in the case of pH probe, because of its internal, I mean because of the glass probes, internal impedance is in the order of several mega ohms.

So, I will need some amplifier. First of all I have to amplify that signal which is very small, DC signal and I have to amplify the signal as well as the main characteristics of this amplifier should have a very, very high input impedance. That means looking from this terminal, if I look at, looking from this terminal the impedance the, the amplifier, the impedance the meter on the amplifier will offer should be extremely high and atleast 100 times higher than the source impedance of the, 100 times higher than the source impedance of the pH probe, clear? So, let us look at the details.

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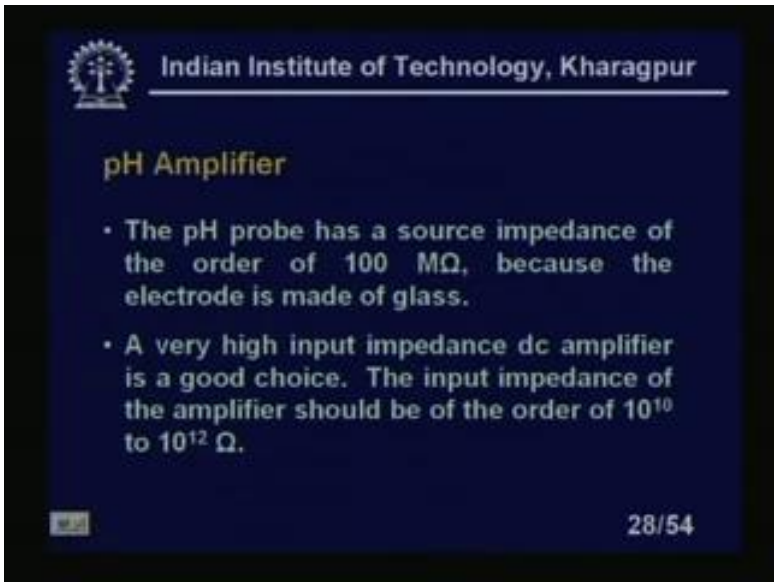

The pH probe has source impedance of the order of 100 mega ohm, because the electrode is made of glass, right, fine? A very high input impedance DC amplifier is a, is a good choice. The input impedance of the amplifier should be of the order of 10 to the power 10, 10 to the power 12 ohm, you can think of. It is, I mean 10 giga ohm to 1000 giga ohm I want, right? This much of higher input impedance is necessary to measure the pH.

How will I achieve that high value of the, because you know that we have studied so many amplifiers and this that, we know that I mean if we use a, suppose if is, you can simply use, those who are from electrolysis, you must be knowing that if I use a common collector amplifier, a single thyristor common collector amplifier, I will get a higher impedance than the common emitter or common base amplifiers. We can have instant, I mean we can have the op amp also. Suppose in the unity gain feedback mode which is obviously used, I mean in many applications we have seen in the instrumentation it is used as a buffer amplifier, right or I can use cascade amplifier also which will give you the higher input impedance.

But this input impedance is not that high that I can measure the pH voltage, right? So, we need some other applications like MOS devices, FET device at least or MOS device. In FET, in the case of FET, as you know the input impedance is very high. In the case of MOSFET input impedance is even higher. So, we should have some devices of some circuit by which I can have, achieve this much of input impedance, right? Let us look at details of that.

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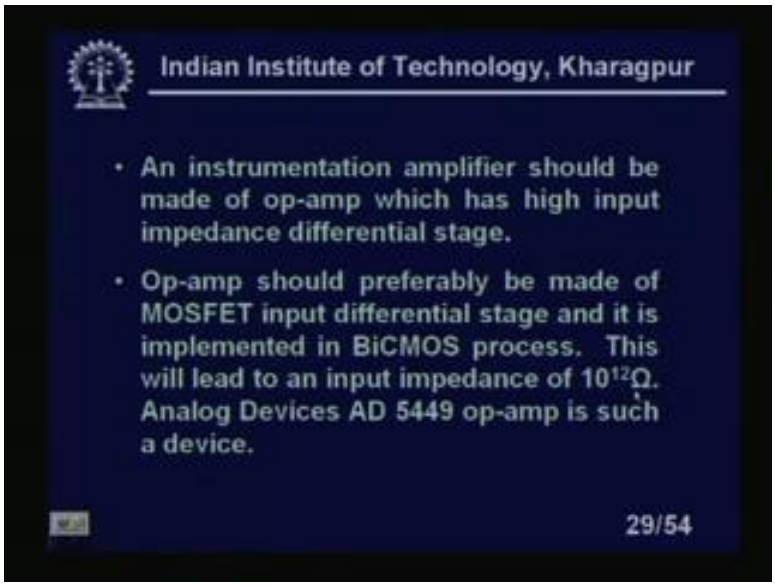

An instrumentation amplifier should be made of op amp which has a high input impedance differential stage, right? So, instrumentation amplifier which is to be made of op amp, so instrumentation amplifier is know, you know there is input impedance is higher than the op amp and its common mode ejection is also better. So, keeping all, this means you can have instrumentation, but first of all I need op amp, very high quality op amp, which is high gain as well as high input impedance, extremely high input impedance, otherwise you cannot measure, please note.

Op amp should be, preferably be made of MOSFET input differential stage and it is implemented in BiCMOS. BiCMOS, as you know, CMOS is complementary metal oxide semiconductor. It is a bipolar complementary metal oxide semiconductor process by which we have, in the same wafer we have, should have both bipolar devices as well as MOS devices and this type of, I mean amplifier will give you a proper impedance which we can, I mean utilized, I mean that amplifier can be utilized to measure the pH voltage. This will lead to an input impedance of 10 to the power 12 ohm. You can see 10 to the power 12 means almost 1000 giga ohm, right? Now, analog devices AD 5449 op amp is such a device which will, can be utilized, safely utilized for measurements of pH value, right?

Now this all, we talked about this pH value. Now, let us come to the, another analytical measurement, which is called the viscosity. Viscosity is also very important, because in many applications we will find that I mean the quality of the food product also depends, I mean viscous, quality of the chocolates depends and depends on the raw materials. So, people try to measure the viscosity of that suppose the ….. in which we are producing in the industry they also measure the quality, because basically it is for the quality control, in the process industry we will find basically for the quality control.

In food industry, this actually gives you the good taste. In some there is restriction of the pipe whether if it is very viscous then there will be a large pressure drop. I need a large pumping cost will, pumping cost will be very, very high. So, in that type of situation, continuous monitoring of viscosity is very much necessary, right? Let us look at.

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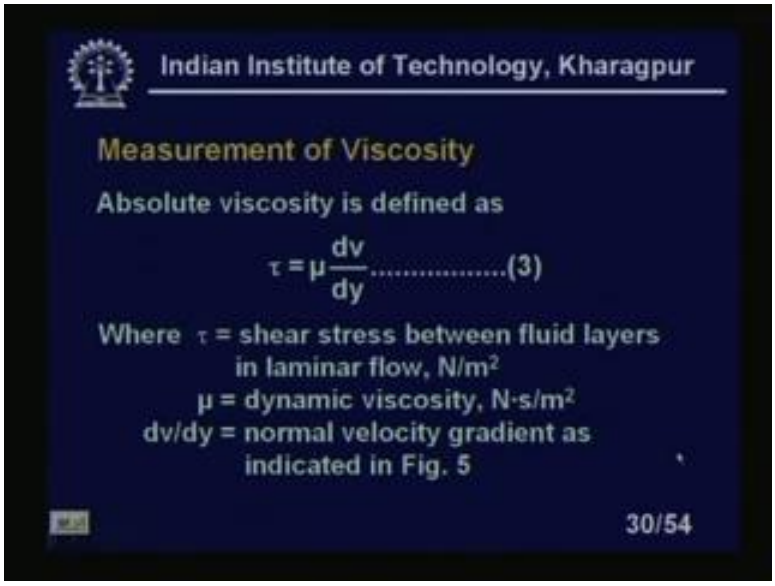

Now, absolute viscosity is defined as tau equal to mu dv by dy. This is equation number 3 in continuation of the p this that is the reason I have given the equation number 3, where tau is the shear stress between the fluid layers in laminar flow, it is in Newton per meter square. Mu is the dynamic viscosity in Newton second per meter square and dv by dy is a normal velocity gradient as indicated in Figure 5. I will show the Figure 5.

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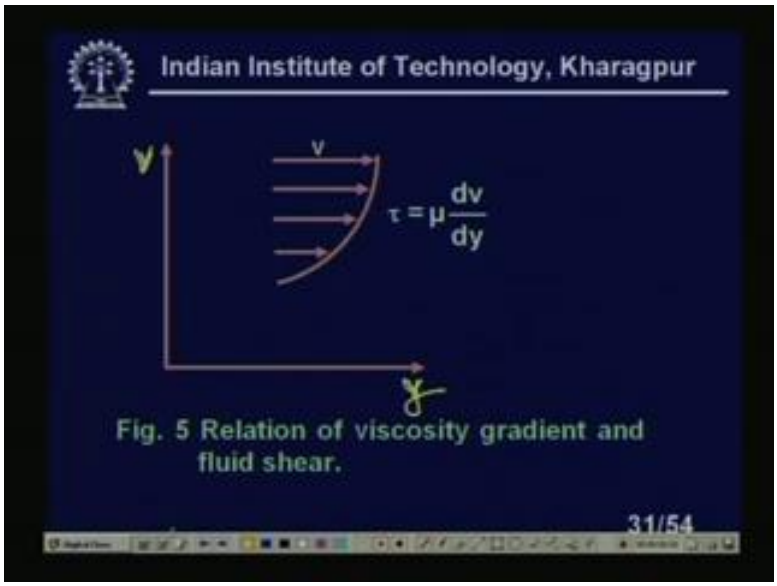

You see this is the relation of the viscosity gradient and the fluid shear. So, this is the tau equal to mu dv by dy, right? This is, sorry, this is v I think and this is y. So, this will be v I think. So, this will be v and this will be y, right?

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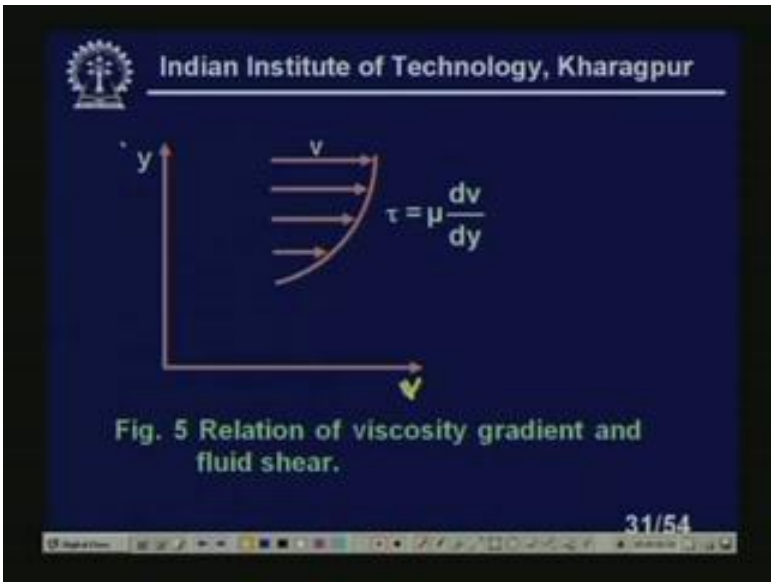

Let me see, this is the v y, so it will be, I am sorry, so if I go back, so, so this will be v and this will be y as it is no problem in that, right, right?

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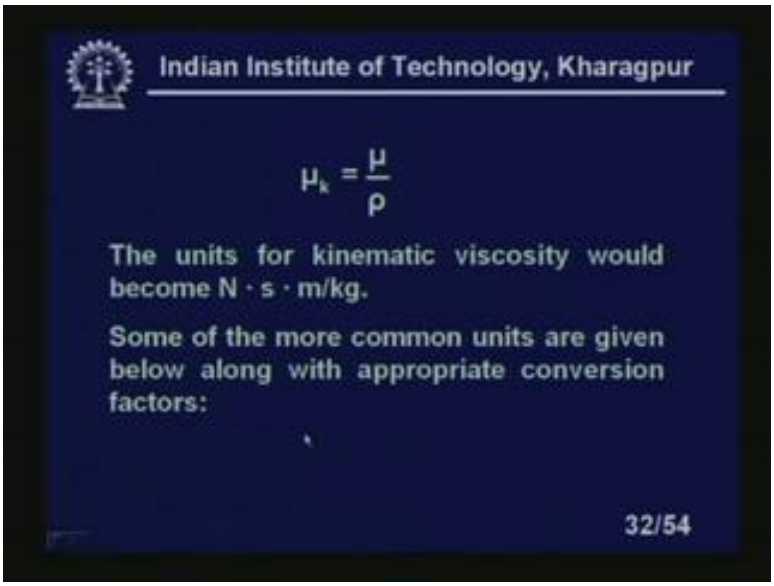

So, mu k or kinematic viscosity we defined as mu by rho. Another term we defined also that is the absolute viscosity or dynamic viscosity. The absolute viscosity, this is absolute viscosity, people sometimes this is a, I am sorry, so units for kinematic viscosity would become Newton second meter per kg, right? That means we have to, I mean divide the absolute viscosity or dynamic viscosity. Mu is the absolute viscosity or dynamic viscosity that is to be divided by the density of the liquid, you will get the kinematic viscosity, right? These units obviously will be different.

The, some of the more common units are given below along with the appropriate conversion factors. What are the different units? Even though, as I told you that those SI unit is not very popular in industry for expressing the viscosity, let us look at all the different units.

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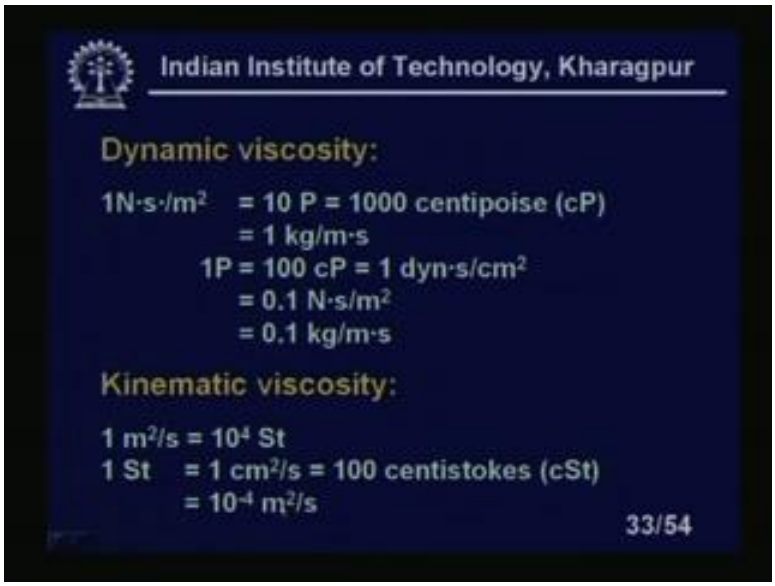

Dynamic viscosity, you see dynamic viscosity or absolute viscosity is given as 1 Newton second per meter square equal to 10 Pascal, sorry 10 poise equal to 1000 centipoises. It is defined as cP then equal to 1 kg per meter second, meter second is in the denominator.

1 poise is equal to 100 centipoises equal to 1 dyn second per centimeter square which is equal to 0.1 Newton second per meter square, right, which is 0.1 kg per meter second and kinematic viscosity is given by 1 meter square per second equal to 10 to the power stokes. This is also 1 stoke equal to 1 centimeter square per second equal to 100 centistokes. Most commonly used, the unit you will find in the process industry is called the, see the industries we will find the cP or centipoises, right which is equal to 10 to the power minus 4 meter square by second.

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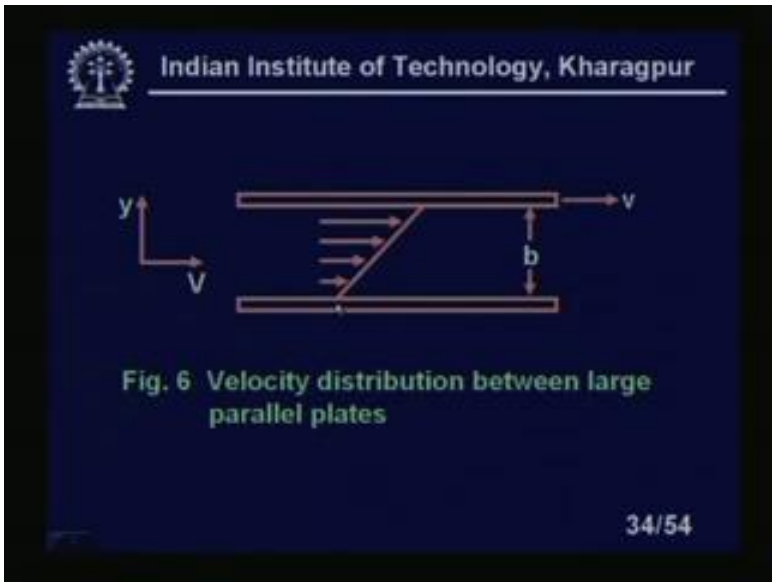

Now, velocity distribution between large parallel plates, we are showing that what is the velocity distribution? Suppose this, the two plates, two parallel plates are there and plates are supposed to be stationary. Now, suddenly suppose if these plates, they start to move in this direction, these plates start to move in this directions, plate is moving in this direction, you see this plate is moving in this direction, then what will happen? You see, the liquid which is in contact with this one will move in a faster direction and liquid which is contact will have no velocity. So, all the liquids have slowly, you will find that the, the velocity distributions will look like this one. This is highest, this is highest, this is low, this is low and which is liquid in contact with this plate, this stationary plate, this is a stationary plate will be stationary, right and the liquids which is in, corresponds to this, this, all this velocity we are measuring with respect to the stationary plates, right? At the top this will be the highest.

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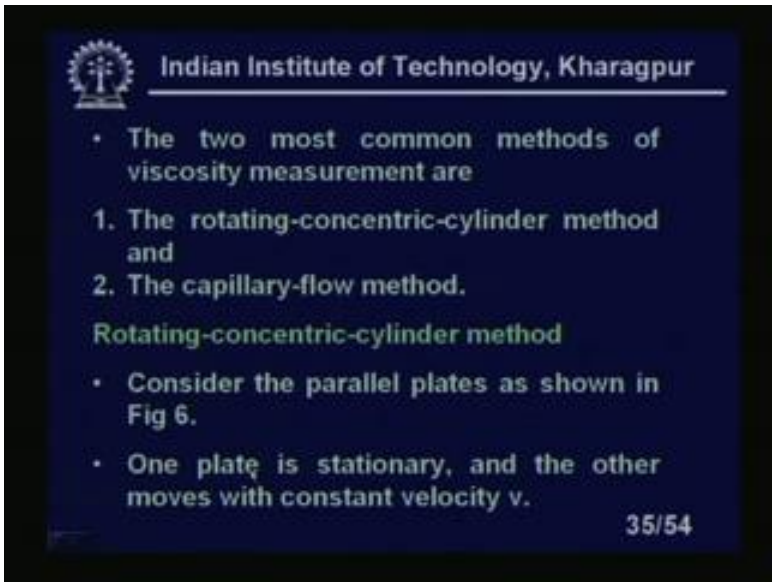

The two most common methods of viscosity measurement are the rotating concentric cylinder method and the capillary flow method. These are the two most important method of measurement. This is the way direct electrical output you will get. Now, rotating concentric cylinder method, let us first discuss this. Then we will come, come to the capillary flow method. Consider the parallel plates as shown in the Figure 6. We have shown in the parallel plates, as shown in the Figure 6. One plate is stationary. That means lower plate is stationary and the other moves with the constant velocity v.

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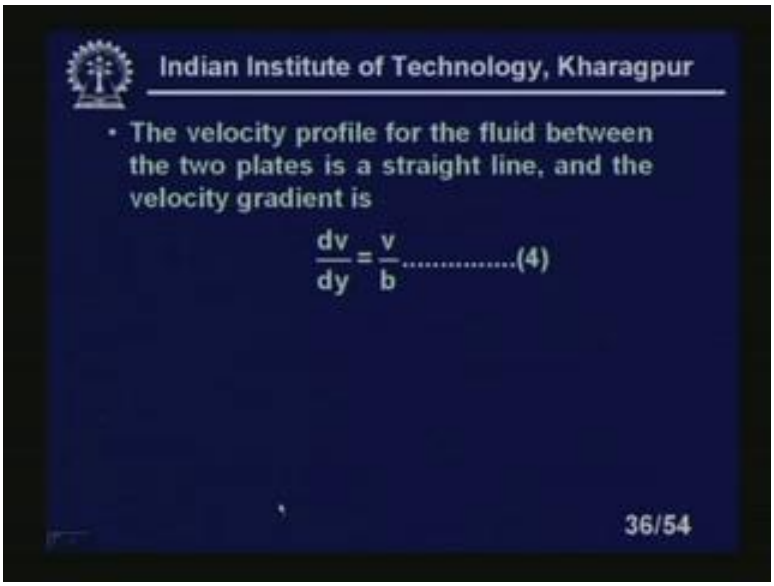

The velocity profile for the fluid between the two plates is a straight line and the velocity gradient is dv by dy equal to v by b.

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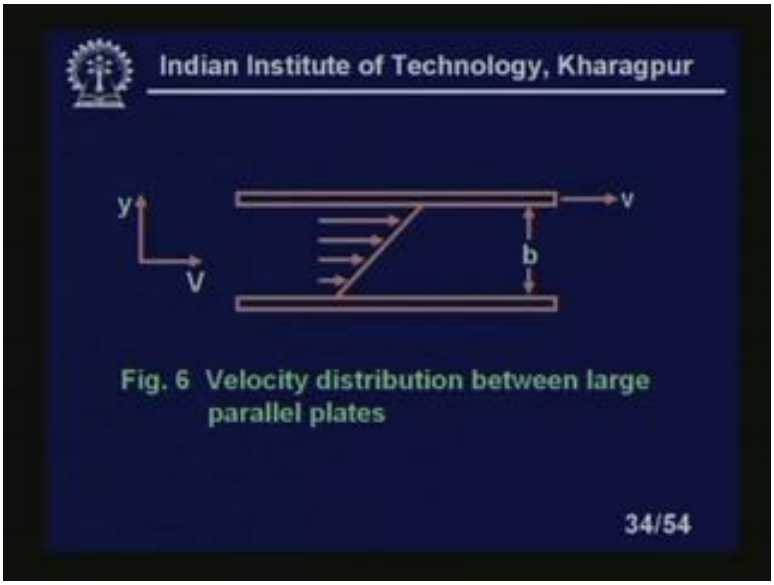

Let us go back. You see, this is the separation between the two plates. This is b. This is stationary plate, this is the moving plate. You see, this is the straight line, right?

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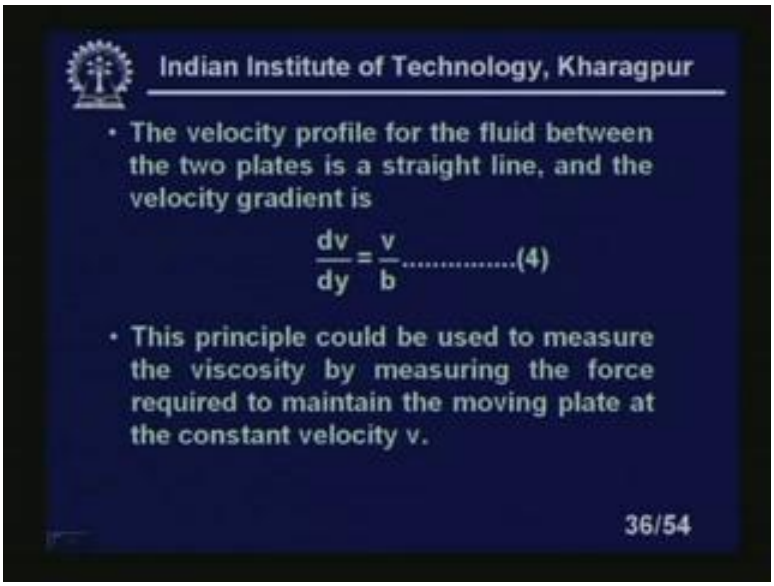

A velocity profile for the fluid between the two plates is a straight line and the velocity gradient is dv by dy equal to v by b, equation number 4. The principle could be used to measure the viscosity by measuring the force required to maintain the moving plate at the constant velocity v. The principle could be used to measure the viscosity by measuring the force required to maintain the moving plate at the constant velocity v.

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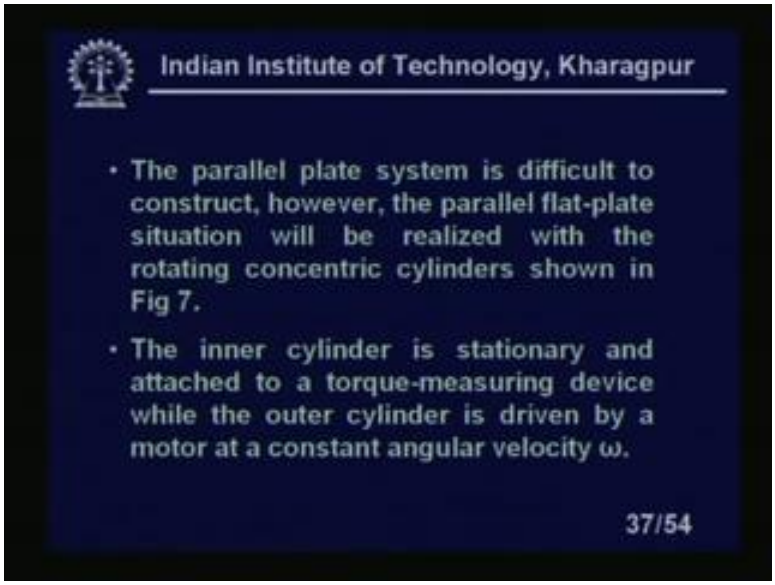

The parallel plate system is difficult to construct. However the, because you see this type of parallel plates are very difficult. Two plates are moving parallel. It is, just because I can have some liquid inside moving in between two parallel plates and the plates are moving, one plate is having it is very difficult to realize. Instead we can make two concentric cylinders, right? One cylinder, I mean, I mean stationary, other cylinder is moving, so that we can realize the parallel plates phenomena there also. That will be easier for us to make, mechanically to make the construction, right?

The parallel plate system is difficult to construct. However, the parallel plate, parallel flat plate situations will be realized with rotating concentric cylinders as shown in figure. The inner cylinder is stationary and attached to the torque measuring devices, while the outer cylinder is driven by a motor at a constant angular velocity omega. Let us look at.

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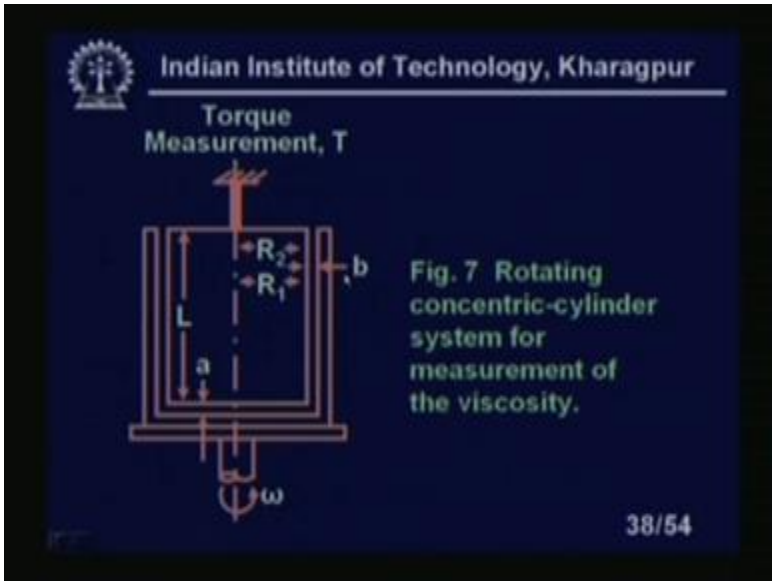

You see this is our, right you see the inner cylinder is stationary and this outer cylinder with a shaft is connected to motor. It is rotating at a constant, constant angular velocity of omega, right? This is shaft. Now this, this torque, this is the torque on this shaft will be measured, right in a, in a stationary it has a length of L. This is, this is a separation between the, bottom separation between the two cylinders, right? This is the separation

between the, that means I mean the inner diameter of the outer cylinder, difference of the inner diameter outer cylinder and inner diameter of the, in a, I mean diameter of the inner cylinders that is in the b, right and L is the length of the cylinder.

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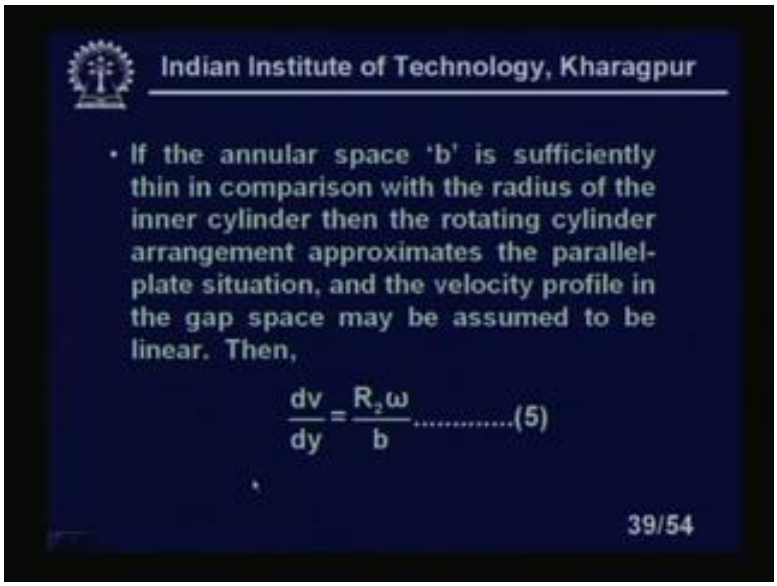

If we have then we can write, if the annular spaces b is sufficiently thin in comparison with the, you see actually, I am sorry, let me go back.

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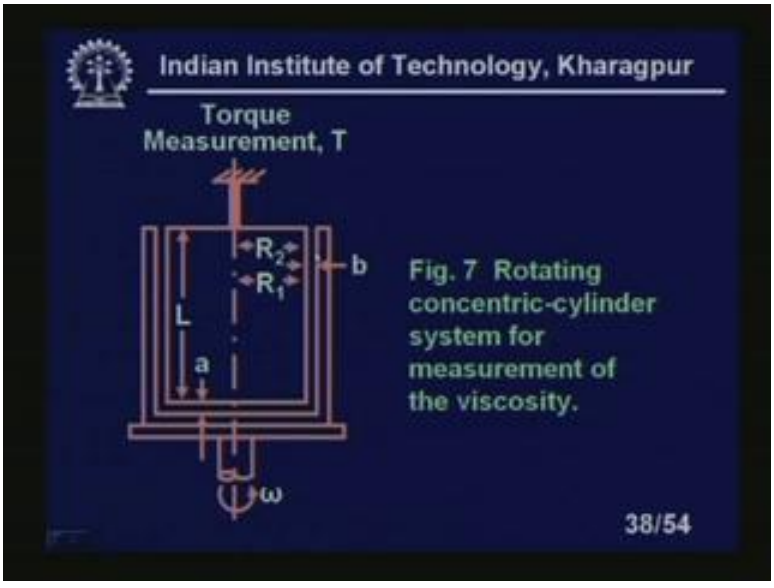

Actually this will be, no, no, no; so, this R 2 actually if you look at, this R 1 will come to this position, right? Now R 2, from the center R 2 will, should come to the, this one. That means I should say by R 2 is equal to R 1 plus b. b is the separation between the two cylinders, separation between the two cylinders or I should say R 2 minus R 1 is equal to b, R 2 minus R 1 equal to b. That means the inner radius of the outer cylinder minus the radius of the inner cylinder is equal to b.

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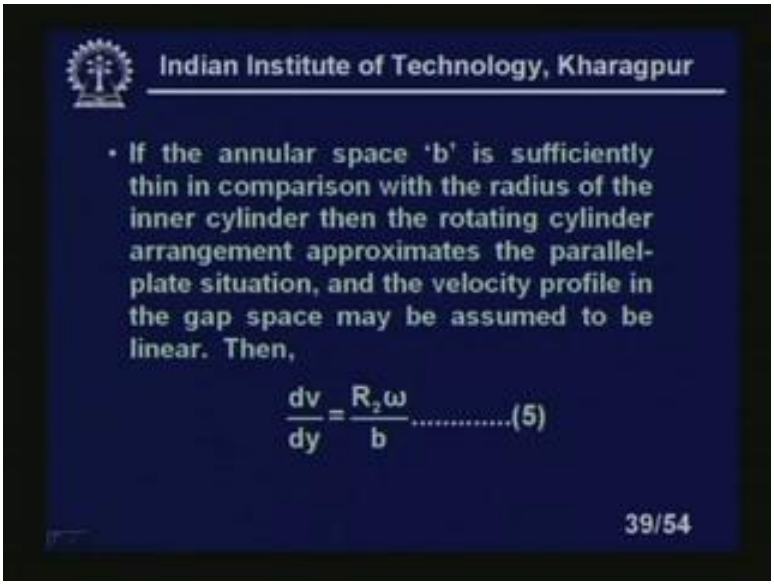

If the annular space b is sufficiently thin in comparison with the radius of the inner cylinder, then the rotating cylinder arrangement approximates the parallel plate situation and the velocity profile in the gap space may be assumed to be linear. Then, dv by dy equal to R 2 omega by b, equation number 5.

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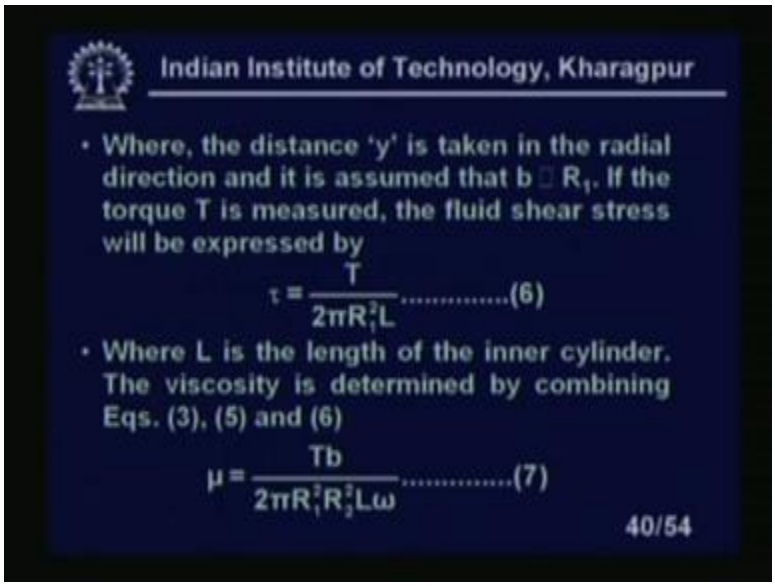

The distance y is taken in the radial directions, right; distance y is taken in the radial directions and it is assumed that that b we have assumed here that the b is, b is much, much less than R 1. It is, did not come, so b is, should be much, much less than R 1. If the torque T is measured and the fluid shear stress will be expressed as tau equal to T upon 2 pi R 1 square 2 pi upon, sorry T equal to tau equal to T upon 2 pi R 1 square into L, right? This is equation number 6, where L is the length of the inner cylinder and the viscosity is determined by the, combining equation 3, 5 and 6, what are the those 3, 5, 6 let us look at.

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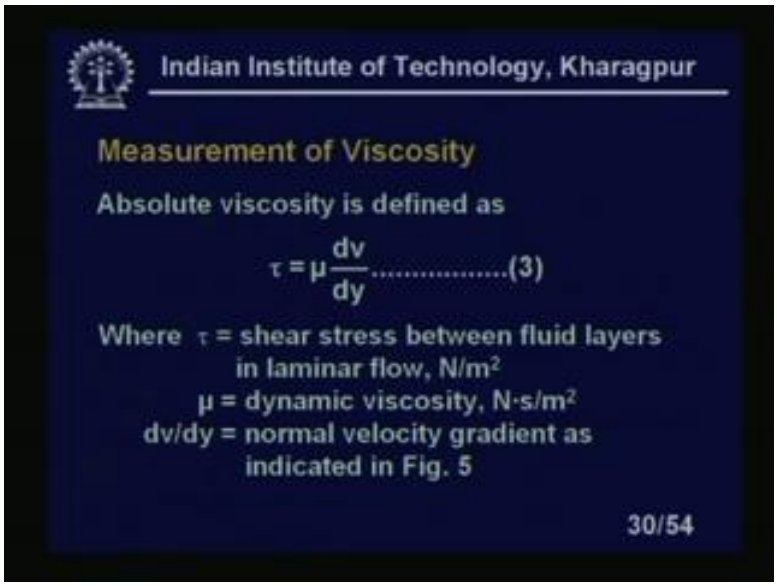

Very beginning we have the equation number of, yes this equation of the absolute viscosity. So, this, this is the equation, then 5, 5 and 6.

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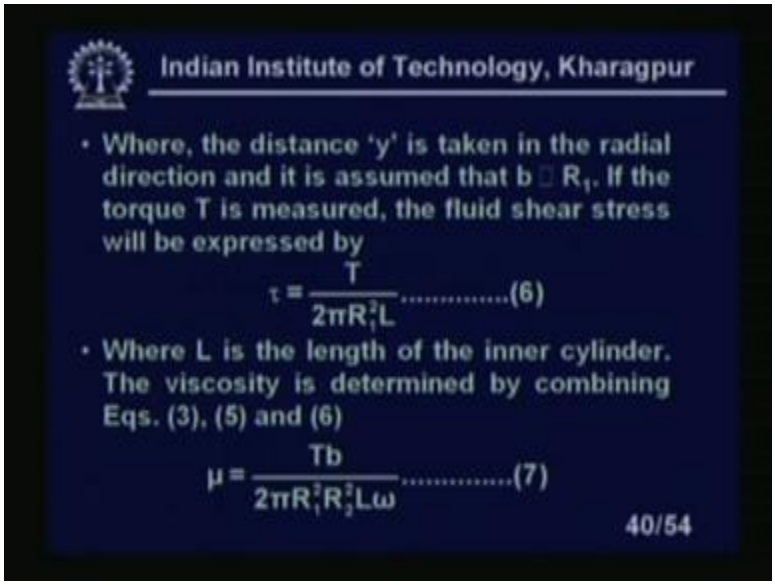

So where the, this I combine, so where L is the length of the cylinder, inner cylinder and the viscosity is determined by combining the equations 3, 5, 6 equal to mu equal to T into

b 2 pi R 1 square R 2 square ,T b upon 2 pi R 1 square R 2 square L into omega. This is equation number 7, right?

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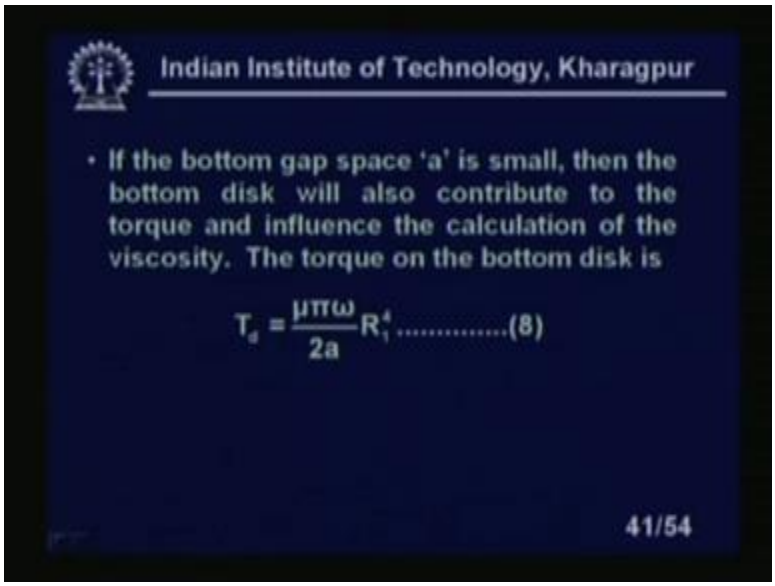

If the bottom gap space a is small, because then the bottom disk will also contribute to the torque and the influence the calculations of the viscosity. Usually it is small, so the torque on the bottom disk will be Td equal to pi mu pi omega by 2 a multiplied by R 1 to the power 4. This is equation number 8.

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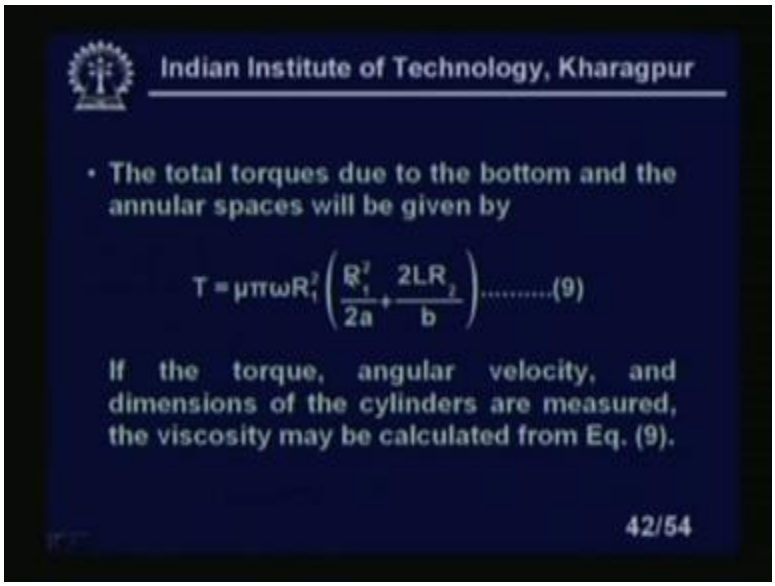

So, the total torque due to the bottom and the annular space actually that will be measured. The total torque by the some torque cell or torque meter, total torque due to the bottom and the annular space will be giving by mu pi omega R 1 square multiplied by R 1 square by 2a plus 2LR 2 by b. This is equation number 9, right, right? If the torque, now angular velocity, these are all constant, so if the torque is measured, angular velocity is measured, dimension of the cylinder that means R 1, R 2, L, a, b, these are all known to us, then the viscosity may be calculated from the equation 9, is not it?

So, because omega is known, because what is the rotation that we can measure by some, I mean our tachometer we know this is the dimensions R 1, R 2, L, a, b. These are the dimension of the, all the cylinders; that also it is known to us. Now we can measure tau T, because by some torque cell, so obviously only unknown is mu, right? So, the viscosity of the liquid, so please note that liquid is to be filled up. That is the most important thing.

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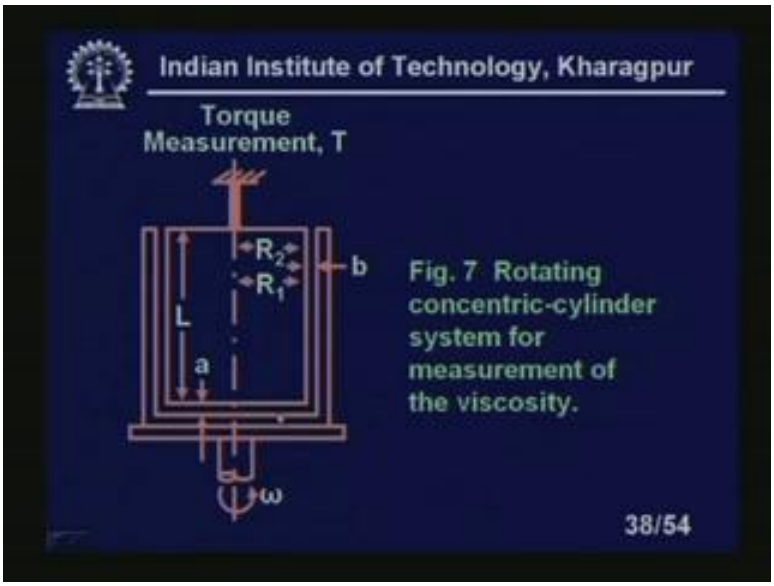

That is I have not, you see, sorry, so this gap, this gap is to be filled up of the, by the liquid. This gap, please look at, this gap is to be filled up with the liquid of which we are interested to measure the viscosity. So this gap, in, that means in between the two cylinders, in a cylinder, in a cylinder …. there is a gap. So, this gap is to be filled up by the liquid by which you will measure, in which we are interested to measure, of which we are interested to measure the viscosity, right? This is the, so the, if I can measure, so obviously from these equations I can measure.

Now, there are many other methods of, very conventional methods we will find in the laboratory, physics laboratory people use. What they use? They use a cylinder, right, a small, a long cylinder and they filled up the liquid, they filed up that cylinder with the, the particular liquid in which we want to measure the viscosity, right? I need, we need a large quantity of the, that liquid, obviously around a liter or something like that. Then, they drop a ball from the top, a steel ball, right, of known diameter or radius, spherical ball, so they are fallen. So, they between two particular points of that cylinder they measure the, when they, when they crosses that particular line, top line they turn on the stop watch. When it crosses the bottom line in the liquid they stop the stop watch.

Then what will happen? So, the total time of fall by, they measure and from that also if we know the dimensions of our, that ball we can find the viscosity. It is a very common experiment, also you will find in many physics laboratory people uses to measure the viscosity of the liquid. But here the problem is that that, the time of fall ….. to measure very precisely. If there is an error, so you will even find the viscosity of any known liquid also which we are, you are getting.

In, usually in a, in a, in the physics lab you will find that they are asked to make the measurement of viscosity of glycerin right? So with some, glycerin is the known, viscosity is known. Obviously you will find that is very difficult to measure, because if the time is short you will find there is a large error in measurement, right? When the time will be short, when the balls will be large, right, when the ball will be large, so it will have a large gravity, I mean gravitational force. So, it will have a large mass, so it will quickly, the time of fall between two points within the liquid is very, very short.

So, in that type of situation it is very difficult to, as I close like this, suppose I have a, I mean cylinder like this one, like this one, so they measure. It is a transparent body, so it should be made of glass. So there is a, there is a mark here. There is a mark here, so we put a steel ball. So, whenever it crosses this mark, I turn on this, our meter, stop watch. When it crosses these marks we stop the meter. We note the distance between these two, right; distance between these two marks. So, obviously if this time is large, so there is a, if this is only large when there is a, I mean the ball size is small. If it is, if it is, if it is large, yes, the time will be large when the ball size is small and time will be very short, when the ball size will be large, right, so there is the problem in two way.

But, the problem of the time measurement is more crucial we found and most of the time it is very erroneous to measure the time, right? I mean turning on the stop watch and stopping the stop watch is very difficult. Rather, if you take a small ball and with a, if, of which we know precisely the radius or diameter, we can find that it is very easy, most accurately, almost accurately you can find the viscosity of the liquid, right? But, there is a very ….. experiments as you can see, it is not, you cannot say it is very industrial sort of

devices, whereas rotating drum method or capillary method is, can be utilized in industry for the measurement of viscosity.

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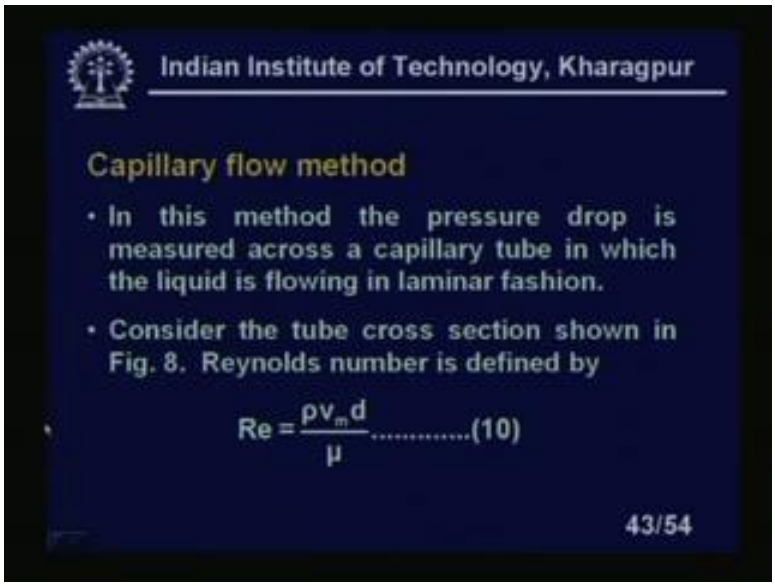

The capillary flow method - in this method the pressure drop is measured across a capillary tube in which the liquid is flowing in the laminar fashion. Consider the tube cross, cross section shown in Figure 8. Reynolds number is defined as, you know, rho, I mean R e rho v m by d is the mean flow velocity, d by mu. Density of the liquid, velocity of the liquid, mean velocity of the liquid through the capillary, d is the diameter and mu is the viscosity of the liquid.

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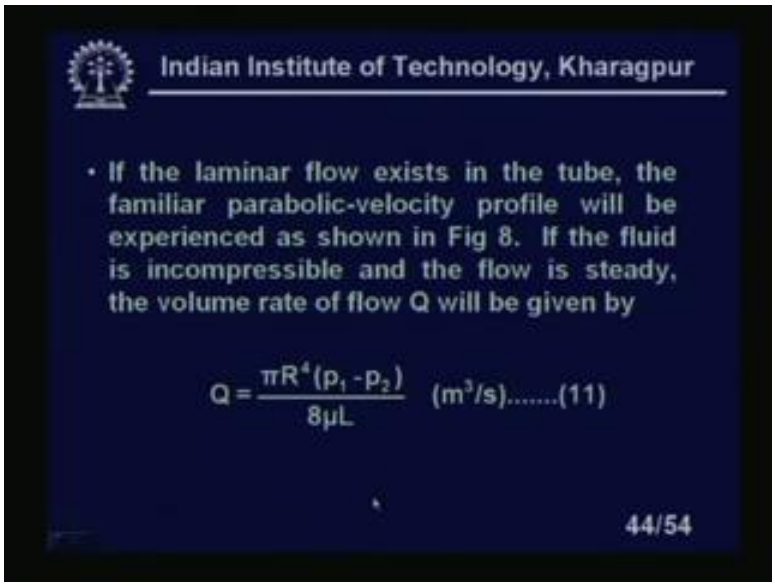

If the laminar flow exists in the tube, the familiar parabolic-velocity profile will be experienced as shown in Figure 8 and if the fluid is incompressible, incompressible and the flow is steady, the volume rate of flow Q will be given by Q equal to pi R to the power 4 p 1 minus p 2 by 8 mu L. It is meter cube per second, right?

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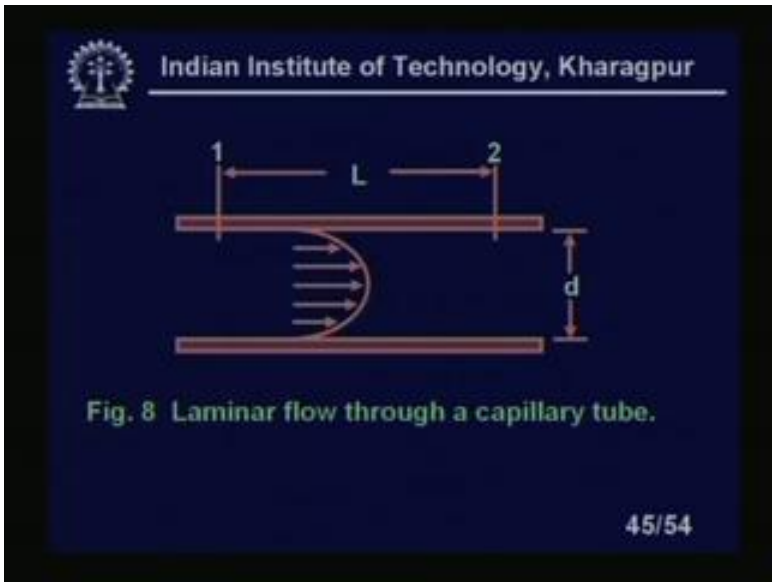

You see here the velocity distributions of laminar flow. The liquid is in contact with the, this pipe diameter, inside pipe diameter there is no motions and here you will find the velocity is maximum at the central point and as we, again it goes to the, this position, what will happen that there will be no movement of the velocity of the liquid which is in contact with the surface of the, surface of the, inner surface of the pipe. It is similarly,
so this is the velocity profile of a laminar flow of a liquid inside a pipe, right? We are talking of v m that is the average velocity including ….. points measuring and taking the average.

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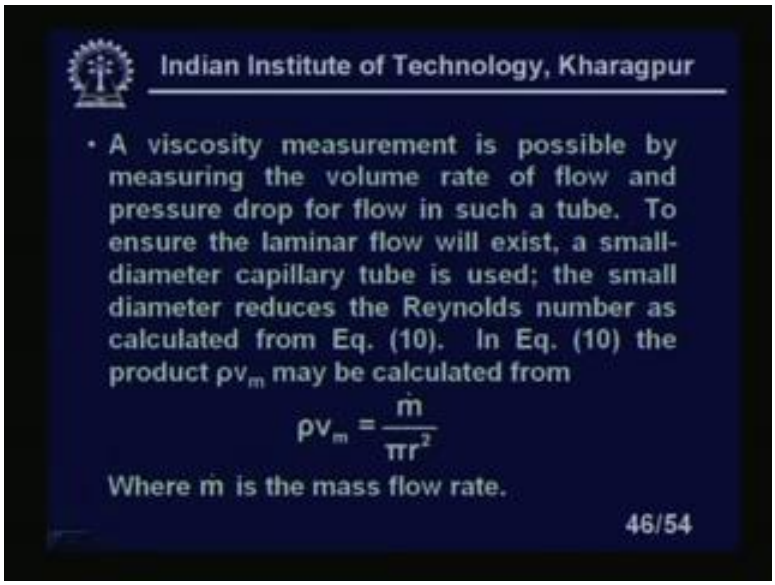

A viscosity measurement is possible by measuring the, this, I mean the very familiar equations all of us know.

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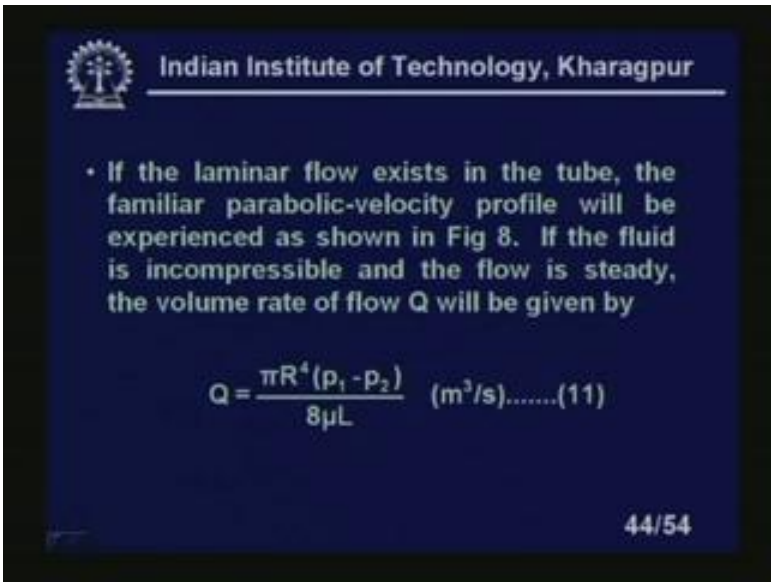

This p 1 is, p 2 is the two points between which we are measuring the Q. It is the pressure at p 1 at terminal 1 and terminal 2. L is the length between the two tapings of the pressures, right?

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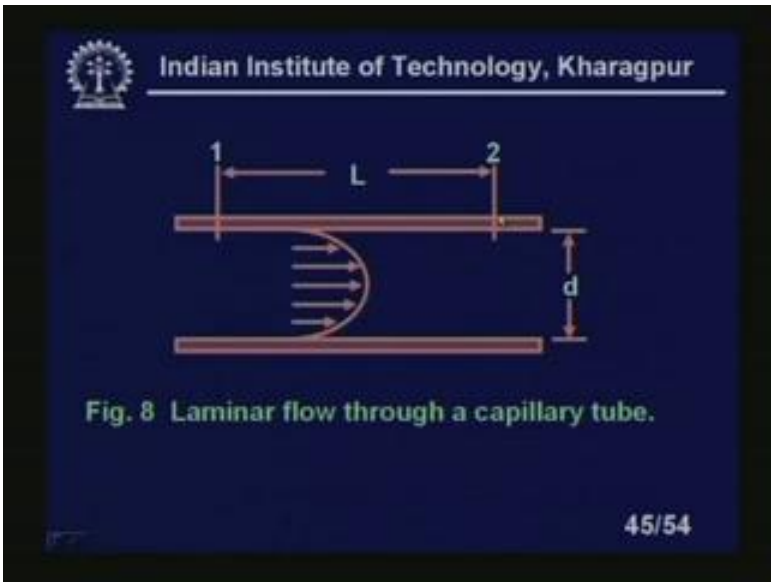

This is, you see the, here we have pressure tap. We have a pressure tap here also, right and this is at length between the two pressure taps.

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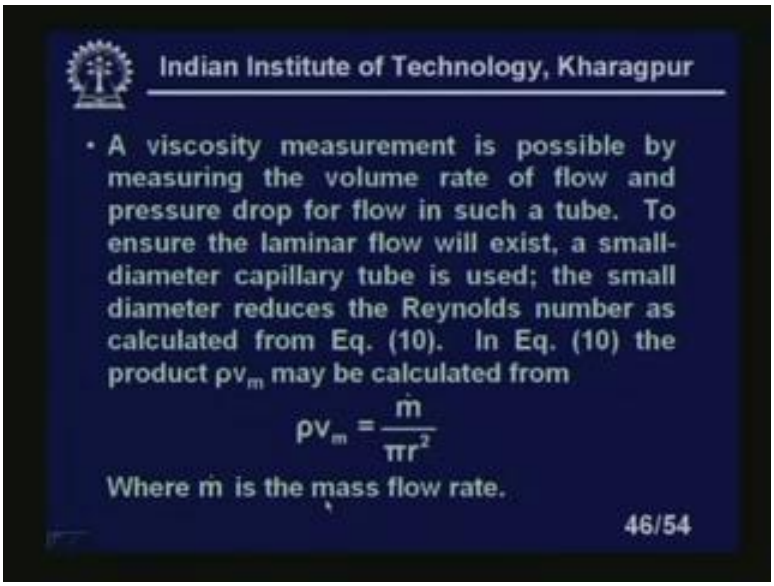

Viscosity measurement is possible by measuring the volume rate of flow and the pressure drop for flow in such a tube. To ensure the laminar flow will exist, a small diameter capillary tube is used and the small diameter reduces the Reynolds number as calculated from equation 10. In equation 10, the product rho, v m may be calculated from rho, v equal to m dot by pi r square, where m is the mass flow rate, right? v m is the mean velocity, mean velocity of the fluid inside the capillary tube multiplied by rho ….. will give you the mass m dot. You see, the m dot is the mass flow rate divided by pi r square.

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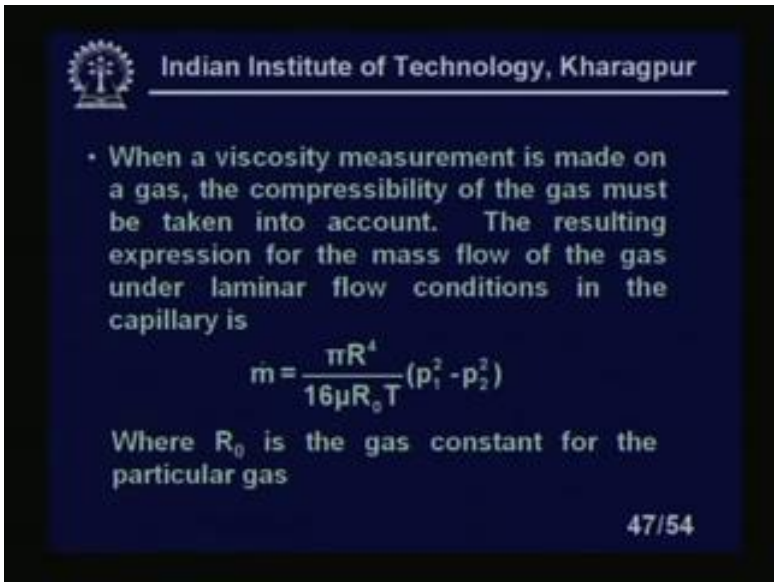

When viscosity measurement is made on the gas, the, the compressibility of the gas must be taken into account and resulting expression for the mass flow of the gas under laminar conditions in the capillaries m dot equal to pi R to the power 4 16 mu R naught T p 1 square minus p 2 square. R naught is the gas constant. We want to differentiate from this radius that is the reason this R, R. So the, we have used the different notations. R is actually radius of the pipe of the capillary through which the gas is in the moving.

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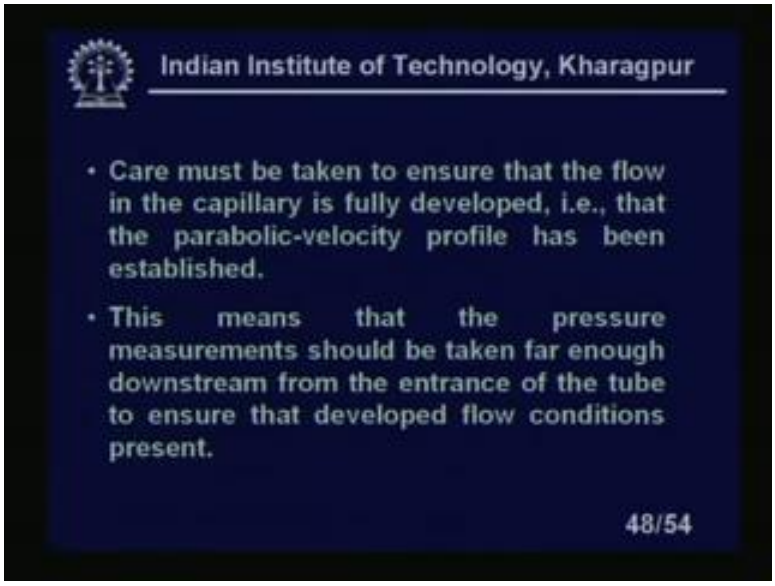

Care must be taken to ensure that the flow in the capillary is fully developed that is that the parabolic velocity profile has been established. This means that the measure, pressure measurement should be taken for a far enough downstream from the entrance of the tube to ensure that the developed flow condition presents.

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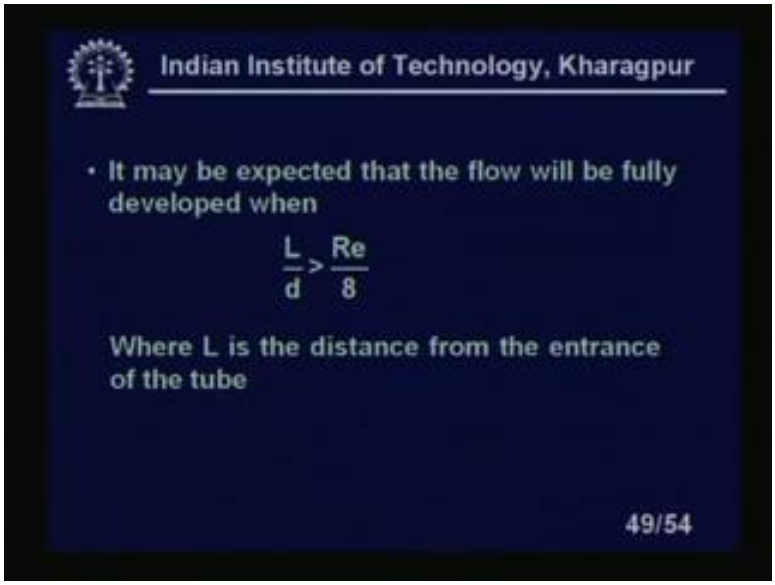

It may be expressed that the flow will be fully developed when capital L by d equal to greater than Reynolds number by 8, where L is the distance from the entrance of the tube.

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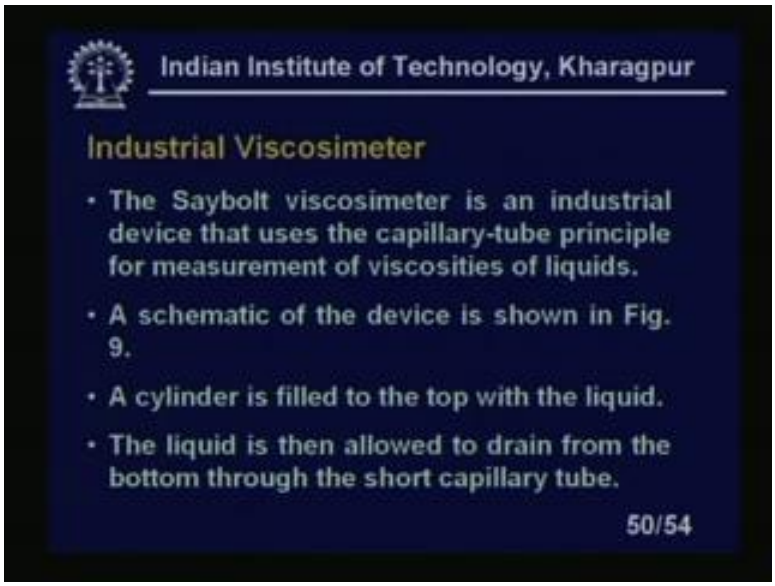

In that industrial viscosimeter you see, the Saybolt viscosimeter is a very commonly used viscosimeter. Saybolt viscosimeter is an industrial device that uses the capillary tube principle for measurement of viscosities of liquid. A schematic of the device is shown in Figure 9. A cylinder is filled with the top, with the liquid and the liquid is then allowed to drain from the bottom through the short capillary tube.

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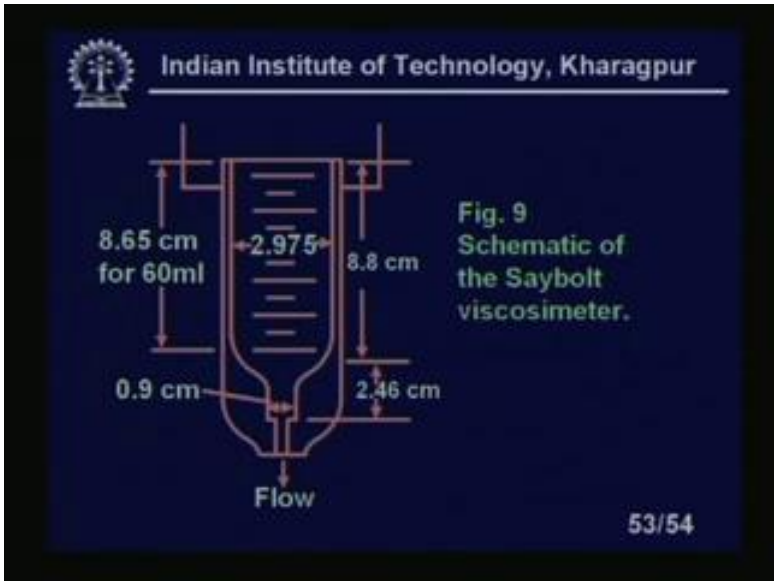

Now, let us go back first to the figure. This is our industrial viscosimeter. You see, this is to be placed in a constant temperature bath. Please note, these are all the dimensions of the same we have given. So, this is to be placed in a constant temperature bath, because viscosity, if the temperature changes also the viscosity changes and this dimension, this is basically if you look at this dimensions is around 0.1765 centimeter just above 1 millimeter, right? This is 0.9 centimeter, this is 0.1765 centimeter, this is 2.46 centimeter. So this, all the dimension are given, right? Let us go back.

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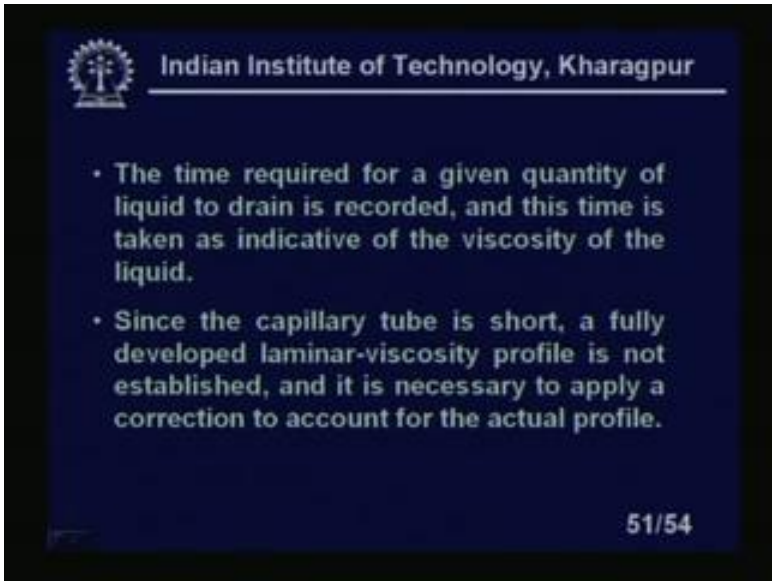

The time required for a given quantity of liquid to drain is recorded and this time is taken as the indicative of the viscosity of the liquid. Since the capillary tube is short, a fully developed laminar viscosity profile is not established and it is necessary to apply a correction to account for the actual profile, right?

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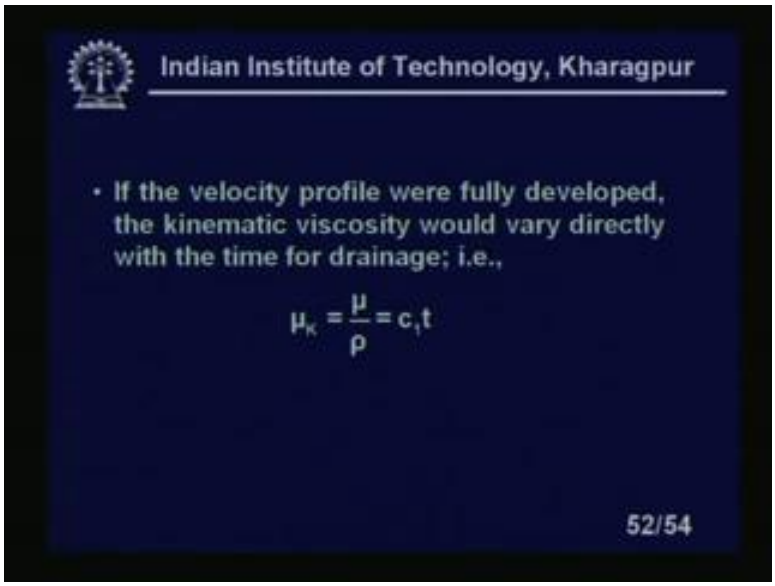

The velocity profile were fully developed. If the velocity profile fully developed, the kinetic, kinematic viscosity would vary directly with the time for drainage. That is mu k is kinematic viscosity which is absolute viscosity upon rho equal to c 1 t, right? This already we have shown, right? All the dimensions we have shown here, we can see here, right? See, industrial viscosimeter, you see a cylinder is filled with the top with the liquid and the liquid is then allowed to drain from the bottom, right, right?

This is all about our viscosity measurements and viscosity measurements as you know also is very much necessary for industry also, I mean for quality and the taste of the food also and I mean both in the food and beverage industry also this measurement is necessary and this is very, paper and pulp industry is very much, viscosity measurement is very much important. We will find that the measurement of viscosity is very much necessary, because as I told you there is, it reduces the pumping costs of the liquid and the quality, I mean control also it by because this is one of the parameters by which you can make the quality control of your liquid or product. So, for all these reason viscosity measurements are equally important as pH, right? So with this, see I come to the end of lesson 20 of Industrial Instrumentation.

Preview of next lecture

Welcome to the lesson 21 of Industrial Instrumentation. In this particular lesson, we will do some exercises. That means I will give you some problems and also we will provide the solutions. The best way to solve the problem you first do not look at the solution. First try to solve the problem and then see whether the, whatever the answer you got it, that is getting, I mean tally it with the results which we have given, right?

So, we will particularly solve in this lesson the problems on the LVDT and then pH probe and McLeod Gauge. As you know, the McLeod Gauge is used for the low pressure measurements, pH is used for the, pH probe is used for the pH measurements and so LVDT, LVDT already we have covered. So we will have, solve different tops of, different types of problems of LVDT, right? So, let us look at the contents of this lesson. So, these are problems and solutions on industrial instrumentation.

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The contents are the problems and solutions – LVDT, linear variable differential transformer, pH meter as well as McLeod Gauge, right?

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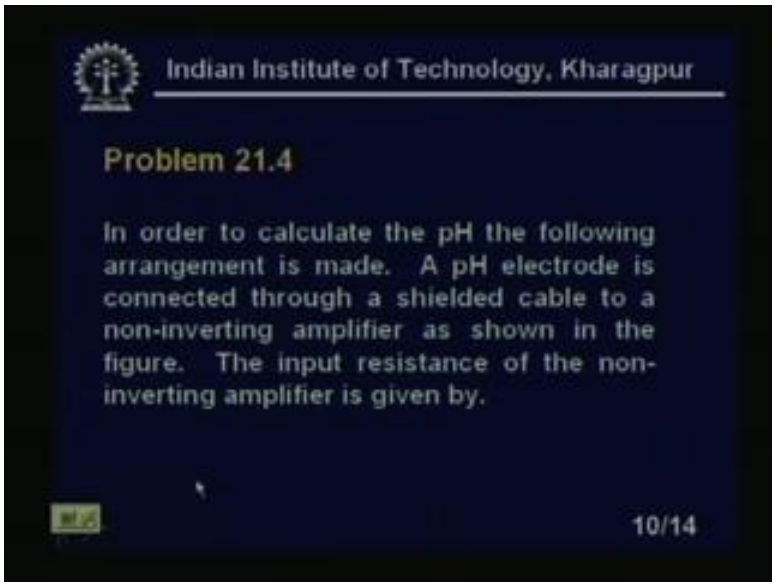

Problem number 21.4: the problem is in order to calculate the pH, the following arrangement is made. A pH electrode is connected through a shielded cable to a non-inverting amplifier as shown in the figure, we will show the figure.

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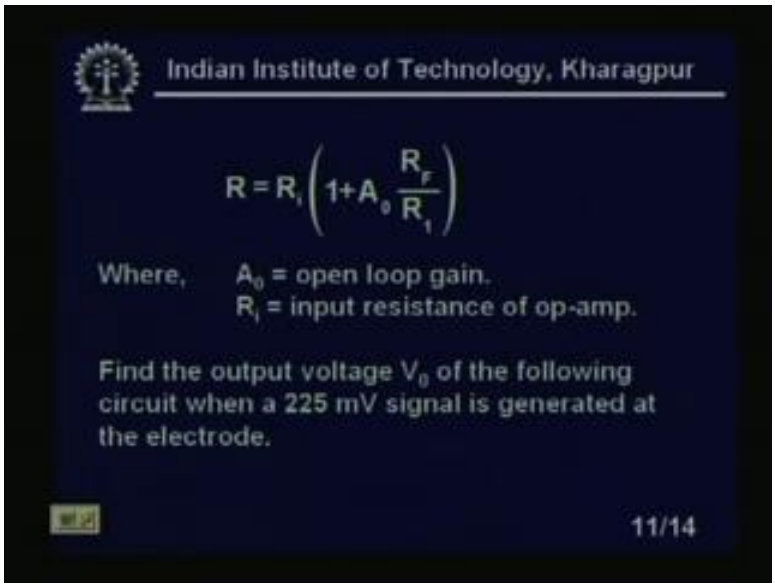

The input resistance or impedance of the non-inverting amplifier is given by R equal to R i 1 plus A naught R f by R 1. Everything will be clear in the circuit, so let us go back.

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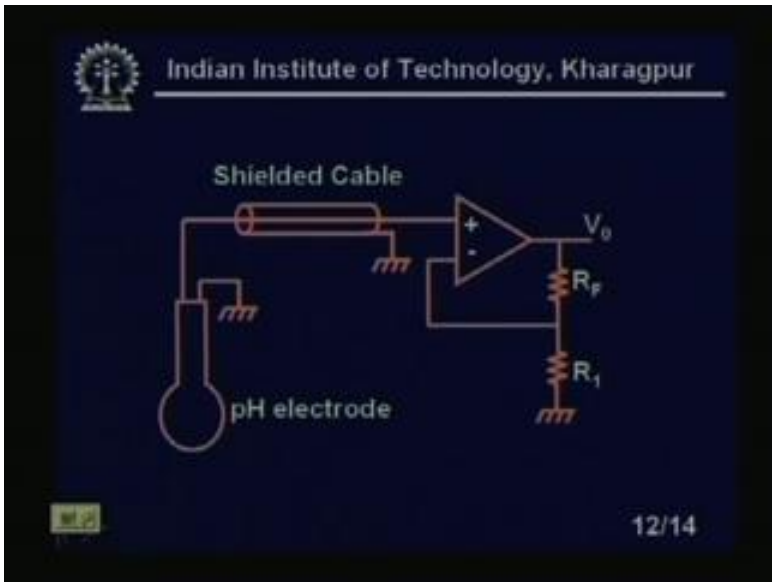

Let us look at the circuit once again, R 1, R f. Now R f, R equal to R i 1 plus A naught R f by R 1. A naught is the open loop gain and R i is the input resistance of the op-amp. Find the output voltage V naught of the following circuit when 225 millivolt signal is generated at the electrode. Shielded cable is, looks like this pH electrode and this looks like this way. So you see, this is buffer amplifiers we have used, supposed to be very high input impedance, so we have used shielded cable.

So, with this I come to the end of lesson 21, where we have solved all the problems.