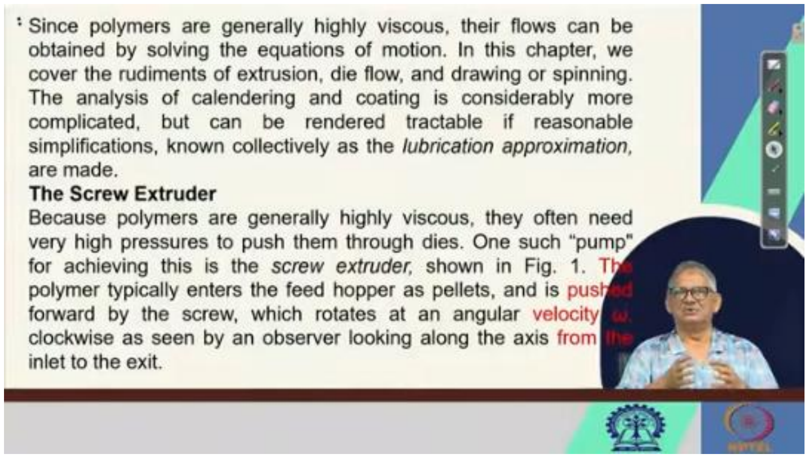
IMPACT OF FLOW OF FLUIDS IN FOOD PROCESSING AND PRESERVATION

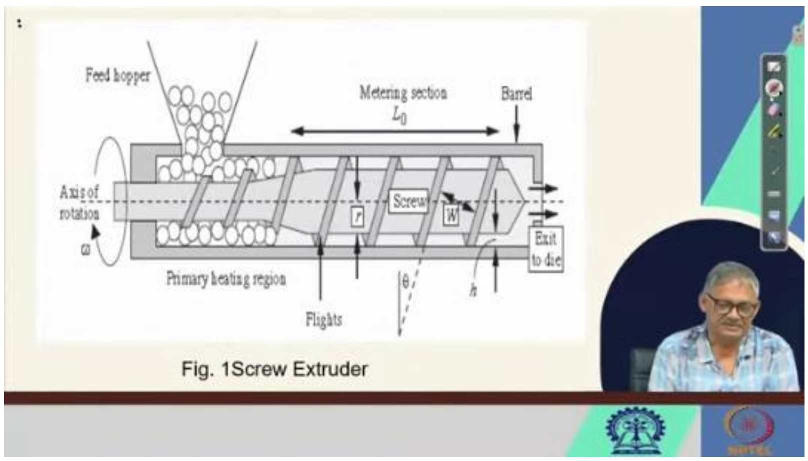
Lecture30

LECTURE 30 : PROBLEMS AND SOLUTIONS ON POISEUILLE FLOW AND COUETTE FLOW

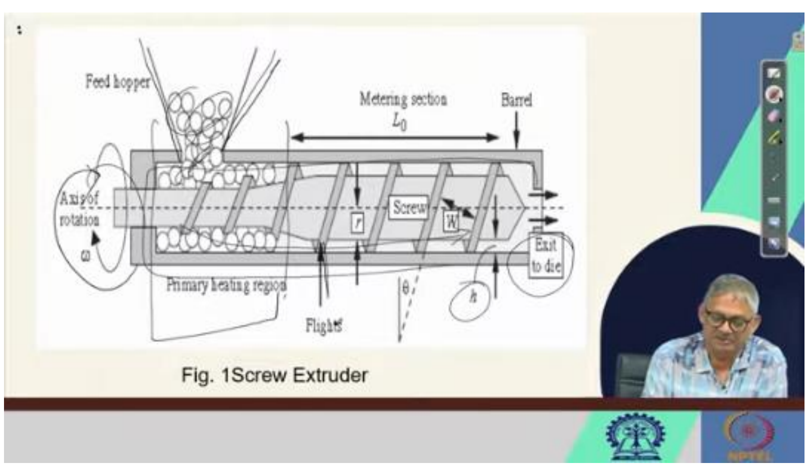
Good afternoon, my dear boys, girls, students, and friends. We are dealing with, as I said, something I have not seen in many fluid flow operations, because fluid flow is such a vast subject, right? Mostly, we deal with the static, but the dynamic conditions are normally not dealt with. So, I thought let me introduce a little, so that it does not become Greek in the future with your academic activities. So, here we are doing some problems and solutions that we have earlier done, where we finished in the last class, whether it is a Couette flow, Poiseuille flow, or a combination, where do we land up, ok?

So, we come to this: we have defined a screw conveyor or screw extruder earlier, right? And we said that we are explaining this screw extruder in more detail in this figure. That figure says that this is the screw extruder, as you see. As you see, you have the feed hopper; this is the feed hopper where you are putting your material, right? This is the axis of rotation of the screw; you have the screw like this, ok? You have the screw axis like this.

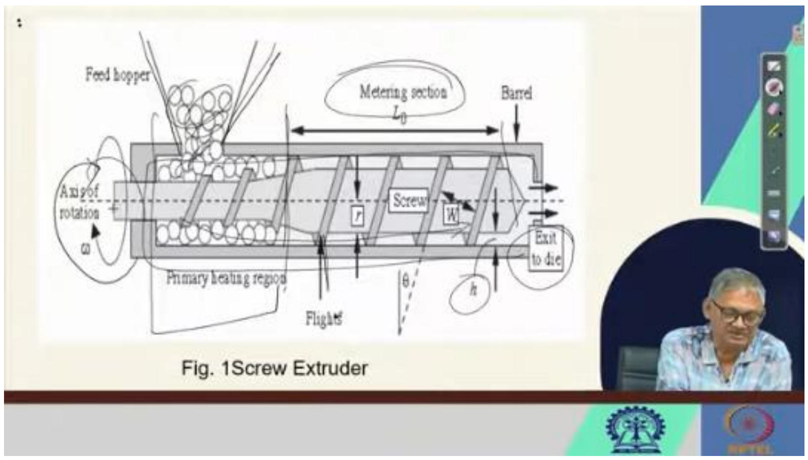




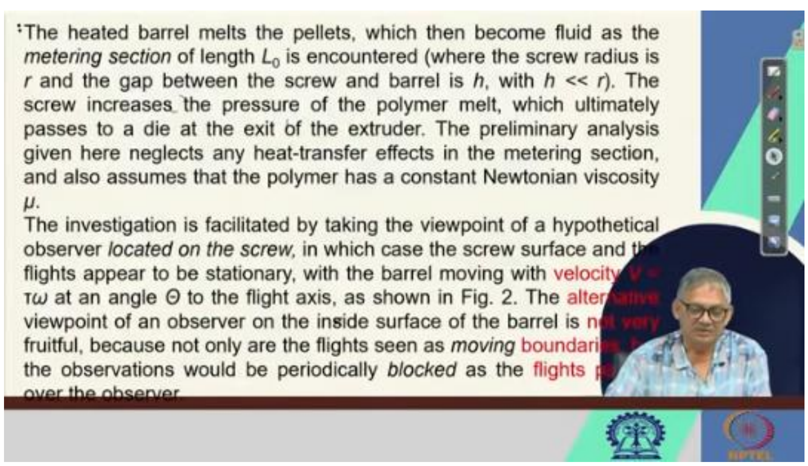
And by that, it is being taken from one end to the other end, right? So, there are many things to say; these are the flights, right? This is called the primary heating zone or heating section. Right, and the angle between this flight and the screw is theta, and it has a high gap, h; it is going to an exit die, and this is called the barrel. Where the entire screw assembly is there, and this is called the metering section, right?



From this point to this point, this is called the metering section, okay. The screw has an axis, right? And, yeah. Let us look into how we can manage this screw, and in many cases, there are screw conveyors also, right? Not only is this for screw extrusion, but there are screw conveyors also. And there also, you need the fluid flow, how it is moving, right? So, from this, we can say that the heated barrel melts these pellets. These are the pellets which we said, no? These are the

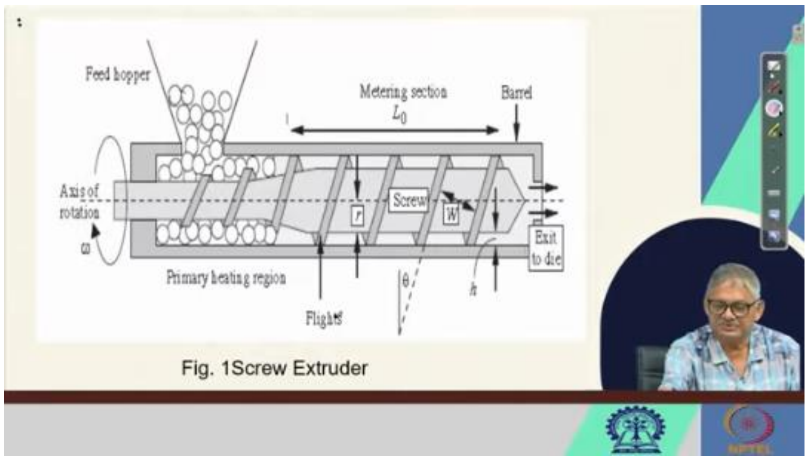


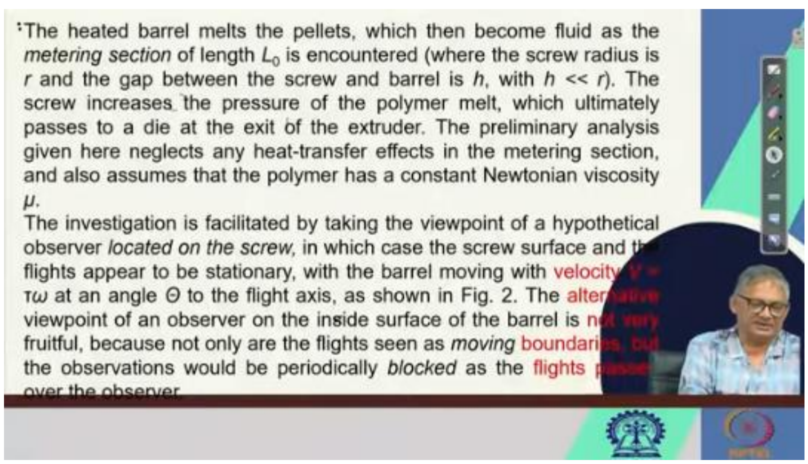
these are the pellets. So, it gets melted here. This has to be; otherwise, it will come to the next, okay. Then we can say once again, We can say that the barrel, within that, the pellets are melted, which then become fluid because it was solid before melting.



So, it was getting into through the hopper, and there, some melting device is there. So, it gets melted, and the moment it gets melted, it becomes a fluid. So, the heated barrel melts the pellets, which then become fluid as the melting section of length L_0 is encountered. The screw radius is R, and the gap between the screw and the barrel is h. The gap between the screw and the barrel is h. So, that is what this gap between the screw and the barrel is; this gap is h, okay.

So, if we see that h is much less than that of R. Right. The screw increases the pressure of the polymer or the melt, which ultimately passes to a die at the exit of the extruder. The preliminary analysis given in this section neglects any heat transfer effects in the melting section. Yeah, it becomes much more complicated if we want to put it all together, that is, melting as well as heat transfer and heat exchange; then it really becomes a

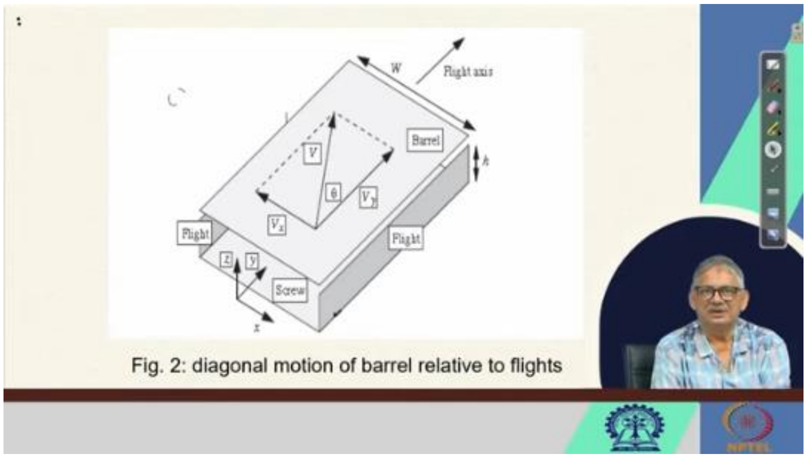




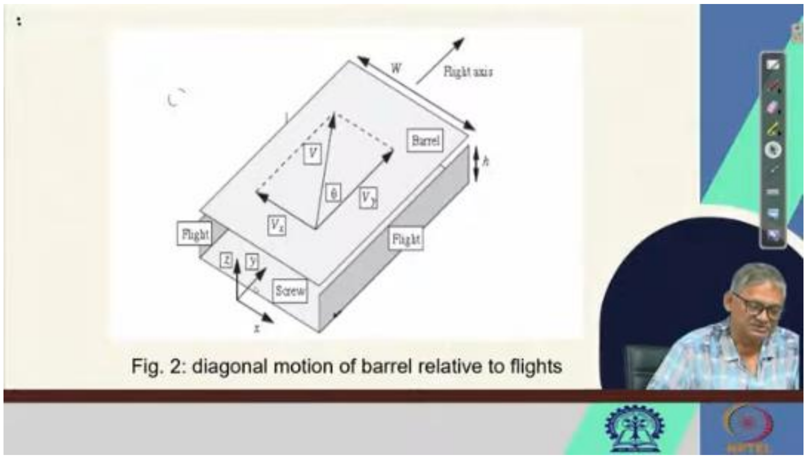
problem for PSD solution. But here we are neglecting that any heat transfer effects are not taken into account in the melting section. And also, we assume that The polymer has a constant Newtonian viscosity. Normally, polymers may or may not be Newtonian.

It depends on the polymer. It could be mostly non-Newtonian. But we assume it to be Newtonian. Otherwise, again, your set of equations will be altogether different. And it has a Newtonian viscosity μ.

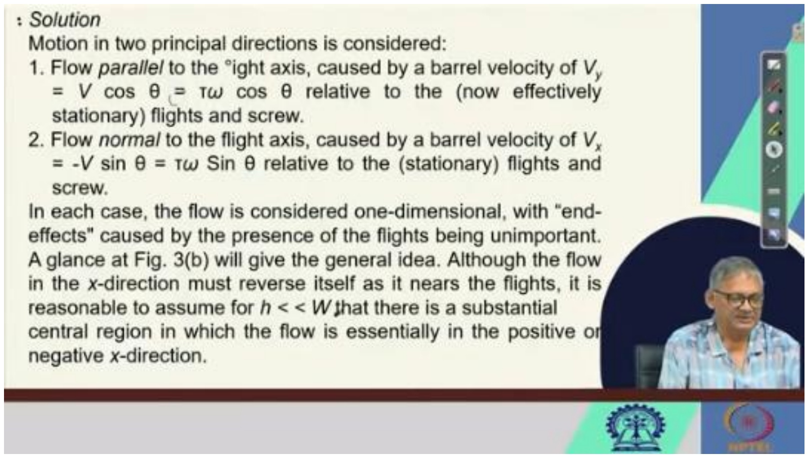
The investigation is facilitated by taking the viewpoint of hypothetical. It is hypothetically seen that the observer located on the screw in which the screw surface and the flights appear to be stationary with the barrel moving with velocity v, and that v is equal to tau_w. At an angle theta to the flight axis. Now, this we can also see in the next figure here, right? Diagonal motion of the barrel relative to the flights, right?



So, our x is this way, this is the This is the flight gap between the flight and the barrel is h, this is the flight axis and W and all three directions v_x, v_y, and obviously, this is the z, right. So, we can see how it is getting moved. So, the alternative viewpoint of an observer on the inside surface of the barrel is not very fruitful because not only are the flights seen as moving boundaries, but the observations would be Periodically blocked as the flight passes over the observer.

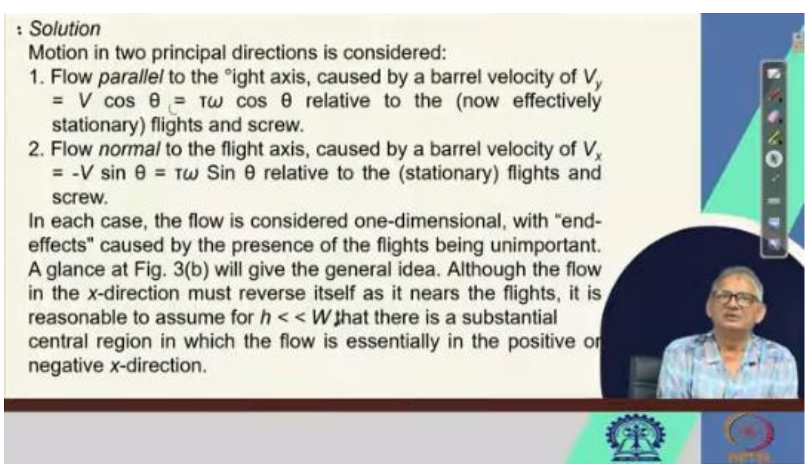


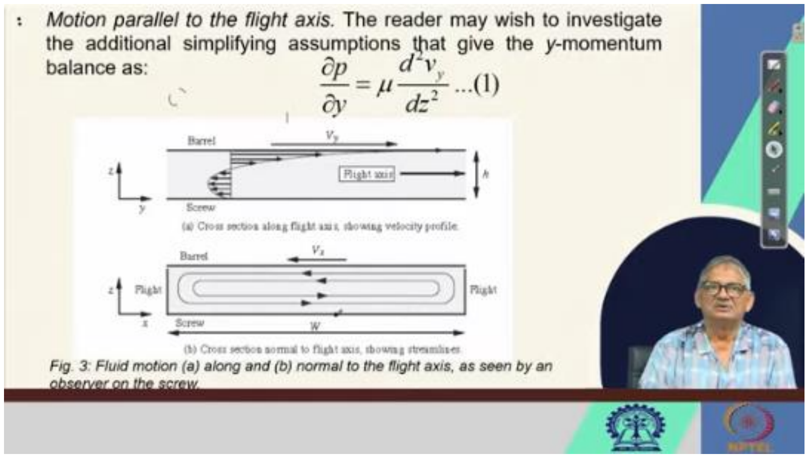
Yeah, like this when it is coming, so you can see now you cannot see it coming like that. The observer cannot see as the flights are coming in between, okay. Then we take the solution in the way that We take the solution in a motion in two principal directions is considered. Number one, the flow parallel to the flight axis caused by a barrel velocity of v_y that is equal to v Cos theta. And this is roughly equal to tau_w Cos theta relative to the flights and screw.



So, now it is assumed to be stationary, and afterwards, it may be going up or down. Flow normal to the flight axis caused by a barrel velocity of v_x that is equal to minus v Sine theta or is equal to tau_w Sine theta relative to the stationary point flights and screw relative to the flights and screw. So, in each case, the flow is considered one-dimensional with end effects caused by the presence of the flights being unimportant. Again, a glance at a figure will give the general idea.

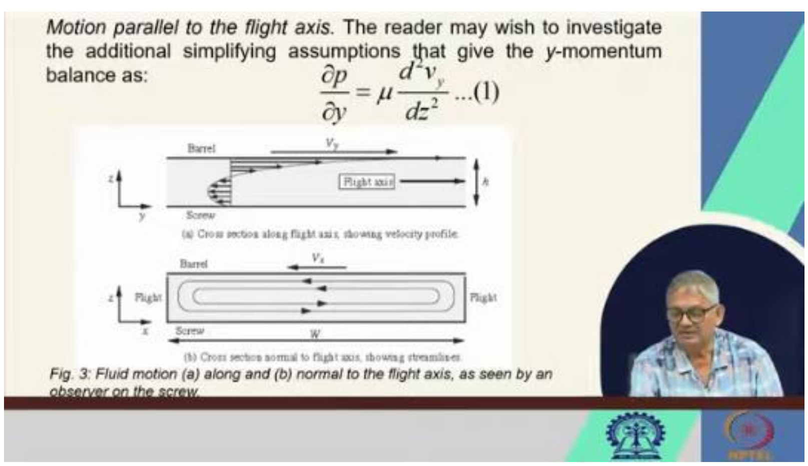
Although the flow in the X direction must reverse itself as it nears the flights, it is reasonable to assume that for h much much less than W, there is a substantial central region in which the flow is essentially in the positive or negative x direction, right? Now, let us also look into the figure. We have two figures, figure A and figure 3, A and B. That we said that cross-sectional normal cross section normal to flight axis showing the streams.



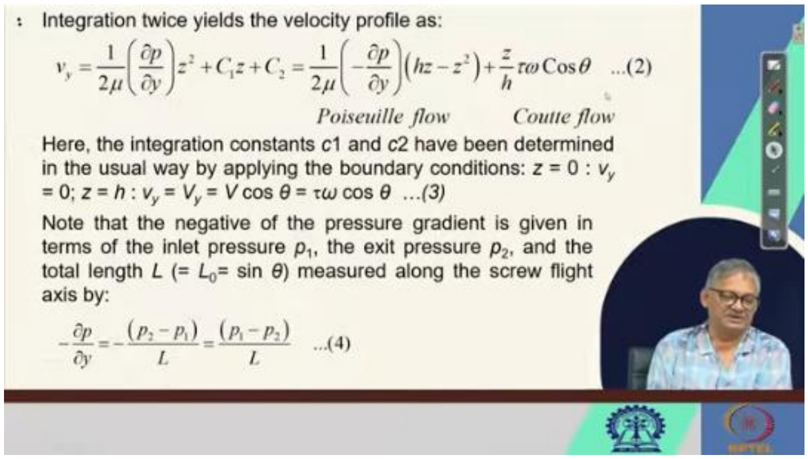


So, this is the barrel here; this is the barrel, and z and x axis are acting on it. So, v_x is the velocity, W is this length, and this is the screw which is moving like this, and the other one is moving like this, and the other one is moving like that, right. And here, as we have seen earlier between y and z barrel, if v_y is in this direction, this is the flight axis, and the gap between the flight and the barrel is h, right. And this is the screw, and you see that some portion is moving this way, and some is in the

So, this is exactly what we are looking at in the barrel and screw, which may not be in the conveying system only, but maybe in the other system that we are talking about, right. So, a motion parallel to the flight that is, the reader may wish to investigate the additional simplifying assumptions that give the Y momentum balance, and that is del P / del y is equal to mu del 2 v_y / del z square. So, we have shown fluid motion along and normal to the flight axis as seen by an observer on the screw, right.

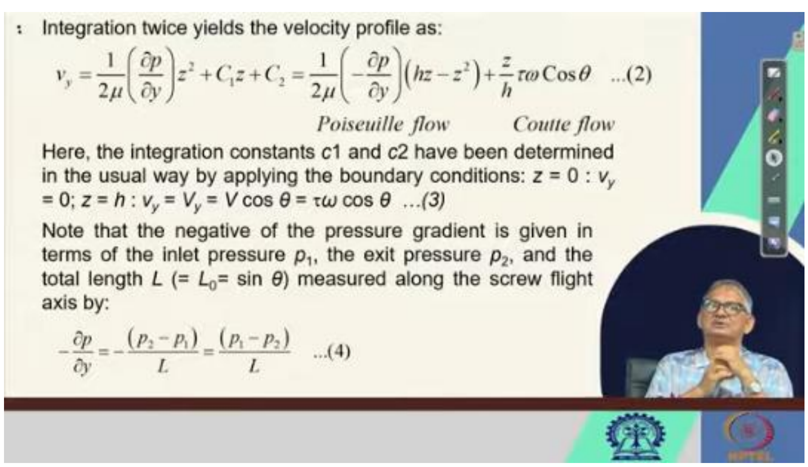


An observer, if he or she looks into it, sees a section along the flight axis showing the velocity profile and the section normal to the flight axis showing streamlines. So, if we take these two figures into consideration with the assumptions, we can say a momentum balance in the y direction is del P / del y is equal to mu del 2 v_y / del z square, right. If that be true, then integration twice else because del 2 v del x square it was. So, in twice integration else, the velocity profile as v_y is equal to 1 by 2 mu del p / del y, z square plus C_1 z plus C_2, and this is equal to 1 by 2 mu

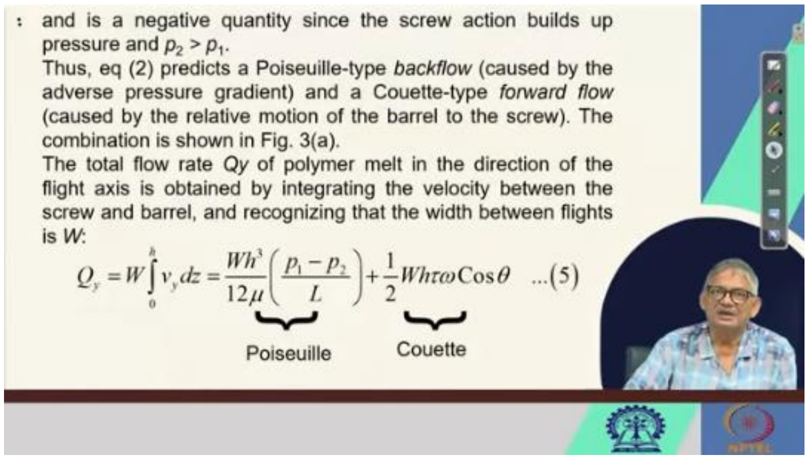


del P / del y, h z minus z square plus this is due to two flows, one is the Poiseuille flow and another is the Couette flow. Right. For the Poiseuille flow, we can say it to be 1 by 2 mu minus del P / del y, h z minus z square. And for the Couette flow, it is plus z by h tau_w Cos theta. Right.

So, in this case, the integration constants C_1 and C_2 have been determined in the Israel way by applying the boundary conditions. What is the boundary condition? The boundary condition is Z is 0, v_y is 0. z is h, v_y is small, v_y is capital V_y, that is equal to capital V Cos theta which is equal to tau_w Cos theta. So, here we should see that the negative

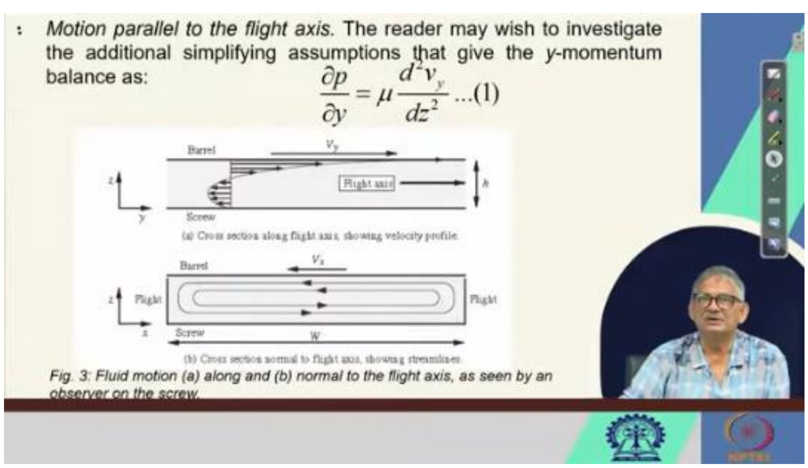


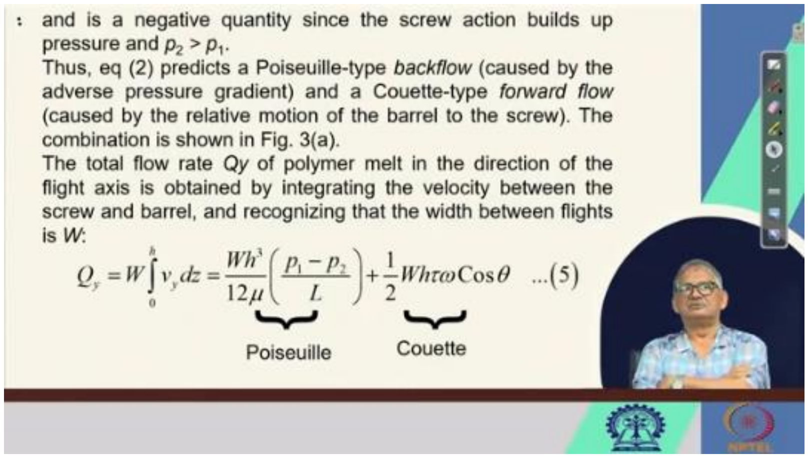
of the pressure gradient is given in terms of the inlet pressure P_1. The exit pressure P_2 and the total length L, that is equal to L_0 equals to Sin theta measured along the screw flight axis by this relation del P / del y negative, minus del P / del y is equal to minus P_2 minus P_1 by L, that is equal to P_1 minus P_2 by L, right. So, P_2 minus P_1 by L that negative is taken inside this P_1 minus P_2 by L, right. Then we come to the point that



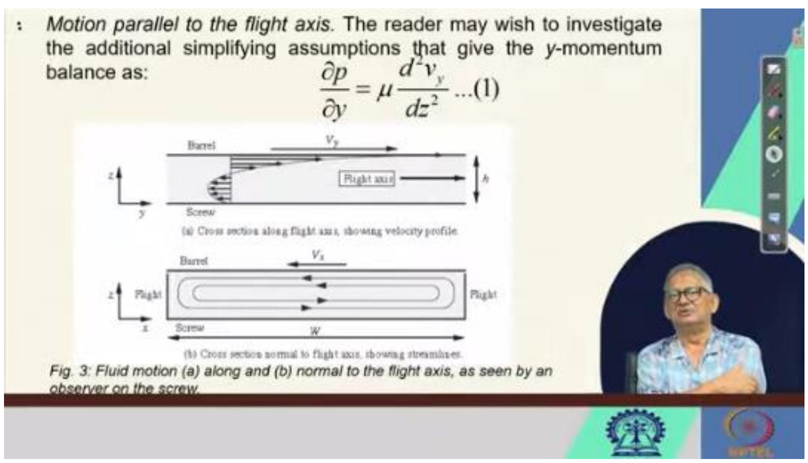
This was the flight screw flight axis and then this is negative quantity since the screw action builds up pressure and P_2 is greater than P_1. Whatever inlet pressure was there, exit pressure is much more. So, it is the other way around. Thus, equation 2. Now, which one is equation 2?

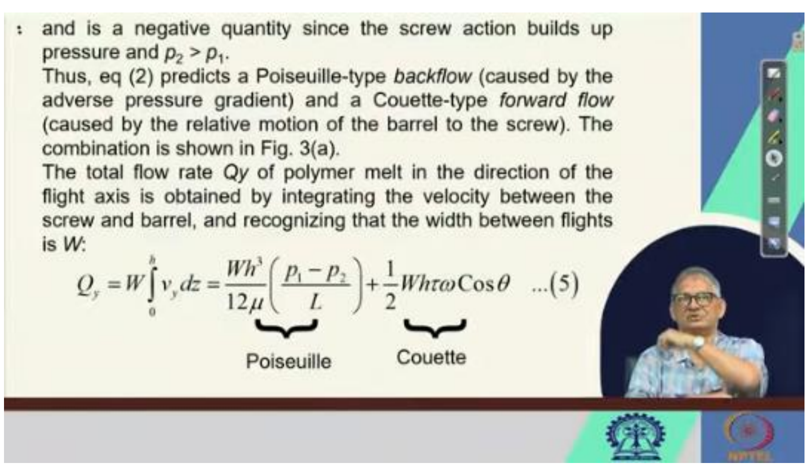
Let us look into 1, and this is equation 2, right, where v_y was explicitly stated in terms of Poiseuille flow and Couette flow, right? So, in equation 2, this predicts a Poiseuille-type backflow caused by the adverse pressure gradient and a Couette flow that is a forward flow caused by the relative motion of the barrel to the screw. The combination is shown in the previous figure, which is this, right?





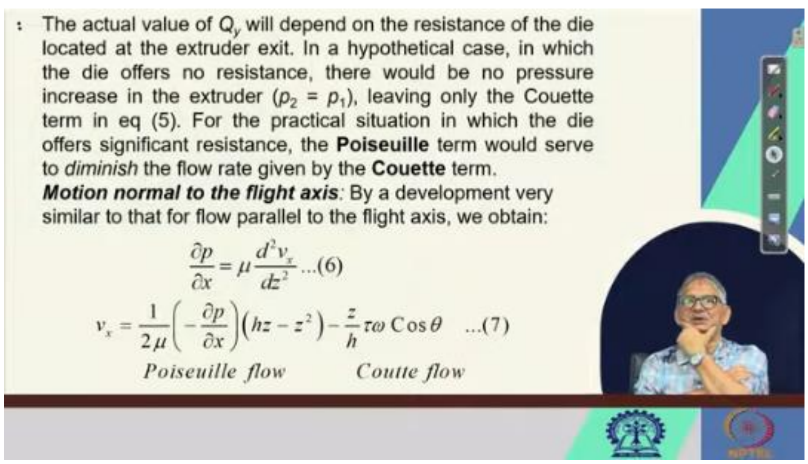
You see, we have a backflow. Where is that? We have a backflow here. And we have a forward flow, right? This is the combination. So, the total flow rate Qy of polymer melt in the direction of the flight axis is obtained by integrating the velocity between the screw and the barrel. And recognizing the width between flights is W, right?



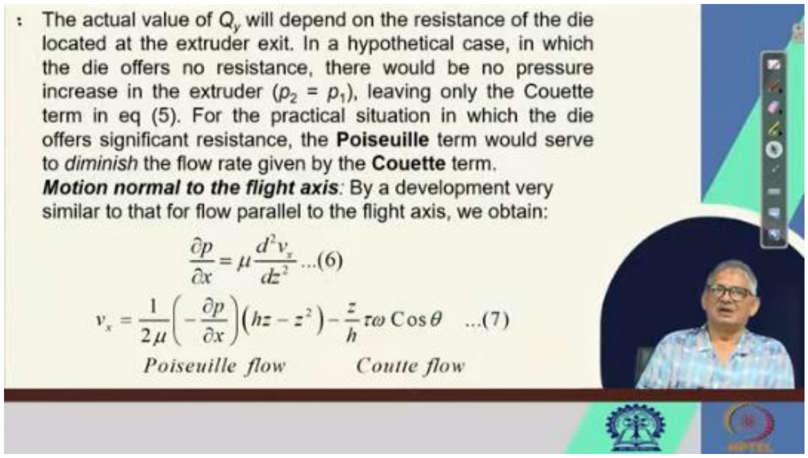


Therefore, we can write Q_y is equal to w integral of v_y dz between 0 to h. And that can be said to be equal to W h cube by 12 mu into p_1 minus p_2 by L, which is the Poiseuille motion, and plus 1 by 2 Wh tau_w tau_{omega}, rather, Cos theta. Earlier, those were all omega So, half W h tau_{omega} cos theta, which is the Couette flow, right. So, Q_y, that is the volumetric quantum of fluid flowing, is w integral of 0 to h v_y dz and, that is equal to W h cube by 12 mu into P_1 minus P_2 by L. This is equivalent to the Poiseuille equation or Poiseuille flow.

And, this plus 1 by 2 W h tau_{omega} Cos theta is the Couette flow. The actual value of Q_y will depend on the resistance of the die located at the extruder exit. In a hypothetical case where the die offers no resistance. There would be no pressure increase in the extruder; that is, P_2 is equal to P_1, which is the ideal condition, right? Leaving only the Couette term in equation 5, which one is this, right? Only the Couette term will remain because P_1 is equal to P_2.



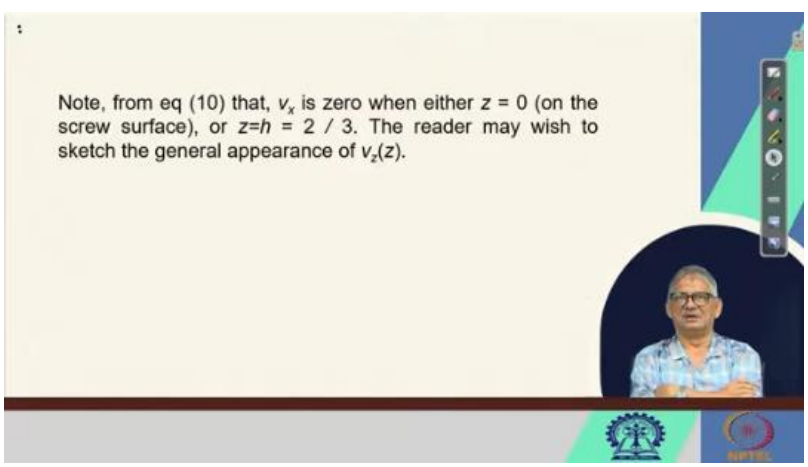
Therefore, for the practical solution or situation where the die offers significant resistance, the Poiseuille term would serve to diminish the flow rate given by the Couette term. Therefore, Motion normal to the flight axis can be described by a development very similar to that for the flow parallel to the flight axis. We can say that del P / del x is equal to mu del 2 v_x del z square, and v_x is equal to 1 by 2 mu into minus del p / del x into h z minus z square.



This refers to Poiseuille flow minus z by h tau$_{omega}$ Cos theta, which refers to Couette flow. Right? So, I think our time is not much. So, yeah, we can finish it up. We can finish it up.

Okay? So, up to this Couette flow, then Q_x is equal to 0 to h v_x dz, that is equal to h cube by 12 mu del P / del x minus, and this is referring to Poiseuille flow, minus 1 by 2 h tau$_{omega}$ Sin theta is equal to 0, that is the Couette flow. Here, Q_x is the flow rate in the x direction per unit depth along the flight axis and must equal 0, because the flights at either end of the path act as barriers. The negative of the pressure gradient is, therefore, minus del P / del x equals 6 mu tau$_{omega}$ Sin theta by h square, and this is so the velocity profile is given by v_x is z by h tau$_{omega}$ into 2 minus 3 into z by h Sin theta, right.

So, here you mind it that the V_x is 0, when either z is equal to 0 on the screw surface or z is equal to h, that is equal to 2 by 3. The reader may wish to sketch the general appearance of V_z, right. So, with this, we come to the conclusion of this. So, I thank you for hearing the class. Thank you very much.



So, at least we have taken up some moving systems instead of all being static.

Thank you.