Experimental Methods in Fluid Mechanics
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Lecture 18
Flow obstruction flow rate measurement (venturi meter/orifice meter), the Rotameter Contd.

Good afternoon, I welcome to this session of Experimental Methods in Fluid Mechanics. This is in continuation of my last lecture, where we have discussed about the Measurement of Flow. In particular, we have seen that how we can measure volumetric flow rate of an incompressible liquid. In fact, we have discussed about the volumetric flow rate measurement of incompressible liquid and using, and flow obstruction fluid measurement.

We have worked out that how by providing the, rather by placing an object of any shape, we can disturb the flow field, which will eventually leads to a drop in pressure and by measuring the drop in pressure, we can calculate the flow velocity, from there we can calculate the flow rate through, either through analytical expression or using empirical relationship.

Now, we also can measure the flow rate or the volumetric flow rate of the compressible fluid and using the same principle. And, as you have seen that if we try to measure flow rate volumetric flow rate using flow obstruction instruments like, the instruments which were used to provide obstruction to the flow field, from there we can measure flow rate. For that, we have seen that we applied continuity equation and then you applied the Bernoulli equation.

But consideration of Bernoulli equation is not the actual, rather it is not the realistic one. In fact, the fluid is not in viscid. But considering Bernoulli equation, the pressure drop that you have calculated through analytical, calculation of procedure, and we have equated that pressure drop which you have measured experimentally using the u tube manometer.

Now, since we have considered in viscid flow, essentially to apply Bernoulli equation to measure the pressure drop theoretically, the measured, the theoretical measured pressure drop and, or give us the correct measurement of the volumetric flow rate, rather it will overestimate. Now, to get the actual flow rate we have, you know multiplied that actual flow rate with one coefficient which is near very close to one, but not exactly one and that velocity coefficient of discharge can be obtained by calibrating through, calibration process.

And this technique is there in most of the undergraduate textbooks, where you can have, you know, fluid measurement in venturi meter orifice meter. And, even then we have discussed briefly. But the same thing can be measured using for the compressible fluid and for that you need to consider the fluid, fluid is frictionless, I mean isentropic flow adiabatic and frictionless flow, but it may not be the case that the fluid is always frictionless, because viscosity is there. So, viscous effect will be there.

So, eventually when will come up with the expression of the volumetric flow rate that should be multiplied by one factor but that part I am not going to discuss here. So today, we will see that again, how we can measure flow rate. So, flow measurement is nothing but the measurement of volumetric flow rate or mass flow rate or it may be the point velocity measurement or determination of the flow stream lines, that is what we have discussed in the last lecture.

So, today we will see that rotameter is also one another instrument, which is used to measure flow rate, in a flow field. So, we will see through a schematic depiction, rather will see the principle by how we can, measure flow rate using rotameter and the principle on which this instrument works. And finally, what are the precautions you need to take into account while we are using this rotameter to measure mass flow rate or volumetric flow rate of the fluid in experiments.

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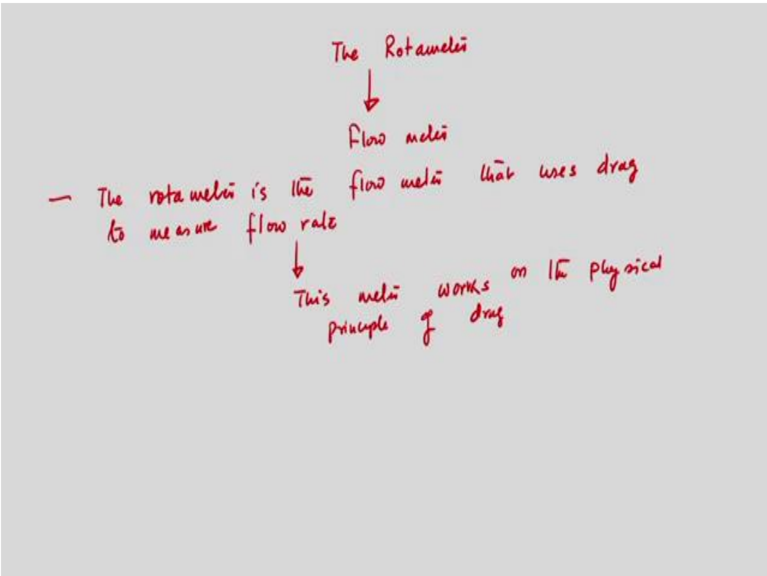

So, today we will discuss about the rotameter. So, this rotameter is also a flow meter and this is used to measure flow rate. Now, important thing to note here that, we have discussed in my last lecture that, that is flow obstruction fluid measurement. And this rotor meter, works on the principle that it uses drag. So, now I will be drawing the schematic so, the rotameter I can write the rotameter is the flow meter that uses drag to measure flow rate.

So, in the last lecture, we have seen that by placing an object in the flow field, we can disturb the flow field, and that will results up dropping pressure. Now, this meter works on the principle that it uses drag to measure flow rate. So, we will see by how we can measure the flow rate using this flow meter.

I can say this meter then, works on the physical principle of drag. Now, if I draw schematic, the schematic will be, the schematic will be helpful to explain the principle, rather the measurement principle and the analytical calculus and which is required to know ultimately the flow rate which you will get using this flow meter.

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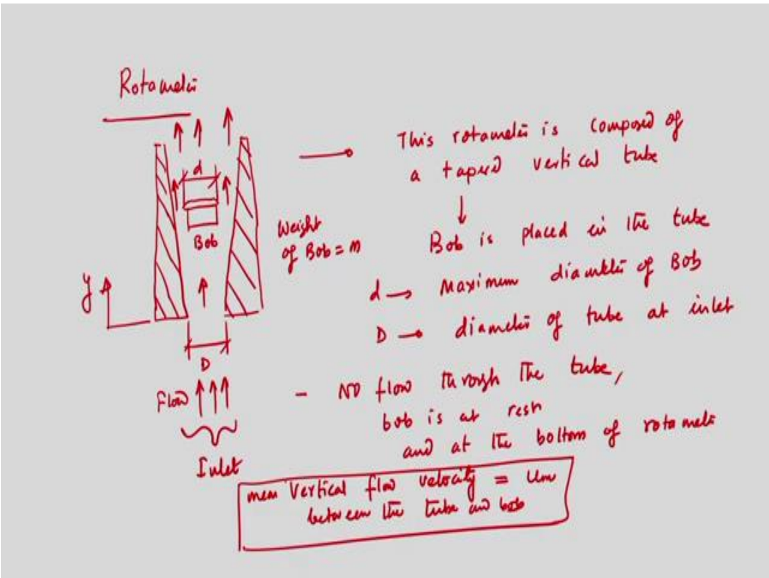

So, I can, so I can draw a schematic depiction of the flow meter that is rotameter, rotameter. So, and, and there will be one bob, the corner on be shaft rather, a bob. And the maximum diameter of the bob is a small d and diameter of this, so essentially this is d. So, the rotameter is essentially what I can say, rather what we can see from this figure is essentially a tapered, it is a composed of taper tube which is vertical and one bob is there, the diameter the maximum, this is bob so, this is bob.

So, this rotameter is composed of a tapered vertical tube and a bob which is placed in the tube. Now, small d is the maximum diameter of the bob and capital D, capital D is the diameter of the tapered tube at the bottom. So, diameter of tube at bottom or I can write inlet. So, flow is taking place from the bottom and this is inlet, and this is outlet. So, this is inlet.

Now, when there is no flow then bob will be at rest, so when there is no flow bob would be at rest and rather bob will be at the bottom of the rotameter. So, no flow through the tube so, this entire, you know system is known as the rotameter. And the bob is having weight, say this is y direction, this is y direction and the bob is having weight, say I can write m, weight of bob is m.

Now, this is the flow direction. So, this is the flow direction. Now, just when we start flow from the bottom, so, the flow will try to keep the bob, that I will try to drag the bob along, and it will be in the fluidics, I mean the bob will be in the fluidic state. So, when there is no flow bob is at rest and it will be no flow through the tube, bob is at rest and at the bottom of the rotameter.

Now, a vertical flow say, a vertical flow is flowing through the tube. If we consider the velocity of the flow is Um, say vertical flow velocity, flow velocity is Um and vertical flow velocity I can write, between the tube and bob. So, this vertical flow between tube and bob is Um. So, when a flow is there from the bottom of the rotameter, the flow will try to push the bob along, rather the flow will try to drag the bob along and it will try to push the bob upward.

And if we considered, the vertical flow velocity between the tube and bob is Um. Now, a vertical flow which is provided at the bottom will try to push the bob until, the mean flow between the, mean vertical flow between the tube and bob is equal to the Um, because, such that the vertical drag. Now question is, this is the mean, mean vertical velocity. So, this is the mean vertical flow velocity between tube and bob.

And if I go to the next slide. Then if I write that now, say when the flow is there from the bottom, so it will push the bob upward and the bob will be, you know, taken by the flow rather, the flow will drag the bob along, until unless the mean vertical velocity between tube and bob is given, such that the drag force due to Um, just balances the bob works as the bounce buoyancy.

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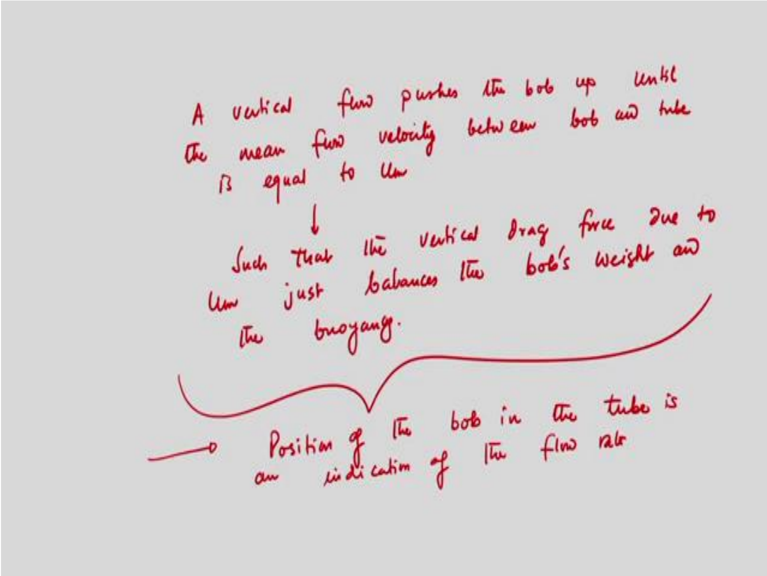

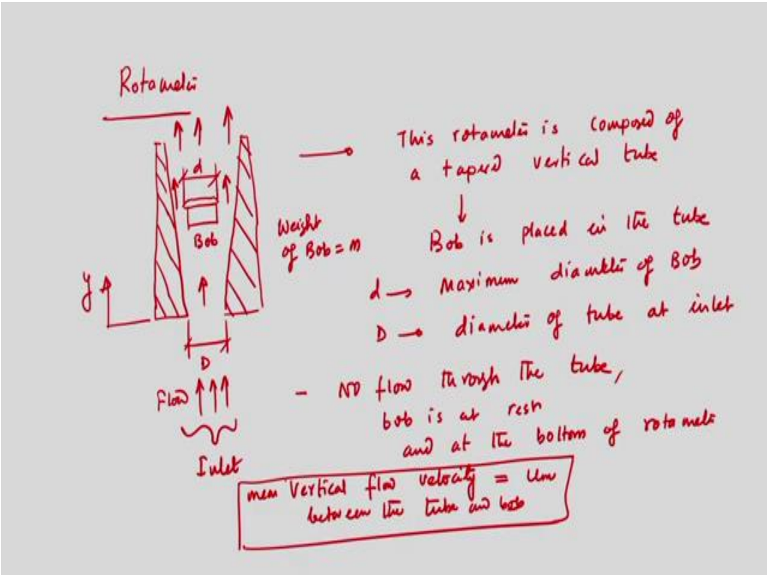

So, I am writing that, a vertical flow pushes the bob up until the mean flow velocity between bob and tube valve or tube is equal to Um. So, and, and such that, that the vertical drag because this instrument works on the principle of drag, vertical drag force due to Um just balances the bob’s weight and the buoyancy.

So, if I go back to the previous slide, then there will be a mean vertical flow between the bob and the tube and since the flow is continuously flowing, the fluid is continuously flowing from the bottom to the top. Then, initial flow will try to push the bob along and it will try to push the bob up and this movement will continue until, the mean velocity between the bob and the valve is Um. Such that, and this condition will be reached when the vertical force due to that, that mean velocity will balance the bob’s weight and the buoyancy.

So, that means, from this discussion, we can say that the position of the bob in the tube is an indication of the flow rate. Because, the main flow Um, between the bob and the tube and the drag, the drag force due to this Um, mean flow that we balanced the bob's weight and the buoyancy.

So, eventually the vertical flow will try to push the bob and this movement will continue until this Um each attained, and what Um, for Um, for which the buoyancy as well as bob's weight will balance with the drag due to the, due to that Um. So, the position of the bob, so the movement will continue, the upward movement of the bob will continue until that height, where the uniform in a velocity. Rather, uniform mean velocity between bob and tube, the drag that, the drag because of that uniform velocity between bob and, mean velocity between bob and tube will balance the bob's weight and the buoyancy.

So, this is very important that means, position of the bob in the tube will be, rather is an indication of the flow rate.

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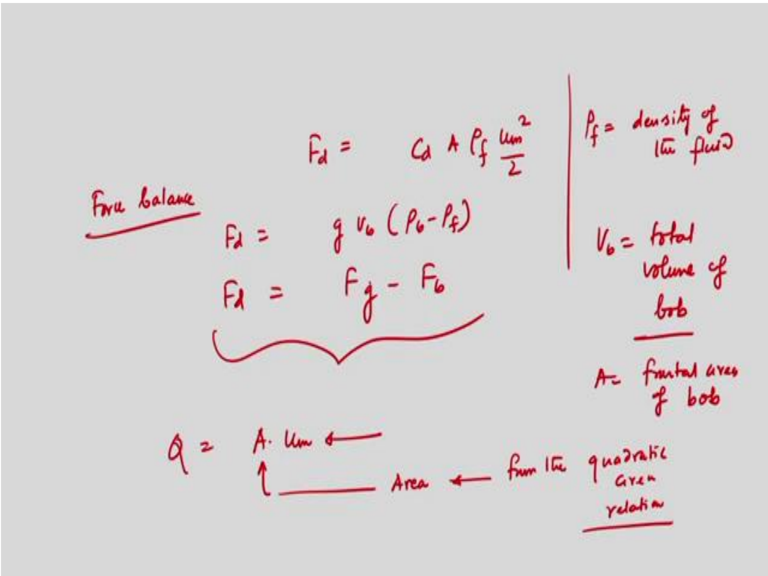

A vertical flow pushes the bob up until the mean flow velocity between bob and tube is equal to U_m

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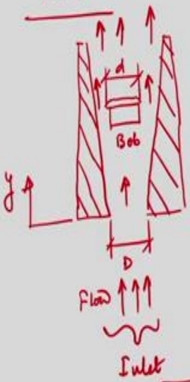
Such that the vertical drag force due to U_m just balances the bob's weight and the buoyancy.

→ Position of the bob in the tube is an indication of the flow rate

Rotameter



Weight of Bob = m

→ This rotameter is composed of a tapered vertical tube

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Bob is placed in the tube

d → Maximum diameter of Bob

D → diameter of tube at inlet

- No flow through the tube, bob is at rest and at the bottom of rotameter

mean vertical flow velocity between the tube and bob = U_m

$$A = \frac{\pi}{4}\left[(D + ay)^2 - d^2\right]$$

a = constant

↓

depends up on the tube taper

$$Q = \frac{\pi}{4}\left[(D + ay)^2 - d^2\right] \times U_m$$

⇒

Bob elevation is dependent on the annular area between it & tapered tube

Now, if I try to write a force balance, so what I can write, so thus, the drag force, we can write Cd into A into rhof into Um square by 2. That means, the here, rhof is the density of the fluid. And this drag force, if I write the force balance, this drag force is nothing but g into Vb into rhov minus rhof and that is F, this I can write Vb, the total volume of the bob.

So, this force balance Fd, this is nothing but I can write Fg minus Fb. So, Fd this is nothing but Fg minus Fb. So, the movement will continue until the location, in that location the uniform velocity or rather the mean velocity between bob and valve will be responsible for the drag force and that drag force will be balanced by the you know, you know bob's weight and the buoyancy force.

So, this is the, where, and this A in this expression, A is the frontal area of the bob, of bob. And the subscripts f denotes fluids; a fluid and the subscript b denotes bob. Now, so, if I know, if I know that means, now question is the Um, this mean velocity. Because, as I said that if I go back to my previous slide, that the position of the bob in the tube is an indication of the you know, mean flow rate. Now this Qm, I can write this Qm, Q is equal to A into Um, See, this Um is the mean velocity, Um is the vertical mean flow velocity between the tube and the bob and this area.

This A is, the A is area, area of what, that area is obtain from the quadratic area relation. So, the area is obtained from the quadratic area relation. And, this is A, you know, pi by 4 D plus ay plus square minus small d square. So, D plus ay square plus small d square, where a is equal to constant which depends, which depends upon the tube taper angle, tube taper. So, a is equal to constant and which depends upon the tube taper.

So, the flow rate Q is equal to pi by 4 D plus ay square minus d square, you know into Um, and from there we can calculate the flow rate. Here, a few important things that I will discuss now, that the important is that when the flow is, you know taking place from the bottom, there is a flow velocity and that flow velocity will try to drag the bob along. How long that flow velocity will try to drag the bob along, that will depend upon the strength of the flow velocity.

Now, as I said that the position of the bob in the tube is an indication of the flow rate that means bob elevation, because bob will be lifted by the fluid velocity from the bottom. Now, the, you know elevation, the bob elevation, which is dependent on the annular, you know area between the bob and the taper valve.

Now, which is other way, that the fluid velocity will try to push the bob and depending upon the strength of the fluid velocity that is what we need to calculate, because you need to calculate the flow rate. So, we will calculate the, we will calculate the flow rate through the pipe or any fluidic confinement where we have used this, where we need to install this flow meter.

Now, by the strength of the flow, you know flow velocity the bob will be pushed up and it will stop certain location. Now, at that location what is the mean velocity between the bob and the tube and because of that mean velocity there will be a drag, and the drag force will try to, the drag force will be balanced by the bob weight as well as the buoyancy force. And by balancing these 2, we can, we have calculated what will be the flow rate, and for that we have just calculated the area, that using the quadratic area relation. And that is very simple, and where A is constant and that will depend upon the tube taper.

Now, here I can tell that this bob elevation is dependent on the annular area between it and tapered tube. So, now, the annular space, so all things are related. Now we can say, the, to have the same flow rate measurement, if the annular space is, the gap between the tube and the bob is not very, you know, large, then we will get one kind of bob elevation. But if it is too large, then we will get another kind of bob elevation, but whatever will be the bob elevation.

Now, bob elevation is important because it will give an indication about the flow rate. So, and that will also depend upon these. Whatever will be the bob elevation, at that elevated level, there will be a mean velocity and for that there will be a drag, and that we know the frontal area of the bob and that, because of that drag, that drag will be balanced by the bob weight. Because the natural tendency of the bob will be try to remain seated at the bottom.

So, that weight plus the buoyancy force that will be, you know balanced by the drag force from there we have calculated the flow velocity. And knowing the mean flow velocity, we can calculate the flow rate by knowing this. Because here you can calculate, by, because we know this Fg and we can calculate the Fb.

So, here I can calculate Um, because the expression of Fd is having Um. Now, Fg that we know the bob weight and that buoyancy force, because we know the bob volume and also the fluid density. So, from there we can calculate Um using this expression from there you can calculate the volume flow rate.

Now, 2 important point that I had like to mention over here that, the, you know, flow rate which we have obtain, is very important that because the entire calculation is based on the drag. Now, we know, the drag is dependent, dependent upon the Reynolds number and that also will depend upon the fluid viscosity.

So, the, when we are designing the rotameter, when you are you know, using this rotameter, the fluid viscosity plays an important role to calculate this drag. And, it is also important to note that, our measurement should not have any bias, should not have any dependent on the fluid density as well.

Because, if you need to ensure that our measurement, that the measurement process using this rotameter should not have any bias not have a dependent on the density. This is an advantage as (())(29:01) And that can be obtained by doing small, you know, calculation. By how, because we have calculated the you know, flow rate, volume flow rate.

Similarly, you can calculate the mass flow rate. Now, mass flow rate can be calculated from the volume flow rate. Now, if we need to know that the, the measurements should not have, should not be dependent on the fluid density, then just simply you can make the mass flow rate, the partial derivative of mass flow rate with respect to the fluid density equal to 0. And from there we can calculate, what will be, the knowing the bob density of the bob material, what will be the density of the fluid.

Rather, which is true, that if I know the density of the, I mean fluid in which we need to install this rotameter, then from there we can calculate what will be the density of the bob material. And also, you can, you know calculate the elevation of the bob knowing the fluid velocity typically, which will, which will vary from this range to this range and so that the design can be optimized.

So, what you have understood that, this simple instrument which is very commonly used to measure the flow meter in most of the industrial applications and also, in, also in the area of experimental research to measure the flow rate. And similar to the, you know, flow obstruction fluid measurement technique, this measurement technique, you know that instrument, this instrument, you know, works on the principle of that it uses drag.

Now, whenever we are placing any weighted, any object, any object of any size in the flow field, of course the, this is free I mean it will try, the fluid, the flow velocity will to try to drag them, you know along. But the, and it will try to, you know the flow velocity will try to push the bob up to a certain height.

Now, the height is restricted by the fact that because, the bob is having weight and also buoyancy will be there. So, these 2 force will be you know, you know balanced by the drag force, from there we can calculate, the velocity because drag force which is related to the fluid velocity, mean velocity of the flow between tube and the drag and from there you can calculate volume flow rate. Knowing the area, and that area also, we obtained from the quadratic area relation and knowing the flow rate you can calculate mass flow rate.

And very important that, the measurements should not be biased or the measurements should not be dependent on the fluid density. To ensure that, we can calculate the relationship between the density of the bob material and the fluid density. And also, an important thing that drag is highly dependent on the Reynolds number, which is also dependent on the fluid viscosity. So, I mean by knowing the fluid viscosity, we can also control or you can modulate (())(32:30) drag which is being applied on the bob.

So, to summarize today's discussion, we have discussed that we can measure flow rate using different instruments that is venturi meter, orifice meter. And these 2 types of instruments, I mean venturi meter and orifice meter, their operational principle, I mean there are operational principle is same. They, I mean, this is flow obstruction fluid measurement technique and what we had, what we have seen that just knowing the dropping pressure because of the change in the, you know, because of the, you know change in the shape of the fluidic pathways. We can calculate the, you know pressure drop theoretically.

And, if you tried, if, if we have equated that pressure drop with the experimental pressure drop from there, we have calculated velocity using the Bernoulli equation. And, knowing if we know the velocity from there, we have calculated area, because we know the area through which the fluid is flowing, I mean throat area.

Now, and again we have seen that there are a few assumptions you know, to because of this assumptions the calculation and is not the actual one and to have the actual value, we have to multiply with this factor and that is the coefficient of discharge.

Now, today, we have seen that using other instrument that is rotameter, which works on the principle of drag, we can calculate. You also can calculate the flow rate, but there are a few restriction that, depends upon the taper and the distance between, that the gap between the valve of tube and the bob. And our measurements should not, to ensure that they are, to ensure that our measurements should not have any bias with the density of the fluid, as well as viscosity of the fluid. We need to take up the precaution. So, with this, I stop my discussion today and we will continue our discussion the next class. Thank you