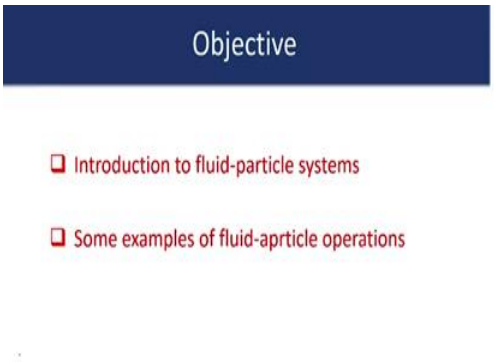
Fluid Mechanics
Prof. Madivala G. Basavaraj
Department of Chemical Engineering
Indian Institute of Technology, Madras

Lecture - 28
Characterization of particles 1

Fluid Mechanics aspects so, far right. So, Sumesh has been teaching about flow through pipes you know flow between cylinders and things like that and he ended up with talking about friction factor. So, he is going to come back in about 5 weeks and then he is going to do a little more of a friction factor and few other things like boundary layer flows and turbulence and things like that ok. I am going to you are going to see me for the next 5 weeks and we are going to talk a little bit about particles ok.

So, what happens if you have particles in the fluid that is the portion that I am going to cover. So, for today's lecture I just want to do a brief introduction that is the purpose of today's lecture.

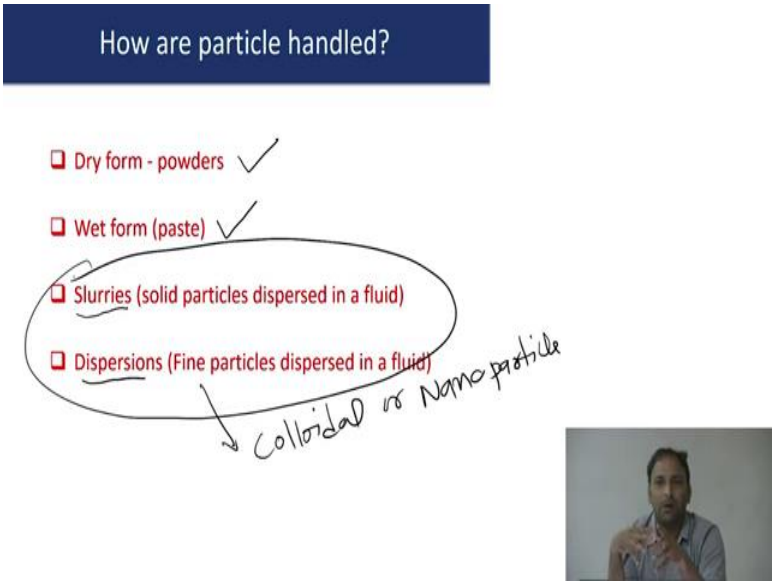
(Refer Slide Time: 00:58)



So, the object is two fold I just want to introduce you to fluid particle systems that is objective 1 for today's class. The second thing is to I am going to talk a little bit about fluid particle operations. So, at least the these operations I mean I think its also there in the if you look at the course contents, if you have gone through I do not know how many have you gone through the course content, but if you have gone through you will see that you

know I am going to discuss some of the terms that are there in the course content in terms of you know what we are going to look at in terms of the fluid particle operations ok.

(Refer Slide Time: 01:36)



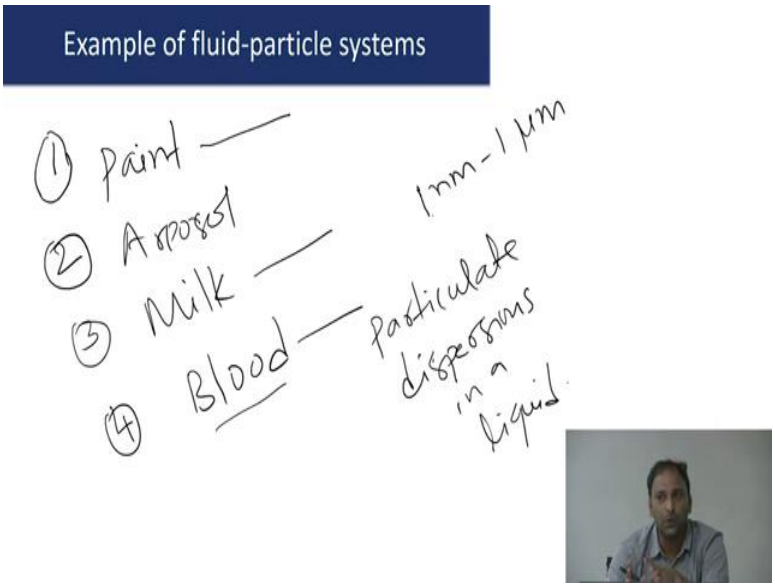
Just to begin with how do I mean particles are kind of everywhere right you look at any chemical industry or any industry in general, you will always have particles right I mean you have particles are kind of dealt with in different different forms as listed here you can either work with particles in the dry form there is a lot of interest in looking at powders, you know processing of powders how do you handle them you know aspects of that sort.

You also have cases where the particles are kind of processed in a you know wet form ok. For example, paste you know things like that and more often people work with the particles dispersed in a fluid that is the last two things you will come across something called as slurries ok, which is basically dispersion of solid particles in a fluid only thing is when the particle size is coarse larger size particles maybe tens of microns or several or millimeter sized objects in a fluid that is when you kind of think about something called as a slurries.

You also have something called dispersions which typically refers to fine particles dispersed in the fluid more of buzzwords if you want to call it as you can think about something called as colloidal or nano particle dispersions that is ok.

So, what we are going to do in the rest of the you know 5 weeks is that, we are going to look at you know how do people handle you know particles when you are going to put them in a liquid that is going to be the goal of the next few lectures ok.

(Refer Slide Time: 03:25)



Any examples of fluid particle systems you know of? Some example that you I just want to list different fluid particle system that you kind of know.

Some names, I am sure all of you know this let us write some examples right how about paint right. Paint is typically you have some solid particles dispersed in a fluid of course, there will be additives like pigments and stuff like that, but definitely there are some fillers and these fillers are going to be in the time in the form of particles and therefore, paint is an example of a fluid particle system any other examples? What is that?

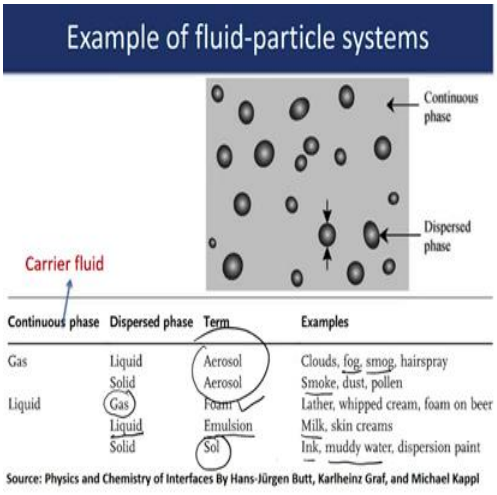
Aerosol is a; aerosol is a kind of fluid particle system yes how about milk right milk essentially has about you know a lot of water plus there are some case in my cells there are some proteins and stuff like that is an example of a fluid particle system how about blood right you have RBCs there is plasma right. So, I can really think of lot of examples where particles coexist along with the fluid right what is common between paint, milk and blood? What is that?

Student: Colloid; colloid.

I do not know if you can really call colloid as a blood as a colloid because typically typical definition of colloids is that, you should have a particle size ranging from 1 nanometer to about 1 micrometer. If the size of the particles are in that range that is when they are called as a colloidal dispersions or nanoparticle dispersion, but if you look at blood the size of the red blood cells is larger its about 8 microns in size. So, its really not a colloidal dispersion, but still there is something that is common between 1 3 and 4 that is paint milk and blood. What is that?

You know emulsions no I mean if you like look at blood its not an emulsion we will come back to some of the classification little later on, but what is common between the three is that the dispersing medium ok. They are all particles in a fluid right and in this case fluid is a liquid if you look at all these things these are particulate dispersions in a liquid right that is a common thing between 1 3 4 right.

(Refer Slide Time: 06:47)



Now, depending upon you know the fluid particle combination that you are going to work with, there are several ways that people classify fluid particle systems that kind of classification is given in this. What you are seeing you know the picture is a cartoon to say that there is something called as a dispersed phase it could be your is your particulate matter and there is something called as a continuous fluid and this continuous fluid if you want to call it as you can call it as a carrier fluid or solvent you know people use different

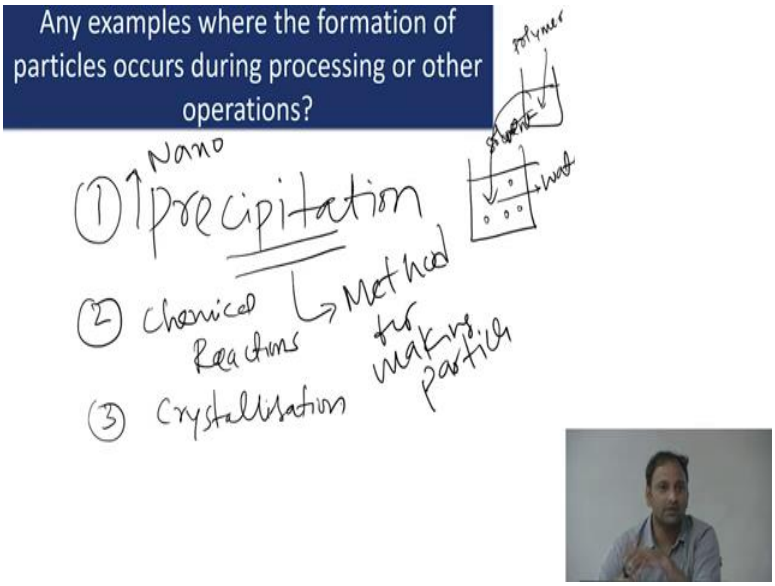
different terms. So, there is a table here. So, if you look at the continuous phase right the continuous phase can be gas and your continuous phase can be a liquid ok.

So, and your dispersed phase can again be liquid, solid or gas depending upon you know what kind of system that you are working with you can have if you have a liquid droplets dispersed in gas or if you have a solid particles dispersed in gas you have what is called as a aerosols right. And again you know aerosol research is again a lot of importance now because a lot of pollution you know stuff like that right. So, examples of aerosols would be your fog, smog, smoke ok. So, all of these are examples of aerosols.

Now, when you have a liquid as a continuous phase and if your dispersed phase is gas you have what is called as a foam right all of you are familiar with foam right I mean if you take a bucket of water you know with some surfactant or some soap, you know only if you open your tap water you know falls in and you know generation of bubbles right. So, that is an example where you know you have gas or air bubbles in this case dispersed in a continuous liquid medium that is an example of a foam. You have what are called as liquid in liquid dispersions examples are I mean they are commonly called as emulsions as somebody said milk is an example of an emulsion, there are lot of skin cream there are lot of two in one shampoos these are all examples of you know liquid in liquid dispersions also called emulsions. So, you also have cases where you have solid particles in a liquid ok.

They are called typically they are called as a Sol and examples would be your ink, muddy water you know paint and things like that ok. So, now that we know a little bit about you know fluid particle systems and their you know different examples.

(Refer Slide Time: 09:23)



Let us think about I have a question to ask ok. Can you think of an example where the formation of particle occurs during a processing operation or unit operations you know whatever that you can think of any examples? I am I want an answer. So, far you know we looked at you know milk and you know paint and stuff like that right.

So, when people of course, milk and blood is naturally occurring. So, there are particles inherently in the fluid right and if you look at like say paint; paint is a formulation wherein what you do is you there are particles and you put these particles into a fluid and you basically make a formulation to get a paint of whatever desired quality right. Now these are examples where the particles are already either there or they are kind of dispersed externally right you take it from you know some source and put them into this fluid ok.

I want an example where you know do you think there are operations where the particles are formed during an operation or the cases where the particles are formed during an operation or it could be any chemical processes.

Student: Grinding.

Grinding ok. So, he is using a term called grinding; grinding is typically I hope all of you know grinding right I mean it is basically what you do is you take a solid particle and you basically reduce the size ok. There are different ways of reducing the size, but if you know chop off particles and makes smaller stuff right that is what is called as a grinding ok. That

is an operation where you start with a larger particle and you break it down into smaller sized particles right. I am I want an example for a case where I have a fluid and the particles are formed during its processing.

Student: (Refer Time: 11:23) precipitation.

Precipitation right precipitation is one example. So, one would be ok. So, all of you have heard this word called precipitation right. This typically happens you know when you have you know if a fluid becomes you know in a loose term if the fluid becomes insoluble for the particle right, if I have like say a solution for example, water plus some particles right or say there you know I have some salt or something you know dissolved in a fluid right and if I have a way of changing the solvent quality that you know that let me take an example ok.

Precipitation actually is again one of the areas where there is a lot of research, I am going to give an example where precipitation of precipitation is used as a method for making particles ok. There is a class of technique called nano precipitation what is done is this what you do is, you take a container your container has water now what you do is you take another solution where you have some solvent and in the solvent, you dissolve a polymer this solvent is a good solvent for the polymer this polymer you know completely dissolves in the fluid and it gives you a clear homogeneous polymer solution.

Now, when I add this into water if the solvent and water they mix they like each other and if the polymer does not like to be in contact with water as soon as I add the solution into water what happens is you know this polymer kind of separates out and it separates out in the form of a particle ok. This technique is what is called as a nano precipitation again one of the widely used techniques for making drug particles and things like that ok. So, one of the examples where the particles can be formed during your you know operations could be nano precipitation. Any other example?

Chemical reactions as well right. So, you can have chemical reactions right you can have a reactant a plus b giving rise to some product and the formation of the product could be in terms of you know chemical reactions I know you doing the reactions any other thing? Tell me at all of you know crystallization right crystallization again under the process where you know whenever there is a you know homogeneous fluid you know if you create

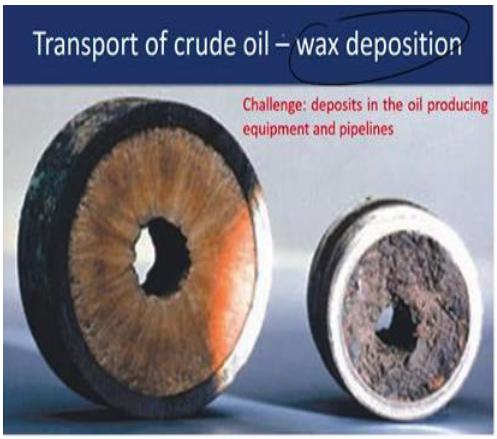
some sort of super saturation right. So, there is going to be nucleation of particles and stuff like that right.

(Refer Slide Time: 14:46)

Now, I am going give tell you an example where particle formation occurs during flowing of a fluid ok. I am going to take a case of a transportation of crude oil, what can you say from the images that you see? That is actually a cross section of a pipe. So, the in this pipe there was a crude oil that was flowing and at some point you know they have cut the pipe and they have taken a picture what can you say from this image? So, that is your pipe wall alright this is your wall what is in the center any guess?

What is that?

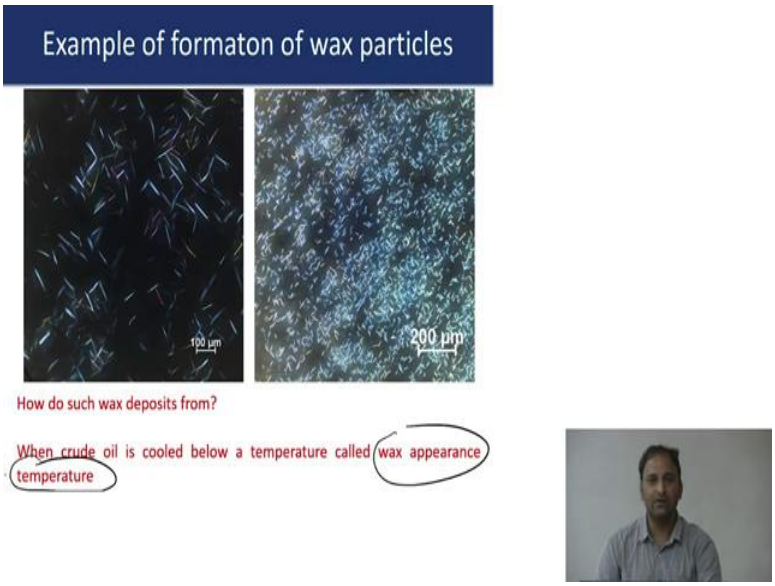
(Refer Slide Time: 15:47)



Any guess? That is your wax deposition ok. So, all of you know that its crude oil it is a complex mixture right it has you know hydrocarbons paraffins you know there is aromatic stuff there is asphaltenes and things like that there are organic compounds of different molecular weight present in the fluid and what happens when you transporting these fluids is that, depending upon you know several conditions this crude oil could be subject to different conditions you know there could be cases where the temperature during its transport temperature around the pipe could reduce you know typically right it depends on weather conditions right there are some like say cases where the weather conditions are hot cold and stuff like that right.

Now, because you have a molecules of different molecular weight right long chain molecules in the crude oil, what happens is that you know when you cool such fluid there is going to be some sort of crystallization.

(Refer Slide Time: 17:01)

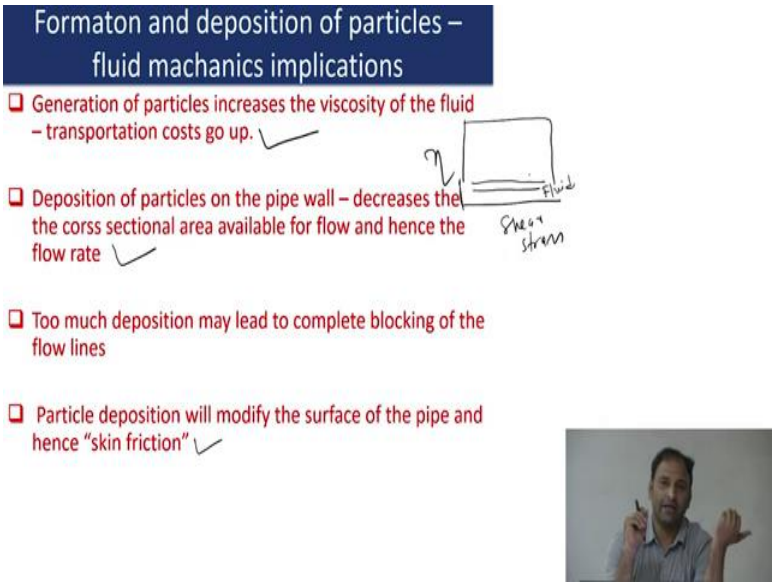


So, what you are actually looking at is images, which are obtained by taking an oil and in this oil some wax is dissolved and then you heat this cold fluid into a high temperature maybe like say 80 degree centigrade right. Now, if we start cooling it down at some point you start seeing the formation of these needle like structures and these needle-like structures are the wax crystals and that form whenever you take this fluid and then cool it down to a temperature, something called as a wax appearance temperature.

So, typically if there is a way of transporting fluid this crude oil under conditions where the temperature is always above the wax appearance temperature, it will continue to flow like a nice fluid there is no issues. But the moment the temperatures surrounding this pipeline goes down below this wax appearance temperature, you suddenly start seeing the formation of these crystals and eventually these crystals what they do is they start depositing on the walls inner wall of the pipes and they know this the skin of the wax that is deposited it basically goes in time and ultimately it may even lead to a blockage ok.

This is an example where you start with you know pumping of fluid or transportation of fluid and then your particles are formed during its transport because of the fact that you know the temperature conditions are kind of you know altered during their flow.

(Refer Slide Time: 18:52)



Now, what do you think would be the implications of you know the formation of deposition of particles in terms of fluid mechanics any thoughts? So, of course, there are several implications right. Now we know that you know whenever you have the there is generation of particles the viscosity of the fluid goes up right we kind of saw an example in the previous in the in one of the lecture that I gave, wherein you have a base fluid you saw adding particles we said that the viscosity was going up right.

Therefore, the generation of particles can lead to significant increase in the viscosity of the fluid therefore, there is going to be associated transportation costs. So, one has to be you know worrying about that. As it is evident from the figures the deposition of the particle on the inner wall it reduces the cross section area right.

Effectively the cross section area that is available for the fluid flow is going to reduce therefore, is also going to be there a going to be reduction in the flow rate as well ok. So, it could have implications on the fluid processing that you are trying to do. Of course, the too much of you know wax deposition can lead to blockage it can completely stop the fluid from you know transportation right and so, we in the previous lecture we talked about the skin friction and form friction right and we said that skin friction basically comes from the roughness that is on the inner wall of the transport you know fluid you know the pipe through which the fluid is being transported right.

Now, when you have; when you have you know wax deposited; obviously, is going to affect the surface properties right and therefore, it is also going to affect the skin friction. So, therefore, so, the formation of particle has is of relevance both in terms of trying to understand when do the particles form plus as well as to now to look at you know fluid mechanical aspects in terms of you know somebody has a question.

The first point first point whyone of the class that, I we I talked about viscosity measurements ok. So, let me just draw something here. So, we had basically discussed about a particular plot, you know where the viscosity was measured as a function of say shear stress where in what we said that you know the viscosity would remain constant as a function of shear stress when you have case where you only have a fluid ok.

Now I put in a small amount of particles what happens you know the viscosity goes up ok. Now the increase in the viscosity purely comes from the because of the fact that you know there is some dispersed species in the fluid ok. Therefore, the viscosity can increase they of course, you know when you want to pump a fluid that has a higher viscosity of course, you know you would have to worry about you know the pumping cost associated with the fluid particle system ok.

So, in that context you know the formation of particles depending upon what is the concentration of particles that are being generated, it can significantly increase the viscosity and that could in turn have you know effect on you know the transportation in terms of you know the pump requirements and things like that.

They there are two aspects in the example that I gave you it so, happened that you know initial stages of wax crystal formation, the example that I gave initial you know when these things start appearing initially they are nicely dispersed in the fluid ok. In that context I have a fluid particle system right a homogeneous fluid particle system, what you seeing here in terms of deposition happens at a little later stage first there is going to be some formation of first layer of wax crystals ok. So, its not you know it just happens instantaneously it happens during a period of time, but initially you could think about crude oil at least when the temperature are around this wax appearance temperature is a homogenous dispersion of you know such particles in a fluid ok.

So, now ok so, at least with this I just want to set a base for you know just to say something about you know particles and that there is some you know particle fluid systems and they can be some implications in terms of you know understanding their fluid mechanics ok.

(Refer Slide Time: 23:57)

Now I am going to kind of now I want to move on to talk about the different fluid particle process that we are going to see in the course, I just want to start by showing you a video let me just show that ok.

So, what you are seeing is a movie, we can do this in our lab if you want if you are interested we can do that. So, what is done is they have a container and the container is filled with water to begin with and all that is being done is take a one drop of milk and just drop it in the fluid ok. Nothing else is happening, just one drop of milk into a container and it is being kept below a microscope objective and you are watching it what do you see? I should go back right you saw the title right what do you see? Brownian motion right this happens when the particles are tiny when you have a very tiny particle if I do the same thing like say let us say you know I have a container I put in millimeter sized objects ok.

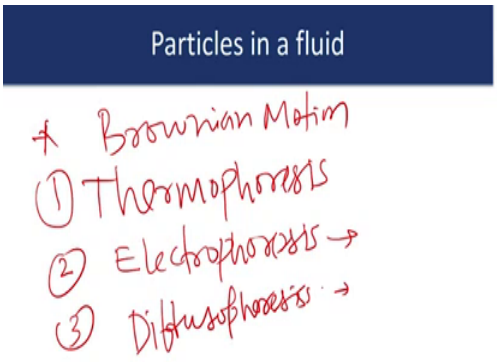
Larger stuff I put in a liquid this is what happen right that is because the particles are really large, then the reason why this motion happens because there are solvent molecules that are hitting the particles right whatever thing that you are jiggling around that is because there are solvent molecules which are continuously hitting the particle and continuous bombardment of the particle and the solid molecule is what is leading to this motion ok.

And this motion happens when the particles are small enough and if I progressively increase the size of the particle, you will see that you know very tiny stuff can move a lot make it little bigger it moves a little less if I make it a little bit more bigger it will not move ok. This is because if the energy with which the molecules are hitting the particles may become much larger than you know much smaller than what is what it is required to move the particle when the particle size becomes larger ok.

So, let us put it that way this point. So, we going to look at in the context of the course we are going to look at some examples where we are going to have a fluid and you know we are going to set the particle into motion. In this case motion happens purely because of the bombardment of solvent molecules with the particle, but I can there are other ways of setting a motion of the particle right can you think of other ways of I have a fluid, but that contains particles I would like to have them move any examples? Any?

You can temperature increase will I do not know if that is the best way to answer this because if you have a like say a tube for example and say that you know I have this tube contains fluid and particle if I heat one end if I cool the other end then there is going to be a temperature gradient right ok. Now because of this temperature gradient the things can move that is what is called as a thermophoresis right.

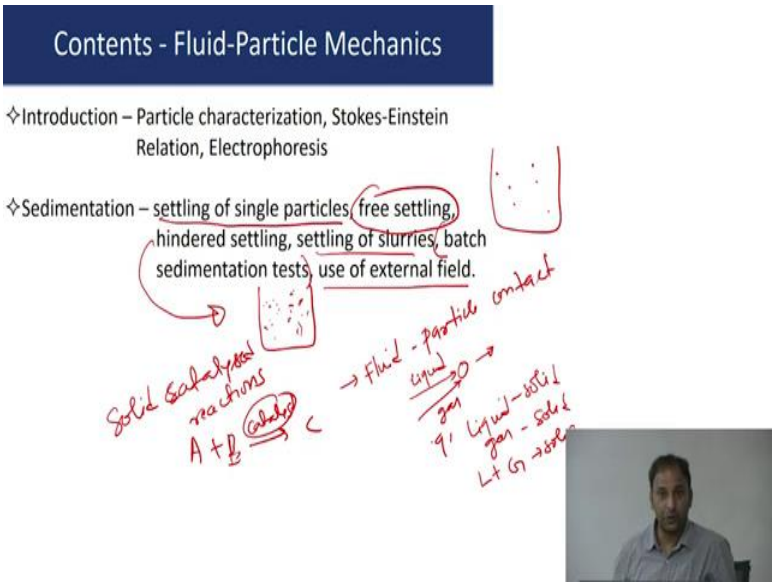
(Refer Slide Time: 27:55)



What we saw just now is an example of any other examples of how to make them move?

What is that somebody says electrophoresis ok. As the name itself says in this case you can set the particle into motion by applying an electric field right about something called diffusiophoresis where in the basically the motion is set by creating a concentration gradient right.

(Refer Slide Time: 28:47)

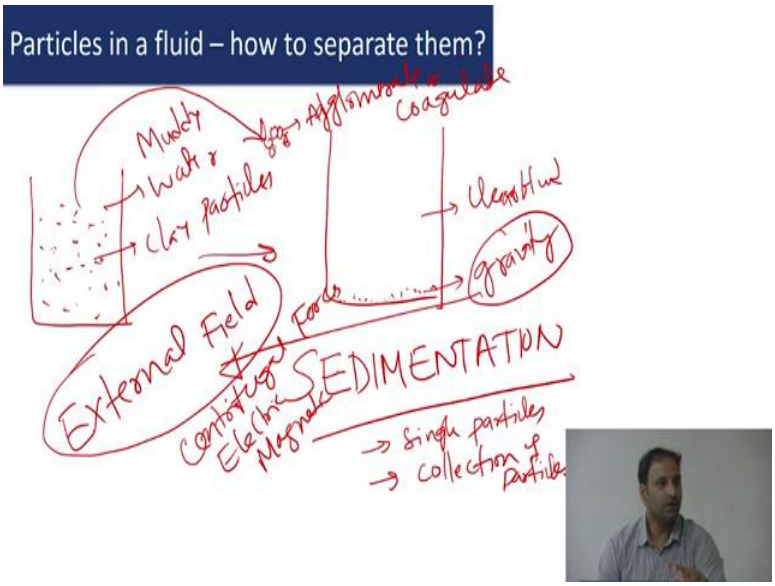


So, we are going to look at some aspects of this in the course. I am going to have one or two classes on looking at particle characterization because before you start looking at a fluid particle system, you should have an idea about you know what is a particle where do they come from, you know what is the typical characterization that one has to do before you work with fluid particle systems.

So, I am going to have some aspects of that in the course. We are going to talk a little bit about something called a Stokes Einstein relationship which is which basically comes from the Brownian motion aspects ok. We will talk a little bit more about it in the course some aspects of electrophoresis just to give you an idea about motion of particles in a fluid that is going to be the few aspects you know.

Now, some aspect that we are going to look at in the course is to look at if I have a fluid particle system, how do we separate particles. So, any thoughts?

(Refer Slide Time: 29:55)



Like say imagine let us think about a case I have a container say that this container has say water and take say some muddy water or a rain water if you want to call it there is lot of particles in it right. So, you have a you can think about this as maybe a clay particles right because when you get rain water lot of you know clay particles will be present in water. So, if I want to like say separate these things what do you think with the best way to do what I would like to do is to take this and then somehow ensure that you know everything is at the bottom and there is a clear fluid.

So, how do you do that any example? Any thoughts? Right. Something called as sedimentation all you have to do is you know take this container which has these you know particles and you let it stand then what is going to happen is, your gravity is going to kick in and the particles are going to slowly settle to the bottom. So, we are going to look at some aspects we are going to we are going to look at sedimentation of single particles we also going to look at sedimentation of collection of particles ok. So, in this example I mentioned that they are going to settle down because of gravity right.

So, are there other ways of inducing sedimentation? Are there other ways by which I can separate on the particles right in this case what you can do is you can use a? What is that?

You can do coagulation as well somebody says coagulation. So, what it basically mean what he is trying to say is that, I have a system like this what I am going to do is whatever particles I have, I am going to make them agglomerate or coagulate what happens when

they agglomerate or coagulate? The particles are going to become larger and when things become larger they can settle right.

So, you can do that and the point that I wanted to say was that you know instead of gravity I can use an external field right I can use what is called as a centrifugal forces or your electric or magnetic forces right I can you know. So, there are ways by which I can either exploit gravity for you know separation of particles or I can use some external fields. So, we are going to look at some aspects of that in the course ok.

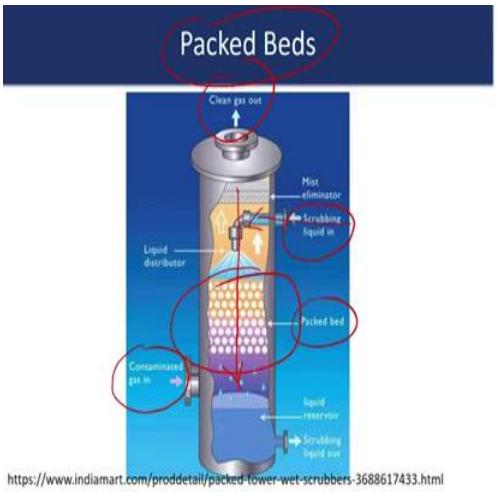
We are going to start with talking about settling of single particles there is something called is a free settling that will happen when the particle concentration is lower or you know when there is when you have maybe very few particles in the dispersion that is your free settling and hindered settling when you have really large number of particles we are going to look at some aspects of that.

Then we will move on to settling of slurries where you have a dispersion of particle, but concentration is really large ok. And people do something called as a batch sedimentation test these are kind of tests where you take dispersions in a column long column and you basically watch them as the particle settle. In indeed you have an experiment in the next semester, where you are going to do something called as a batch sedimentation test to look at the sedimentation of behavior of slurries we are going to do some of that and we will talk about some aspects of using external field ok.

So, now in processing you often come across cases, where I would like to have a fluid particle contact ok. What I mean by that is say there you know I have a particle now I would like to pass maybe a stream of say liquid or a gas over it there are certain devices for doing this ok. Can you think of examples where I want something like this to happen? I have let us think about like say solid catalysed reactions right.

So, where you have something like you know A plus B going to C if this reaction happens on a catalyst surface therefore, you would like to have a catalyst I would like to hold it in this place maybe by some means, but I would like to have the stream of A come in stream of B come in and I would like to have the contact between the two occurring on the catalyst surface and you know and that would lead to some reactions right.

(Refer Slide Time: 36:51)



So, there are a lot of processes in chemical engineering, where you have to ensure a proper liquid solid contact or a liquid gas solid contact you could have a two phase system where I am talking about liquid ok. I am talking about a liquid solid contact or a gas solid contact or a liquid plus gas solid contact and there are devices for doing that and one of the very commonly used device is something called as a packed bed its a fairly simple set up what you have is basically a long column.

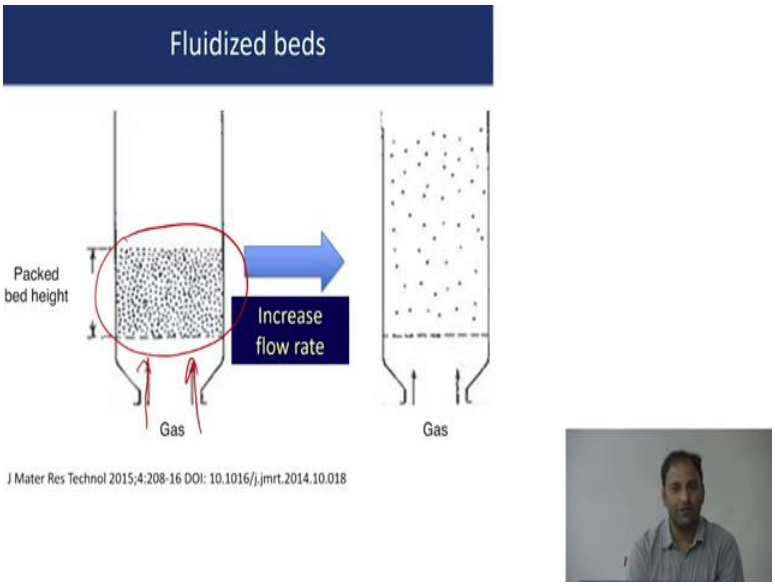
And in the column right the region that is marked you have you see these spherical things these are particles these are kind of put in the column that is what is called as a packed bed right its a solid particles you know packed into a bed and then in this particular example what you have is basically there is a liquid that is coming out. So, basically there is a scrubbing liquid and this scrubbing liquid is let me put this way.

At the bottom there is an entry for something called as a contaminated gas this gas contain some liquid droplets ok. The objective is to have a clean gas go out at the top and whatever gas that is entrained that is there in the whatever liquid that is entrained in the gas I want to take it out ok. What I do is I introduce a liquid and what this liquid does when it is coming down the column is that, it will take out all the liquid that is coming along with the gas right and when it comes down it takes out all the liquid. So, that you know the clean gas can go out. So, there are such devices of course, in this case it is used for some kind of a mass transfer operation right.

So, you basically want to transfer the liquid that is there in the gas stream that is entering I want to transfer that into a liquid stream that is basically coming down right. So, the now if you want to do this without the packed bed is very hard right because you know of course, the gas will go up and your liquid that is coming from the top would come down right, but a proper contact between the liquid and the gas is not going to happen right. Therefore, when it when these fluids flow through the packed bed this when I say packed bed this is a bed of particles of course, there is going to be gap between the particles right and when the when things flow between these gaps right. So, there is going to be a proper liquid gas contact in this case right.

So, therefore, there are cases where you want to ensure either a liquid contact liquid gas contact you know or a liquid particle or gas particle all kinds of you know fluid particles operations where you want to ensure a proper contact between different you know species people use this concept called packed beds we are going to look at a little bit more of that in the lecture.

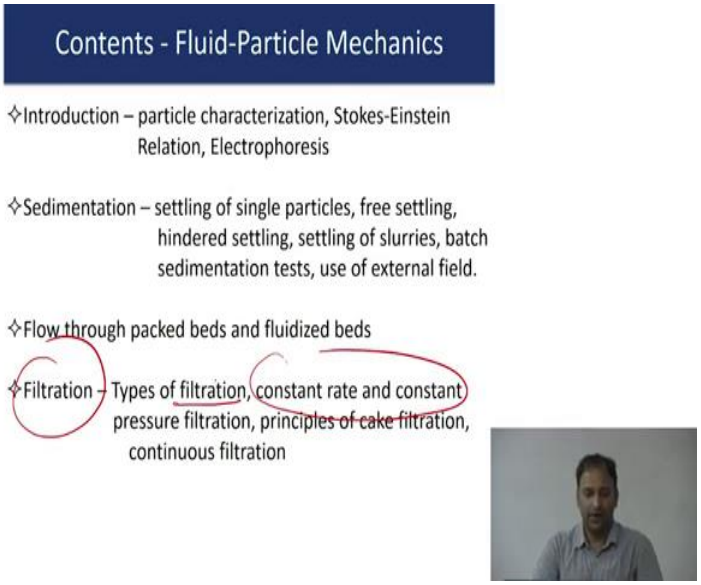
(Refer Slide Time: 40:01)



Now the other examples where you know one could look at ensuring a good contact between the particle and the fluids is by something called as a fluidized bed ok. So, what you are looking at is basically a case where on the left again you have a column and you know all these particles are kind of packed into a bed now what you do is if you increase the velocity ok.

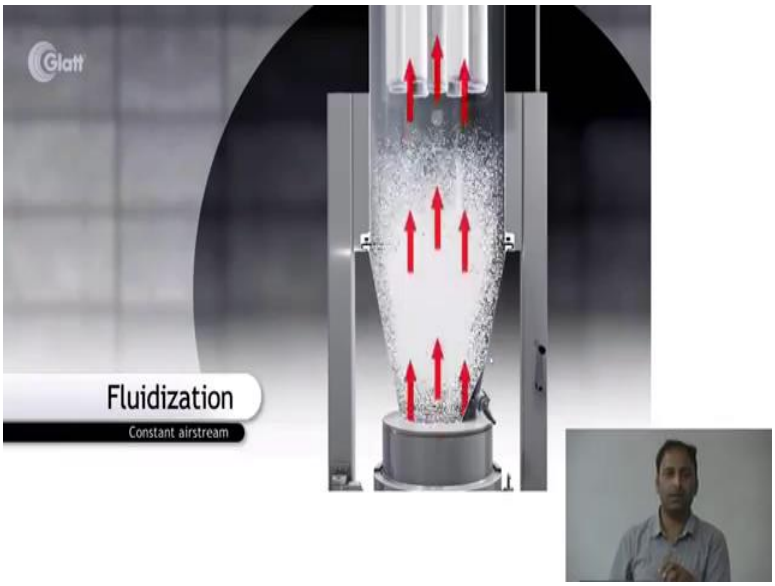
So, I just wanted to say that in the packed bed what happens you know what keeps the packed bed in the packed bed configuration is that there are basically support plates ok. There are two plates that are basically holding these particles and you know no matter what kind of fluid velocities you use, the particles are going to be in a fixed state ok. Now if you have a fluidized bed if you remove the top plate the top plate is not there anymore if I increase go on increasing the velocity of the fluid that I am sending from the bottom at some point they are going to be in a nice dispersed state right that is what is called as a fluidized bed. So, we are going to look at some aspects of that.

(Refer Slide Time: 41:11)



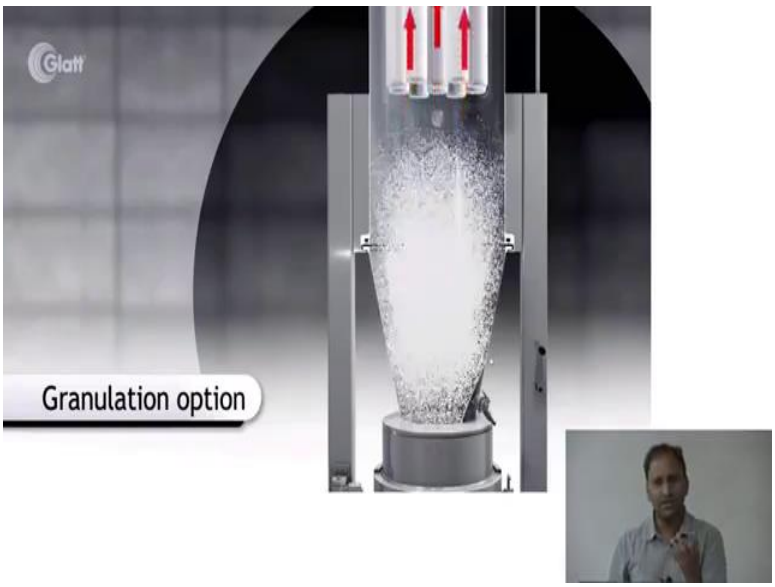
So we are going to look at flow through packed beds and fluidized beds, we are going to analyze flow through packed bed in terms of you know we have learned flow through pipes we going to use that concept to look at flow through packed beds and then look at some pressure drop and things like that.

(Refer Slide Time: 41:33)



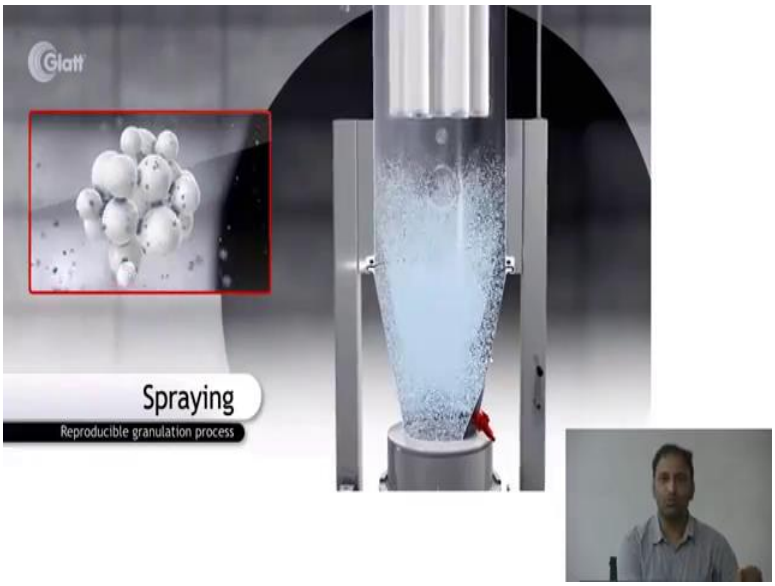
So, I have again a nice video if you in pharmaceutical industry there is a need for looking at coating drug particles ok.

(Refer Slide Time: 41:43)



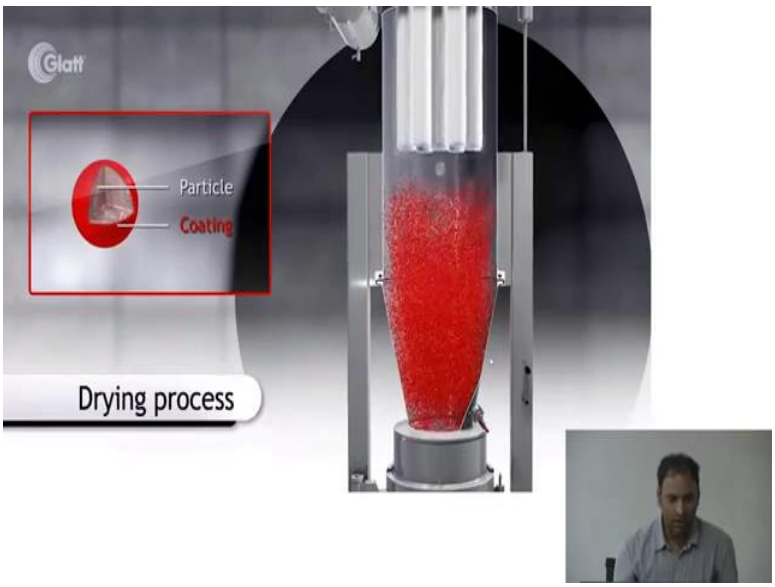
And coating of drug particles can be done for several reasons one of the reasons could be that you know I would like to control the release right.

(Refer Slide Time: 41:45)



So, if I have people talk about controlled release right, one of the way of controlling the release is that you know I have a particle and I do a coating on the surface ok. Or this is a case where there is some kind of agglomeration that people somebody was talking about a process called granulation ok; that means, you start with smaller particles and then you kind of induce some sort of aggregation between the particles ok.

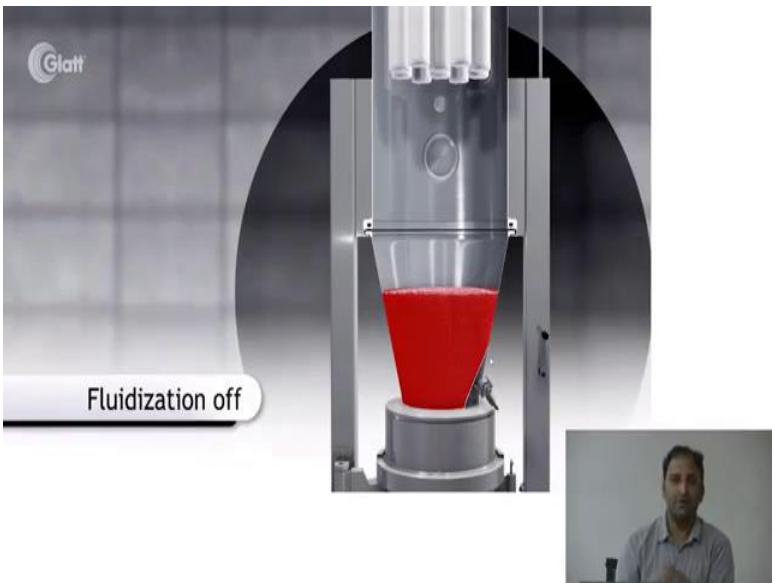
(Refer Slide Time: 42:11)



Fluidized beds are used for granulation purposes what you do is, you have a packed bed to start with and then you introduce some gas and then introduce some way if you know

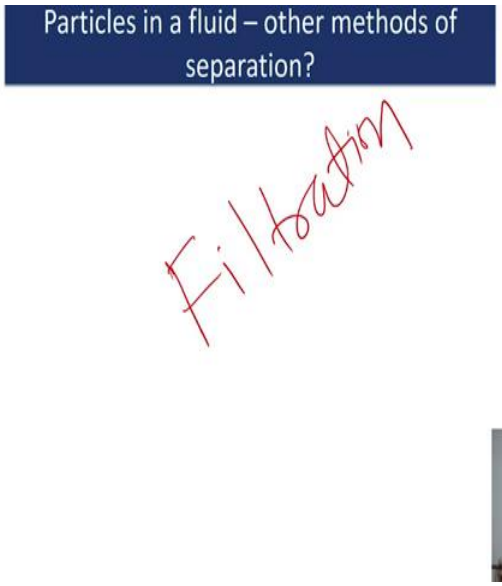
joining the particles. There is another example where fluidized bed using being used for coating applications. So, you fluidize a bed to begin with and then whatever coating material that you want; that you want to put on the surface, you again put it as a another fluid and then you know you can ensure a nice homogeneous uniform coating of you know the stuff on the particle surface.

(Refer Slide Time: 42:54)



So, the idea would be to make this core shell kind of particle where the core is your maybe a drug molecule for example, drug particle and then you know your and the coating could be something that you are trying to use for controlling the release ok. I just want to end by the last one piece. So, we talked about separation by sedimentation and you know and using external forces right any other ways of separation you can think of? Have you heard of an operation called filtration? Right ok.

(Refer Slide Time: 43:39)



If you have you know I am sure all of you may have seen a water filter right if you look at water purifier; there is a pre filter that takes water from you know tap and you know it removes some particles to begin with it goes into a purifier there is going to be some carbon filters and things like that right. So, we are also going to look at some aspects of filtration during the course look at types of filtration, there are some special specific types of filtration something called as a constant rate filtration and constant pressure filtration devices, we are going to look at analyzing filtration in the context of flow through packed beds ok. So, these are the some of the things that we are going to do in the class.