Fundamentals of Food Process Engineering
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Lecture - 06
Measurements of Rheological Properties

Hello everyone, welcome to the online certification course Fundamentals of Food Process Engineering. We are in the first chapter of our syllabus that is Food Rheology. We have discussed so far, the deformation and flow behavior of different food. In the last class we have discussed the various properties of fluid food, the rheological properties of fluid food. Now, in today's class we will see that how we can measure those Rheological Properties.

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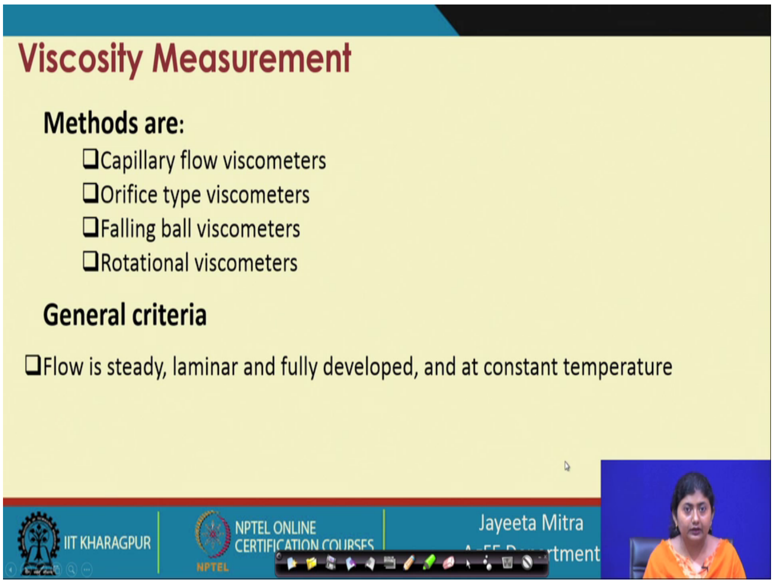

So let us start. So, first is viscosity measurement. We know that viscosity is the most important rheological property of fluid food and if it is Newtonian fluid, we call it viscosity and if it is non-Newtonian fluid, we call it apparent viscosity. So, basically what we do is we try to develop a relation between the shear stress that is causing the shear stress and the shear rate. We try to develop a relation between them, a straight line is coming; if it is a Newtonian fluid with and that straight line will pass from the origin. And if it is a power law model, we take l n of both the side and try to get a straight line from that, we can get the apparent viscosity.

So, first we will see that what are the different methods by which we can measure the rheological properties that is viscosity. There are different methods are there. One is the Capillary Flow Viscometer, it is very simple method. We will discuss, how we can measure, what is the principle behind the measurement of viscosity by capillary flow viscometer. Next one is Orifice type viscometer, third one is Falling ball viscometer, fourth is Rotational Viscometer.

However, under the rotational viscometer, there are different kind of geometry is there which are in use and all the methods under the rotational viscometer works based on the similar principle; however, there are certain difference in the geometries is there. So, to measure the viscosity by all the methods written over here, there are certain general criteria that are taken. So, those are basically defining the condition of the fluid for which we are measuring the viscosity, because we have understood in our last class that there are certain parameters which can affect the viscosity.

So, while measuring viscosity we want to nullify the effect of those variations; so that the exact behavior of the fluid can be understood. So, flow should be steady so; that means, the velocity we want to make constant. So, steady flow is desirable for measuring viscosity. Flow should be laminar because we know that in laminar flow, the velocity flows velocity is less and each fluid layer is slight by one another. If we take turbulent flow, so the lateral mixing of the liquid layers will be there which can hinder the proper viscosity measurement.

We consider the fully developed flow because in fully developed flow, we can analyze the velocity profile in a proper way. So, we can relate the viscosity shear rate, velocity, shear stress properly. So, we will consider that and also constant temperature. We know that temperature has significant effect on viscosity. With temperature in gases, we find that with increase in temperature viscosity increases; however, in case of the liquid sample, we have found that with increase in temperature viscosity decreases. All though there are some effect of pressure as well, but under the normal condition normal pressure; this is the phenomena that is why we need to follow this general criteria for measuring the viscosity.

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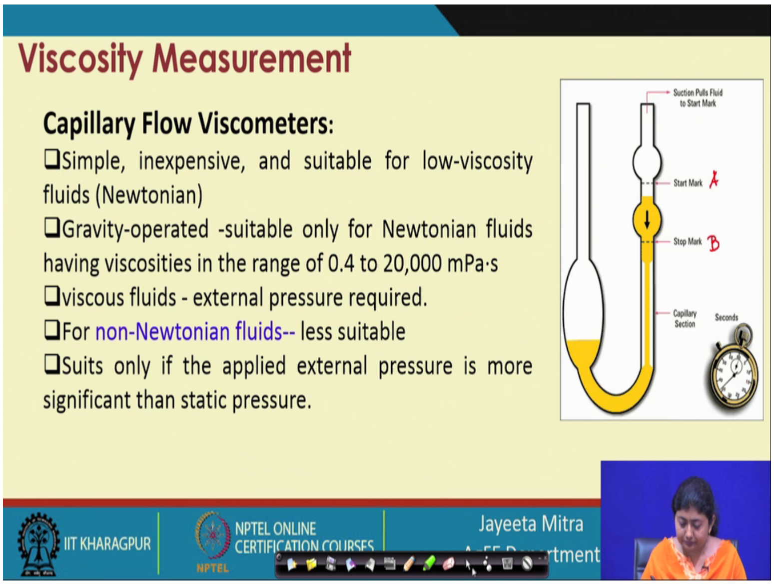

So, let us first take the case of capillary flow viscometer. This is the pictorial representation of a capillary flow viscometer; however, we may find that different kind of you know pictures, different kind of representation keeping the basic principle intact. So, it is very simple, inexpensive and it is suitable for the low viscosity material. It is not that much suitable for the high viscosity. What happened that in case of capillary viscometer?

We can see that there is a there is a capillary tube and there is some (Refer Time: 07:08) at few points are there. We mark this point. Let us say A and B and we want to measure that how much time it will take for a known volume of sample to pass from one point to the other. And also we want to know that what is the volumetric flow can happen under certain driving force. So, normally the driving force is the action of gravity for the low viscous material and gravity operated fluids if we take, so the range of viscosity 0.4 to 20,000 milli Pascal second can be handled by capillary viscometer.

Now, if we want to use this for higher high viscous fluid, in that case what we do is we apply certain external force in addition to gravity; that may be compressed air or by some mechanical means. However, for the Newtonian fluid, this is not suitable ok. The reason is that in capillary flow viscometer, we cannot maintain constant shear rate. So, shear rate is changing; so that is why it is very difficult to measure the non-Newtonian fluid. However, if at all we measure the non-Newtonian fluid viscosity by capillary flow viscometer, so then what we do is we apply some external pressure and consider that this external pressure is more significant compared to the static pressure.

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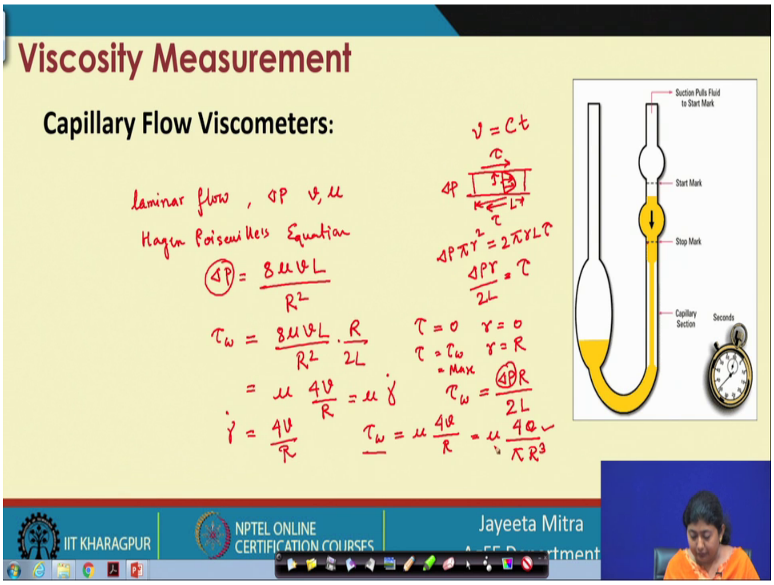

Now, we will see now we will see that what is the principle behind the viscosity measurement by capillary flow viscometer? So, as I said that we want to measure the volumetric flow rate that can happen under a certain pressure gradient or a certain driving force. So, to know the volumetric flow rate, we need to know the diameter of this capillary and the diameter is generally kept very small to cause the laminar flow only and that can be determined by you know calibrating this capillary viscometer by a liquid, generally Newtonian oil of which the viscosity is known to us.

So, then we can determine this diameter and radius, from that we can identify the volumetric flow rate and during the calibration, we find out that what is the what is the diameter and what is the time taken for that known viscosity to pass through and then we try any unknown liquid through this.

So, in this method we get an idea of kinematic viscosity because it gives us some indication of the dynamic viscosity as well as the effect of density. So, we know that kinematic viscosity is equal to dynamic viscosity divided by the density and it also called the momentum diffusivity. So, if we can represent the kinematic viscosity nu that is equal to some calibration constant c into time ok.

Now let us imagine a fluid element here in the capillary tube which is if I draw it here, we have consider this as incompressible laminar flow, temperature over the whole region is constant, then in the fluid element the delta p pressure that is acting because of the gravitational pressure will be balanced by the shear force tau and also we consider this as a fully developed flow. So, the parabolic velocity profile will be there.

So, in this case if we try to balance the force; that means, the force that is causing the flow that is the pressure force and the shear force that is opposing the flow that is tau. So, making a force balance we can write delta P pi r square that will be equal to 2 pi r into considering the length L. So, 2 pi r L into tau which is the shear stress ok. So, from here, we can write that delta P into r by 2 L that is equal to tau ok.

Now, we know that in case of a pipe flow, we consider that at the centre shear stress and shear rate will be equal to 0 when r equal to 0 at the centre and shear stress will be equal to tau w or maximum when r equal to the outer radius capital R. So, therefore, we can write the shear stress at the wall delta P r by 2 L ok. Also we can write that in case of laminar flow, inside a pipe delta P delta P and the velocity viscosity of the liquid can be related by Hagen Poiseuille's equation. So, that is equal to delta P 8 mu v L by R square.

Now, if we replace this delta P here in this equation, so we can get that tau w; this is equal to 8 mu v L by R square into R by 2 L; so, mu into 4 v by R right. So, this can be further represented as mu into gamma dot where we know that gamma dot is shear rate. Therefore, gamma dot is nothing, but four into v by R where v is the velocity of the liquid inside the capillary tube and mu is the dynamic viscosity of the liquid in Pascal second.

So, now, we can express the shear stress and shear rate by this equation that tau w that is equal to mu into 4 v by R or velocity v can be related with the volumetric flow rate as mu equal to 4 Q pi R square into R, so pi R cube right. So, now we are able to make a relation with shear stress with respect to volumetric flow rate Q or shear stress with respect to velocity and from that slope we can get the dynamic viscosity mu. So, therefore, we have established this relation for the Newtonian fluid where tau w that is nothing, but delta p into R by 2 that is equal to mu into 4 Q by pi R cube.

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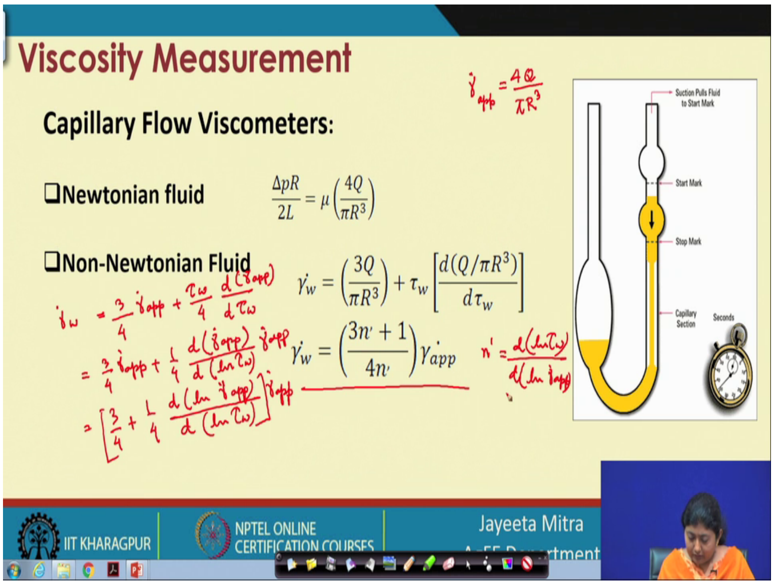

Now, for the Non-Newtonian fluid, similarly we can find that the shear rate gamma w dot that will be equal to that is shear rate at the wall will be equal to 3 Q by pi into R cube plus tau w that is shear stress at the wall into d of Q by pi R cube divided by d of tau w. And we can also consider here, as we can also consider here that gamma dot apparent that is equal to 4 Q by pi R cube ok. So, if we consider that because we have taken gamma dot we have taken gamma dot equal to 4 Q by pi R cube in case of the Newtonian fluid, since it is non Newtonian fluid; so we are calculating obvious we are supposed to take this as gamma apparent dot that is equal to 4 Q by pi R cube. So, that we can convert this equation to gamma dot w 3 by 4 into gamma dot apparent plus tau w by 4 into d by d tau w into gamma dot apparent.

And from here, we can write 3 by 4 gamma dot apparent plus 1 by 4 d of gamma dot apparent by d of l n tau w into gamma dot apparent. Taking gamma dot apparent common, we can find 1 by 4 into d of l n gamma dot apparent divided by d of l n tau w and from here we can get this expression, gamma w dot that is equal to 3 n dash plus 1 by 4 n dash gamma dot app taking n dash equal to d of l n tau w by d of l n gamma dot apparent so; that means, we are now getting the relation as this one for the Non-Newtonian fluid ok. So, that is how we have measured the we can measure the viscosity by plotting the shear stress and shear rate in case of the Newtonian and Non-Newtonian fluid using the capillary flow viscometer.

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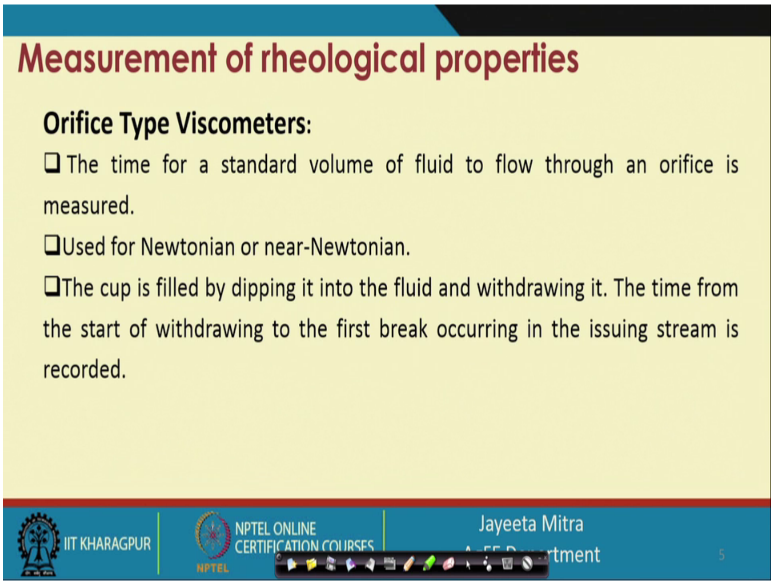

Next we have come across with orifice type viscometer. This one is used only for the so, this is used only for the low viscous fluid. The time for a standard volume of fluid to flow through an orifice is measured here and it is used mostly for Newtonian and near Newtonian fluid. So, there is a there is a cup here which is filled by dipping into the fluid and withdrawing it. So, the time from the start of withdrawing to the first break occurring in the issuing stream is recorded and from that the measurement of viscosity is done.

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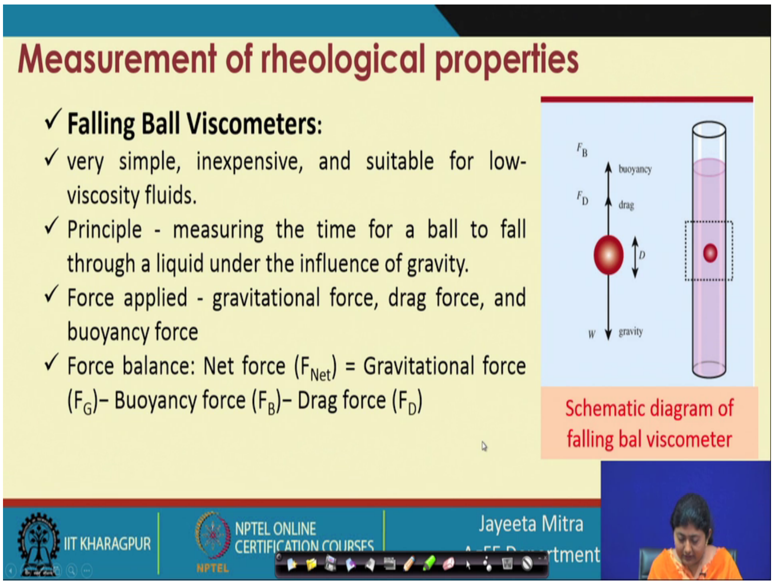

So, next is the falling ball viscometer, falling ball viscometer also very common and we can we can see the diagram, how we measure it; we take a cylinder and fill it with the fluid for which we want to measure the viscosity and here the criteria is that, we should take at least the particle ten times smaller than the diameter of the this tube to get the wall effect neglected.

So, when we drop a ball of let us say a radius R in the tube, this will fall down because of gravity and other than gravity, there will be a buoyancy force that will try to take the ball up and also a drag force which is acting in the upward direction. Now if we try to do the force balance, this ball will try to come to an accelerating condition to the bottom of the tube; however, if we think of the equilibrium condition, what will happen that the force will be in the balanced condition and the ball will come to the bottom with a constant velocity; it will not accelerate, but it will come to a constant velocity to the ground; that velocity is considered the terminal velocity ok. So, if we can measure the terminal velocity, from there we can get the idea of the dynamic viscosity of the liquid.

So, here we measure the time for a ball to fall through the liquid under the influence of gravity and it is it is also suitable for the high viscous material and force, we have already discussed that what we are applying. So, force balance will be the net force that is equal to gravitational force F G which is coming downward minus buoyancy and drag which is acting in the upward direction.

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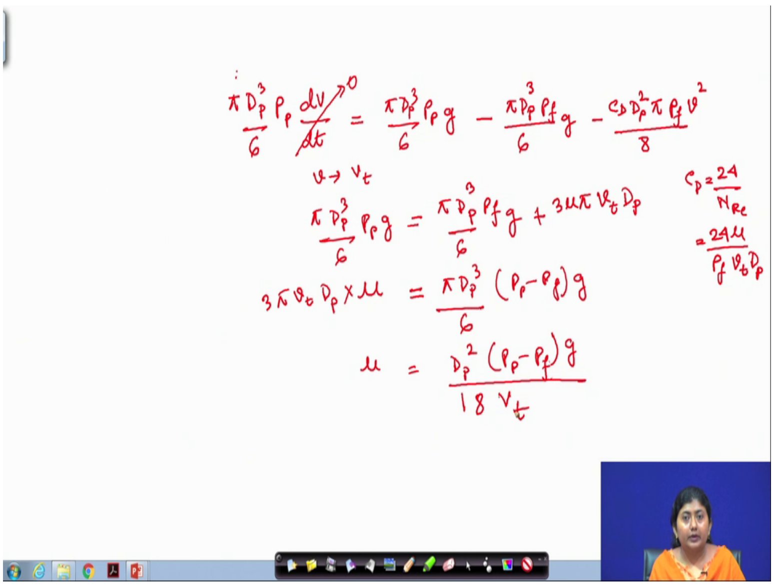

So, let us see first that ok; so we will see that how in the equilibrium condition, when the ball will attain the terminal velocity, then what will happen? So, the net force is pi into D P cube by 6 into rho P into dv by dt. So, this is the mass into acceleration of the ball that will be equal to pi D P cube by 6 into rho P into g gravitational force which is acting downward minus pi D P cube rho f. So, this is the buoyancy force minus there will be drag force a constant C D into area D P square pi into rho f velocity by 8.

So, in the case of equilibrium dv by dt this tends to 0, since it is coming with a constant velocity. So, v will be V terminal and then, we can write pi D P cube by 6 rho P g that is equal to pi D P cube rho f by 6 g minus C D. In the laminar condition we can consider, 24 by N RE which is Reynolds number and that is equal to rho v d by mu.

So, we can write it 24 mu by rho v D P. So, it will become 3 mu pi v t ok. So, then we can calculate we can calculate the dynamic viscosity as so mu into here we are getting, 3 pi v t and D P and here it is we can take common pi D P cube into rho P minus rho f g by 6. So, mu is equal to D P square rho P minus sorry this will be rho f. So, rho P minus rho f g by 18 v t where v t is the terminal velocity of the particle or the ball that is coming, D P is the diameter of that, rho P is the density of the particle in kg per meter cube, rho f is the fluid density kg per meter cube and g is acceleration due to gravity. So, here we can get the idea of dynamic viscosity. So, that is how we can calculate the viscosity by the falling ball viscometer.

So, we will continue in the next class.

Thank you.