Fundamentals of Food Process Engineering
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Lecture - 01
Importance of Rheology in Food

Hello everyone welcome to the first lecture of the course Fundamental of Food Process Engineering. I am Jayeeta Mitra assistant professor, Agricultural and Food Engineering department IIT Kharagpur. My two research scholars Soumen Ghosh and Amrish will be associated with me for development of this course throughout. Today I will start the first chapter which is importance of rheology in the food. So, let us first discuss why rheology is so important in the context of food.

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Food having a diverse nature we know that various kind of a solid, semi solid liquid products are available, purely solid we not get that much in case of food only for very very low amount of strain this kind of behaviour elastic behaviour is visible, but mostly fluid and semi solid nature is widely available. So, let us first see that what are the various kind of food, we see normally around us and what is the nature of those food, right. So, first let us see, this is a picture of a glass of water ok, water we all know that a it is a fluid and it is considered as you might have heard that Newtonian fluid ok. So, water is having a linear relation among the stress and shear rate ok. So, if we try to plot the behaviour let us do that.

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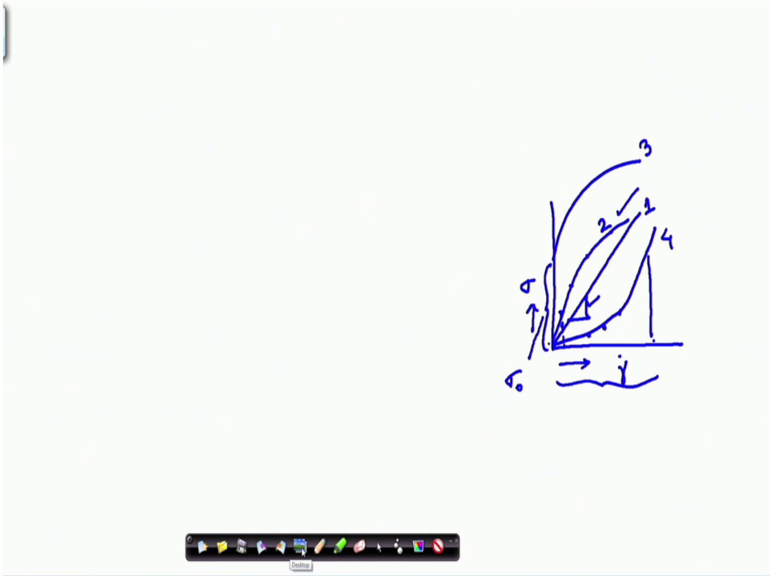

Let us plot the shear stress and shear rate behaviour for pure water. So, we will get a straight line and the slope of this line is an important parameter that define the rheological property of water ok.

So, so this water is a fluid, that is a Newtonian fluid and it has a linear relation between shear stress and shear rate. Now, if we see the clarified juice ok, clarified in the sense there is no suspended particle in the juice. So, a fully clarified juice showing the similar behaviour that is it also show a linear relation between the shear stress and shear rate. Pure honey, so pure honey it is a viscous material, pure honey also follow the similar trend that is a constant slope we are getting if we apply a changing shear rate and plot it with the corresponding share stress.

Finally, edible oil we all are very much aware of all kind of edible oil whether it is from ground nut source, whether it is from mustard seed. So, this edible oil also follow the similar nature. So, one thing in common in all such food material is that there is only one property, one rheological property that can express the nature of all such material and that is called viscosity right. Now, it is not so simple in many other kind of food ok, in them if we see the shear stress and shear rate behaviour. So, we may not get a straight line nature, so let us see those food.

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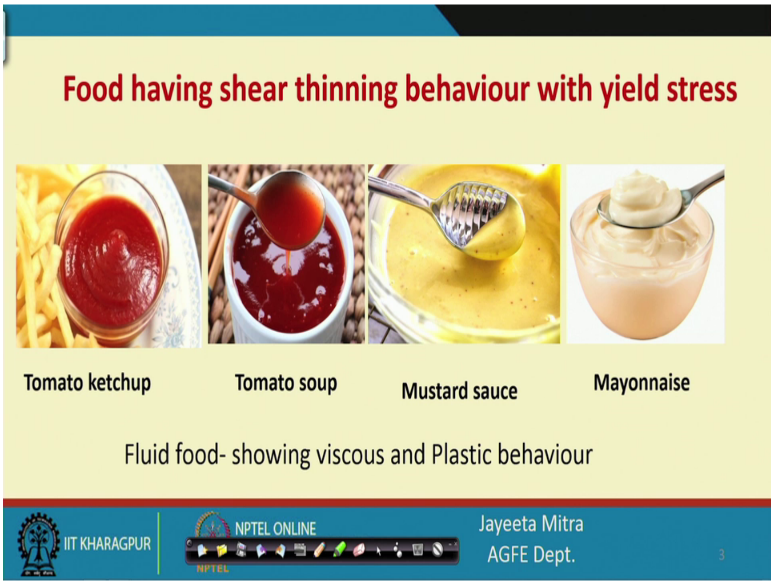

So, now coming to the next slide we see that there is tomato ketchup, tomato soup there is mustard sauce and mayonnaise, all four food are very common to all of us we normally have this in my, in our house we eat day to day basis. So, see what it what the title says it shear thinning behaviour with yield stress right. So, all such food having a shear thinning behaviour, now what is that actually?

If we go back to this diagram, so shear thinning; that means, in x axis where our shear rate is increasing and corresponding shear stress we are measuring in y axis. So, it will give us a plot of this kind; that means, with increasing shear rate it is having a decreasing slope ok. So, viscosity is decreasing at each instant, if we measure the slope here, here, here and then here. So, we are getting that constantly lowering in the viscosity we may see for those kind of material ok. So, it is see how much varied nature in different food sample we are getting, so coming back to the slide.

So, these are the fluid food showing the viscous property and we also say that plastic behaviour. So, plastic behaviour; that means, it is it is somewhat related with the this phrase that is yield stress. Now, again we will move on to its shear thinning behaviour which was visible by this, now when yield stress is added to that, so let us say this is sigma 0 and from here this kind of a plot we are getting. So, it shear thinning behaviour with yield stress right. So, that means, a initial threshold is required to cause the deformation or flow of such material right. So, again very special kind of category we can observe here.

So, from this we can see that different kind of food which is having shear thinning behaviour with yield stress.

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Now, we will see the next category, here we are getting food having shear thickening behaviour, so just the reverse of the earlier case that we are getting. So, these are what sample this is partially gelatinised starch first one, then we are getting a cream, this is also cream used as a toping of shake kind of material. So, again this kind of product is showing a different nature. So, if just we look into the structure of this material we can say the structure is somewhat more rigid. So, they have a properly framed structure and to break that structure; that means, to cause the flow its needs a higher amount of stress or higher shear rate is required.

So, this phenomena we can again observe here. So, this is called the shear thickening behaviour. So, in the stress strain shear rate diagram we can get this kind of a plot right. So, one first which was showing the linear relation then we have got which is showing non-linear relation shear thinning behaviour then we have seen that the shear thinning with yield stress and finally, we are getting a behaviour which is shear thickening behaviour. That means, as shear rate is increasing in x direction we are getting a higher slope at each and every point ok, so that means, viscosity is continuously increasing right ok.

So, why this happened because, when we are putting a shear rate and we are increasing a shear rate, so there are certain product which may form their structure and their structure is so ah, you know the structure modification is such that to break or to cause the flow from them it needs a higher amount of stress.

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Now, next we are having food having time dependent shear thinning behaviour ok, now the new thing came that is time dependent. So, till now we were discussing about the foods which is behaving differently with changing shear rate ok. Now, we are getting certain amount, certain kind of food material like salad dressing, then soft cheese, whipped cream.

For them what we are observing is that, that if we apply a constant shear rate, but for a prolong time so shear thinning behaviour; that means, the lowering of viscosity we can observe ok. So, here the time is important that for how long we are giving that shear right. So, all such different kind of nature is available in the in the diverse food system.

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So, next is food having viscoelastic behaviour that is semisolid food. Now, this is again how different from the earlier discussion is that by now we were discussing about the fluid food, the food which is having a the nature is viscous right. Now, here we are getting a viscoelastic food so; that means, it has the property of viscous material and is also having the property of elastic material.

So, very interesting feature we can observe in this kind of material, mostly different kind of dough sample comes under this. So, this one is chapatti dough with normally we prepare in household cooking every day, then there is ice cream mix, there is chocolate brownie batter ok. So, all such material will have nature that they will, if if they are being applied certain force.

So, we can observe the nature that some amount of deformation will be there that cannot be recovered. However, certain amount of deformation can be recovered so; that means, they show both the elastic property which says that upon withdrawal of force the product will come to its initial shape, at the same time some deformation we can observe here. So, that is why these are called the viscoelastic food and mostly this is widely visible in the different kind of food sample, the semisolid pattern ok.

So, we can see that a vary diverse nature of the food available and for that sometime when the, when it is better to be explain by this diagram that sometime one rheological property is enough that is this slope to express the food characteristics or nature.

Sometime we need to have different different slope at different different location; that means, we need to cover a range of shear rate. So, that what is the behaviour of the material of the food within that strain rate that is of important, important issue.

So, in that case not maybe 1 parameter may be more than 1 parameter we require to characterize properly the food in terms of rheological behaviour. And this is important because we may not need to give the shear rate or the range of shear rate that is applicable for processing of all kinds of food, this rate depends on what kind of processing do you want for your product. So, that is why for rheological properties are very important for processing point of view.

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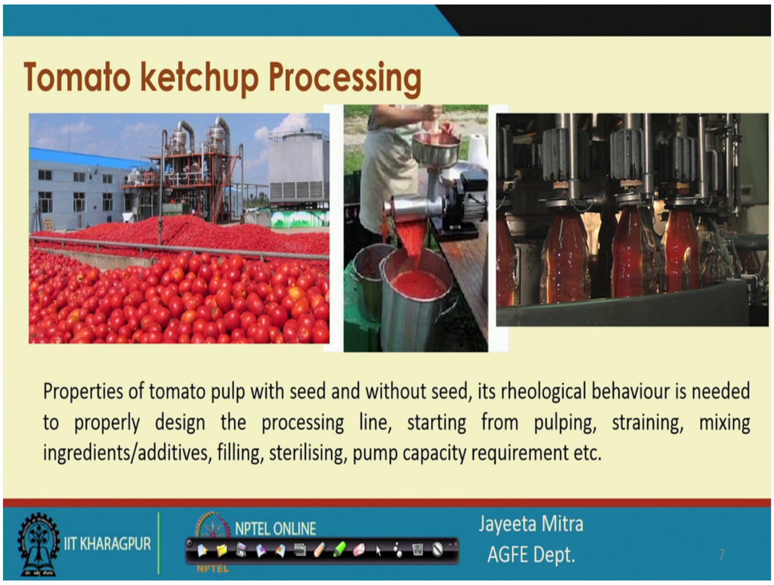

So, we will see now or try to just you know try to just think over that, where the rheological properties will help and why it is important? So, we have taken a case of tomato ketchup processing unit and we can see that what are the various steps maybe, first the proper quality good quality of tomato, possibly of similar variety a good coloured, a shape freshness those are received. Then they will be grading of the material after that there will be pulping of the juice and we need then deseeding mechanism then sometime we mix a certain ingredient to it, certain spices ah, certain preservative.

So, all such thing we add ok, then what we do? We do certain processing like we do pasteurization or then after processing we do filling or canning ok. So, the properties of this pulp with seed, without seed and its rheological behaviour all this we need to understand to design the system in a better way. So, design in terms of the consistency of this pulp from the making the pulp to final product is very important and while we are designing the processing line the pipe or the pumping requirement.

So, all things depends on the rheological behaviour of this product, let us say if you are heating this and then the viscosity is changing or if the shear rate is increasing, so how the viscosity is behaving. So, all such thing is very you know is of interest and is of preliminary understanding before designing such kind of a system. So, one case I can just discuss is that.

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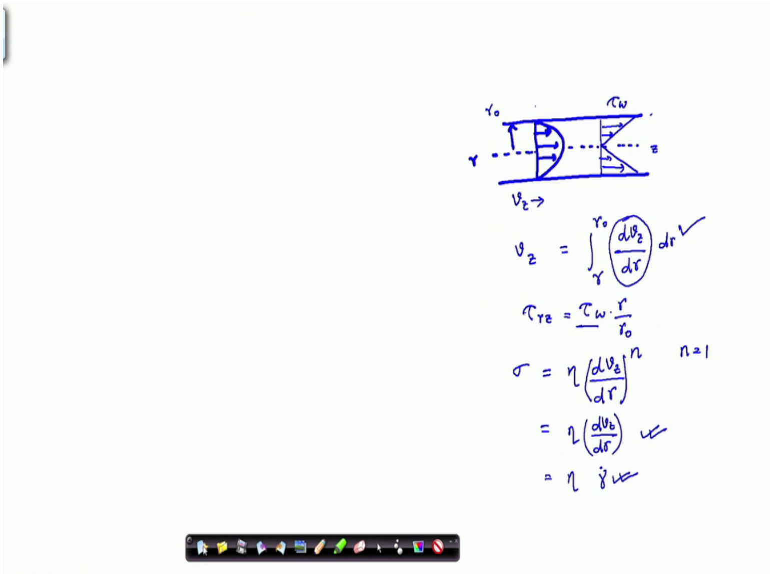

Let us say this is the pipe flow and we consider a fully developed flow in laminar region, so we may get this kind of a profile velocity profile ok.

So, one cross section we have taken and we are getting this kind of velocity profile. So, this is the centre r and here it is r o the radius at the outside of the wall. So, so this is um, so r o this at the wall and r is at the centre and we also know that if we try to draw the stress, so this stress will be minimum at the centre and it will be higher at the wall.

So, this is the stress at the wall that is tau w and this is let us say z direction velocity v z ok. So, velocity will be maximum at this centre and it will be 0 at the wall because, it is fixed and there will be no flow at the wall. So, if we want to know the velocity profile so we can have r to r 0, dv z by d r, into d r and also we know that stress at any distance r will be equal to stress at the wall into radial distance, where we want to measure the shear stress and divided by r o that is the distance from the centre to the pipe wall. Also we know that if the nature of the fluid that is the rheological behaviour of the fluid is known to us so stress is, I mean any any point of time if we want to measure.

So, we know that it is viscosity eta and dv z by dr to the power n will come to detail of all the nature of the ah different fluid. However, just to express this particular case we will take that n is equal to 1. So, this will be a case of Newtonian fluid so dynamic viscosity into dv z by dr right.

So, now if we want to know the velocity profile of this fluid which we are handling in in the in a processing line that that we are intended to, let us say in this case the tomato processing line we want to develop or design. So, velocity profile analysis will be easy if we know the nature of the rheological behaviour. That means, the velocity is can be calculated by this equation where we need to know the dv z by dr this is nothing, but shear rate. So, this behaviour if we know then we can calculate the vz from this or else if we know the velocity, we can calculate what will be the shear stress at different section and the wall and based on that we can design the whole processing line ok.

So, so similarly very much interesting features can be identified or the nature of different food can be analyse, different inference of the nature of the food can be drawn by analysing the rheological property ok.

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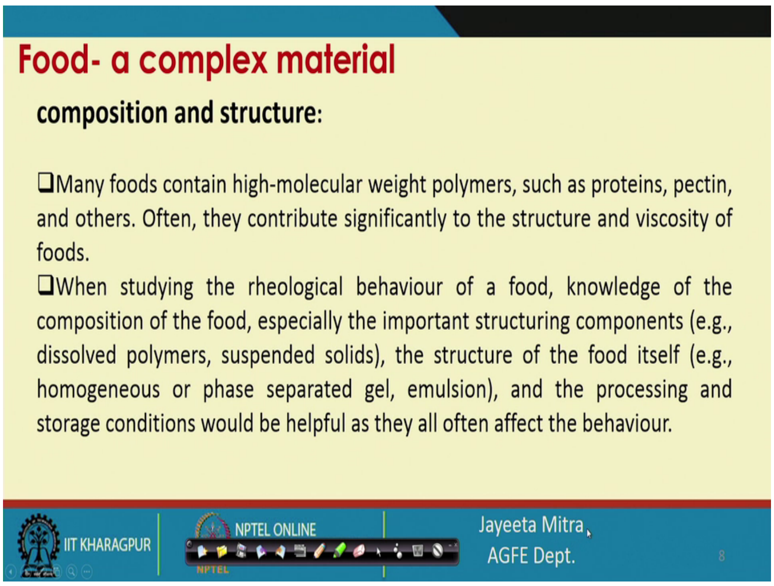

So, we have understood that food is a complex material and the complexity depends on the composition and nature of the food. So, mostly this foods are you know these are they contain high molecular weight polymers like protein, pectin and other material and often they contribute significantly to the structure formation and viscosity of the food.

So, when studying the rheological behaviour of a food a knowledge of the composition of the food specially the important structuring component, that is the dissolved polymer or suspended solids this should known to us and structure of the food itself. That means, it is a homogeneous or a heterogeneous composition or the, what is the phase of that emulsion or what kind of materials. So, the structure should be known to us and processing and storage condition because sometime with changing temperature or with the shear rate with prolong time. So, all this change the rheological nature of the food. So, this is very important to know.

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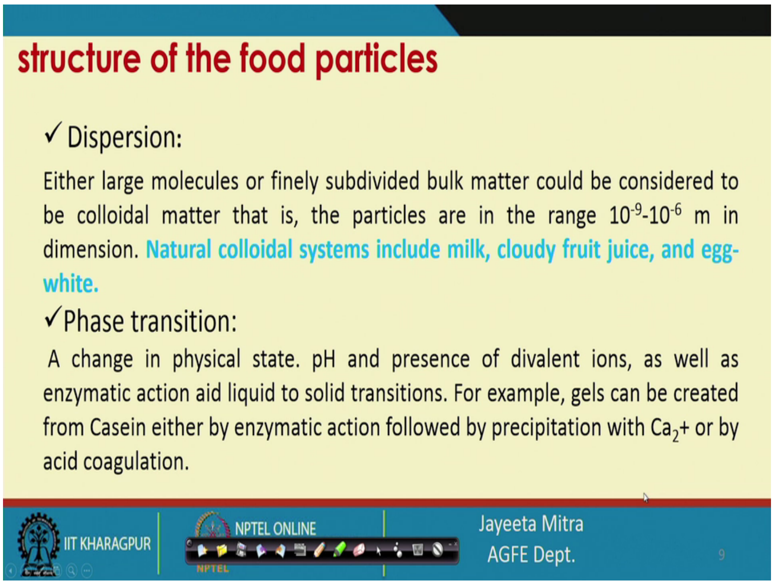

Now, structure of the food particle if we consider we will take one example like dispersion. So, dispersion we call if large molecules of or fine molecules, fine subdivided bulk matter they are considered to be colloidal matter, if the particles are in the range of 10 to the power minus 9 to 10 to the power minus 6 meter in dimension. So, these kind of colloidal matter which are dispersion, so they are exist like milk or cloudy fruit juice and egg white ok, then there are may be phase transition. So, phase transition we know that this is a change of one phase to the other that is liquid to solid liquid and gas this interchange is called the phase transition.

So, most of the cases and in case of food we are getting liquid to solidified state or vice versa ph and pressure ph and presence of the divalent ion as well as enzymatic action and these are helpful in conversion of liquid to solid ok. For example, gels can be created from casein, either by enzymatic action followed by precipitation with calcium ion or by acid coagulation. So, by that the liquid to solid conversion can happen.

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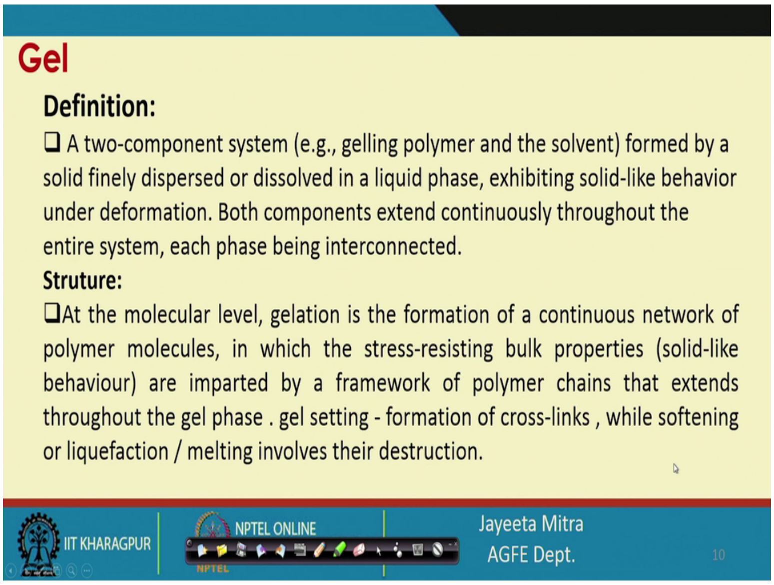

There is another which is gel. So, by definition gel can be defined as a two component system that is the gelling polymer and the solvent, formed by a solid finely dispersed or dissolved in a liquid phase, exhibiting solid like behaviour under deformation. So, both components that is the gelling polymer and the solvent they extend continuously throughout the entire system and each phase being interconnected.

So, what will be the structure of this? So, at the molecular level, gelation is the formation of a continuous network of polymer molecules, in which the stress resisting bulk properties which is the solid like behaviour these are imparted by a framework of a polymer chains that extend throughout the gel phase. So, when we call gel setting, that signify the formation of cross link, while softening or liquefaction of the gel; that means, melting or the destruction of the structure.

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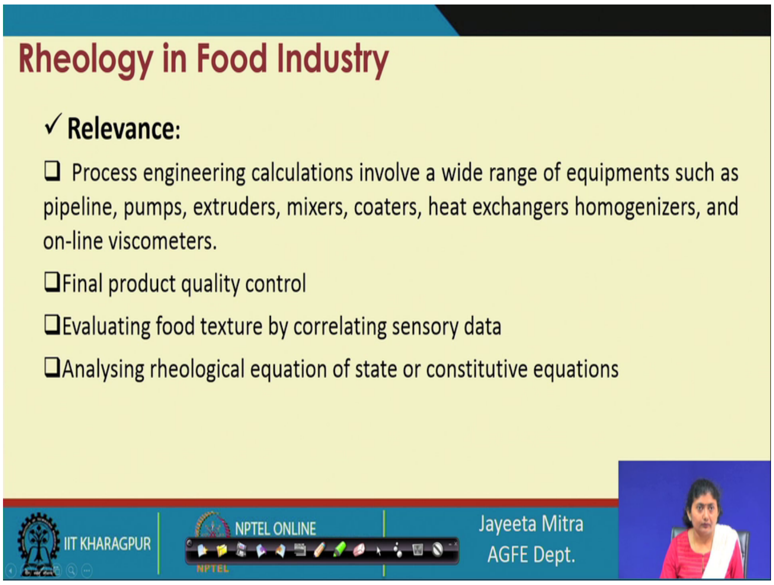

So, to sum up I can say that in the food industry rheology has a significant role, process engineering calculation involves a wide range of equipment such as pipeline, pump, extruder, mixer, coater, heat exchanger, homogenizers and online viscometer.

So, all this need a proper rheological understanding that what is the effect of shearing or increasing shear or increasing time on it, similarly final product quality control is very easy if we know before and the rheological nature of the material. Then evaluating the food texture by correlating the sensory data because sensory perception is very important for any food material based on with which we design a food because consumer acceptance is very important.

So, to mimic properly the sensory data texture analysis is being done which is you know getting an insight important insight of the rheological nature of the food and analysing rheological equation of state or constitutive equation which given understanding of the flow phenomena or the behaviour. So, this is very important.