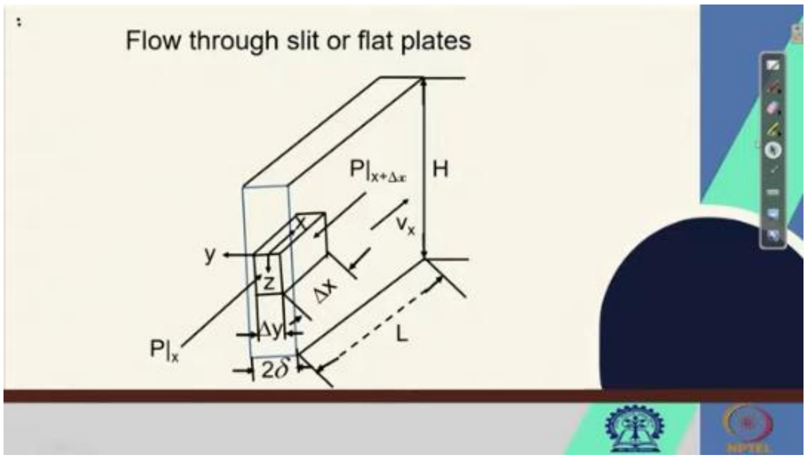
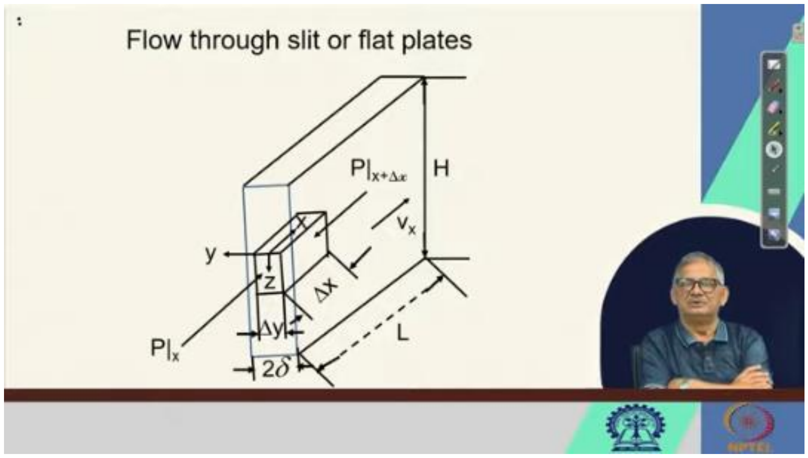
IMPACT OF FLOW OF FLUIDS IN FOOD PROCESSING AND PRESERVATION

Lecture27

LECTURE 27 : FLOW BEHAVIOUR THROGH NARROW SLIT

Good morning, my dear friends, students, boys, and girls. We are handling the course: flow through pipes, flow through annulus, flow through some slits or flat plates. Some of them we have already done, right? Maybe flow through a slit or a similar thing we have done earlier also. But why am I inclined to repeat here?

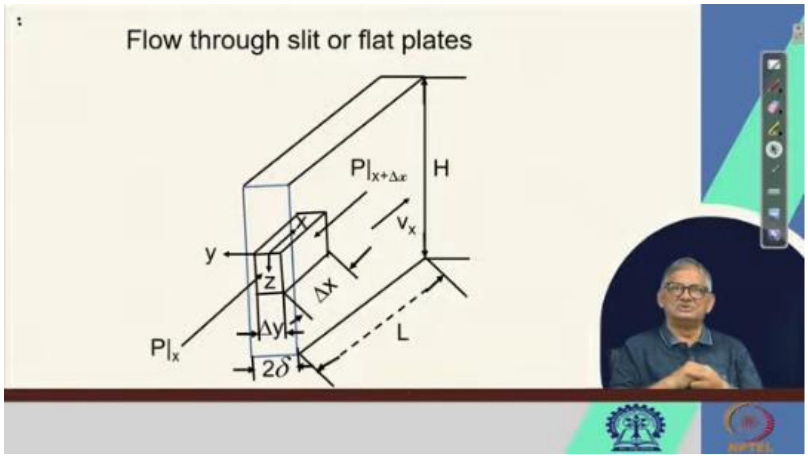




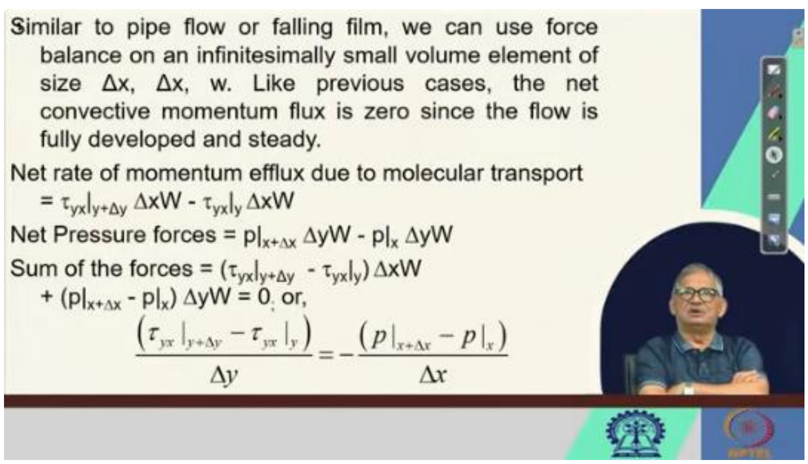
It is because, as I said earlier, if you know these flow behaviors, then you can find out. What is happening during homogenization. If you know how homogenization is made, that fluid at high pressure is passed through a very narrow slit, and then the size of the fat globules, which may be 2 to 30 microns in size or even more. They are shattered and disintegrated into smaller uniform sizes.

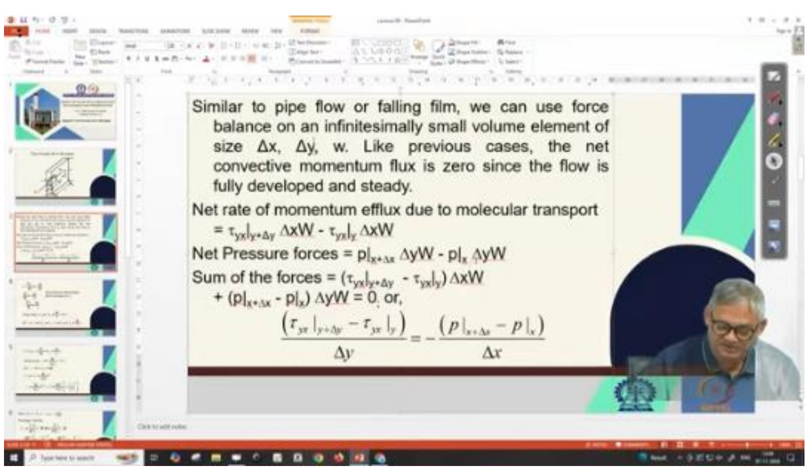
This helps to preserve the milk for a longer period, right? That is why homogenization is I gave an example of milk; it could be some other many things. So, that is why I do not know whether it was done earlier, but maybe in a different way. So, we are doing flow through a slit, and after this, we will quickly go through because we may have some points which are already handled; we will do some problems and solutions.

So, that is the fundamental or prime reason why I am bringing this here also. So, as you see from the pictorial view, we have taken a small volume element. Right, and this is in the x and y axis, and the third dimension is H, right. delta y, delta z, and the third dimension is x. So, we have taken the volume element and that the thickness of the volume element is 2 del, and we have to find out the pressure, more than pressure, velocity distribution, and shear stress distribution.



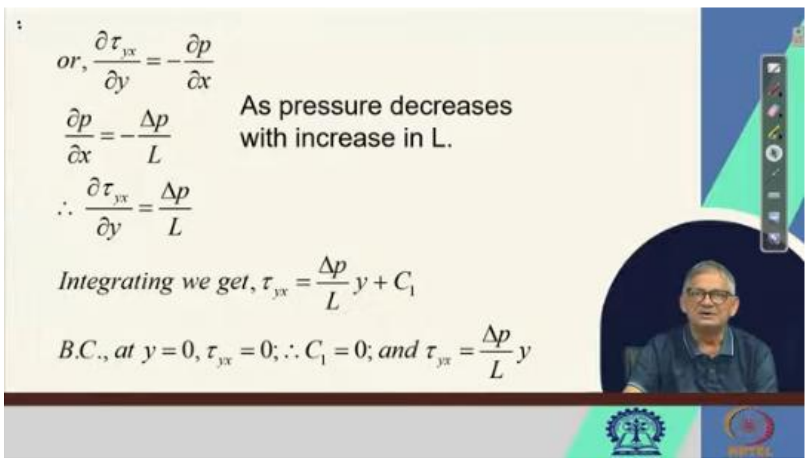
Right. So, similar to the pipe flow or falling film, we can use force balance on an infinitesimally small volume element of size delta (Δ) x delta (Δ), w delta (Δ) x delta (Δ) y, and this is 2 del x, sorry again, that cut and paste problem. So, Δ x Δ y. OK, and W. So, like previous cases, the net convective volume or convective momentum flux is 0, since the flow is fully developed and in steady state.



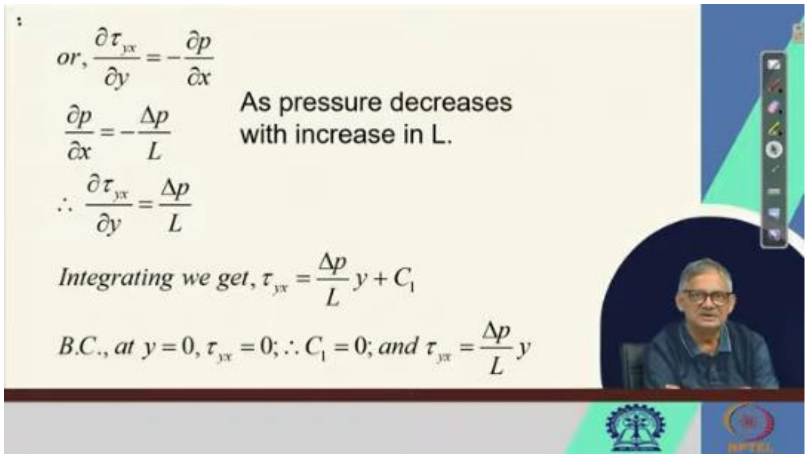


So, we can also write that the rate of momentum efflux due to molecular transport could be tau$_{yx}$ at y plus delta y into area delta x into w minus tau$_{yx}$ at y. into delta x w, that is net, OK, mind it. And net pressure forces are P at x plus delta x minus P at x, obviously, into the area that is delta y into w. Then, if we take the sum of the forces, that is tau$_{yx}$ at y plus delta y minus tau$_{yx}$ at y times the area delta x w plus P at x plus delta x minus P at x into area delta y into w. So, this is equal to 0. So, we can write

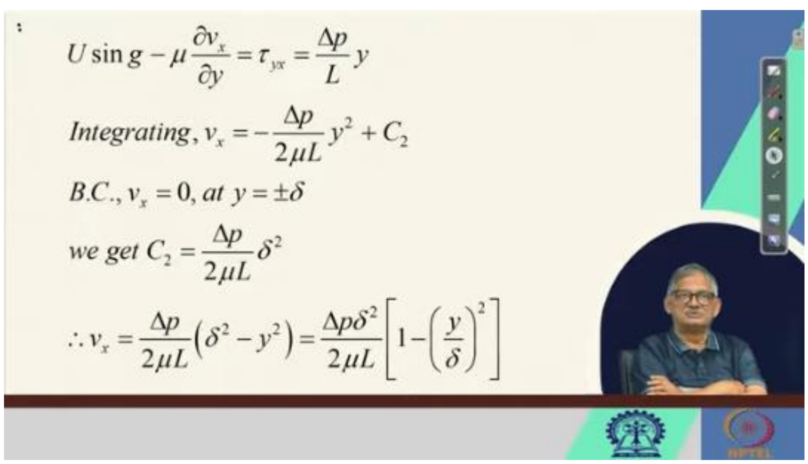
tau$_{yx}$ at y plus delta y minus tau$_{yx}$ at y over delta y is equal to p at x plus delta x minus p at x over delta x, ok. Now, putting the limit and then according to the definition of derivative, we can write delta yx del y is equal to minus del P / del x or del P / del x is equal to minus del P over L, as pressure decreases with increase in L, the negative sign is there. So, the negative sign is because the pressure is decreasing due to the increase in length.



So, we can write del tau$_{yx}$ / del y is equal to delta P by L, and integrating, we can write that tau$_{yx}$ is equal to delta P by L into y plus C_1. So, we have to find out the integral constant. So, that is why the boundary conditions, and the boundary condition is that at y is equal to 0, tau$_{yx}$ is equal to 0, therefore, C_1 is 0, therefore, tau$_{yx}$ is delta P by L into y. So, again using the definition of shear stress in terms of viscosity, we can write minus mu del v_x / del y is equal to tau$_{yx}$ is equal to delta (Δ) P by L into y.

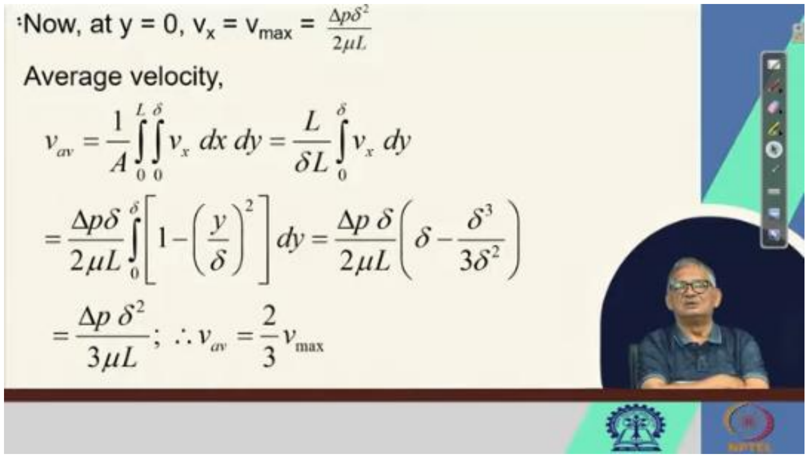


And then integrating, we can write v_x is equal to minus delta p by 2 mu L into y square plus C_2, and the boundary condition is v_x is equal to 0 at y is equal to plus minus del, because we have taken y, 2 del, you remember 2 del means, one plus del, & one minus del, this is 2 del. So, we get from there the value of the integral constant C_2 as delta p by 2 mu L into del square. Therefore, v_x is equal to delta p by 2 mu L into del square minus y square, and that can be simplified as delta p del (δ) square by 2 mu into 1 minus y by del whole square, again this is parabolic in nature. So, now, at y equals to 0, v_x is vmax, and that is delta p del square by 2 mu L. Average velocity is like this vaverage is 1 by A, 0 to L, 0 to del, v_x dx dy.

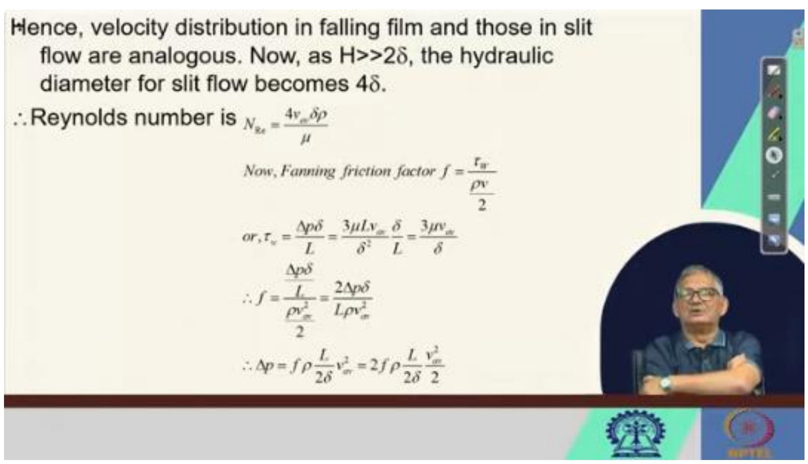


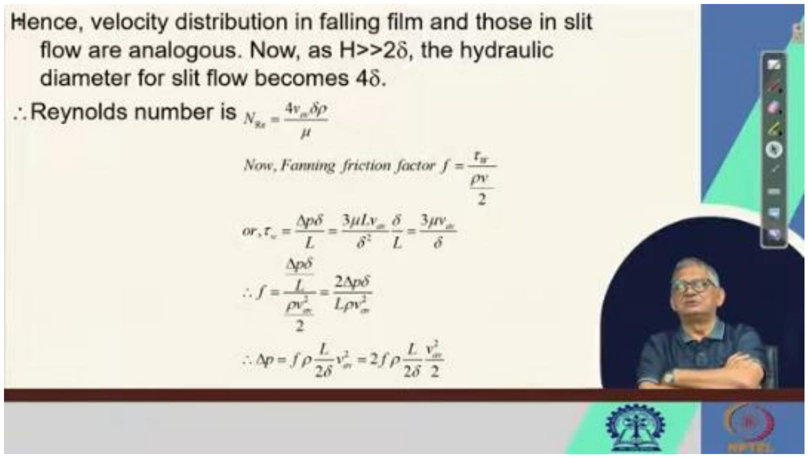
And that is equal to L by del into L into 0 to del v_x dy. Substituting the values of v_x and taking out the constants out of the integration, that is, delta P del by 2 mu L, integration between 0 to del of 1 minus y by del whole square into dy. So, that is delta P del by 2 mu L into del minus del cube by 3 del square, that is, delta P into del square by 3 mu L. We have already seen that v_{max} is delta P del square by 2 mu L, here it is delta P del square by

3 mu L. So, vaverage is nothing but 2/3 of v_{max}, right. Hence, velocity distribution as it was in the falling film and those in slip flow are analogous.

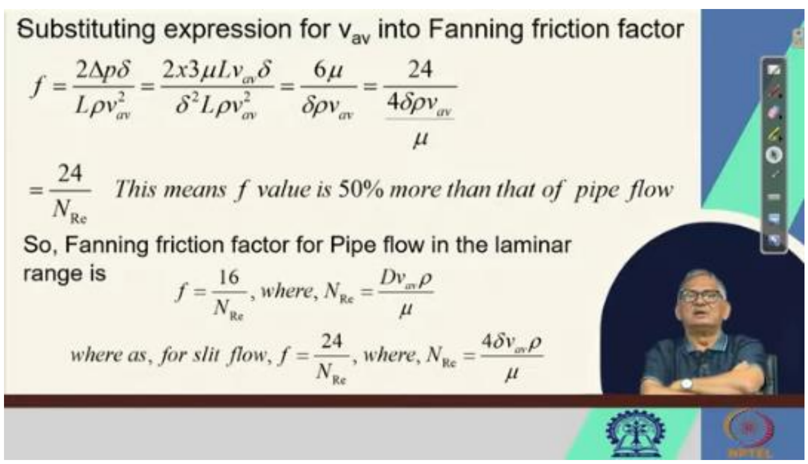


So, as H is much much greater than 2 del, the hydraulic diameter of the slit flow becomes 4 del and therefore, the Reynolds number can be written as N_{Re} is 4 vaverage del rho by mu. Fanning friction factor, which we have defined earlier as f, equals to tau_W at the wall, shear stress at the wall over product of, product of velocity head and density, right. So, rho v_{av} by 2 or tau_W is delta P del by capital L, equals to 3 mu L vaverage by delta square into del by L. So, that is 3 mu $v_{average}$ over del.



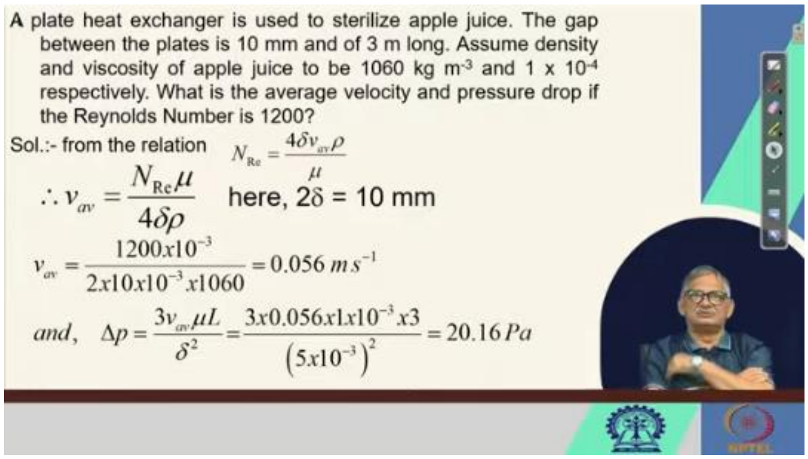


Therefore, f is delta P del by L over rho $v_{average}$ square by 2 and this is equal to 2 delta P del by L into rho $v_{average}$ square. Therefore, delta P is f into rho into L by 2 del into $v_{average}$ square, that is equal to 2 f rho rather into L by 2 del into $v_{average}$ square by 2. So, by substituting expressions for $v_{average}$ into fanning friction factor we can write, f is 2 delta P del by L rho $v_{average}$ square is equal to 2 into 3 mu L $v_{average}$ del by del square L rho vaverage square. that is equal to 6 mu by delta P rho $v_{average}$ is equal to 24 by 4 del rho $v_{average}$ square $v_{average}$ by mu.

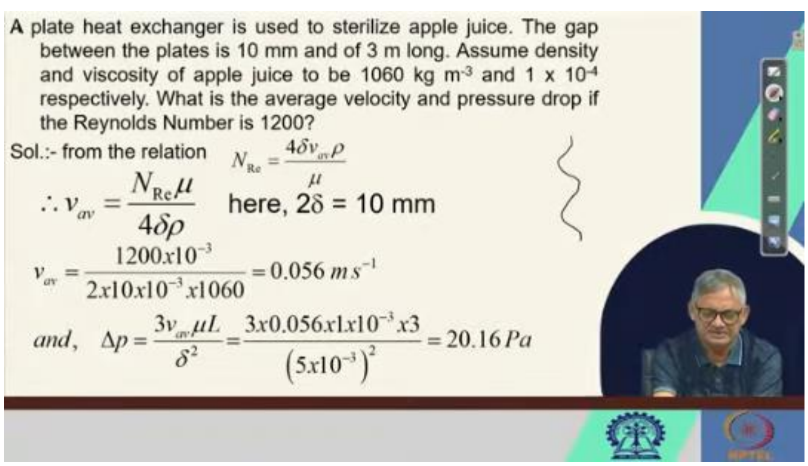


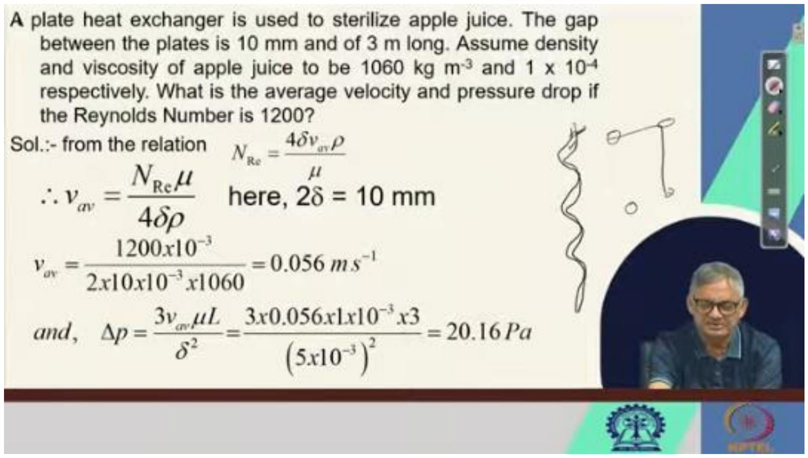
So, that is nothing but 24 by N_{Re}. This means that the f value is 50 percent more than that of the flow through the pipe. So, finding the friction factor for pipe flow in the laminar range is f equals to 16 by N_{Re}, where N_{Re} is D $v_{average}$ rho by mu. Whereas, for slit flow, f is 24 by N_{Re}, where, of course, N_{Re} is 4 del $v_{average}$ rho by mu, right? Now, we come to some problem solutions because, most of the time, I, not only me, but many faculties, do say that solving problems makes the subject easier to understand.

So, we are given a problem; here is the problem: A plate heat exchanger is used to sterilize apple juice. The gap between the plates is 10 millimeters and 3 meters long, rather than 20 millimeters. Assuming the density and viscosity of apple juice to be 1060 kg per meter cubed and 1 into 10 to the power of minus 4, respectively. What is the average velocity and pressure drop if the Reynolds number is 1200? So, we have stated the problem. For understanding, we repeat: A plate heat exchanger is used to sterilize the apple juice.



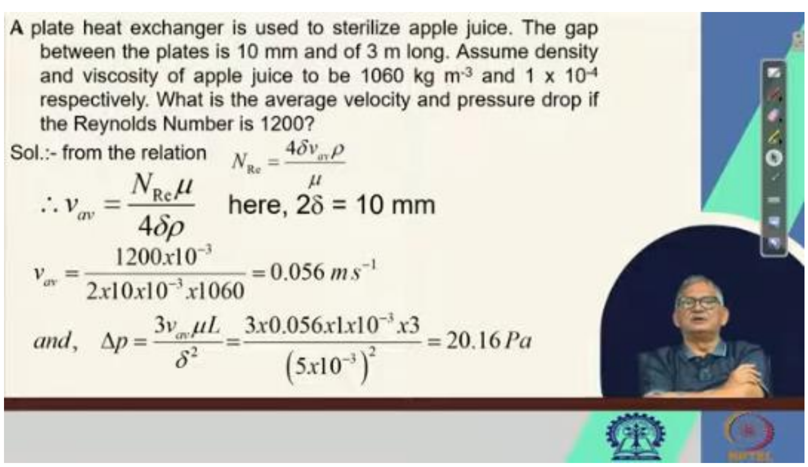
The gap between the plates, I hope plate heat exchanger, you have seen, or if you have not seen, let me just show you that this is nothing but this type of plate. So, one plate is here, another similar plate could be here. And the fluid flows through this. There are four holes, right? There are four holes in the plate. So, depending on which flow, which hole is open, the flow is accordingly because the next plate will receive or deliver the fluid.



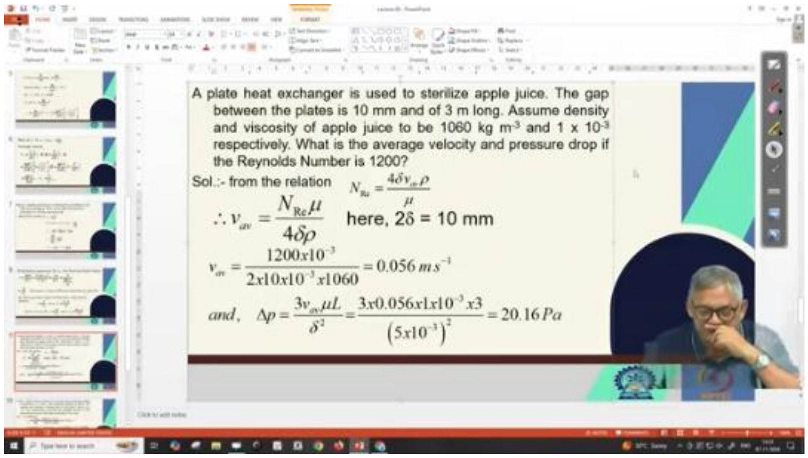


So, that is how plate heat exchangers work, and these plate heat exchangers are very useful not only in the food industry but also in many other industries, okay? So, the apple juice is sterilized in a plate heat exchanger, and the gap between the plates is 10 millimeters. And it is 3 meters long, and we are assuming the density and viscosity of the apple juice to be 1060 kg per cubic meter and 1 multiplied by 10 to the power of minus 4, obviously, Pascal second, respectively. What is the average velocity and pressure drop if the Reynolds number is 1200? Now, from the given relation, we know what the value of N_{Re} is.

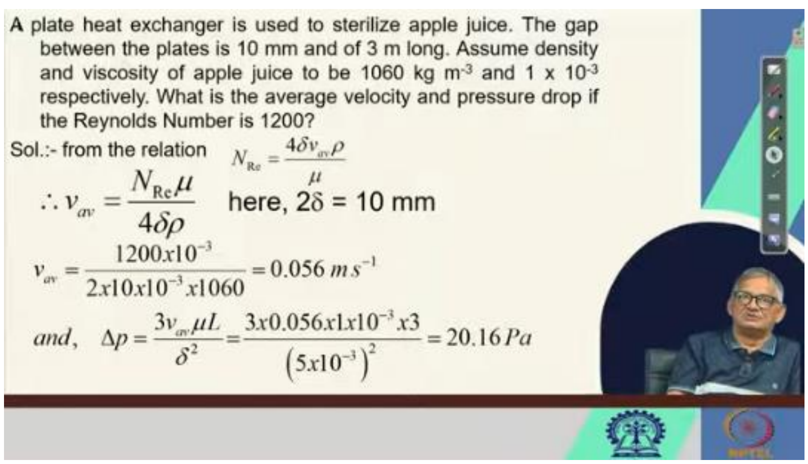
N_{Re} is 4 del vaverage rho divided by mu. So, vaverage or average velocity is N_{Re} multiplied by mu divided by 4 del rho, right? Here, we are given 2 del, that is, the thickness is 10 millimeters, right? So, if we substitute the values, vaverage is, N_{Re}, given already 1200, right, and mu is 1 Mu, yeah, mu, I think here we have given 10 to the power of minus 4, but we have taken actually 1 multiplied by 10 to the power of minus 3, right?



So, there should be a correction. So, instead of 10 to the power of minus 4 here it is 10 to the power of minus 3, right? So, there should be taken, okay?



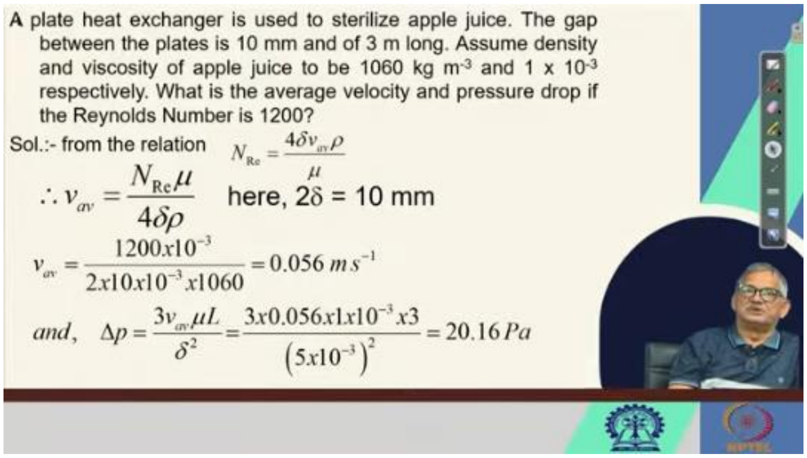
So, what we are doing is 2 del is 10 millimeter, $v_{average}$ is 1200 N_{Re} and mu is 1 into 10 to the power minus 3 divided by 2 del, that is 2 into del. We have said 2 del is 10 millimeter. So, 4 del means 2 into 2. 2 into 10, rather, into 10 to the power minus 3, this is in millimeter. So, in meters, it is 10 to the power minus 3 into rho, rho is given as 1060. So, this becomes equal to 0.056 meters per second.

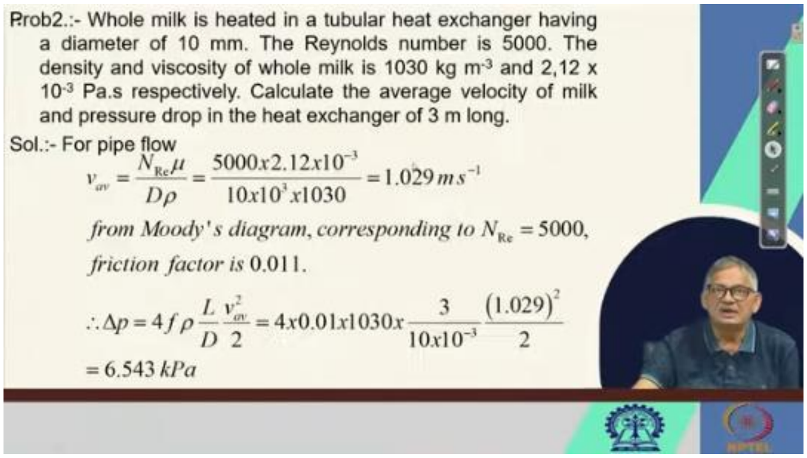


Right. Therefore, we can find out what is the delta P? Delta P is 3 $v_{average}$ mu L by del square, or it is 3 into 0.056. Right, 3 into 0.056 into 1 into 10 to the power minus 3 into L, L is 3 meters. So, 3 divided by del square, now 2 del is 10.

So, 1 del is 5, 5 into 10 to the power minus 3, all square. So, that becomes 20.16, delta P, right. What could be the unit? Unit is, of course, Pascal.

So, once we know how much pressure is dropped for such heat exchangers where the apple is getting sterilized, then we can roughly say that around 10 or rather around 20 Pascal is decreased, right, delta P. Next, another problem we can say is that whole milk is heated in a tubular heat exchanger having a diameter of 10 millimeters. This is another example of a heat exchanger, right.

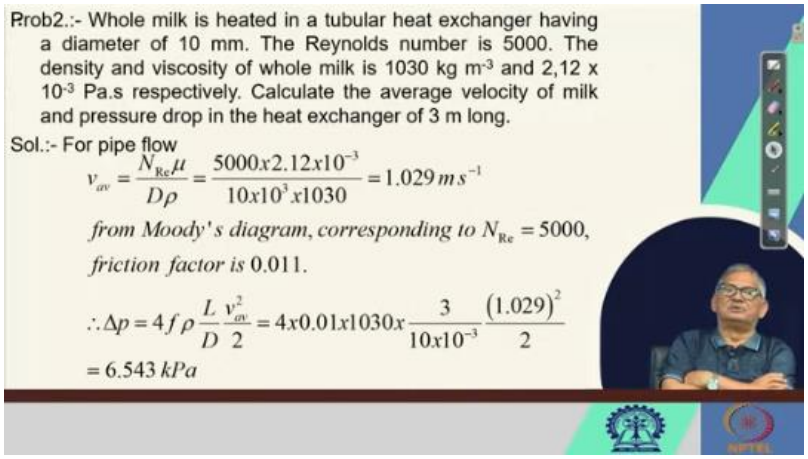




You see how the flow of fluid is also being used in different parts, different engineering. This is used in the heat exchangers, right. Whole milk is heated in a tubular heat exchanger having a diameter of 10 millimeters, the Reynolds number is 5000, The density and viscosity of whole milk are 1030 kg per meter cube and 2.12 into 10 to the power of minus 3 Pascal second, respectively. Calculate the average velocity of milk and pressure drop in the heat exchanger of 3 meters long.

So, we have read and we can Understand by reading once more that whole milk is heated in a tubular heat exchanger having a diameter of 10 millimeters, the Reynolds number is 5000, density and viscosity of whole milk are 1030 kg per meter cube and 2.12 into 10 to the power of minus 3 Pascal second, respectively. Calculate the average velocity of milk and pressure drop in the heat exchanger of 3 meters long, right. So, all the values are given. So, we can find out differently.

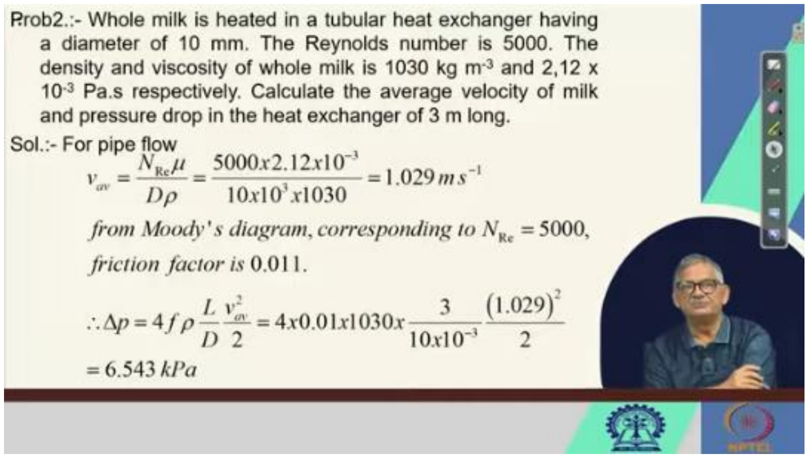
For pipe flow, we have seen that vaverage is N_{Re} general or N_{Re} other mu by D rho. Where N_{Re} is given as 5000, mu is given as 2.12×10^{-3}, and D is given as 10 millimeters. So, $10 \times 10^{-3} \times 1030$. Here also, you see there is a mistake. So, here you mind it is not 10^3, it is $10^{-3} \times 1030$.



So, this becomes equal to 1.029 meters per second, right? As we said earlier, now it is also a heat exchanger. So, earlier we said that the length of the heat exchanger or any such pipe which we consider may not be equal to the one which we are considering. In many cases, it is more than that, and that was established by the great scientist called Moody.

So, based on the Moody's chart, he made a chart based on Moody's chart, we can find out from the Moody's chart corresponding to January 5000, the fanning friction factor is 0.011, right? So, if it is 0.011, then we can say that delta P is nothing but 4 f rho L by D vaverage square by 2. So, it is 4 f is 0.011, you have taken only 1, okay? into 1030 into L 3 meters long. So, 3 divided by D is 10 millimeters.

So, it is 10 into 10 to the power minus 3 into v average is 1.029 whole square over 2. So, this becomes equal to 6.543 kilo Pascal. If you remember, in the previous problem, for apple juice in a plate heat exchanger, we have seen the delta P is around 20 Pascal. And now, for a tubular heat exchanger with milk,



we are finding that the delta P required or obtained is 6.53 kilo Pascal, which was Pascal. So, if it is in Pascal, that was 20 Pascal, here it is 6543 Pascal. So, that means, on the system, depending on the property values, these delta P or any other, that varies, may be widely sometimes, or sometimes may not be widely. So, what I suggest to you is to try to find out from books or the internet or wherever different problems and try to solve them with respect to the profile of the flow of the fluid. Profile, I mean, whether it is with respect to pressure drop or whether it is with respect to velocity distribution or shear transport, shear force distribution, or finding out viscosity, etc., whatever is required, ask for it. So, take that in the spirit of calculating the fluid flow problem. So, you do as many problems as possible, and the more solutions you find, the clearer the subject will become, right?

So, with this, I think we have come to the end of the class, and I thank you all for attending. Obviously, we will move to the next class with a new chapter so that, by this time, you can also bring yourself up to date with the topics we have already covered, okay? Thank you all.