Experimental Methods in Fluid Mechanics
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Lecture 17
Flow obstruction flow rate measurement (venturi meter/orifice meter), the Rotameter

Good afternoon, I welcome you to this session of Experimental Methods in Fluid Mechanics. Today we will start our discussion on flow measurement. And in this module, we will be discussing flow obstruction flow rate measurement. Then, will see that how we can measure using drag.

In fact, the flow obstruction flow rate measurement technique which we will be, which we will be discussing today. This part we have studied in our undergraduate fluid mechanics part, but we will try to recapitulate and will try to discuss a few critical issues while we are using these instruments to measure flow rate. And then we will discuss that how we can use, how we can measure flow using another instrument which is known as rotameter where we will be using drag.

Now, the flow rate measurement is considered to be the measurement of volumetric or mass flow rate through duct or any fluidic confinement or it may be a point velocity measurement and determination of flow streamlines. The measurement of volumetric or mass flow rate is common, rather I can say is the common by far and has (())(1:57)applications to define thermodynamic and chemical processes. And also, the accurate flow measurement is important, you know in different commercial applications.

In fact, I can tell you that, or we talk about flow rate rather flow measurement flow rate, the mass flow rate or volumetric flow rate is very important quantity irrespective of the length scale of the system which we are considering. Almost over all the length scale, the volumetric flow rate or mass flow rate is of immense interest. Because that is what we need to consider while we are designing those devices, any particular device for typical for a many applications.

Say, starting from macro to micro, whether it is pipe or it is channel or it miniaturized systems or devices where we need to focus our attention while designing to check whether that system device will provide the result flow rate or volumetric flow rate or the mass flow rate. Now, because of this, the volumetric flow rate, or mass flow rate, measurement rather I can say is important by its own right. On the other hand, as I said that the flow measurement is considered to be 3 define aspects.

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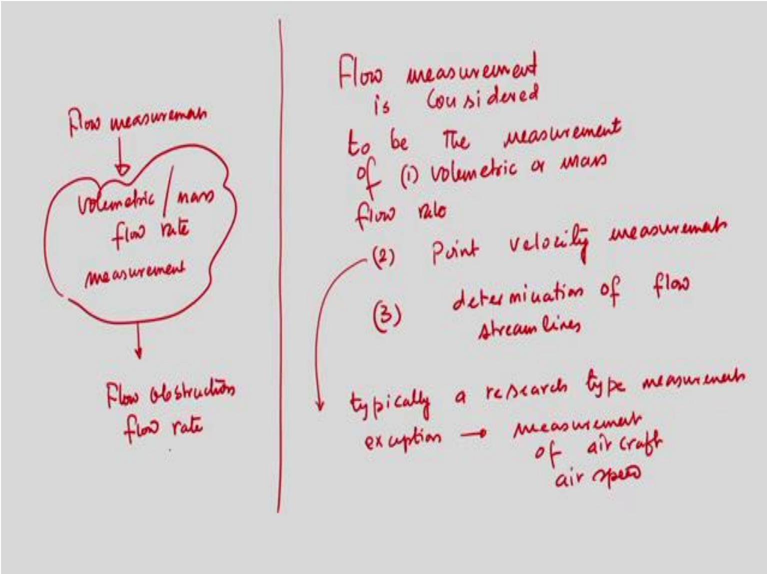

So, I can write the flow measurement is considered to be the measurement of volumetric or mass flow rate, number 1, number 2. It maybe point velocity measurement, or it maybe the determination of flow streamlines. So, when you talk about flow measurement, we are considering either the measurement of volumetric or mass flow rate, that is you know very common as I said, it finds many you know applications, engineering application to be precise.

Then, second is the point velocity measurement and third one is the determination of flow stream, stream lines. Now, the volumetric flow rate, volumetric flow rate or mass flow rate, as I said we have studied in our undergraduate fluid mechanics course, there are many instruments which are used to measure the volumetric flow rate. In particular, just now, I have said that flow obstruction flow rate measurement, I will be discussing this part today.

And other is the other, second one is the point velocity measurement, which is measurement by research. This is very important that our research type measurement, I can say the number 2, this is you know typically research type measurement. So, the point velocity measurement is typically a research type measurement, I can say the measurement, exception is there that we cannot measure the speed of the aircraft.

So, exception I can write is the measurement of you know, aircraft air speed. And third one, determination of flow stream lines it has a long and productive history, and we will try to briefly touch upon it. So, we have discussed that flow measurement, which can be considered as the measurement of the volumetric or mass flow rate number 1. Number 2, point velocity measurement, which is typically a research time measurement except the measurement of speed of air or aircraft air speed.

And last one is the determination of flow stream lines. Now, see, today, we will be focusing our discussion on flow measurement, that is the measurement of volumetric and mass flow rate. So, this flow measurement that is volumetric or mass flow, mass flow rate measurement. So, we will be focusing on this part today. And we will see that how, in fact we have seen in our undergraduate course of fluid mechanics course that, this is called flow obstruction in a flow rate measurement, whether it is volumetric flow rate or mass flow rate.

So, flow obstruction flow rate measurement that means, we have seen venturi meter, orifice meter that we have studied in our undergraduate course, fluid mechanics course. Now, we will briefly discuss today rather we recapitulate those.

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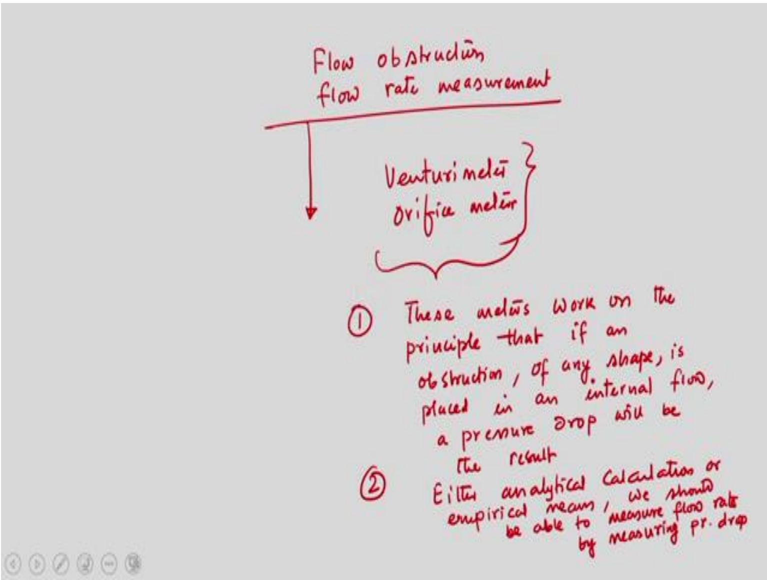

Now so, if I now start our discussion, flow obstruction flow rate measurement. Typically, devices, instruments which are used to measure flow rate following the principle of flow obstruction, in fact I can say those devices or instruments works on the principle of the fact that obstruction of any safe, if it is placed in the flow field, then it will leads to a rise in the pressure, difference, pressure drop.

And, if we measure the pressure drop, then either through empirical relationship or analytical calculation, we can calculate the flow rate and that is what we have learned. So, the instruments as I said venturi meter, say venturi meter, orifice meter. So, these 2 devices, instruments working on the principle that, obstruction of any safe if it is placed in the flow field, then it will, the placing of that obstruction will results in a drop in pressure, and if we calculate the pressure drop using empirical relationship or either using empirical relationship or using analytical method, we can calculate the flow rate. And that is what we have learned.

So, I am writing that these meters work on the principle that if an obstruction, of any shape, is placed in an internal flow field, flow of pressure drops will be the result. Now, if we can measure the pressure drop, then using, rather measuring the pressure drop we can calculate the flow rate. And that is what we know, and today I will try to outline those calculation, not in a greater detail, but we will try to discuss briefly. So, then this is 1.

And then 2, then either analytical calculation or empirical means, we should be able to measure flow rate, by using the measured pressure drop, so by measuring pressure drop. So, this is the outline, rather the principle of using flow rate, using the flow obstruction, flow rate measurement instruments.

We can start our discussion in fact, as I said I would not able to discuss that, I would not discuss this aspect in a greater detail, rather I will discuss, in a briefly to just to outline, and in fact to recapitulate what we have learned.

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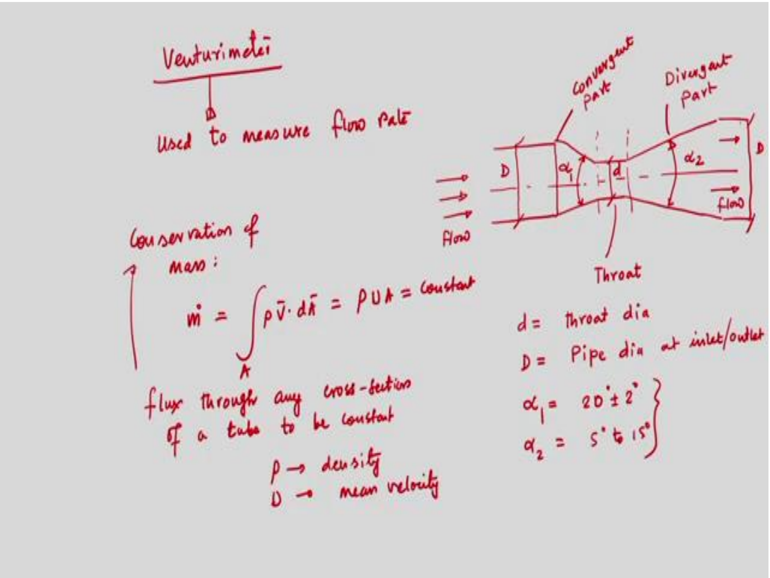

So, see, if we start using venturi meter, in fact, I will discuss only one instrument venturi meter which is used to measure flow rate so, which is used to measure flow rate. So, we know that, this venturi which is used at least to have a drop in pressure of the in the flow field. So, if I try to draw a schematic, which is very simple.

So, this is the incoming flow and say this is center line, there are 3 different parts that is clearly seen from the schematic. This is throat, and that one is convergent part, and other is the divergent part, and this is the pipe diameter D. So, this is the flow direction. So, this is divergent part, and this is convergent part. And, the diameter, the pipe is connected to the convergent part diameter D. And this angle say, you know, alpha 1 and this angle is alpha 2 and diameter of the throat, is small d.

So, d, small d is the throat diameter, capital D is the, you know pipe diameter at the inlet and outlet. So, this is pipe at the outlet, D pipe dia at inlet comma outlet. And the alpha 1 and alpha 2 these 2 are the angles, this alpha 1 these 2 are the you know, the core angle and this angle are the angle of the convergent and divergent part that is near about 20, 20 degree plus minus 2 degree.

And this is, alpha 2 is equal to 5 degree plus, 5 to 15 degrees I can say, 5 to 15 degree. Now, this is the flow direction. So, this is incoming flow and this is the outgoing flow. So, this is,e the schematic we have you know, we have seen we have studied many times. Now, this is flow obstruction fluid measurement that means, that fluid is provided, so this is a kind of obstruction.

So, the pipe diameter D which is dia at the inlet and outlet, but the pipe diameter d which is connected with the convergent part and the same pipe is connect to the divergent part in between we have of flow obstruction. So, we have venturi kind of thing. Now so, this venturi is rather, is used to provide rather a pressure drop, I can say, this when flow is approaching to the convergent part, then velocity, the stream lines will follow the geometry of the nozzle rather convergent part of the, that section of the venturi.

Now, when flow is approaching towards the throat stream lines will be deflected towards the center, and then again when the flow is coming out from the throat and towards the, approaching towards the divergent part again there will be a change in pressure and velocity that we know. So, essentially to disturb the flow field, to have a pressure drop the venturi is provided. Now, measuring the pressure drop that we need to connect pressure tapping between throat and the, we have seen that we need to connect a manometer between the throat and the upstream of the throat, that is within the convergent part.

And that, there are some issues that the pressure tapping should be connected at least one diameter, you know ahead of the one tap will be taken from the convergent part, but which is one diameter, one throat diameter ahead of the, from the throat and at least 0.5 diameter downstream of the throat, towards the divergent part. And this is done normally to check whether, because if the stream lines are not parallel to each other then the measured pressure drop using the manometers should not be the correct one and we may not get the correct result.

So, to ensure that the stream lines are parallel and the measured pressure in the flow stream, measured pressure from the flow stream is the actual pressure, to ensure that these precautions are taken that the pressure taping should be taken, connection should be taken. This location in the convergent part and that location from the divergent part, that is the condition.

Now, the measurement of pressure that is very straight forward we can get it from the u tube manometer, by observing the height (())(21:16) manometric liquid height. And then, by doing some simple algebraic calculation, we can calculate the total flow rate, rather which is, flowing through the duct rather through the pipe. And, this simple calculation we have studied in our undergraduate days.

Now, but the simple calculation we need to know, or in a fluid mechanics understanding which you have learned that continue conservation equation, that is mass conservation and then we should apply the, if we, if we consider, the flow is incompressible then, and we can apply the Bernoulli equation.

But we will discuss that, we can apply one Bernoulli equation if the fluid is in viscid, but it is not really the case. So, one correction factors should be taken into account because, because of the frictional losses the measured pressure should not be the, should not be equal to the pressure drop that is their actual in the system.

So, conservation of mass that is m dot, that I can write rho v dA, A, that is rho into u into A is equal to constant. Conservation of mass, which records the flux through any cross section of the tube is constant. So, this records that flux through any cross section of a tube to be constant. So, that is we have written in terms of mathematical expression, where rho is the density and use the appropriate mean velocity respectively.

Now, where I can write rho is the density and u, see if I apply conservation equation you can write rho times velocity times area, times is constant. So, rho times velocity times it is constant and this, you know simplification of the mass conservation equation is based on the assumptions that the velocity is uniform on that particular cross section. Density is not changing because if you consider incompressible flows, we are considering density is not changing from one cross section to other cross section.

Definitely cross section area will be changing, but the mean velocity, the velocity which is taken mean over that cross section and that is the one, that is one of the important assumptions of this simplification. So, that is the mean velocity. Now, if I write the Bernoulli equation, because we can apply Bernoulli equation in this case only under the assumption of that flow is in viscid.

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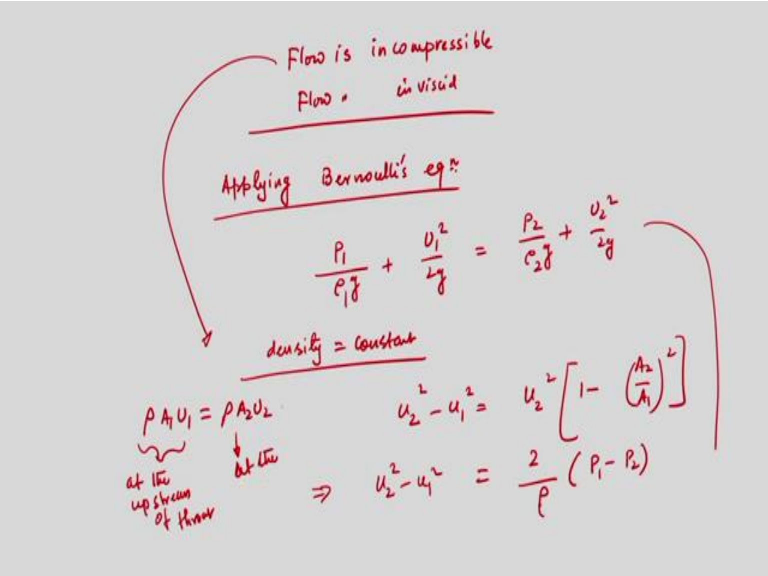

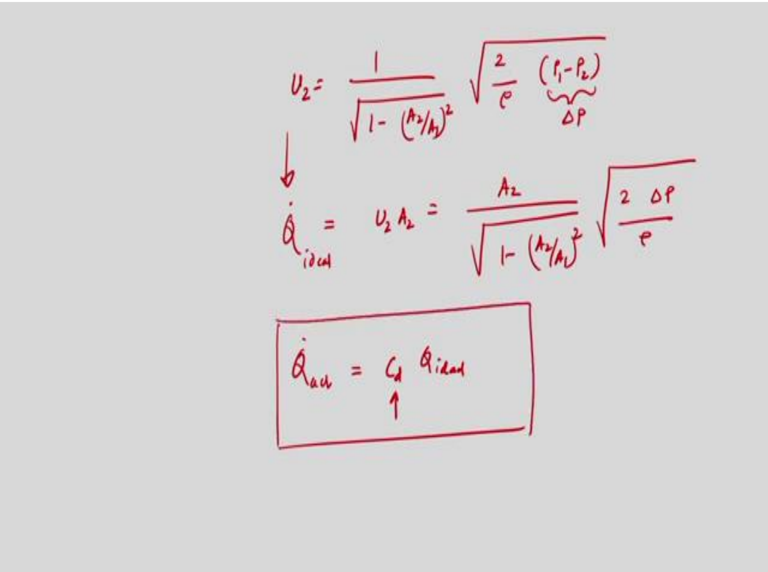

So, initially we are considering, flow is incompressible and then we are considering is flow is in viscid. But this is not the case, because this is not the case, but we are taking this assumption essentially to apply Bernoulli equation from where we can calculate the drop in pressure theoretically. And that dropping pressure if we equate with the measure dropping pressure from the manometer, from there we can calculate the velocity and then subsequently the flow rate.

Now, applying Bernoulli equation. If I apply Bernoulli equation between 2 sections, that means, one section that is at the middle of the throat and which is up stream of the throat and that is what I said that, the location of tapings should be taken carefully, so that in those locations stream lines would be parallel to each other.

So, because of the curvature effect of the stream line, the pressure will not be the actual pressure that that we are going to measure. So now, if I apply Bernoulli equation, I can write P1 by rho 1 plus V1 square by, rather I can write U1 because I have taken u. So, I am writing u1 square by 2 g is equal to P2 by rho 2 plus u2 square by 2g. And from there, in fact, I am going to write that. As you consider incompressible flow, in fact, I am considering density is also constant, density constant with a special class of, a special out class of incompressible flow.

But fine for the time being we are considering the flow is incompressible, that does not mean that density will be constant, density may change in space and time in such a way that the total effect will be, I mean substantial derivative will be 0 but, but we are going to consider that the density is equal to constant. And if density is constant, then we can write that you know, U2 square minus U1 square that will be equal to U2 square into 1 minus A2 by A1 square.

And this is nothing but, if I try to write U2 square is equal to, because from for constant density flow from the mass conservation equation I can write, rho A1 U1 is equal to rho A2 U2. From there we can write that, U2 square minus U1 score is equal to this, and this is nothing but from Bernoulli equation we can write, this is nothing but twice by rho into P1minus P2.

So, this is U2 square minus U1 square. So, this U2 minus U1 square that is nothing but 2g by 2g by rho into P1 minus P2. So, that is we have obtained. So, now, this P1 minus P2 delta P that we will get, from our experiments that is by, we have by since we have connect, since we need to connect manometer between these 2 points.

Now, I can write from that equation U2 will be equal to 1 minus, straightforward formula that we have start it many times, 1 minus A2 by A1 square root of twice by rho into P1 minus P2 that is delta P. So, knowing the velocity this U2 is the velocity, so, if we go back to my previous slide, the one, this is at the out stream, up stream of throat and this is at the throat so, this is at the throat.

So, U2 is the velocity of flow and a flow velocity at the throat. If we know there is a cross section area of the throat, we can calculate the volumetric flow rate Q. That is U2 into A2 and that is nothing but, A2 by root of 1 minus A2 by A1 square root of twice delta P divided by rho. So, this is the volumetric flow rate. We have this is Q dot I can write so, the that we have calculated. Now, this is very straight forward and we have studied this.

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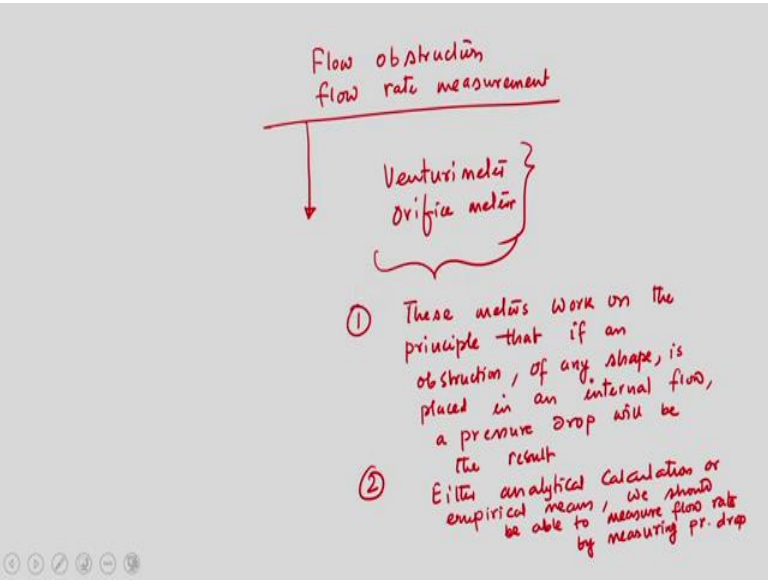

Only thing is 2 important points, that I have written in the beginning that, this flow obstruction fluid measurement techniques because venturi meter, orifice meter and also we will see that another rotavator which you know, works on the principle of drag which is you know, the flow drag.

Now, the flow obstruction fluid measurement, the venturi meter and orifice meter, these 2 meters works on the principle that if an obstruction of any safe is placed in the in an internal flow field, that obstruction will lead to drop in pressure, and if we can measure the drop in pressure from there we can calculate the velocity and from there we can calculate the flow rate that is what we have seen.

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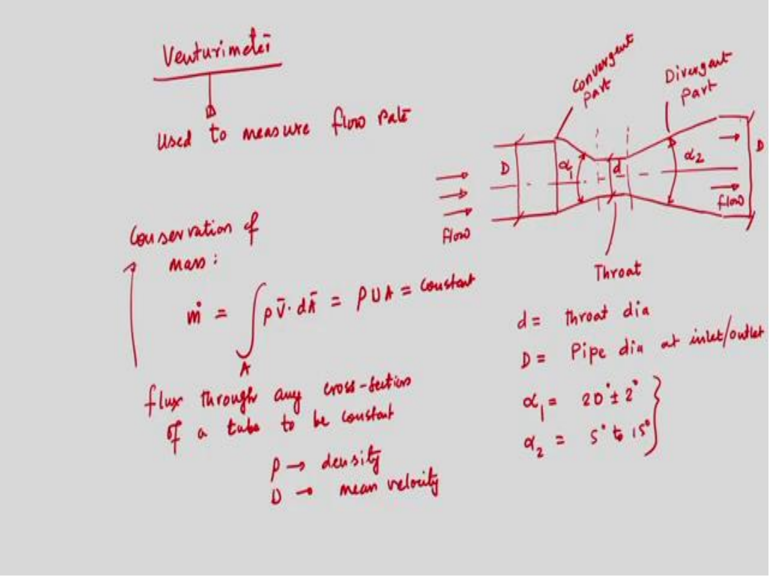

Now, these aspects are also detailed in undergraduate textbooks. In most of the undergraduate textbooks that, you know when you are connecting, you know when you are taking, you know pressure connection to measure the pressure from throat, we need to ensure that the pressure tapings should be connected from, pressure tapping should be taken from those locations where streamlines are perfectly parallel.

Because of the deflection of the streamlines, the measured pressure may not be the correct pressure, so the, our entire calculation measurement may not gives us the correct result. And this is what this schematic of the typical venturi I am not going to discuss in detail because this aspect has been discussed in most of the undergraduate textbook, where the constructional feature, there geometrical safe and all those things are described.

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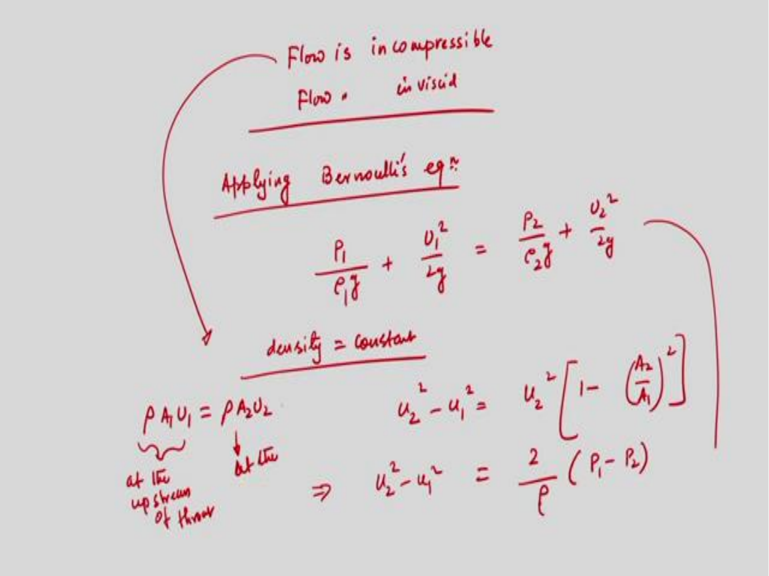

But only thing is that, we have considered 2 assumptions the flow is incompressible. So, again, I said that flow incompressible that does not mean the density has to be constant, but we have considered density is equal to constant. Variable density flow might be incompressible so, incompressible flow will be the, incompressible flow means density constant it is not the case. But we have considered density constant, if we consider density constant by applying mass conservation equation at 2 sections, we can calculate the velocity.

Now, that you know, change in velocity between these 2 sections can be correlated in terms of pressure drop that is obtained from Bernoulli equation. And we are applying Bernoulli equation forcefully because, fluid is not in viscid at all. But one of the most important assumptions of applying Bernoulli equation is that the flow fluid has to be in viscid. But applying that Bernoulli equation, if we can calculate pressure drop and we can relate pressure drop in terms of velocity field, and velocity change and ultimately, we can come up with the flow rate at the throat.

Now, since we have considered 2 assumptions, the first one is, that much, first one is not that much problematic for this analysis, density will be more or less constant for the incompressible flow.

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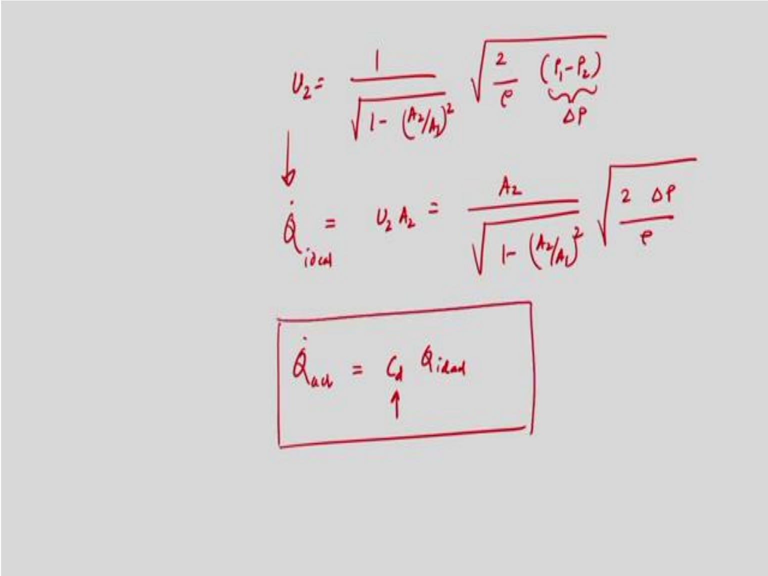

Now, since you are considering in viscid flow, the but relative fluid is not inviscid because of the viscous (())(33:41) field here, you know there will be a fictional effect between the fluid layer.

So, that effects will leads to mismatch in the measured pressure that we are getting from the u tube manometer. So, the flow rate that we are getting from this formula is not the correct one. And that is, should be multiplied one factor. So, this Q actual so, this is ideal case because here I have considered the fluid is in viscid, but in actual case the flow rate will be slightly less than the actual one and that is multiplied by one constant, that is coefficient of discharge into Q ideal. And this is close to one, that is experimentally proved value, typically from point 9 to point 9 to like this.

So, from there we can calculate the actual flow rate of the, you know internal duct and this also can be applied in any other fluidic confinement. But 2 important things is that, that the measured flow rate is not the current actual one, to obtain the actual value we have to multiply it by the CD, and the CD we have to obtain from the literature.

Now, this is all about the incompressible flow, that measurement. So, as I said in the beginning of my lecture, that flow rate measurement can be considered to be the measurement of flow or volumetric or mass flow rate. In first one, it is always not the case that fluid flow measurement is only the volumetric and fluid measurement. But since, our discussion today is focused on the flow rate measurement, means the volumetric, flow measurement is the rather today's discussion is focused on the volumetric flow rate measurement or the mass flow measurement.

So, we have discussed that part only today and we will see that, even if we focus on the volumetric or mass flow measurement, mass flow rate measurement, then what will, how we can measure the compressible flow, that the flow always may not be the incompressible one. But we need to know, if we need to measure the compressible flow, volumetric flow rate of the compressible fluid then, how we can measure.

So, that part will discuss in my next class. And along with I will try to discuss the other things that how we can calculate the flow rate using the drag that is what I have, that I have told that we can use drag to measure flow rate. So, measurement of compressible flow in an internal duct, along with measurement of flow using drag that part will be discussing in our next class. Thank you very much.