Fluid Mechanics
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Lecture - 34
Applications of settling - I

So, we are going to look at some applications of what we have learned so far. So, though we termed you know the last few classes as we are looking at motion of particles in a fluid ok, and that naturally occurs when you are talking about settling of particles in a fluid right.

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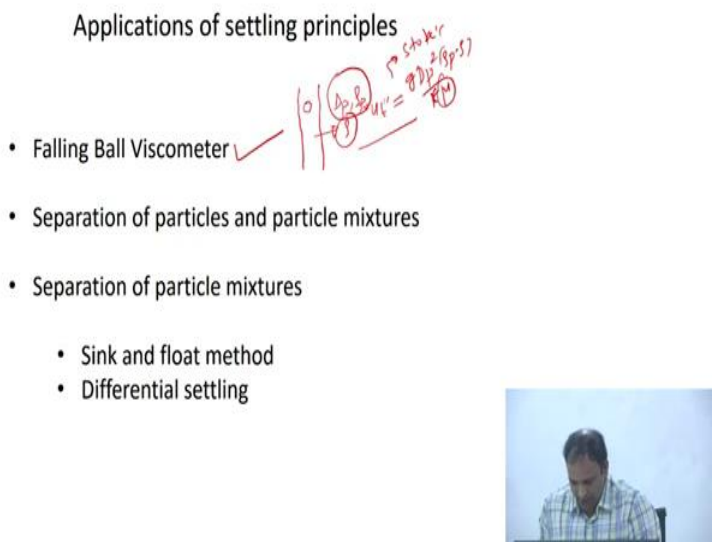

So, we looked at something called as a falling ball viscometer right ok, in which you basically had a container right, a capillary, and you take a particle of known properties ok, that means, known diameter and known density ok.

And if you have a way of measuring what is the density the fluid that you are working with right, and then you know if you have a way of calculating or measuring what is the terminal velocity that is the maximum possible velocity that the particle attains in a given external fluid, and if you are working in the in you know under the influence of gravity right if right. So, therefore, what I can do I know there you know this u t, I can really you know it goes as g D p square into rho p minus rho divided by 18 mu right that is for your stokes regime ok.

And if you look at the formula for settling velocities only in the Stokes regime there is a dependence of the you know settling velocity on the viscosity right. If you look at the Newton's regime, your settling velocity does not depend on the viscosity of the fluid ok. Therefore, what they do you know, they use particles of appropriate dimension ok, so that the settling falls in the, you know in the stokes settling regime that is your Reynolds number is less than 1 ok. As long as you ensure that I can basically exploit the Stokes settling principle. And if I am working with particles of well in a defined sizes and densities and fluids you know known you know density, I can actually calculate what is the viscosity right that is one of the application that we have looked at already so far.

Separation of so settling principles are kind of exploited a lot in particle separation ok. If you have like say particles of one size or multiple size ok, one type or multiple types ok, you could have a case where I have particles of same type of a given density, but different sizes. Or I could have a case where I have a mixture of particles in a particle 1, 2, 3 of different materials; it could be like say glass beads plus polymer beads for example, ok. So, if you have particles of different sizes and different properties ok, so you can actually exploit these things. We will talk a little bit about some of these things in the remainder of the class.

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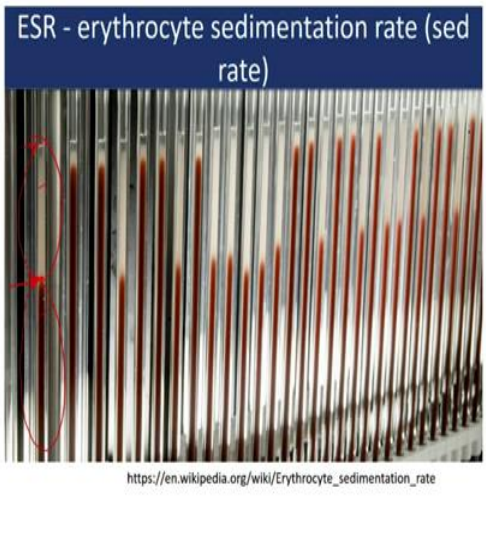

So, before I go further looking at separation of particles, I just want to give you a little bit of heads up with some places where you know sedimentation is kind of really useful. I

know how many of you have heard of the ESR which is called as a erythrocyte sedimentation rate. Have you heard of this term? No? Yes? Somebody says yes. Where you have heard?

It is a test that is done when somebody goes for a diagnosis right. What they do is, they take a small amount of blood sample ok, and one of the tests that they do is this sedimentation measurement ok. The experiment basically involves taking blood in a small capillary, you just let it sediment ok. And looking at the sedimentation rate, you can actually tell something about whether the blood belongs to a male or a female, somebody who is young or old ok. Plus it also is one of the nice ways of measuring you know or finding out if there is something of a inflammation whenever somebody has some disease there is going to be inflammation right. So, basically this sedimentation rate measurements are simpler measurements for kind of as a first tool for diagnosis ok. And so in that context you know people do.

So, I again picked up some you know image from Wikipedia wherein these are basically capillaries which are filled with blood and made to sediment you know for some period of time. And you can clearly see that you know there is a interface between the clear capillary and the you know the brown or reddish mark you know from finding out you know what is that interface I can say something about sedimentation right.

If I had a you know homogeneous so maybe just to tell you, so initially the blood was say in this case the blood was filled up to this level ok. After you know some time, you can clearly see in all the whatever particles that you had in blood RBC is another stuff that has you know now the mark is here. Therefore, this is a clear plasma there is no particles there ok, and all the particles are now kind of concentrated here right.

So, basically by measuring this interface between the clear fluid and you know the samples where there are blood particles, I can actually measure the sedimentation rate ok, this is what is typically done. And depending upon as I said disease conditions and another type of you know a person you are dealing with will have different values ok. So, this is one applications you know where he actually can actually use exactly the same equations that you used ok. You if you know the dimensions of a blood, if you know the viscosity of the blood, you can actually also calculate what is the settling rate.

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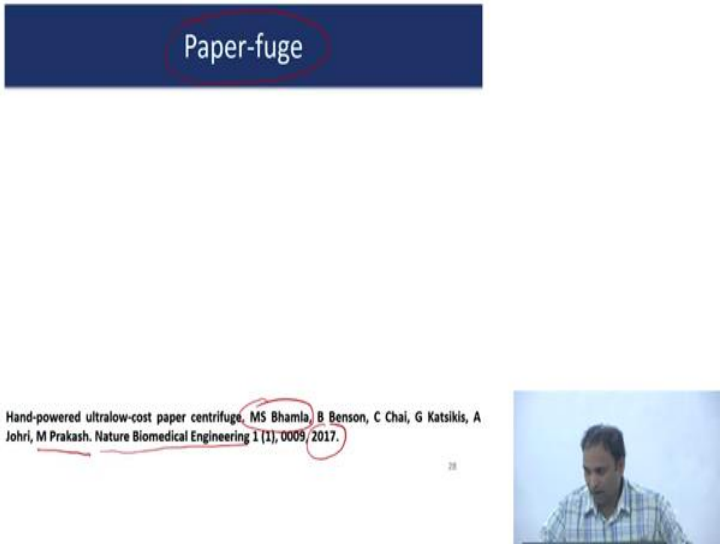

I am going to talk about an application that kind of people have. So, in the class so far I only talked about mostly sedimentation and the influence of gravity right. Of course, we did mention that you know you can use external force in the form of centrifugal forces to do sedimentation as well right.

So, there is a nice concept called paper-fuge ok. Any thoughts what it could be? Ok that is actually it comes from paper that appeared in 2017 in a journal called Nature Biomedical Engineering. It is published by a group in Stanford which is headed by Manu Prakash ok. And there is one person who is Saadbhamla who is in involved with this book, is he is in IITM undergrad. He finished his B.Tech few years ago, finished his Ph.D Stanford ok.

So, the title of the paper is Hand-powered ultralow-cost paper centrifuge. Ok the reason why they call it as paper-fuge, is because it is a centrifuge and we can actually make it make it out of paper right. So, I just have a video from ok, let me just try and show you a video of this.

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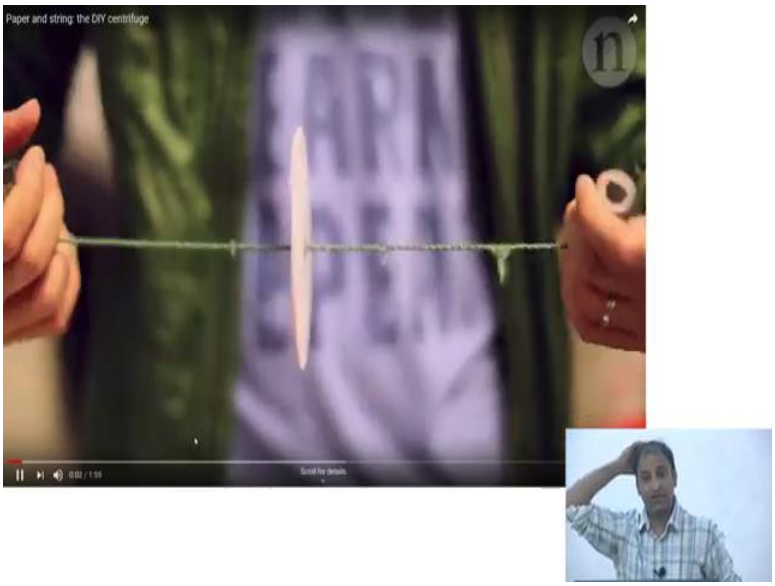

I am sure all of you have played with this at some point.

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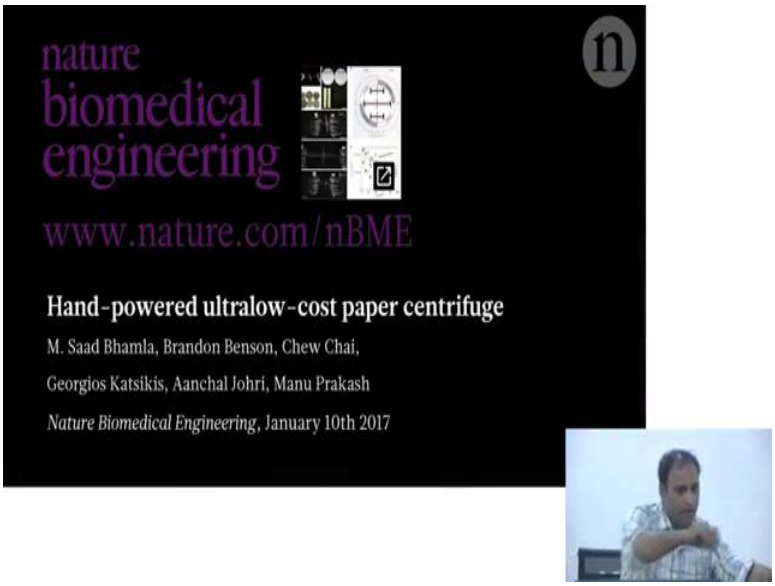

Ok. So, there is a lot of you know study before this kind of let me just I have some you know slides from the paper. So, an interesting aspect of this is if you noticed, so when you are pulling it right, there is a there is a linear motion that you are applying that kind of kind of translations or rotation right.

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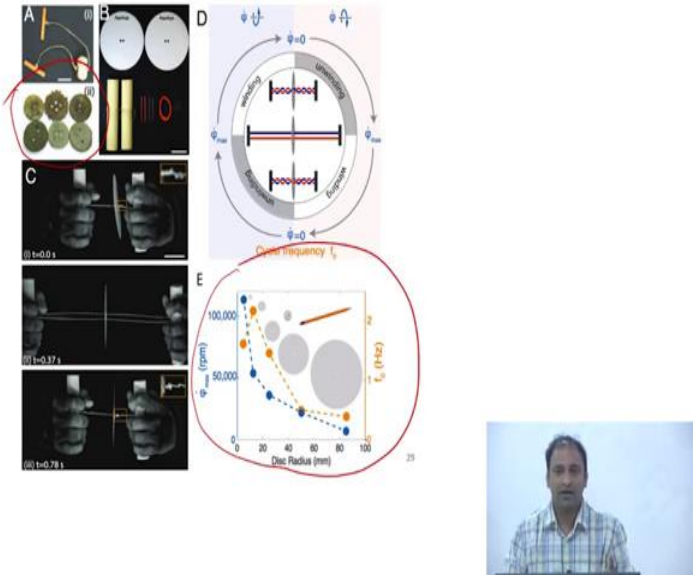

And what they did is they looked at so, basically what is happening when you do this, there is a winding and unwinding right. And you know at some point if you clearly see that you know the spinning disc actually stops right. You know when there is a complete winding

right. So, what they have done is they have taken different designs ok, they did experiments with you know a lot of different designs of these discs ok. And they used high speed camera to measure what is the rotation speed. And as it was mentioned in the video, they can actually reach speeds which are as high as a 1000 you know a 125000 rpm ok, and that can actually translate into a gravitational force of the order 25000 to 30000 g that which is really really huge ok.

And you have a plot here that is measuring phi max which is the maximum rotation speed as a function of disk diameter right. It turns out that you know if you make it smaller, you rotate it faster right if you really want to go for; go to a very high gs right, therefore, you would be using a smaller diameter disk. And if you go, if the; this diameter becomes larger, now your speed is going to go down ok. So, depending upon you know what kind of speeds you want to generate you can actually you know exploit the fact that you know the maximum phi max varies with the disks speed.

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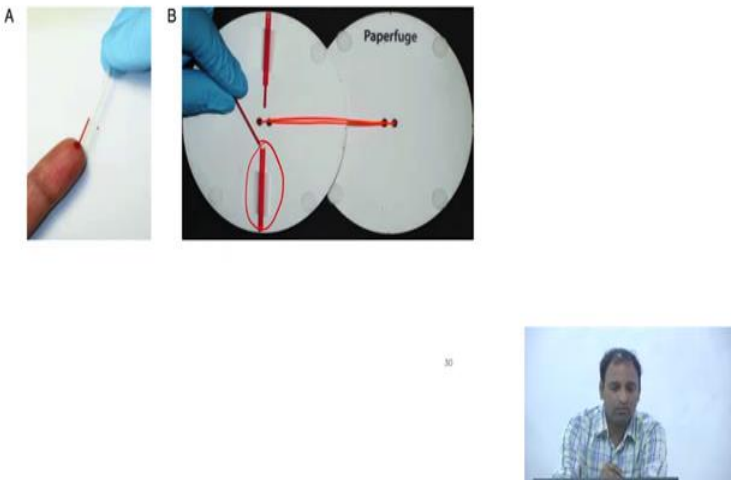

And this is again the device that was mentioned what you have here is that is a kind of a hollow tube in which you can put a capillary with any sample that you have right, and all you have to do is close it and then spin it ok.

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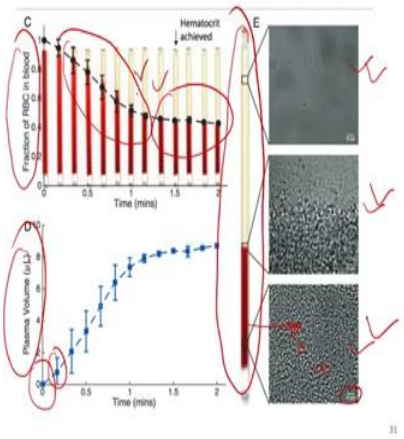

This is a demonstration of what basically happens that is the fraction of RBCs in the blood that the y-axis go from 0 to 1 right, and you know your x-axis is the time ok. And of course, as the clear fluid you know kind of starts you know appearing, I can also measure what is the plasma volume right. When, the fraction of the RBCs in the blood is like 1 here, your plasma volume is 0 right because it is a homogeneous fluid here ok.

At some point you know somewhere here you start seeing some small volume of you know clear fluid that is when a in a small volume of the plasma appears here. So, basically it is a simple demonstration of the you know the how the separation happens in terms of monitoring what is the fraction of RBCs in the blood and the fraction in and the plasma volume. And these are the microscopy images taken at different location, and the stop region where it is only plasma, there is absolutely no cells ok, that means, all the cells there were they have kind of settle, and that is the interface your between the clear fluid and you know the settle you know RBCs and that is your image where you know you have lot of RBCs ok.

So, it is a very simple tool which is kind of, you know kind of developed which is again exploits the fact that you know you can basically use very high external force right. External force of very high magnitude to really separate stuff ok, any questions? Yeah.

So, do you understand the plots? Ok, the plots is basically you have a when you have the blood particles you know RBC is kind of homogeneously dispersed homogeneously

dispersed in the entire fluid you know then RBC fraction is 1 ok. The movement you know a small amount of you can also think about this in terms of the volume ratio as well right. I have the entire volume of the fluid ok, and of course, I do not have any fluid you know without the particle. So, in that case my you know the reference is 1 ok. Therefore, in the next stage what I see is I have a very small fraction of the clear fluids are form that volume divided by the total volume of the blood that I had taken that this gives you some fraction as is it basically a measure of you know how much of sedimentation has occurred right.

Now, on the on the right what you have is a basically microscopy images ok. The fact that you know I clearly see a visually there is a difference for sure between when I started, and you know and at some instant during your, you know a separation. And other way of confirming this would be just to take out some small sample from different locations and you do microscopy ok.

And if I do microscopy from the after small sample or I take from the top, I do not see anything right ok. However, if I take some sample from the bottom ok and if I do microscopy it is not a very high magnification image here. But what you see is can you see some small circle like things here right, these are basically RBCs ok, red blood cells which have a typical dimension of in about 8 micrometer ok. The scale ball here is about 10 micrometer ok. So, therefore, you will see typically I mean the object that you see are sub 10 micrometer dimension ok.

This is just to say that you know the visual observation that you see here is you know it is kind of confirmed by doing some microscopy measurement that is all, yeah.

Oh, it is a basically I mean no this is a see what they have done also you are talking about see this you see this large error bars right ok. These are actually done over several measurements ok. There could be some fluctuations because of you know conditions as well you know the person you know who is being whose blood has being drawn, there could be some other fluctuation. So, basically you know but the point is you know that you basically these some kind of a plateau right, if you wait for sufficiently long time you see that you know absolutely that that means, at that point all these RBCs are kind of packed there is no more space for them to even you know sediment further you know if you even if you continue to do prolonged you know centrifugation so on yeah ok.

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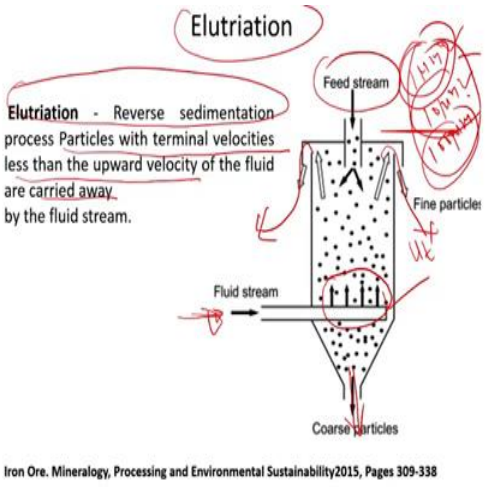

So, I have kind of talked about elutriation in the last class, maybe you know I was trying to draw picture myself, so it was probably it was not clear. So, elutriation is again a technique that is typically used for separation of particles ok. So, if you have a mixture of particles like say just to give an example let us say I have a mixture which is like say 1 micrometer, 10 micrometer and 100 micrometer particle ok.

Now, elutriation is actually it is a reverse of sedimentation ok. Now, if you look at the schematic here, what you have is there is a there is a feed stream ok, that feed stream basically carries the mixture of particles that you know are that want to be separated ok. So, I have a mixture of different sizes, you could think about maybe feed stream consisting of say 1 micron, 10 micron you know 100 micrometer particle that enters the feed. And at the bottom you have a fluid stream ok, and with this fluid stream, what I can do is I can basically maintain a particular flow rate right. I can; I have a control over which what is the flow rate with which I can send the fluid stream in right. Because I have control over the fluid stream you know volumetric flow rate, I also have control over the velocity right.

Now, what happens you know these particles are going to come down because of gravity ok. Now, what I can do that I can actually manipulate the fluid stream velocity such that it to maintain a particular value such that. For example, let us say that 1 micrometer, I have a particle, and 100, 10 micrometer particle. I can calculate their settling velocities right, you know under gravity what is the settling velocity that they going to have.

Now, if I have information about that, if I want to separate out ok, if I want to separate out 100 micrometer particles from this mixture. What I do is, I maintain a fluid stream velocity such that the velocity of the fluid stream is larger than the settling velocity of 1 micrometer particle and the 10 micrometer particle such that when the fluid stream goes up ok, the smaller particles basically come out ok, 1 and 10 micrometer particles, they come out of the you know the container and the larger ones basically sediment out ok.

Therefore, what you do is I can actually manipulate the fluid stream velocity, and I can actually by, you know by design I can actually find out or I can I can say hey I only want 1 micrometer to come out ok, I can do that. I want a mixture of 1 and 10 to come out, so basically that is how the typically separation is done in the case of elutriation ok. So, what you do is the particles with the terminal velocities less than the upward velocity of the fluid are basically carried out you know carried along with the fluid ok, that is what happens in the elutriation ok. And this typically is used if you have you know particles of different sizes, but of same density present in a given mixture ok.