Overview of various surface tension measurement techniques

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Lecture-5

Wilhelmy plate, capillary rise, ST, and contact angle

Welcome back. So, in today's video lecture, we will look at the list of techniques that are available to measure surface tension. So, we will continue from where we left. And then we will look at in detail the working principles of a few of the techniques, right? That are, you know, quite often used, right? In determining surface tension if contact angle is known or contact angle if surface tension is low, okay? And let's, you know, let's begin our lecture, yeah.

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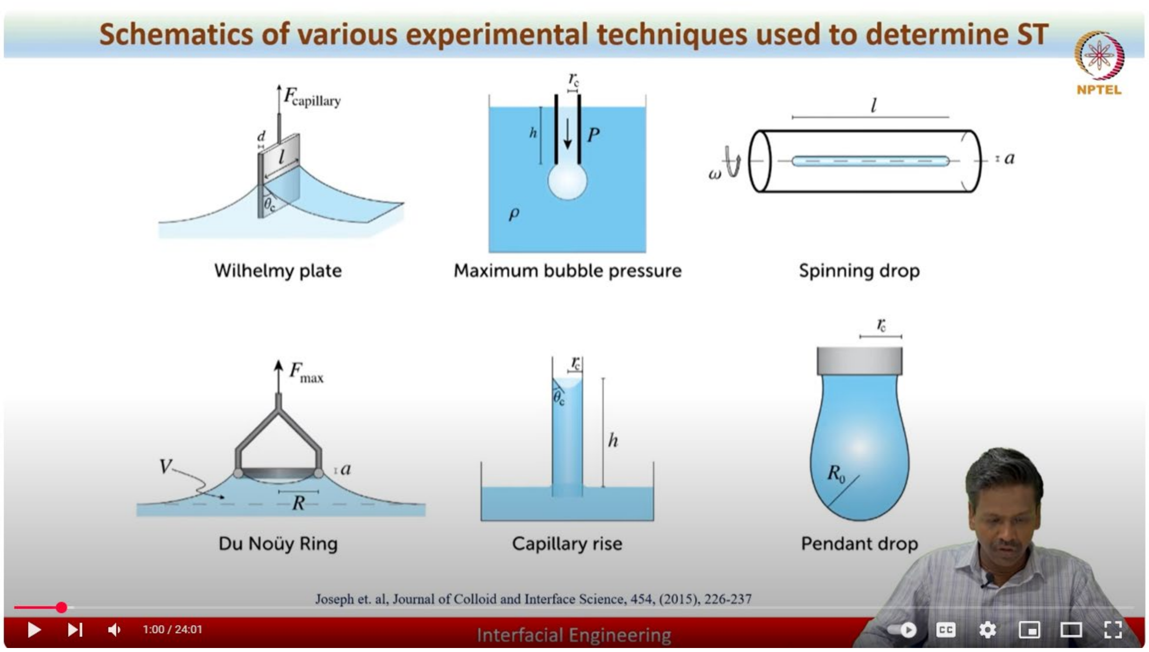

So, these techniques are widely available. If you want to measure surface tension, for example, we know Wilhelmy plate, which is You know, one of the very popular methods that people often use, right? And then we have what is known as Du–Noüy ring.

So it is Du–Noüy ring and we then make it work under the same principle of operation, right? and only the geometry that are used are different and apart from that this capillary raising is a very classical method, okay and in this one can measure what is the you know surface tension and what is the capillary radius, okay what is the height at which the liquid column, you know, liquid, you know, walks a climb up the, you know, a climb on the surface, right? So, these things we can measure, readily. And we have what is known as maximum bubble pressure, one of the advantages of this method is you don't need to know or specify what contact angle is. So, we will see them in detail. Pendant drop and spinning drop are also some of the techniques that are also used quite often.

right, depending on the conditions right in which we we want to measure surface tension or theta, right, so in today's video lecture we will look at the working principle of Wilhelmy plate and capillary rise and also the maximum bubble pressure, before we even look into the the overview of some of the devices.

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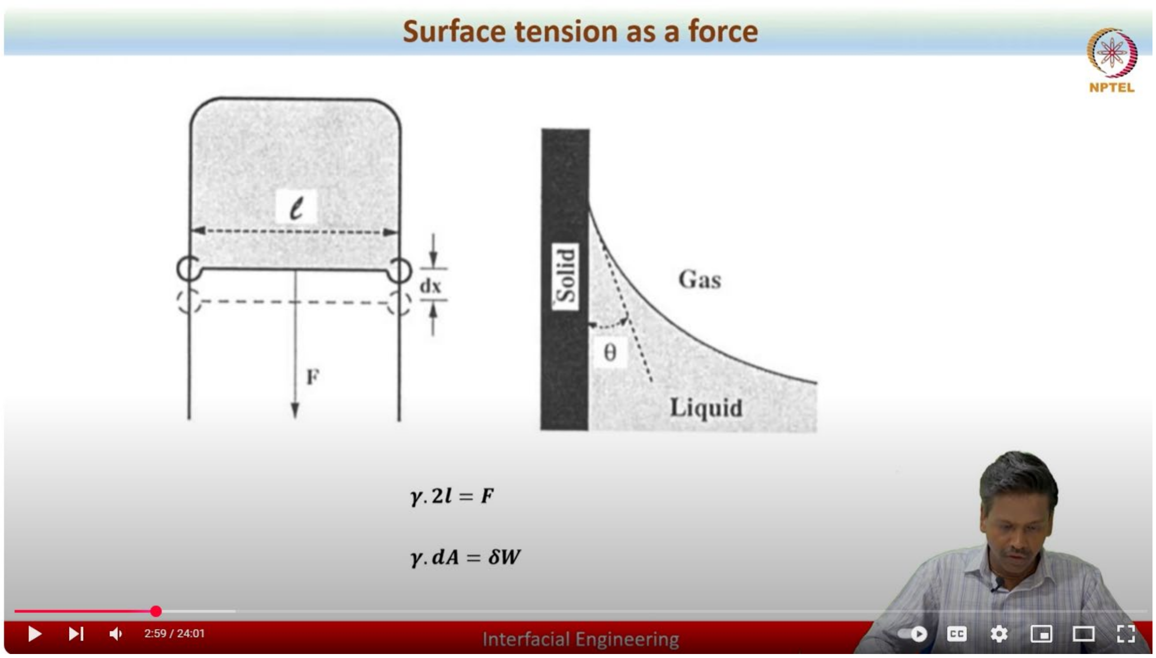

Let's first ask a question. Let's first describe surface tension as a force. First let's understand how surface tension can be regarded as a force. So, this schematic we have also seen in previous lecture, but this schematic is quite easy to understand the clarity.

I mean, you'll get a little bit more clarity. So here, what they, I mean, what, you know, the insight that we get into this schematic is, how surface tension, so surface tension, as I told earlier in the lecture, in previous lecture, the work done by the system, due to surface tension. So, let's say we have a container which is filled with water in this case. okay for brevity this container is shown upside down ,okay, it is just kept inverted, although it is you know, in reality it is, I mean it is just to show you know the action of surface tension, so that it is very easy to capture right so that's why this schematic is short so you assume that this container is filled with water and it is kept upside down now this particular, so this part is this dotted line represents the tin wire, okay, which was raised at time t equal to zero right and you can understand this solid line represent the position of the thin wire, so you know, after some time t, right, after the action of surface tension you know is taken place okay so you can see clearly Because the surface tension acts downward in this case, this will pulls this wire, towards the inside. So as a result of which this wire would have made some displacement which we can say delta x.

So it would have made some delta x, displacement because of the surface tension which is acting downward because it pulls the liquid towards it. So, this thin wire, we made to move because of the action of surface tension. So because this dotted line was initially placed at you know x = zero and this moment if you can denote as delta x, right, then we can clearly say the some work is being done, in this case, right, so how we can define in this case gamma as force is let's say we know what is surface tension, right, surface tension is nothing but force acting along the length of the surface which is usually denoted as Newton per meter, right so because it is denoted as force per unit length when you, you know multiply that with, you know, the perimeter in this case since we consider the thin wire, right, so it as in a very you know we just got you know length, right, just got length and breadth, so here we are assuming that, uh, the width of this wire is very, uh, i mean negligibly small so the perimeter although the perimeter of this should be, two into l plus b, since b is very small we know that for the time being, so you can simply multiply this with respect to uh you know, the perimeter, here in this case, i mean parameter in this case is simply nothing but two l right so when you multiply that with the perimeter one would get the force, right, so which would be simply Newton, right, so you can also consider surface tension sometime you can also express surface tension as surface energy which is nothing but Joule per meter square, okay you can also express surface tension as Newton / meter, our surface energy as joule/meter^2 when we express surface tension, as you know, surface energy which is in joule per meter square, you can multiply that with the change in area, okay, The change in area is the surface tension which is acting on the area, which is along the entire, wherever this surface tension is applicable, along the entire line of action. I think this we have also seen in the previous lecture.

$$F = \gamma \cdot 2l$$

$$\delta W = \gamma dA$$

So, that is what exactly we captured in this equation, okay? This is sufficient as a force. Now, we can also look at the capillarity rise we have also discussed to some extent in previous lectures. Here you will see whenever you introduce solid. Whenever the liquid shares a greater affinity with the solid. You would expect liquid to climb up the surface. Because they share a better affinity with the surface.

So, they want to maximize their contact with surface. So, in such case you would expect elevation. if the affinity is not, you know, appreciatable then if the I mean if affinity between solid and liquid is not very much you know pronounced then in that case you would expect depression instead of elevation, right, so in this case we have shown an example where the liquid would want to establish the contact with the solid because they share better affinity in this case there will be you know this liquid will rise up okay so now the question is how long the liquid will you know you know rise up on the surface the answer is whenever the liquid rise up due to surface tension force there is also counteracting force which is acting downward that is nothing but the force of gravity that you know so at some point of time there will be balance between the two okay because surface tension you know causes the rise in liquid, the mass of liquid, okay, on the other hand which would you know put speed breaker for the liquid column that is you know rising up right, so because this gravity is acting opposite direction you would expect at some point of time there will be equilibrium okay so in this way you can expect that there will be a liquid will rise but not to infinite distance it will rise up to finite distance that is dictated by the gravity i mean force of gravity okay now in this case if you can balance two forces, one is surface tension force and the other hand gravitational force at equilibrium what would be equal now additionally what we need to also look at is here surface tension is a tangential force but because there is an angle to it the liquid establishes contact with some angle one has to include the components of forces so using the geometric rule we can deduce this tangential force as gamma cos theta, we will see them in detail right so this is the, you know, some of the,

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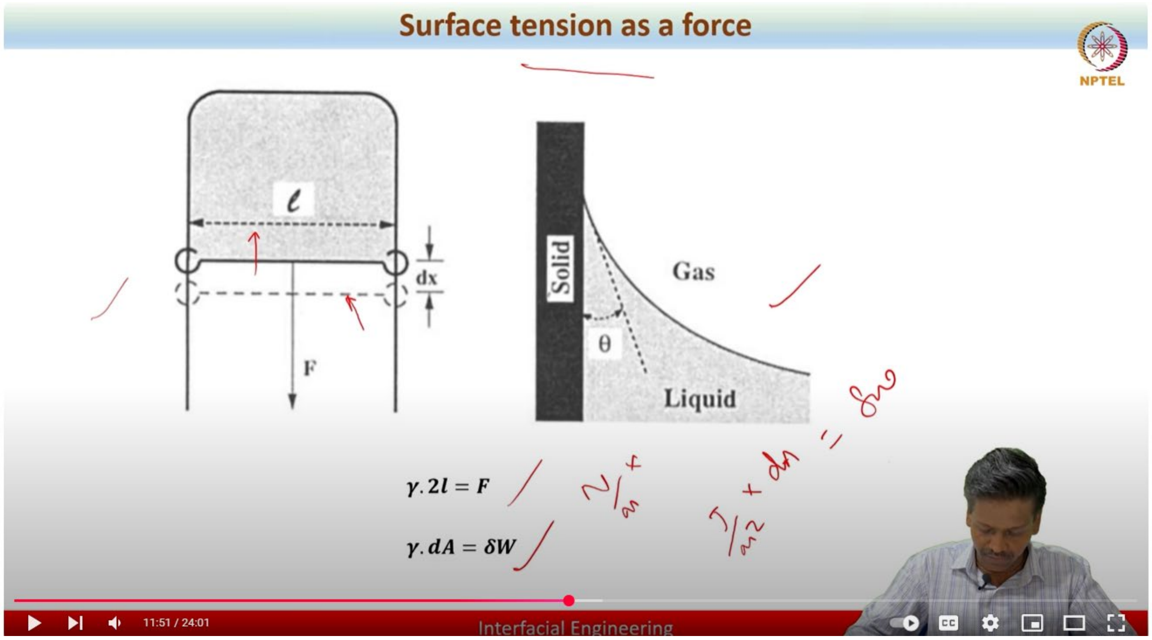

I mean concepts I mean in this way we can explain surface tension as a force, okay, right, so now we will look at how the Wilhelmy plate is used to measure the surface tension So basically, what we do is simple force balance, right? We just do simple force balance.

So how it works is very simple. So whenever we introduce a plate which is called Wilhelmy plate, uh ,this plate, whenever ,uh, so this plate is connected to what is known as the ,uh ,you know, the balance weighing balance very sophisticated ,uh ,weighing balance, okay so, so what this weighing balance does is, it actually takes this, uh ,Wilhelmy plate, okay ,measure is weight at before it touches the liquid and you know and take that, I mean and you know, take into account I mean, take this weight of plate as you know reference weight, then ,when we, when the plate, when you introduce the plate and when it exactly touches the liquid surface you would see that there will be meniscus, okay, that's because the liquid shares greater affinity with solid okay so there will be, you know, capillary rise so because of which the water will try to climb the surface, climb up the surface okay so in this way because this meniscus is held up by the tension on the liquid surface the weight acting, weight which acts on this plate, will be recorded by the balance again, which will be again compared with the reference weight The change in weight that results out of this process is nothing but, a surface tension. One can measure surface tension out of this. This is a simple force balance. So you can see that the weight which is nothing but mass into gravity can be equated at equilibrium.

because one hand there is gravity which is acting downward and the other hand surface tension which is acting upward because it shares greater affinity with the solid and it wants to maximize its contact area with the solid surface so in this case you have two counteracting forces one is surface tension and another one is gravity so when you equate both these forces at equilibrium you can get this relation again we get gamma cos theta okay this is components of force right because surface tension act tangentially so perpendicular to the liquid surface, right, so you can actually deduce this gamma cos theta you know from the geometric rule if you can also look at this schematic ,in this schematic it is, you know, clearly depicted what we actually measure is the tangential force which is perpendicular to the liquid, right ,surface so basically the perpendicular the tangential force is nothing but gamma cos theta in this case you can get this gamma cos theta from the simple geometric rule and when you multiply that with the perimeter we will get the simple I mean we get the expression in simply in you know force unit, right, that is what exactly we do here On the other hand, we also can easily understand the capillary rise using the same principle. We do the same force balance in this case as well. So, what is different in this case is simply the perimeter is not rectangular anymore since it is a capillary tube. perimeter which is acting the surface tension acting along the line of contact is different in this case so which is nothing but the 2 π r in this case right that is the only change here you can see that so what we can do is we can you know break this mass into gravity,

$$W = P\gamma\cos\theta$$

$$\mathrm{mg} = P\gamma\cos\theta$$

$$\rho V g = P\gamma\cos\theta$$

$$\rho.\pi R^2 h.g = 2\pi R\gamma\cos\theta$$

$$\Delta P.\pi R^2 = 2\pi R\gamma\cos\theta$$

$$\mathrm{Rc} = \frac{2\gamma\cos\theta}{h\rho g}$$

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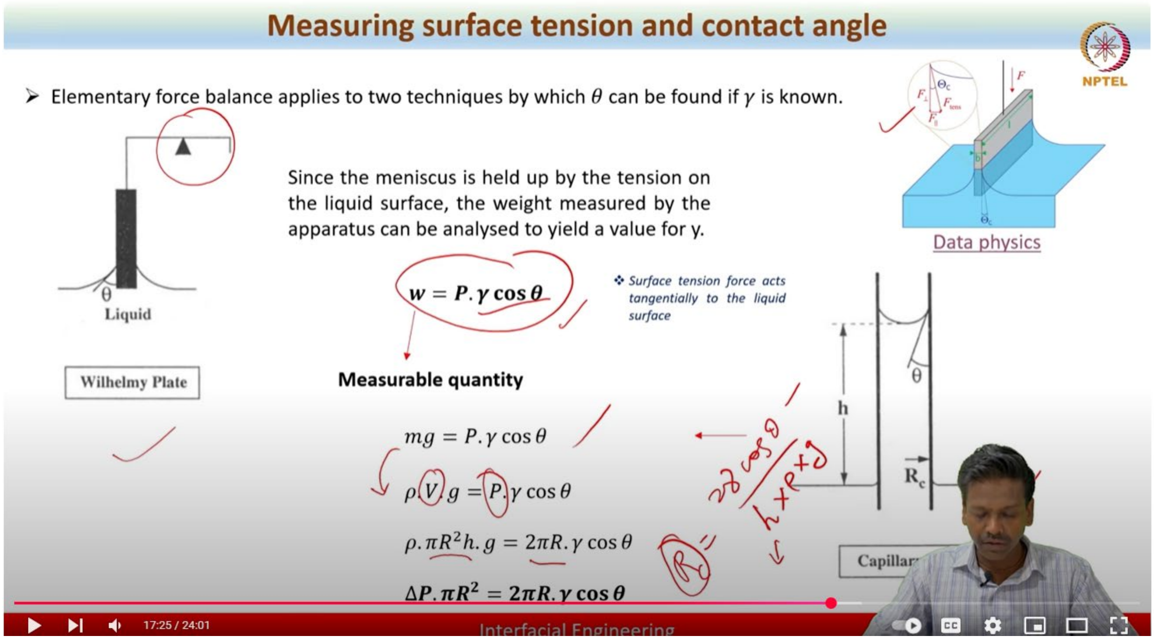

You can also write delta p as h, ρ, g. okay, so using this equation one can calculate theta if rest of the parameter is known or height of the column right or sometime the capillary radius so all these three parameters can be determined usually using this capillary rise method okay right

So now coming to the maximum bubble pressure method, this is quite simple because in this method, the advantage that we have in this method is it doesn't require the contact angle measure. I mean, you don't need to measure, or you don't need to know the contact angle. So here, what we actually measure is the pressure required to detach the bubble.

So, pressure required to detach the bubble will give you a relation between gamma and sufficient and the Laplace pressure. So basically the pressures whenever we purge gas, through the tube, which is submitted in the liquid at the end of the tube it forms bubble okay as the pressure increases the bubble grows up okay but at some point of time the radius of the bubble is same as the radius of the capillary tube at that point one would capture the maximum pressure okay it can also be shown that the the Laplace pressure, okay, of this spherical bubble is nothing but 2 gamma by r which we will also see in detail in following lecture, okay and after this so this is where the equilibrium between the pressure force and surface tension force both you know exist right okay after that beyond this point ,beyond this point, okay ,beyond this point as you increase the pressure because there is when you increase the pressure what happened is the bubble wants to you know get released from this tube but on the other hand there is also surface tension which actually pulls back okay there is a affinity between liquid and solid surface which actually resist the bubble to you know get detached from the tube okay but beyond when

when when the pressure is you know, more dominant than the surface tension force, one would see that the bubble is easily released from the tube. So, what we can do is, we can actually perform a simple force balance because we have pressure from both the end, one is from the top through the tube. okay from top side that is let's say P1 the other one is hydrodynamic pressure because the tube is emerged in the liquid column right liquid pool so you would have also pressure right from the bottom okay the change in pressure there is also another force that is acting upward in this direction because the bubble is held by the surface tension force okay so since force is acting on the opposite side you can actually perform a force balance between the pressure force and surface tension force which is nothing but you can when you perform this force balance you know you would get finally you know in terms of this equation which is nothing but

$$P_1 \pi r^2 = P_2 \pi r^2 + 2\pi r \gamma$$

$$P_1 = P_2 + \frac{2\gamma}{r}$$

$$\Delta P = P_1 - P_2 = \frac{2\gamma}{r}$$

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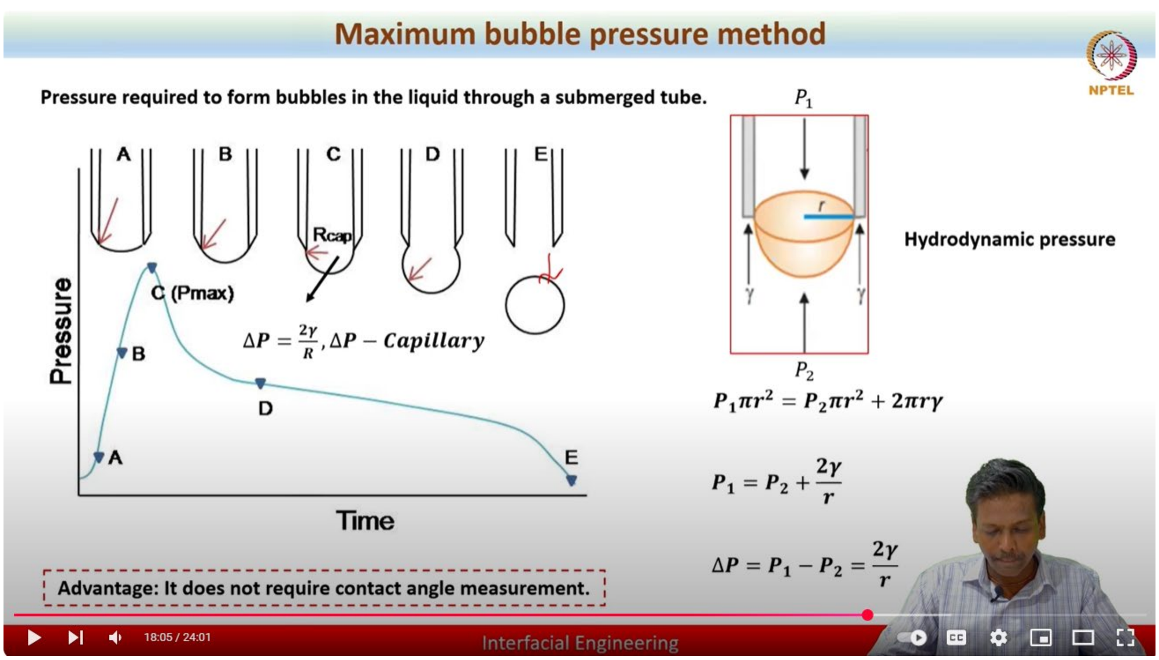

It is same as the Laplace pressure for a spherical geometry which we will also show you know in the following lecture So, I think these techniques are very clear and based on these techniques, one can measure the surface tension if theta is known or theta if surface tension is known. In the case of maximum bubble pressure method, the advantage is we don't need to know the conduct angle, before the measurement. So, one thing I forgot to mention, uh, you know when it comes to Wilhelmy plate, the Wilhelmy plate is,uh, i mean the manufacturer is surprised Wilhelmy plate such that the Wilhelmy plate is made up of a special alloy, okay, uh, the advantage is uh they you know they make um you know contact with the water okay you know in a such a way that you know the theta is negligibly small okay

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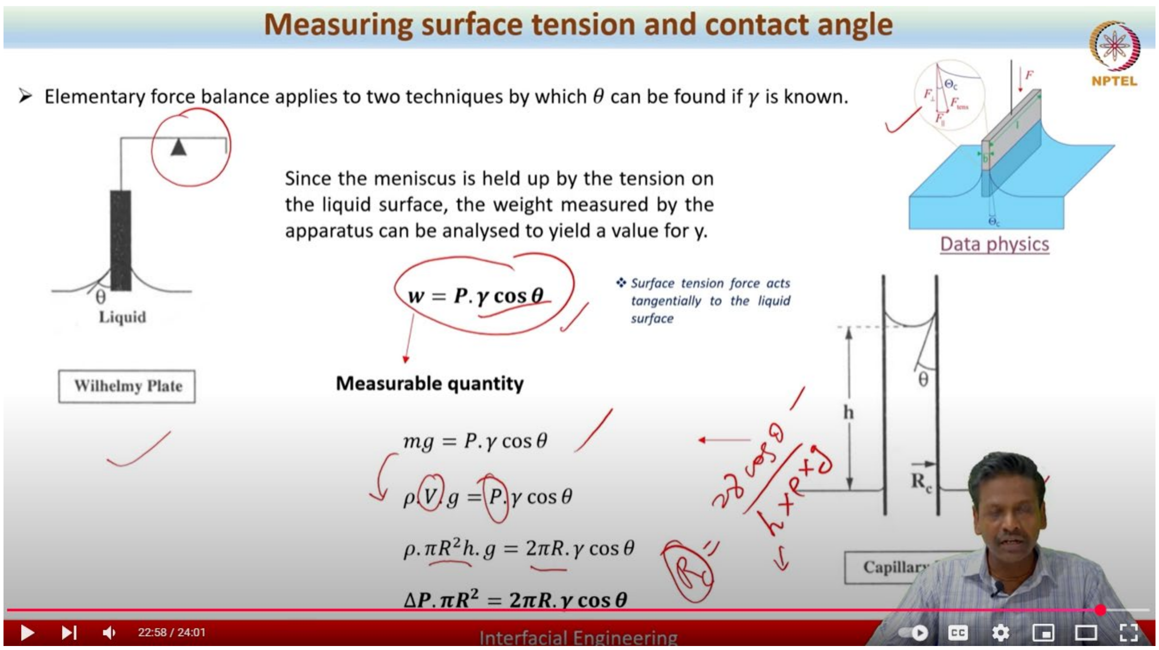

their wettability with the water is very good so that the theta is negligibly small you can actually ignore this you know the this component you know the the component of theta so in such case you don't need to worry about the measurement of theta, right, all you need to do is just you need a perimeter and you need to measure the, you know ,the weight of the liquid that is acting on the plate Then one can easily measure gamma.

In this case also you don't need to measure theta. With the current, sophisticated instrument that we have today. You don't need to really worry about theta. And again, in the case of maximum global pressure method also. We don't need to really worry about theta.

So we will stop here. We will continue from the next lecture. Thank you.