Flow measurement – fluid mechanics

Summary

In this experiment many different meters were used to measure fluid flow rate; the orifice plate, the venture meter, the rotameter and the weigh tank. Each meter works by its ability to alter a certain physical property of the flowing fluid and then allows this alteration to be measured. The measured alterations are linked directly to the flow rate and these measurements are subbed into adjusted equations to solve for it. The outcome of Each method is then analyzed, compared against each other.

1. Objectives

- To introduce the student to three typical methods of measuring the flow rate of an incompressible fluid namely;
    1. Venturi metre
    2. Orifice plate
    3. Rotor metre
- To compare the accuracy of each device.
- To give insight into appropriate industrial applications for each device.

2. Theory

Water enters and first flows through the Venturi meter, then through the Orifice plate, and then through the Rotor meter. On leaving the Rotor meter the water flows via a control valve to the weigh-tank of the hydraulic bench.

At the inlet and the outlet of each flow measuring device is a connection to the manometer board, this allows the head loss to be determined across each device. For an incompressible fluid flowing through a pipe the following equations apply:

Continuity, Q= V1A1= V2A2(1) Bernoulli's P1ρ g+V122g+z1= P2ρ g+V222g+z2(2)

Venturi Rewriting Bernoulli's equation for the experimental apparatus PAρ g+VA22g+zA= PBρ g+VB22g+zB

Since the apparatus is horizontal ZA= ZB therefore, PAρ g+VA22g= PBρ g+VB22g

Rearranging VB22g+VA22g= PAρ g+PBρ g

Since P/ρ g is the hydrostatic (pressure) head, h at any given point we can rewrite the above equation as,

VB22g+VA22g= hA-hB(3)

Where hA and hB are read directly from the apparatus. To solve for velocities, we rearrange equation (1),

VA= VBABAA Filling into equation (3),

VB22g+VBABAA22g= hA-hB(4)

Hence the only unknown as VB. Therefore, to find the flow rate, determine VB from equation (4) and then Q is given by. Q= VBAB (5)

Orifice Q is calculated using the same procedure as the Venturi meter using ports E and F as opposed to A and B.

However, because the orifice plate is less ideal, it causes turbulence in the flow it requires a correction factor known as the coefficient of discharge, K. For this apparatus K= 0. 601 therefore, the calculated Q must be multiplied by K, Qactual= Qtheoretical × K

Rotor meter

The flow rate is read directly off the rotor meter calibration curve as seen in the graph h below.

3. Apparatus:

The bulk of the apparatus used in this experiment is as shown below on a labeled diagram.

The flow of water was manually varied by a screw-type tap. The weight balance is not shown but is acted on a counterbalancing weight system. In this experiment, a 4kg weight was dropped and the time was started. The length of time was determined by how long it would take for the water to raise the weight. This (with a 1: 3 weight is to water ratio) allowed the mass flow rate to be calculated.

4. Orifice

Venturi Procedure: 1. Set flow rate to the maximum. 2. Record the monometer readings A, B, E, and F. 3. Measure the discharge using the weigh-tank. 4. Repeat steps 2 and 3 for 6 other flow rates. 5. Draw a graph of the volumetric flow rate measured by the weigh-tank versus volumetric flow rate measured by the other three devices (all on one graph). 6. Discuss the advantages and disadvantages of each device from an installation view.

5. Experimental Results:

-	A mm	B mm	E mm	F mm	Rota-meter	Flow rate (weigh – tank) @4kg (s)

1	378	131	349	86	21. 4	25
2	345	162	326	130	18. 4	31. 8
3	320	188	304	165	15. 2	37
4	298	202	288	191	12. 3	47. 5
5	282	222	274	211	9. 3	59. 4
6	266	236	262	232	5. 4	91. 5

Position	A	B	E	F
Diameter (m)	0. 026	0. 016	0. 051	0. 020

6. Sample Calculations

Venturi: As Q= VA, the volume (V) and the area (A) must be calculated first.

Volume is found from the equation (4) as shown in theory being rearranged;

VB22g+VBABAA22g= hA-hB

VB2-VB2AB2AA2= hA-hB2g

VB21-AB2AA2= hA-hB2g

VB2= hA-hB2g1-AB2AA2

VB2= hA-hB2g1-AB2AA2

VB= hA-hB2g1-AB2AA2

From this equation, V can now be calculated using the results from the experiment. Calculation carried out for the first instance:

AA= 5. 3093 × 10-4m2

AB= 2. 0106 ×10-4m2

h = the height read from the manometer in the experiment.

VB= 0. 378-0. 131(29. 8)1-(2. 0106 × 10-4)2(5. 3093 × 10-42)2

VB= 4. 4120. 85659

VB= 5. 6517

VB= 2. 3773m/s

Now that the velocity at point B and the area of point B is calculated, Q can now be worked out;

QB= VBAB

QB= 2. 3773 × (2. 0106 × 10-4)

Volumetric Flow Rate

B= 4. 7799 × 10-4m3/s

To convert into kg/s;

QB=(4. 7799 × 10-4) / 1000

Mass Flow rate B= 0. 4779kg/s

Orifice: To calculate the mass flow rate using the orifice method, calculations very similar to the venture method are used. The positions are now different so therefore the diameters are changed in finding Q. AA/VA and AB/VB are now obviously changed to AE/VE and AF/VF but otherwise the exact same method is used to find VF.

However, the overall mass flow rate has to be corrected by a factor of K= 0. 0601 due to a less efficient apparatus being tested.

AE= 2. 0428 × 10-3m2

AF= 3. 1416 × 10-4m2

VF= hE-hF2g1-AF2AE2

VF= 0. 349-0. 08629. 811-3. 1416 × 10-42. 0428 × 10-32

VF= 5. 16. 97635

VF= 5. 2851

VF= 2. 298m3/s

Q= VFAF

Q= 2. 2983. 1416 × 10-4

Q= 7. 223 × 10-4

Now multiplied by correction factor and converted to kg/s; Q= 7. 223 × 10-4) (0. 601)(1000) Q= 0. 43406 kg/s

Rota-meter The mass flow of water is worked out in this method by feeding the results read from the rotor meter into the graph as shown below;

Weigh Tank

The ratio of the weight of the load to the weight of the water in this lab is 1: 3. A weight was applied to the time the discharge was 4kg. Therefore the time taken for this discharge can allow us to calculate the mass flow rate as Mass flow Rate = KG/S.

So for the first test;

Q= 4325

Q= 0. 48kg/s

7. Calculated results

-	Venturi (kg/s)	Orifice (kg/s)	Rotameter(kg/s)	Weigh tank(kg/s)
1	0. 4779	0. 4341	0. 463	0. 48
2	0. 4116	0. 3747	0. 404	0. 3773
3	0. 3496	0. 3156	0. 341	0. 3243
4	0. 2981	0. 2636	0. 284	0. 2526
5	0. 2357	0. 2124	0. 224	0. 202
6	0. 1667	0. 1466	0. 152	0. 1312

8. Discussions

The measurement of fluid flow can prove very important in day to day applications. For example, the measurements of blood-flow rates in a human artery or the measurement of liquid oxygen in a rocket are hugely important in their field of work. Although the methods used in this lab may not all work in these cases, the selection of the proper instruments for a particular application is hugely important. Flow-rate-measurement devices frequently require accurate pressure and temperature measurements in order to calculate the output of the instrument so choosing the correct method of measurement is hugely important.

Each of the flow measurement devices used had its own advantages and disadvantages. Comparing the venturi meter the orifice plate there are some noticeable differences. Although both are suitable for clean or dirty fluids the orifice plate has a relatively low cost compared to the venturi meter. But on the other hand, the orifice plate does require a smaller diameter in comparison to the venturi meter. In day to day applications, these two factors could have a huge effect on the choice in the application. Cost is always a huge factor in any application decision and depending on the requirements for the application size could also play a vital role.

The weigh tank is a somewhat more basic approach to measuring the mass flow rate of a fluid. The human element of error in the timing of the displacement of the weight can be easily corrected by machinery and could prove very effective for applications measuring flow. The rotameter is also a

simple but effective method of flow measurement. The simple effects of parallax are a disadvantage to this application but again in day to day modern applications, computerized sensory machines can correct this very easily.

9. Conclusion

Overall this lab was a success. The results are all within the range of having explainable errors such as;

- The main error predicted is due to the ‘ snowball effect’ in calculations, where a rounding off of results at the beginning of a number of equations has a greater effect on the end result. This rounding error can have greater effects than thought and can drastically vary the end result.
- Parallax is another error caused across each application. The heights read across the manometers and the rotameter can be easily read wrong. Along with the meniscus of the fluid giving a false level and a wrong angle at the result reading can change the end result also.

Human error is always a small error to be taken into account, especially when using the stopwatch in the weight tank method of measuring the flow rate. The likelihood of reading the exact time needed is very small. This again can have a huge effect on the accuracy of the result achieved. By carrying out this laboratory students were able to become comfortable with calculations and equations that were run through in class. The ‘ hands-on approach’ of this lab allows students to understand the theory better and this, in turn, results in easier revision when studying for exams.

Overall this laboratory and its results proved successful, with results accurate with an explainable percentage of error and with students having a greater understanding in this area.

10. Bibliography:

1. CIT laboratory manual: Fluid mechanics-B. S. Massey, Applied mechanics - J. D. Walker, Fluid mechanics - Irfan A. Khan, Mechanical EngineeringScience- J. Hannah and M. J. Hiller.
2. Wikipedia – formulas / units confirmation
3. http://fetweb. ju. edu. jo – general information on each measuring meter used.