Fundamentals of Food Process Engineering
Prof. Jayeeta Mitra
Department of Agricultural and Food Engineering
Indian Institute of Technology, Kharagpur

Lecture – 04
Food Rheology (Contd.)

Hello everyone, welcome to the NPTEL online certification course on Fundamentals of Food Process Engineering.

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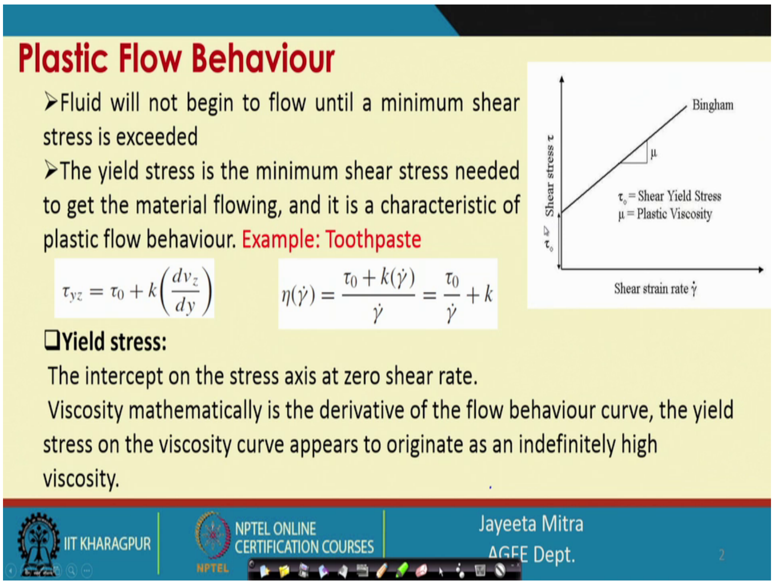

So, we were discussing with the property of the fluid food in the last class. We will continue with different, Non Newtonian behaviour ok. So, in the Non Newtonian, we have discuss the pseudo plastic and the dilating flow behaviour, which is termed as shear thinning and shear thickening behaviour.

Now, in this particular, in this particular class, we will first see the plastic flow behaviour. So, what is plastic flow behaviour? Is that, some kind of material will need some initial stress value before they flows ok. So, the initial stress that is tau 0 is equal to cos flow in this kind of a material, but when they start flowing they will follow the linear pattern ok; that means, again the slope of the shear stress versus shear strain. Diagram will be constant and one property will enough to explain their, their flow behaviour in this region, that is called the plastic viscosity.

And this tau 0, which is called the Yield stress. So, this kind of flow behaviour is termed as Bingham plastic behaviour. So, fluid will not begin to flow until a minimum shear stress is exceeded and this minimum shear stress is called the yield stress. So, for an example, we can see the toothpaste, where we need to put some initial stress, then only it will squeeze out. So, flow will start.

. So, this kind of material, we can express by, the equation tau y z that is equal to tau 0, that is the initial stress or yield stress required, to cause the flow plus k into dvz by dy. So, k the consistency index and dvz by dy is the shear rate ok. Now, if we, try to analyze the apparent viscosity, in this case. So, our apparent viscosity is a function of shear rate that is equal to, shear stress by, shear rate. So, stress will be tau 0 plus k into gamma dot divided by gamma dot. So, that is equal to tau 0 by gamma dot plus k.

So, the intercept on the stress axis at 0 shear rate ok. This is the yield stress and in this region since, we can, will observe that. Although, we are putting stress, there is no change in the, strain ok. So; that means, the viscosity is mathematically um, the derivative of the flow behaviour curve. So, the yield stress on the viscosity curve appears to originate as an indefinitely high viscosity ok. So, this shows the indefinitely high viscosity and because of this no flow we can observe ok.

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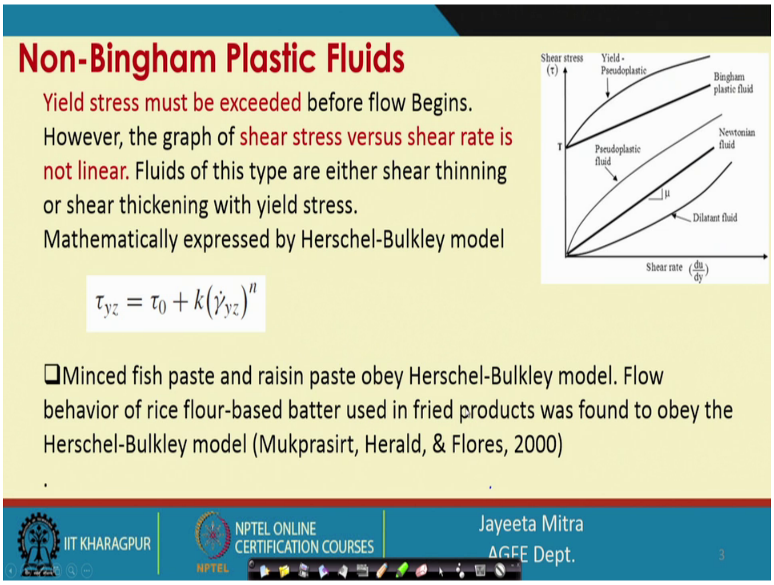

So, viscosity is actually to resist the flow, then, we can see that for a Non Bingham plastic fluid. So, Bingham plastic fluid; that means, the fluid which follow the

Newtonian, law, but need some yield stress, but Non Bingham in the sense, they will also need an yield stress, but when this starts flowing, they does not follow the, linear pattern like the Newtonian fluid ok.

So, if we plot that Shear stress versus Shear rate the curves will be a non-linear and in this particular case, it is again showing a shear thinning kind of a behaviour. So, this kind of phenomena can be mathematically expressed as Herschel Bulkley model that is tau y z, which is equal to tau 0 plus k into gamma dot y z to the power n.

The example will be minced fish paste and raisin paste. They obey the Herschel Bulkley model and flow behaviour of the rice flour based batter, because sometime we use the rice flour based batter for preparing different snack item, or the fried products. So, they will follow the Herschel Bulkley model; that means the Non Bingham plastic behaviour.

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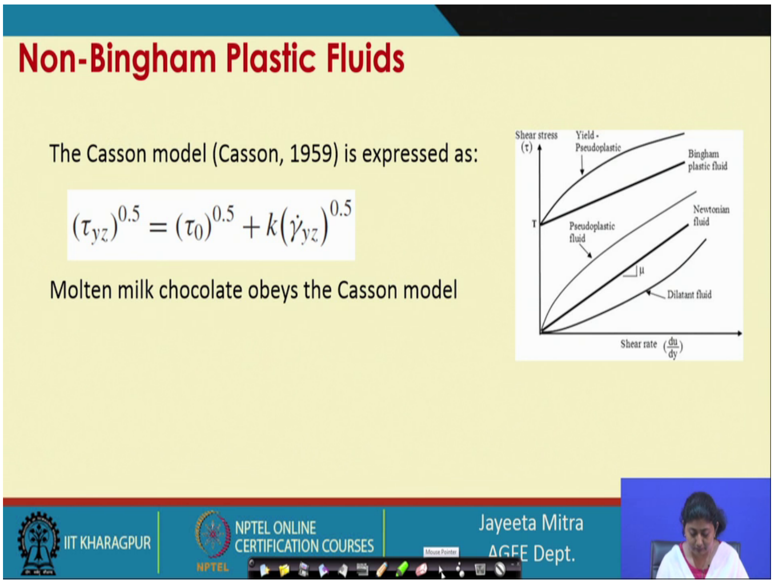

Now, another model which is called the Casson model., Casson model will also show the Non Bingham plastic, nature of the food, this is shown as tau y z to the power 0.5 that is equal to tau 0 that is the Yield stress to the power 0.5 plus consistency index into Shear rate to the power 0.5, specially this kind of phenomena has been found in case of molten milk chocolate.

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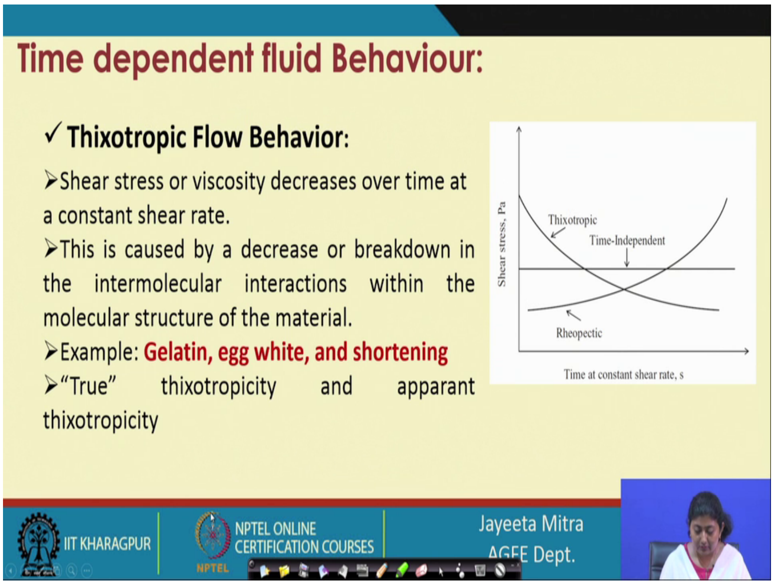

. So, then we will consider the, fluid switch of time dependent. So, till now, we have considered the behaviour, which are time independent. So, their viscosity will change on the rate of shear, but does not change with time, but now, we will consider certain Non Newtonian fluid, which will also, show different rheological behaviour with time if the Shear rate is constant ok.

So, first one that will consider that is Thixotropic flow behavior. So, in case of Thixotropic flow, behavior if we apply a constant, Stress constant shear rate, shear rate is constant then also the stress is decreasing or the viscosity will be decreasing and another flow behaviour is there, where we are getting just the reverse strain that at constant shear rate with increase in the time the shear stress is increasing.

Ok; however, for the time independent fluid like Newtonian fluid, we are, we are getting that, there is a constant shear stress with respect to time for a constant shear ok. So, the shear stress or viscosity that decreases over time at constant shear rate, this caused by a decrease or break down in the intermolecular interaction with in the molecular structure of the material. For example, gelatin egg white and shortening.

Now, here also we can offer, we can see this kind of behaviour like true Thixotropic and apparent thixotropic; that means, the material, which show decreasing nature of shear stress at constant shear rate over time and when we, you know, when we want to show the effect of the, I mean, when we want to change it, it is force or, or the shear rate and bring it to the initial condition, then it's viscosity will be recovered then we termed it as, two thixotropic.

But if it is structure has been changed completely and initial condition cannot be regained when we have, remove, the shear stress then we can call it apparent Thixotropic.

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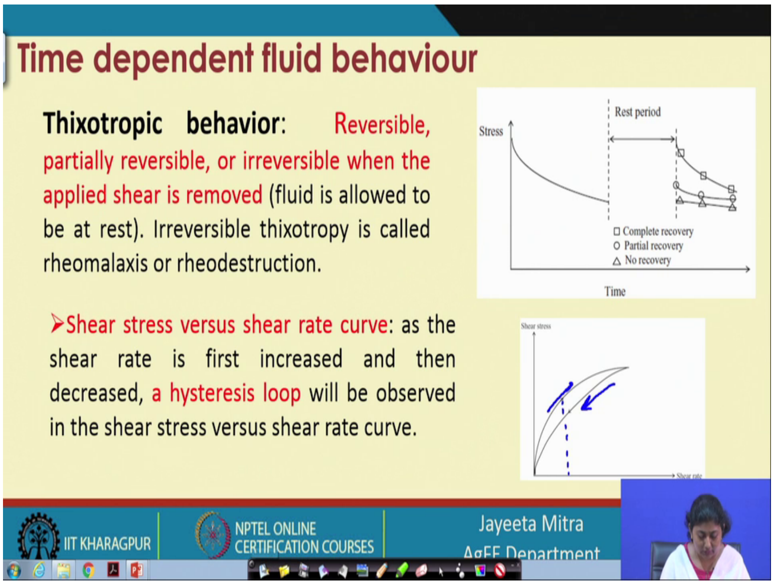

So, Tixotropic; that means, may be reversible partially, reversible or irreversible when the applied shear is removed. So, fluid is allowed to be at rest and, with time we can, we can see this behaviour. So, Irreversible Thixotropy is also called Rheomalaxis or Rheodestruction.

So, what happen that with time, if at constant shear rate, we apply and the stress is gradually reducing, then at certain time if we rest it at that position. So, what happen that the some material can completely recover that, if the shear is removed those are called the reversible and some may partially can gain the initial structure, those are called the partial partially reversible thixotropic behavior and some material were they cannot regain at all.

So, they will just whenever we again apply shear, they will start from that point only where it has already reached when the stress condition. So, these are the nature.

Now, so, Shear stress versus Shear rate curve, if we plot in case of a, this kind of a material as the shear rate is first increased ok. As the shear rate is increased towards this direction and then it again decreased, we will get a hysteresis loop ok. So, here, in case of Thixotropic behavior, we can observe that when we, when we have, increase the shear rate, the curve that will get and when we decrease the shear. There will be certain change. So, this change happened of some change or some permanent deformation that has happened in the structure of the material.

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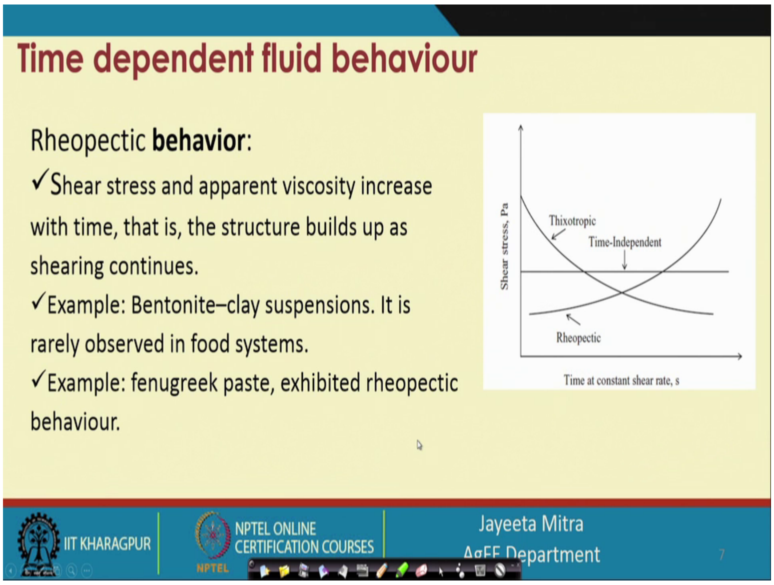

Rheopectic behavior, which is just reverse of Thixotropic that Shear stress and apparent viscosity increases with time. There is the structure builds up and the shearing continues. For example, bentonite clay suspensions, it is clearly observed in foods system. So, example is fenugreek paste, this exhibited the Rheopectic behavior ok. So, at a constant shear rate, if time increase, a shear stress and viscosity increases, this happen because of some kind of, interaction molecular interaction between the product and it has, increase it's viscosity over the time.

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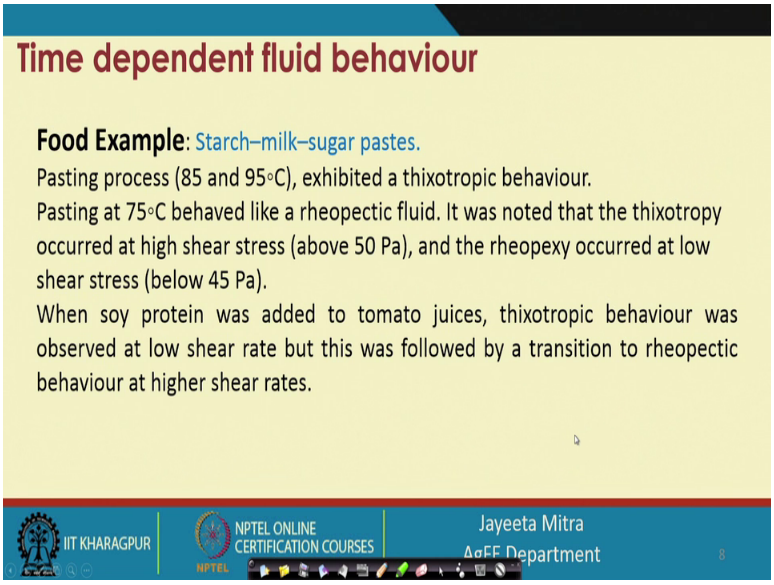

For example, the starch milk and the sugar paste. So, the pasting process can happen at 85 and 95 degree celsius. This exhibited a thixotropic behavior; however, pasting at 75 degree centigrade behave as a rheopectic fluid. So, here temperature is a factor that is causing some change in the material property and, because of that the structure has been taken or the viscosity has been increased.

So, it was noted that the thixotropy occurred at high shear rate that is above 50 pascal and the rheopexy occurred at low shear stress below 45 pascal. So, all such food material they are very specific kind of nature, because there is no generalized, way of that, because processing has been done in different pressure, different shear, different temperature, different duration of time.

So, all such are the research based on the research based results and, and there are certain modeling has been developed for the different and from where we can gain this kind of inferences.

For example; when soy protein was added to tomato juice, thixotropic behaviour was observed at low shear rate, but this was followed by a transition to rheopectic behaviour at high shear rate ok. So, thixotropic; that means, viscosity was reducing with time as at the constant shear and just reversed and we are getting, when the, when we just increase the shear rate ok. So, whenever we perform any kind of industry, industrial process for,

for product development and. So, we need to therefore, very much aware, should aware of the all the rheological nature.

Because when we mix and when we you know see the, see the different fluid line or, or the different capability of the pumping and all will be changed based on this nature of change of the material. Therefore, the rheological understanding of the product, that we want to make in a processing plan is very important to assess.

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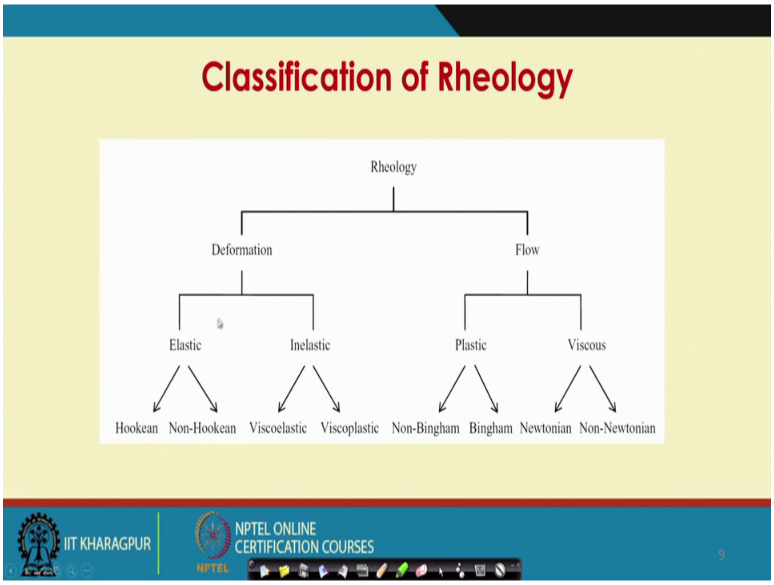

So, on the whole if you can see the classification of rheology. So, rheology as can be termed as can be categorised into two broad category, deformation under flow. So, the flow is basically the property of the fluid that will show continual deformation over time and it can be categorized as plastic and viscous material, plastic material that needs an initial stress to flow; that means, initially they show the, infinite viscosity unless they reaches the or they exceed the yield stress, there again Bingham and Non Bingham nature. Bingham means those material, which show the Newtonian behaviour, when they attend the yield stress.

And the Non Bingham, when they does not show the Newtonian behaviour, starts flowing viscous then will be Newtonian and Non Newtonian. Newtonian, they will follow the Newtons law of viscosity that is linear relation between stress and shear rate Non Newtonian; that means, this material, this fluid will does not obey the Newtonian behaviour. Neither they will pass through the origin, they will follow the power law equation then from the deformation, we can categorize them elastic and inelastic material elastic material follow the, Hookean deformation or non hookean whereas, inelastic is viscoelastic and viscoplastic right.

So, viscoelastic; that means, they have possessed both the property of the viscous material that, that a fluid behaviour and plastic nature, they need. They need some yield stress to flow viscoelastic. This is very important in terms of food, we will eventually discuss in our later class regarding this, because most of the food items comes under this category viscoelastic. For example, you dough and many kind of batter or, or mix ok.

So, this will possess the viscous property as well as the elastic property; that means, they have some, some quality, because of that they can regain it's initial behaviour partially. However, some deformation will happen that is a permanent deformation that cannot be recovered ok. So, this is all about the overall classification of Rheology.

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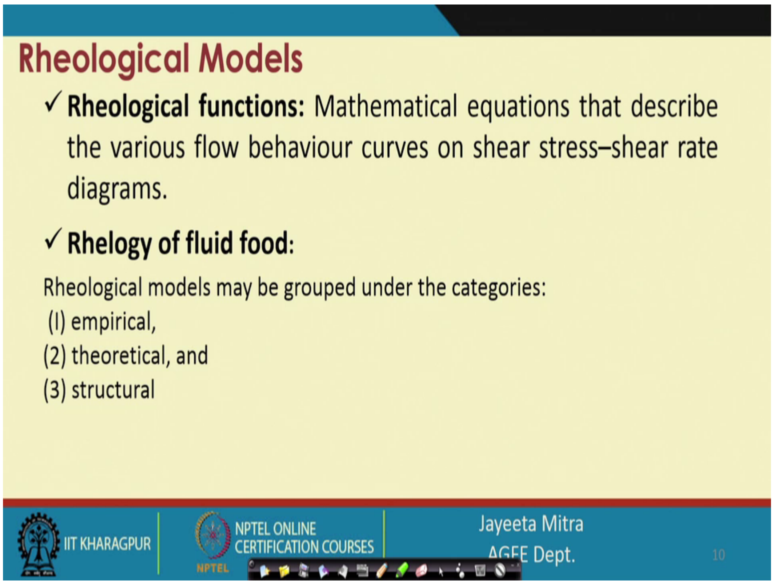

And lastly, there are many rheological functions are there. Mathematical equations that describe the various flow behaviour curve on Shear stress and Shear rate diagram. . So, Rheology of the fluid food, if we consider Rheological models can be grouped into three categories empirical theoretical and structural empirical, in the sense when we plot the shear stress and shear rate diagram and we prior does not have any idea about what? What is the structure, we cannot do any modeling, unless we get the trend of that change of shear stress and from that plot what we are getting? We can derive or we can generate certain kind of a model.

So, we termed them in Empirical model. Theoretical means that derived from the physics based principles that already we, we know the, the physical expression or the relation between the, stress and strain. So, from that we can categorize these models structural models. This based on the internal structure or the composition of the food. So, all three kinds of models are available for analyzing the, rheological behaviour of different food sample. So, we will stop here.

Thank you.