

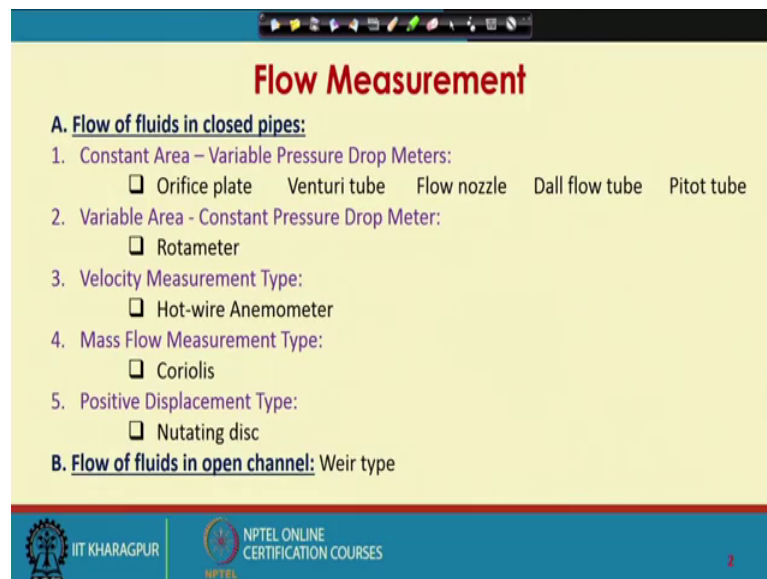
Chemical Process Instrumentation
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Lecture – 43
Flow Measurement (Contd.)

Welcome to lecture 43. We are talking about flow measurements and in our previous lecture we started our discussion on flow measuring instruments based on fixed area variable pressure drop principles.

So, all such instruments flows through a flow restriction with fixed area and then, we measure the pressure drop across the flow restriction using a differential pressure gauge and relate the flow rate to the measured pressure drop. In our previous lecture we have talked about orifice meter and Venturi meter today we will talk about flow nozzle dull flow tube and pitot tube.

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Flow Measurement

A. Flow of fluids in closed pipes:

1. **Constant Area – Variable Pressure Drop Meters:**
 - Orifice plate Venturi tube Flow nozzle Dall flow tube Pitot tube
2. **Variable Area - Constant Pressure Drop Meter:**
 - Rotameter
3. **Velocity Measurement Type:**
 - Hot-wire Anemometer
4. **Mass Flow Measurement Type:**
 - Coriolis
5. **Positive Displacement Type:**
 - Nutating disc

B. Flow of fluids in open channel: Weir type

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Temperature Measurement

Today's Topic:

- Flow Nozzle
- Dall Flow Tube
- Pitot Tube

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So, today's topic flow nozzle dull flow tube and pitot tube.

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Flow Measurement: Flow Nozzle

The flow nozzle combines some of the best features of the orifice plate and Venturi tube. It is a variation of Venturi where exit section is omitted. The approach section is bell shaped with cylindrical throat. Flow nozzle has a discharge coefficient close to unity because of its curved inlet.

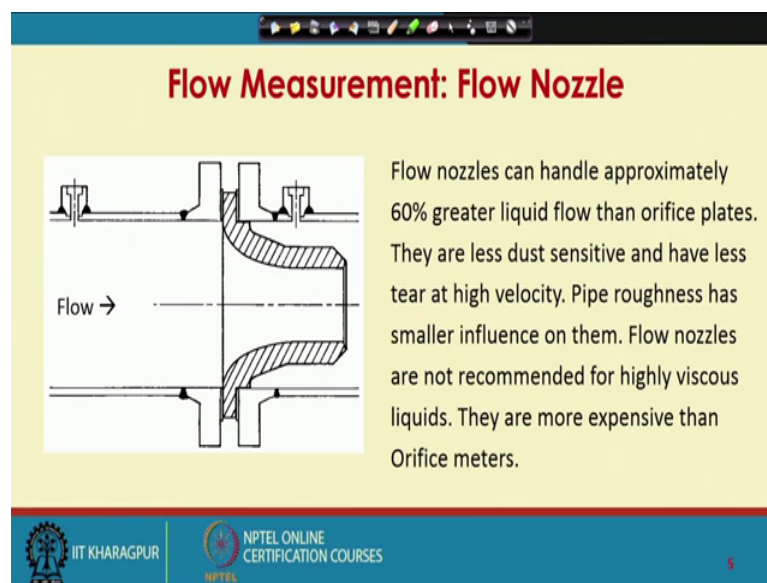
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The flow nozzle combines some of the best features of the orifice plate and Venturi tube. It is a variation of Venturi where exit section is omitted; the approach section is bell shaped with cylindrical throat, flow nozzle has the discharge coefficient close to unity because of its curved inlet. So, this is the flow nozzle, you have 1 pressure drop of 1 pressure port here another pressure port here. So, the nozzle is attached is connected in the pipe using flange. So, as the flow approaches nozzle due to flow restriction velocity

decreases velocity increases, pressure decreases you measure the pressure drop across the nozzle and then using Bernoulli's equation you relate the flow rate with the pressure drop.

So, the principle is very much similar to orifice or nozzle or Venturi meter. So, nozzle or flow nozzle is some kind of variation of venturi, where the exit section is omitted. The approach section is bell shaped with cylindrical throat because of its curved inlet the flow nozzle has a very high discharge coefficient it is close to unity.

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Flow Measurement: Flow Nozzle

Flow nozzles can handle approximately 60% greater liquid flow than orifice plates. They are less dust sensitive and have less tear at high velocity. Pipe roughness has smaller influence on them. Flow nozzles are not recommended for highly viscous liquids. They are more expensive than Orifice meters.

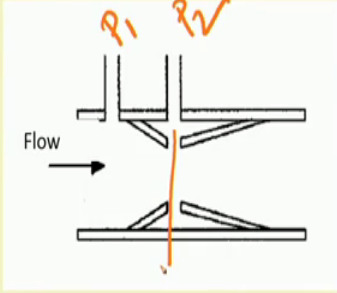
The slide features a diagram of a flow nozzle on the left, showing a bell-shaped inlet section leading to a cylindrical throat. A horizontal arrow labeled 'Flow' points from left to right through the nozzle. The nozzle is mounted on a pipe with two pressure taps: one in the approach section and one in the throat. The slide has a yellow background with a blue header and footer. The footer contains the logos for IIT KHARAGPUR and NPTEL ONLINE CERTIFICATION COURSES.

Flow nozzles can handle approximately 60 percent greater liquid flow than orifice plates, they are less dust sensitive and have less tear at high velocity. Remember that we talked about the dependency or sensitivity of the orifice plates to the flow, which has suspended particles because the sharp edge orifice plates can undergo wear and with that can change the calibration because it can change the discharge coefficient.

The flow nozzles are less dust sensitive and have less tear at high velocity pipe roughness has smaller influence on them flow nozzles are not recommended for high viscous liquids they are more expensive than orifice meters.

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Flow Measurement: Dall Flow Tube




The diagram illustrates a Dall flow tube, which is a pipe with a tapered throat and a smooth, elongated exit. An arrow labeled 'Flow' points from left to right. Two pressure measurement points are indicated by vertical lines: P_1 is located upstream of the throat, and P_2 is located at the throat. A vertical line with a downward-pointing arrow is shown at the exit of the tube.

Typical measurement inaccuracy $\pm 1.5\%$

Somewhat similar to Venturi tube, but they do not have the entrance cone. Dall flow tube has a tapered throat and the exit is smooth and elongated. They have shorter length compared to Venturi.

Less permanent pressure loss than orifice meter. Widely used for large pipe applications. Less expensive than Venturi meter.

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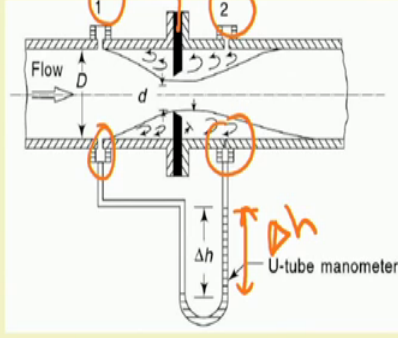


Dull flow tube this is somewhat similar to Venturi tube, but they do not have the entrance cone. Dull flow tube has a tapered throat and the exit is smooth and elongated, they have shorter lengths compared to Venturi. So, you see the exit is smooth and elongated, there is less permanent pressure drop compared to orifice meter, it is widely used for large pipe applications and it is of course, less expensive than Venturi meter. So, this is somewhat similar to Venturi tube, but much simpler to Venturi tube and less expensive than less expensive than Venturi meter.

The typical measurement in equivalency is plus minus on 1.5 percent whereas, for Venturi meter the inaccuracy is about plus minus 0.5 percent. Again you have 2 pressure connections 1 is upstream here the another 1 is right near the throat.

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A Numerical Example: Obstruction Flow Type



A Typical Case:

- Pipe diameter = 20 cm
- gas density = 1.20 kg/m³.
- Differential pressure drop measured by manometer = 10 cm of manometer liquid
- Manometer liquid has sp gr = 0.8
- Orifice dia = 5 cm
- Cd = 0.7
- Flow rate = ?

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Now, we have talked about the flow obstructions, flow meter flow measuring instruments. We have talked about orifice meter Venturi meter, flow nozzles and differential flow meters. In all these instruments there is a flow restriction whose area is accurately known. Then the resulting pressure drop is measured using a differential pressure gauge. It may be as simple as manometer for simple applications in laboratory or you can also use dp cells or any other pressure transducers which can measure differential pressure.

Then we make use of Bernoulli's equation to relate the flow rate to the measured pressure drop. Now we will take a typical numerical example which is applicable to all such flow measuring instruments. It may be orifice meter, it may be Venturi meter, it may be flow nozzle all flow measuring instruments which are obstruction type; that means, there is a flow restriction and you measure the flow rate by measuring the pressure drop across the flow restriction of known area. So, what the schematic source is an orifice, but the problem that we talked about is applicable to orifice Venturi flow nozzle differential everything all such for obstruction type flow meters.

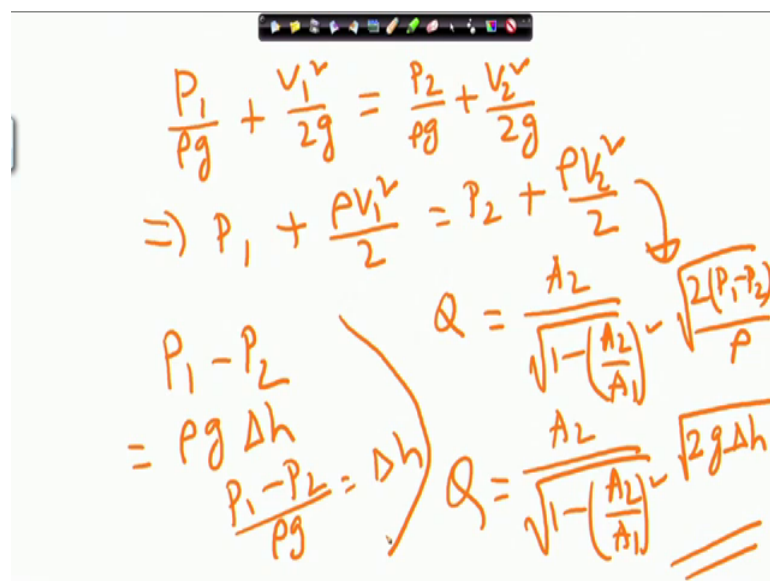
So, a typical case is like this, you know the pipe diameter, you know the fluid that is flowing you know the density of the fluid that is flowing through the pipe. So, imagine you are measuring the flow rate of a fluid flowing through a pipe using any of these obstruction type flow meters. So, you know the pipe diameter, you know the density of the fluid that is flowing through the pipe. Let us say we are measuring the differential

pressure drop or the pressure drop by a manometer. So, you will get a reading in terms of say inches of mercury or centimeter or manometer fluid, then you need to know the manometer liquids density or specific gravity and of course, you will know the diameter of the flow restriction.

Let us say if it is orifice I know the orifice diameter, if it is Venturi I will know the diameter of the Venturi throat. We will need to know the discharge coefficient of the flow meter. Now knowing all these things how do I calculate the flow rate. So, let us take a typical example where I am measuring the flow rate of a fluid which is gas here let us say, which is passing through this orifice plate. The pipe diameter is 20 centimeter, the density of the fluid is 1.20 kg per meter cube, the pressure drop I measure using a manometer is 10 centimeter of manometer liquid. Manometer liquid maybe some oil let us say.

The manometer liquid has specific gravity 0.8. The orifice diameter is 5 centimeter discharge coefficient is 0.7. So, what is the flow rate? So, what I will do is, I have this pressure connections 1 and 2 and I have put this I put both the limbs of the manometer to these ports and the manometer shows me this delta h. So, now, let us see how we solve this problem.

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$$\frac{P_1}{\rho g} + \frac{v_1^2}{2g} = \frac{P_2}{\rho g} + \frac{v_2^2}{2g}$$

$$\Rightarrow P_1 + \frac{\rho v_1^2}{2} = P_2 + \frac{\rho v_2^2}{2}$$

$$P_1 - P_2 = \rho g \Delta h$$

$$\frac{P_1 - P_2}{\rho g} = \Delta h$$

$$Q = \frac{A_2}{\sqrt{1 - \left(\frac{A_2}{A_1}\right)^2}} \sqrt{\frac{2(P_1 - P_2)}{\rho}}$$

$$Q = \frac{A_2}{\sqrt{1 - \left(\frac{A_2}{A_1}\right)^2}} \sqrt{2g \Delta h}$$

So, between point 1 and point 2 if I write the Bernoulli's equation P_1 by ρg plus v_1 square by $2g$ will be equal to P_2 by ρg plus v_2 square by $2g$ the flow meter is at

horizontal position. So, there is no contribution of h term here if you multiply this equation throughout by rho g I will get P 1 plus rho V 1 square by 2 equal to P 2 plus rho V 2 square by 2.

P 1 minus P 2 can be written as rho g delta h, the differential pressure head delta h can be written as P 1 minus P 2 equal to rho g into h. Now this equation when coupled with the continuity equation e 1 V 1 equal to a 2 V 2, we know that we will obtain Q equal to A 2 by 1 minus A 2 by A 1 whole square into 2 into P 1 minus P 2 by rho. Of course, this can be corrected by multiplying the discharge coefficient term cd, but the point we want to make here is this P 1 minus P 2 term, if it is expressed in terms of the same fluids lane that is flowing through the tube, I will be able to write P 1 minus P 2 by rho g equal to delta h.

So, this equation then can be written as A 2 by 1 minus A 2 by A 1 whole square into 2 g h. P 1 minus P 2 by rho is P 1 minus P 2 by rho is g times delta h. So, this is the equation I can get.

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Handwritten derivation showing the calculation of flow rate Q:

$$Q = \frac{C_d A_2}{\sqrt{1 - \left(\frac{A_2}{A_1}\right)^2}} \sqrt{2 \rho \Delta h}$$

$A_1 = \pi (20)^2 / 4$
 $A_2 = \pi (5)^2 / 4$
 $C_d = 0.9806$
 $Q = 49806 \text{ cm}^3/\text{s}$

10 cm of manometer liquid with spgr 0.8
 $10 \times (0.8 \times 10^3)$
 (1.20) cm of gas
 $= 6.6667 \text{ cm of gas}$

Now, we apply this equation as applicable to the problem. So, what I get is Q is A 2 by 1 minus A 2 by A 1 whole square into 2 P 1 minus P 2 by rho that can be written as 2 g and delta h.

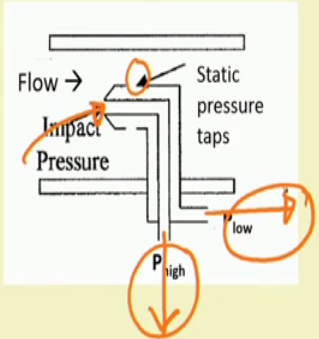
Now, I have been given the pipe diameter is 20 centimeter and the nozzle diameter is 5 centimeter. So, if pipe diameter is given as I can find out this $A_1 A_2$ term. A_1 term can be find out as πd^2 by 4. So, $\pi 20^2$ by 4. A_2 is the noz for orifice dia A_2 is the orifice or nozzle or the Venturi throat dia which is given as 5 centimeter. So, πd^2 by 4. So, these terms now will be obtained how do I get Δh .

So, the pressure differential indicated by the manometer fluid, pressure difference indicated by the manometer fluid is 10 centimeter of manometer liquid, which has specific gravity 0.8. This is same as centimeter of the gas that is flowing through the flow meter. So, this will come out as 6.6667 centimeter of the gas or fluid that is flowing through the flow meter.

Now, Q equal to this C_d times A_2 by this into $2gh$. So, this I have calculated in terms of now centimeter of the gas that is flowing through the fluid, g is given as 981 centimeter per second square and $A_1 A_2$ are calculated from here C_d is given as 0.7. So, Q can be obtained by putting all these values and if you do that you will get Q as 49806 centimeter cube per second. So, this is how you will be able to calculate the flow rate for all this obstruction flow obstruction type flow meters that we have talked about so far.

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Flow Measurement: Pitot Tube


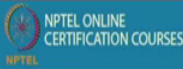



A Pitot tube consists of two coaxial tubes.

The open end of the inner tube faces the incoming fluid and senses the impact or stagnation pressure.

The outer tube has a closed end and has few holes in its walls. This senses static pressure of the fluid and its velocity head.

The flow rate is measured from the difference between static pressure and impact pressure.

Now, let us talk about another instrument known as pitot tube. The pitot tube consists of two coaxial tubes. So, this is a pitot tube, please note that there are two coaxial tubes.

The open end of the inner tube faces the incoming fluid and senses the impact or the stagnant stagnation pressure. So, this is the stagnation pressure or impact pressure. So, this is a total pressure, the open end of the inner tube faces the incoming fluid and senses the impact or stagnation pressure. The outer tube has closed end and has few holes in its wall these senses static pressure of the fluid and its velocity head.

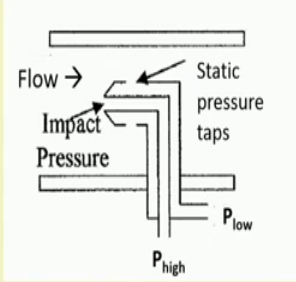
So, pitot tube consists of two coaxial tubes, the inner tube faces the incoming fluid and this faces this senses the impact pressure or the stagnation pressure. The outer tube has holes in its wall and this senses static pressure of the fluid and is velocity head.

The flow rate is measured from the difference between static pressure and impact pressure. So, this is the inner tube and faces impact pressure, these are the holes on the outer tube which measure static pressure and so, impact pressure and static pressure is higher. So, this is the pressure connection for higher pressure to the differential pressure gauge and this is the lower side of the pressure which measures the static pressure.

So, basically you now have to attach this pitot tube to a manometer or to a dp cell or to a pressure measuring instrument that measures differential pressure. So, the inner tube is the high pressure connection and the outer tube which measure static pressure that is the lower pressure connection. The flow rate is measured from the difference between this impact pressure or the stagnation pressure and static pressure.

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Flow Measurement: Pitot Tube



Alignment of tube-axis and velocity vector is important.


Assumption: Steady, one dimensional, frictionless, incompressible flow.



$$\frac{P_{stat}}{\rho} + \frac{v^2}{2} = \frac{P_{impact}}{\rho}$$

$$\Rightarrow v = \sqrt{\frac{2(P_{impact} - P_{stat})}{\rho}}$$

Aircraft application:
Air velocity is found from impact pressure and static pressure.

Static pressure alone can be used to find altitude.

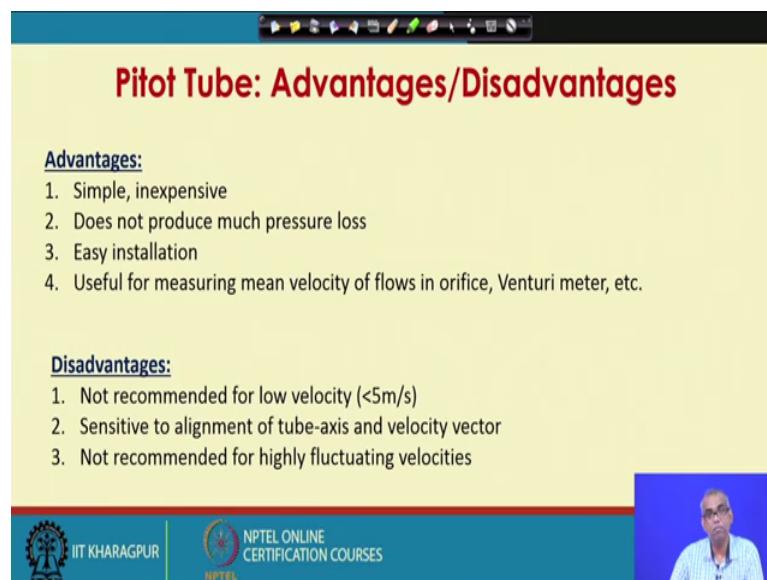


Again we making use of Bernoulli's equation the assumptions, we make we make is usual steady flow, one dimensional flow frictionless and incompressible flow. So, if I apply Bernoulli's equation, I will write static pressure divided by rho plus v square by 2 is impact pressure divided by rho, from which after rearrangement we can get an expression of velocity as follows.

So, velocity equal to square root of 2 into impact pressure minus static pressure divided by density of the fluid. Pitot tube finds an interesting application in aircraft or missiles air velocity is found from impact pressure and static pressure. Static pressure alone can be used to find altitude of the aircraft or missile. Remember that alignment of tube axis velocity vector is important for proper functioning of pitot tube.

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The slide is titled "Pitot Tube: Advantages/Disadvantages" in red text. It lists four advantages and three disadvantages. The advantages are: 1. Simple, inexpensive; 2. Does not produce much pressure loss; 3. Easy installation; 4. Useful for measuring mean velocity of flows in orifice, Venturi meter, etc. The disadvantages are: 1. Not recommended for low velocity (<5m/s); 2. Sensitive to alignment of tube-axis and velocity vector; 3. Not recommended for highly fluctuating velocities. The slide also features logos for IIT KHARAGPUR and NPTEL ONLINE CERTIFICATION COURSES, and a small video inset of a speaker in the bottom right corner.

Pitot Tube: Advantages/Disadvantages

Advantages:

1. Simple, inexpensive
2. Does not produce much pressure loss
3. Easy installation
4. Useful for measuring mean velocity of flows in orifice, Venturi meter, etc.

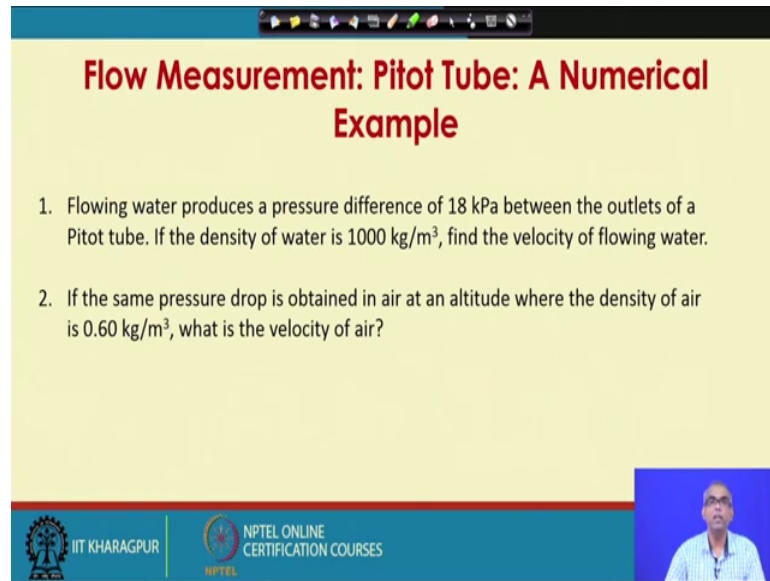
Disadvantages:

1. Not recommended for low velocity (<5m/s)
2. Sensitive to alignment of tube-axis and velocity vector
3. Not recommended for highly fluctuating velocities

Here are some advantages and disadvantages of pitot tube. Pitot tube is simple inexpensive does not produce much pressure loss, it has easy installation pitot tube is also useful for measuring mean velocity of flows in orifice Venturi meter etcetera. The disadvantages are as follows, this is not recommended for low velocity; velocity lower than 5 meter per second, what will happen is this under such situations measuring the pressure difference will be difficult.

The functioning of pitot tube is sensitive to alignment of two axis and the velocity vector, pitot tube is also not recommended for highly fluctuating velocities.

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The slide features a yellow background with a red title. At the top, there is a navigation bar with various icons. The title is in red, and the two problems are listed in black. In the bottom right corner, there is a small video inset showing a man speaking. The bottom of the slide has a blue footer with logos for IIT Kharagpur and NPTEL.

Flow Measurement: Pitot Tube: A Numerical Example

1. Flowing water produces a pressure difference of 18 kPa between the outlets of a Pitot tube. If the density of water is 1000 kg/m^3 , find the velocity of flowing water.
2. If the same pressure drop is obtained in air at an altitude where the density of air is 0.60 kg/m^3 , what is the velocity of air?

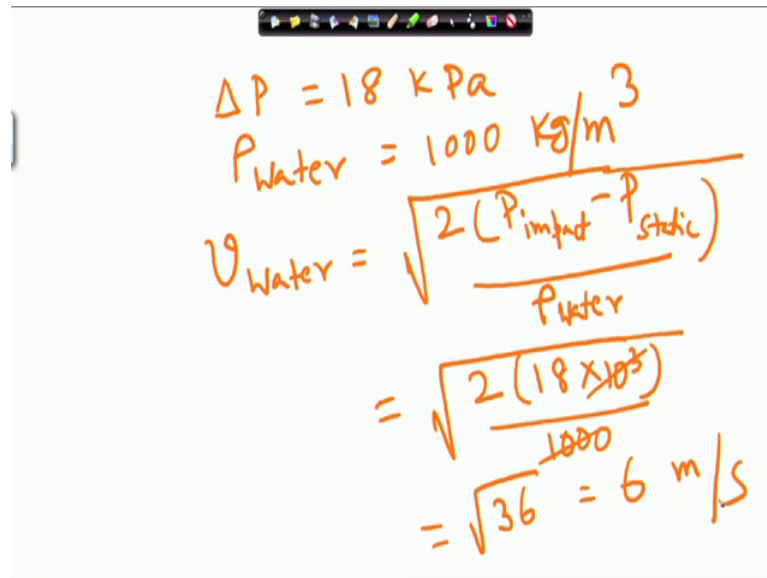
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Now, let us take a numerical example on pitot tube. Let us say water is flowing and I am using a pitot tube to measure the velocity of the flowing water. Flowing water produces a pressure difference of 18 kilopascal between the outlets of a pitot tube. So, the pressure difference between the inner tube connection and the outer tube connection is 18 kilopascals. If the density of the water is given as 1000 kg per meter cube, what is the velocity of the flowing water?

So, I am measuring the velocity of a flowing water using a pitot tube, and it has produced a pressure difference of 18 kilopascals, the density of the water is 1000 kg per meter cube what is the velocity of the flowing water. So, how do I solve this problem?

The first thing that we do is, let us write down what are the information's that are available.

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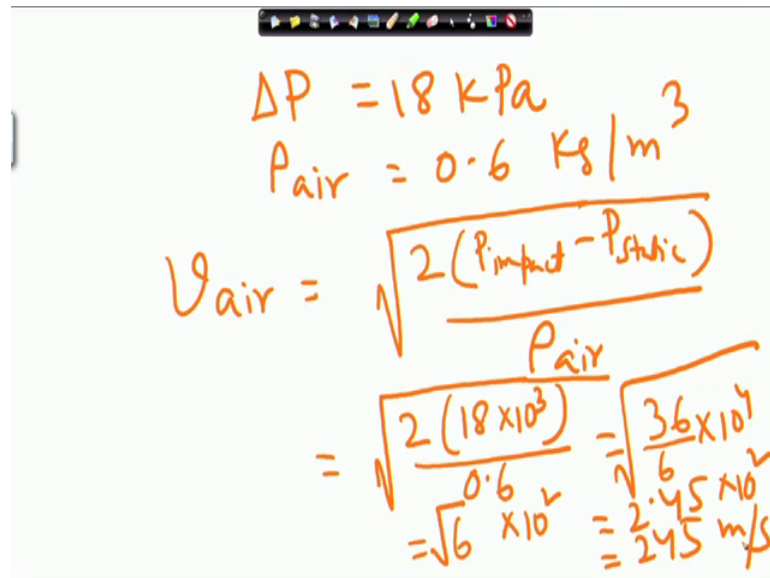

$$\begin{aligned}\Delta P &= 18 \text{ kPa} \\ \rho_{\text{water}} &= 1000 \text{ kg/m}^3 \\ v_{\text{water}} &= \sqrt{\frac{2(P_{\text{impact}} - P_{\text{static}})}{\rho_{\text{water}}}} \\ &= \sqrt{\frac{2(18 \times 10^3)}{1000}} \\ &= \sqrt{36} = 6 \text{ m/s}\end{aligned}$$

The information that is available is pressure difference between the outlets of the pitot tubes inner tube and outer tube, which measures the two pressures namely stagnation pressure impact pressure and static pressure. Delta P is given as 18 kilopascal; density of water is given 1000 kg per meter cube.

So, let us make use of the equation velocity of water, which is square root of 2 into impact pressure minus static pressure divided by density of water. So, we know all these values 18 kilopascal which is; 18 into 10 to the power 3 Pascal and density of water is given as 1000 kg per meter cube. So, this this cancels out. So, this is 2 into 18 36. So, this is 6 meter per second is the velocity of water.

So, the next part is, if the same pressure drop is obtained in air at an altitude where the density of air is 0.6 kg per meter cube, what is the velocity of the air. So, basically the same problem, now instead of water we have air and again the pressure drop is same 18 kilopascals. So, you have to find out the velocity of the air. If the same pressure drop is obtained in air at an altitude, where the density of air is 0.6 kg per meter cube what is the velocity of air?

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The image shows a handwritten calculation on a whiteboard. At the top, it lists the pressure difference $\Delta P = 18 \text{ kPa}$ and the density of air $\rho_{\text{air}} = 0.6 \text{ kg/m}^3$. Below this, the formula for air velocity is written as $V_{\text{air}} = \sqrt{\frac{2(P_{\text{impact}} - P_{\text{static}})}{\rho_{\text{air}}}}$. The calculation then proceeds to substitute the values: $= \sqrt{\frac{2(18 \times 10^3)}{0.6}}$. This is simplified to $= \sqrt{\frac{36 \times 10^4}{6}}$, which is further simplified to $= \sqrt{6 \times 10^4}$. The final result is given as $= 2.45 \times 10^2 = 245 \text{ m/s}$.

So, you can find it exactly same way again delta P is given as 18 kilopascal and density of air is given as 0.6 kg per meter cube. So, velocity of air is again impact pressure minus static pressure divided by density of air. So, 2 into 18 into 10 to the this is Pascal and density of air is given as 0.6 kg per meter cube. So, this becomes. So, this becomes 36 by 6 10 to the power 4 square root, which becomes 6 square root of 6 into 10 square square root of 6 is roughly say 2.45 into 10 square.

So, it becomes 245 meter per second. So, the velocity of the air is obtained as 245 meter per second. So, this is a straightforward application for the equations of the pitot tube.

So, we will stop our discussion on flow measuring instruments that are based on rest flow restriction type. So, we have talked about orifice plate, Venturi tube, flow nozzles dull type flow meter as well as pitot tube.