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EXPERIMENT TITLE: BERNOULLI EQUATION

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INTRODUCTION

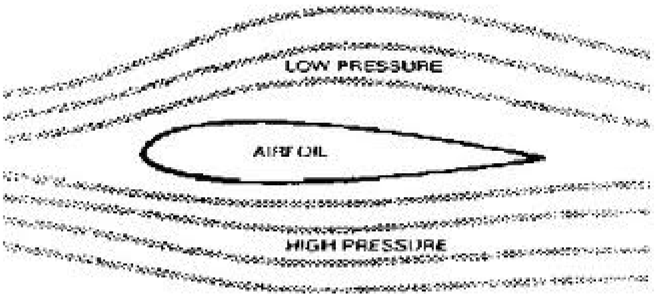
Bernoulli's principle states that for an inviscid flow, an increase in the speed of the fluid occurs simultaneously with a decrease in pressure or a decrease in the fluid's potential energy Berrnoulli's principle is named after the Swiss scientist Daniel Bernoulli who published his principle.

Bernoulli's principle can be applied to various types of fluid flow, resulting in what is loosely denoted as Bernoulli's equation. In fact, there are different forms of the Bernoulli equation for different types of flow. The simple form of Bernoulli's principle is valid for incompressible flows (e.g. most liquid flows) and also for compressible flows (e.g. gases) moving at low Mach numbers (usually less than 0.3). More advanced forms may in some cases be applied to compressible flows at higher Mach numbers (see the derivations of the Bernoulli equation).

Bernoulli's principle can be derived from the principle of conservation of energy. This states that, in a steady flow, the sum of all forms of mechanical energy in a fluid along a streamline is the same at all points on that streamline. This requires that the sum of kinetic energy and potential energy remain constant. Thus an increase in the speed of the fluid occurs proportionately with an increase in both its dynamic pressure and kinetic energy, and a decrease in its static pressure and potential energy. If the fluid is flowing out of a reservoir, the sum of all forms of energy is the same on all streamlines because in a reservoir the energy per unit volume (the sum of pressure and gravitational potential ρ g h) is the same everywhere.

Bernoulli's principle can also be derived directly from Newton's 2nd law. If a small volume of fluid is flowing horizontally from a region of high pressure to a region of low pressure, then there is more pressure behind than in front. This gives a net force on the volume, accelerating it along the streamline.

Fluid particles are subject only to pressure and their own weight. If a fluid is flowing horizontally and along a section of a streamline, where the speed increases it can only be because the fluid on that section has moved from a region of higher pressure to a region of lower pressure; and if its speed decreases, it can only be because it has moved from a region of lower pressure to a region of higher pressure. Consequently, within a fluid flowing horizontally, the highest speed occurs where the pressure is lowest, and the lowest speed occurs where the pressure is highest.



Theory:

Starting from a fluid element along a streamline derives the Bernoulli equation for steady one-dimensional flow of an incompressible, in viscid fluid:

$$\frac{V^2}{2g} + \frac{P}{\gamma} + z = \frac{P_0}{\gamma}$$

g is the specific weight of the fluid, z is the elevation, V is the velocity on the center streamline in the Venturi tube, P and P_0 are the static and stagnation (total) pressure, respectively. Then derive the expression for the velocity V along the streamline as function of g, P and P_0.

After that, the following equation becomes:

$$\frac{p}{\rho \cdot g} + \frac{v^2}{2 \cdot g} + z = h^* = const.$$

Where (in SI units):

p = fluid static pressure at the cross section in N/m^2.

r = density of the flowing fluid in kg/m^3

g = acceleration due to gravity in m/s^2 (its value is $9.81\ m/s^2 = 9810\ mm/s^2$)

v = mean velocity of fluid flow at the cross section in m/s

z = elevation head of the centre of the cross section with respect to a datum $z=0$

h^* = total (stagnation) head in m

The terms on the left-hand-side of the above equation represent the pressure head (h), velocity head (h_v), and elevation head (z), respectively. The sum of these terms is known as the total head (h^*). According to the Bernoulli's theorem of fluid flow through a pipe, the total head h^* at any cross section is constant (based on the assumptions given above). In a real flow due to friction and other imperfections, as well as measurement uncertainties, the results will deviate from the theoretical ones.

In our experimental setup, the centreline of all the cross sections we are considering lie on the same horizontal plane (which we may choose as the datum, $z=0$), and thus, all the 'z' values are zeros so that the above equation reduces to:

$$\frac{p}{\rho \cdot g} + \frac{v^2}{2 \cdot g} = h^* = const.$$

(This is the total head at a cross section).

From the continuity equation for steady incompressible flow, the mean velocity U at each cross-section of the Venturi tube is:

$$U = \frac{Q}{A}$$

Q is the volume flow rate, *A* is the cross-section area.

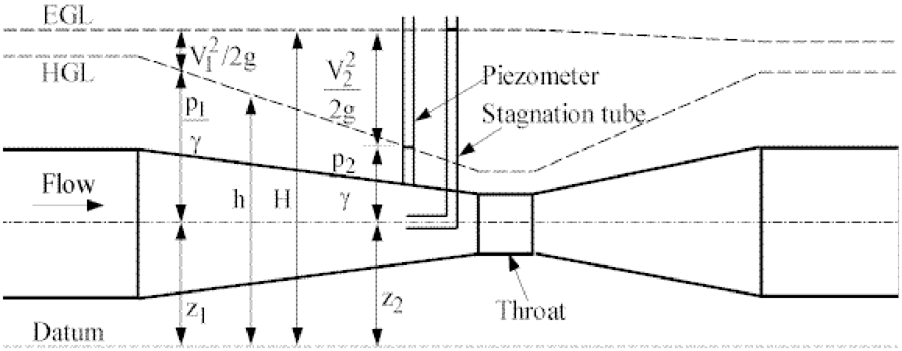


Fig. 1-Experimental Apparatus to Illustrate Bernoulli's Equation and Grade Lines

These are the heads that used in fluid mechanics:

Head	**Terms**	**Grade line and position**
elevation head	z	centerline of pipe
pressure head	$\frac{p}{\gamma}$	between centerline of pipe and HGL
velocity head	$\frac{V^2}{2g}$	between EGL and HGL
piezometric head	$h = \frac{p}{\gamma} + z$	HGL
total head	$H = \frac{V^2}{2g} + \frac{p}{\gamma} + z$	EGL

For flow in a pipe, z is usually taken to be the elevation of the centerline of the pipe. A *hydraulic grade line* (HGL) can be drawn to show the variation of the piezometric head. The distance from the centerline of the pipe to the HGL is the pressure head. An HGL above a pipe corresponds to positive pressure while an HGL below the centerline means that the pressure is negative.

An *energy grade line* (EGL) shows the variation of the total head. Since the difference between the total head and the piezometric head is the velocity head, the distance between the EGL and the HGL is also the velocity head. (The flow disturbance and the internal shear in the expansion are large enough that Bernoulli's equation does not apply. The result is a decrease in the Bernoulli constant as the flow goes through the expansion. These effects will be discussed further in conjunction with the energy equation and flow in conduits.)

OBJECTIVE

- To verify the Bernoulli equation using a Venturi tube.
- To investigate the validity of the Bernoulli equation when applied to steady flow of water in a tapered duct.

METHODOLOGY

Apparatus and materials:

Hydraulics bench, Bernoulli apparatus test equipment, stopwatch\

Procedure:

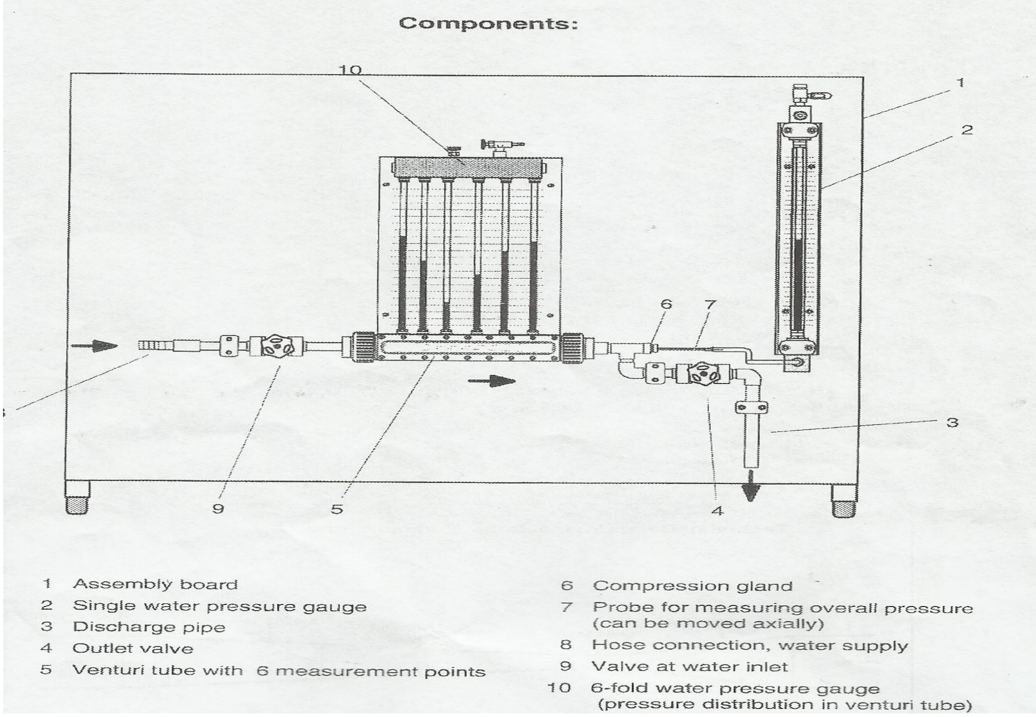

Components:
10
1
2
6
7
3
9
5
4
1 Assembly board
2 Single water pressure gauge
3 Discharge pipe
4 Outlet valve
5 Venturi tube with 6 measurement points
6 Compression gland
7 Probe for measuring overall pressure (can be moved axially)
8 Hose connection, water supply
9 Valve at water inlet
10 6-fold water pressure gauge (pressure distribution in venturi tube)

Diagram 1

1. The diagram 1 shows that the apparatus is already set up.
2. Water flow rate is adjusted as a minimum by switched on the bench valve.
3. The reading of static head h1 and h6 is observed and recorded when the reading stablized.
4. The time taken of the water filled into 10L from 0L is recorded using stopwatch after the ball valve at the bottom of the hydraulics bench is closed.
5. The step 2 until 4 are repeated by changed the water flow rate as minimum to moderate (2nd set) and maximum (3rd set) by adjusted the bench valve.

RESULT

H	**Distance into Duct (m)**	**Area of Duct A (m^2)**

H^1	0.00	490.9×10^{-6}
H^2	0.0603	151.7×10^{-6}
H^3	0.0687	109.4×10^{-6}
H^4	0.0732	89.9×10^{-6}
H^5	0.0811	78.5×10^{-6}
H^6	0.1415	490.9×10^{-6}

Figure 1.1

Section	**Static head (m)**	**Water flow rate**		
		Minimum	**Moderate**	**Maximum**
1	H_1 (total head measured)	0.100	0.200	0.280
2	**H_2**	0.085	0.160	0.230
3	**H_3**	0.070	0.130	0.190
4	**H_4**	0.055	0.090	0.140
5	**H_5**	0.035	0.030	0.055
6	**H_6**	0.045	0.080	0.135
Time taken of the water filled into 10L from 0L (s)		122s	82s	71s
Volumetric flow rate, m^3/s (Q)		1×10^{-2} m^3/122s = 8.197×10^{-5}	1×10^{-2} m^3/82s = 1.220×10^{-4}	1×10^{-2} m^3/71s = 1.409×10^{-4}

Table 1.1

Static head (m)	**Water flow rate**					
	Minimum		**Moderate**		**Maximum**	
	Velocity, m/s (V)	**Velocity head, m ($\frac{v^2}{2g}$)**	**Velocity, m/s (V)**	**Velocity head, m ($\frac{v^2}{2g}$)**	**Velocity, m/s (V)**	**Velocity head, m ($\frac{v^2}{2g}$)**
H_1	0.1670	1.42×10^{-3}	0.2485	3.15×10^{-3}	0.2870	4.20×10^{-3}
H_2	0.5403	1.49×10^{-2}	0.8042	3.30×10^{-2}	0.9288	4.40×10^{-2}
H_3	0.7493	2.86×10^{-2}	1.1152	6.34×10^{-2}	1.2879	8.45×10^{-2}

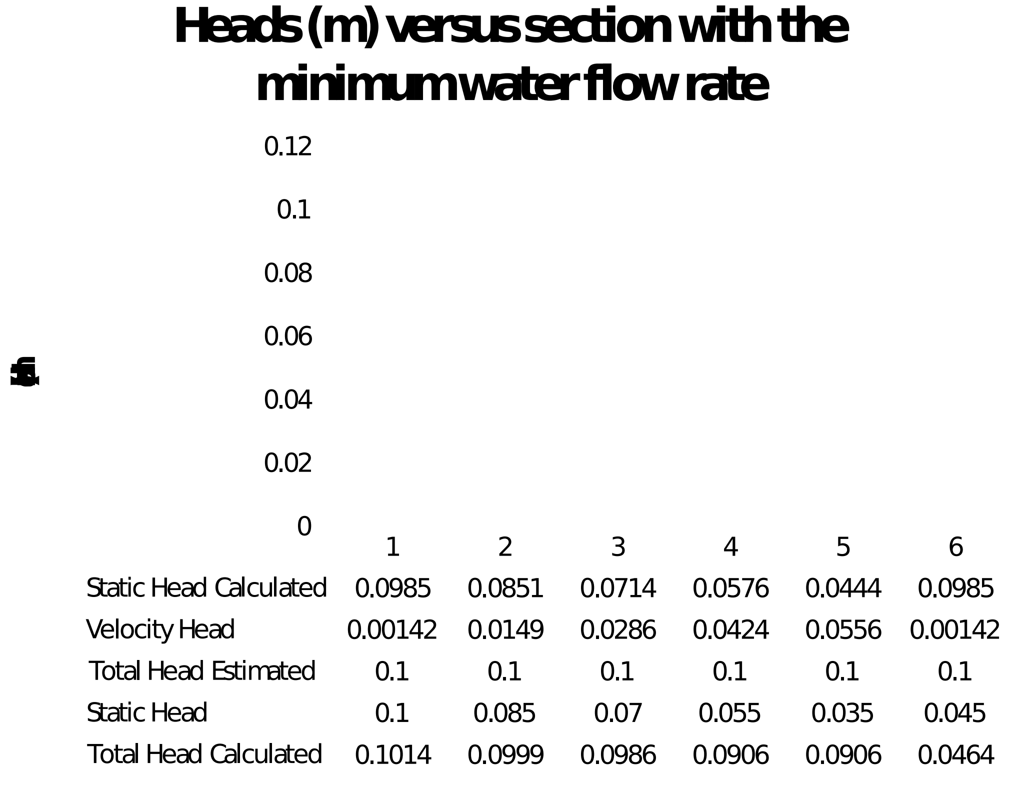
H_4	0.9118	4.24 x 10^{-2}	1.3571	9.39 x 10^{-2}	1.5673	1.25 x 10^{-1}
H_5	1.0442	5.56 x 10^{-2}	1.5541	1.23 x 10^{-1}	1.7949	1.64 x 10^{-1}
H_6	0.1670	1.42 x 10^{-3}	0.2485	3.15 x 10^{-3}	0.2870	4.20 x 10^{-3}

Table 1.2

Static head (m)	**Water flow rate**					
	Minimum		**Moderate**		**Maximum**	
	Total head calculated, m	**Static head calculated, m**	**Total head calculated, m**	**Static head calculated, m**	**Total head calculated, m**	**Static head calculated, m**
H_1	0.1014	0.0985	0.2032	0.1969	0.2842	0.2758
H_2	0.0999	0.0851	0.1930	0.1670	0.2740	0.2360
H_3	0.0986	0.0714	0.1934	0.1366	0.2745	0.1955
H_4	0.0974	0.0576	0.1839	0.1061	0.2650	0.1550
H_5	0.0906	0.0444	0.1530	0.0770	0.2190	0.1160
H_6	0.0464	0.0985	0.0832	0.1969	0.1392	0.2758

Table 1.3

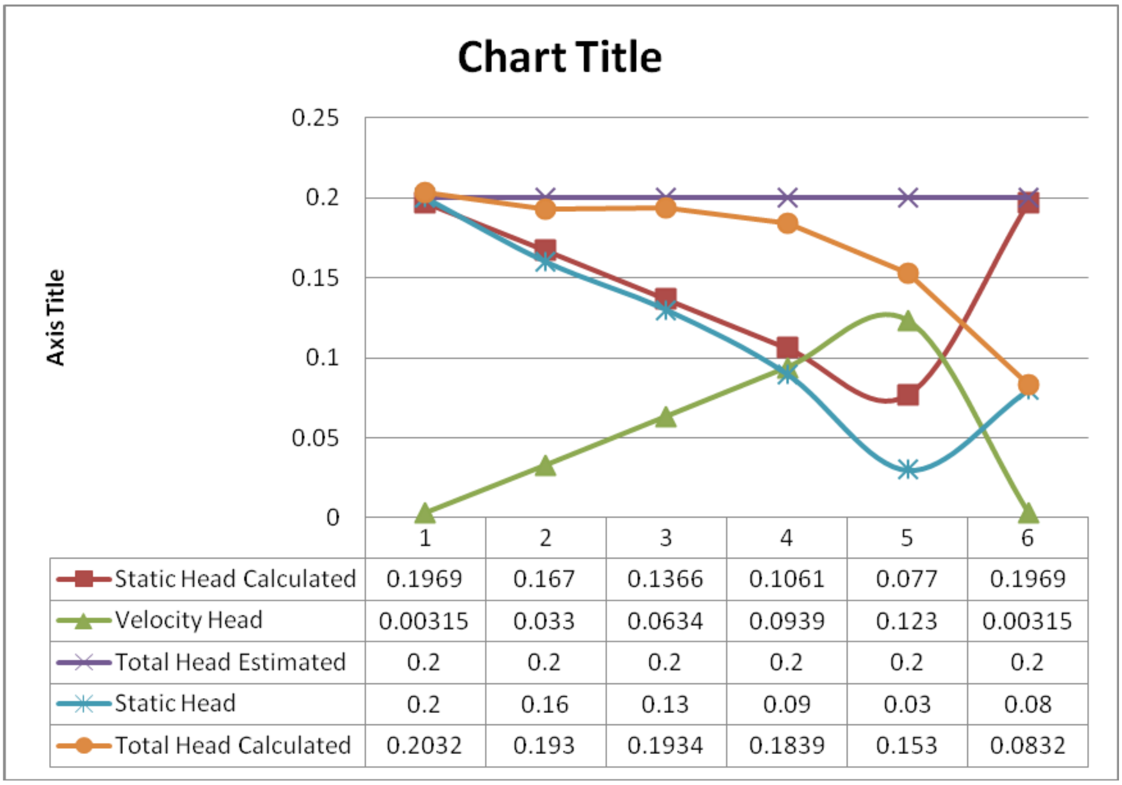
Graph:



Heads (m) versus section with the minimum water flow rate

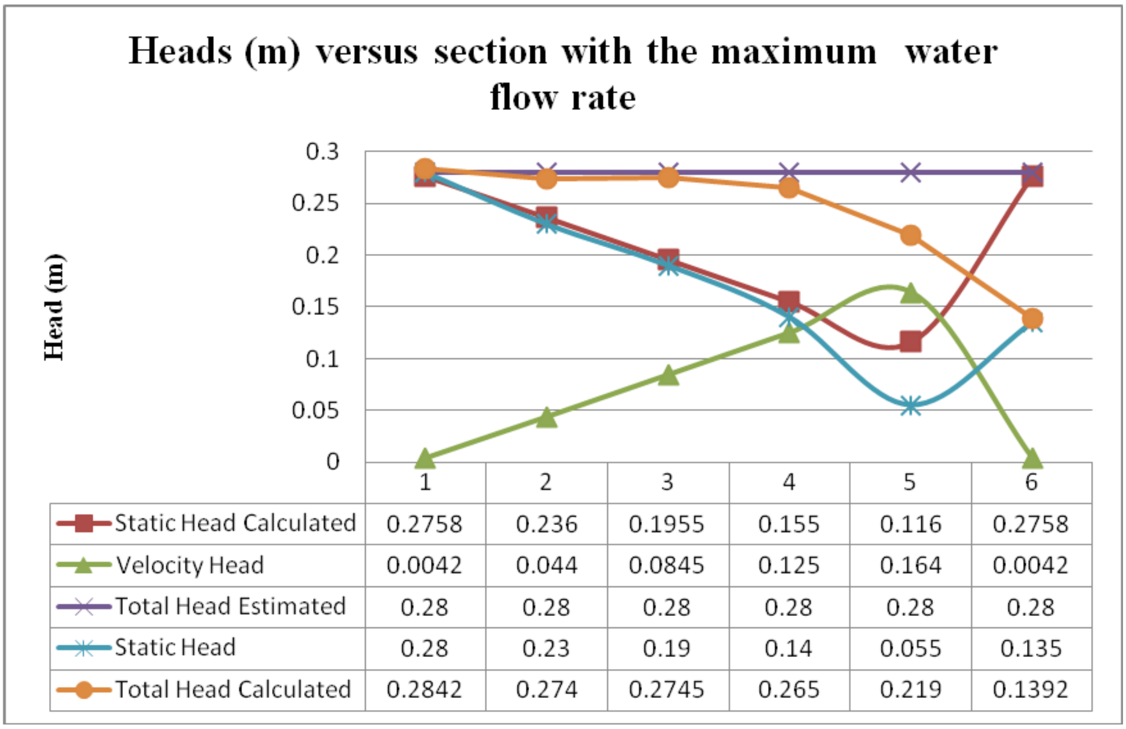
	1	2	3	4	5	6
Static Head Calculated	0.0985	0.0851	0.0714	0.0576	0.0444	0.0985
Velocity Head	0.00142	0.0149	0.0286	0.0424	0.0556	0.00142
Total Head Estimated	0.1	0.1	0.1	0.1	0.1	0.1
Static Head	0.1	0.085	0.07	0.055	0.035	0.045
Total Head Calculated	0.1014	0.0999	0.0986	0.0906	0.0906	0.0464

Graph 1.1



	1	2	3	4	5	6
Static Head Calculated	0.1969	0.167	0.1366	0.1061	0.077	0.1969
Velocity Head	0.00315	0.033	0.0634	0.0939	0.123	0.00315
Total Head Estimated	0.2	0.2	0.2	0.2	0.2	0.2
Static Head	0.2	0.16	0.13	0.09	0.03	0.08
Total Head Calculated	0.2032	0.193	0.1934	0.1839	0.153	0.0832

Graph 1.2



	1	2	3	4	5	6
Static Head Calculated	0.2758	0.236	0.1955	0.155	0.116	0.2758
Velocity Head	0.0042	0.044	0.0845	0.125	0.164	0.0042
Total Head Estimated	0.28	0.28	0.28	0.28	0.28	0.28
Static Head	0.28	0.23	0.19	0.14	0.055	0.135
Total Head Calculated	0.2842	0.274	0.2745	0.265	0.219	0.1392

Graph 1.3

Calculation:

For Table 1.1:

* 1L = 1 x 10^{-3} m^3

10L = 1 x 10^{-2} m^3 (volume of the water)

* Volumetric flow rate, m^3/s (Q) = volume of the water, m^3 / time taken to filled 10L of water, s

For Table 1.2:

* Velocity, m/s (V) = volumetric flow rate, m^3/s / area of duct for each section, m^2 (A)

Velocity Head, m = ($\frac{V^2}{2g}$)

Where: Acceleration due to gravity, $g = 9.81\ \text{m/s}^2$

For Table 1.3:

$*\ H_{Theoretical} = \frac{p}{\rho g} + \frac{1}{2g}\left(\frac{Q}{A}\right)^2 + z$

Where $z = 0$, $P = \rho\, g\, h_{\text{experimental}}$

$$H_{Theoretical} = h_{experimental} + \frac{1}{2g}\left(\frac{Q}{A}\right)^2$$

$H_{Theoretical} = h_{experimental} + \frac{V^2}{2g}$ (Velocity head)

* $H_{\text{Theoretical}}$ = Total Head Calculated, m

* Static Head Calculated, m = Total head measured, m (h_1) – Velocity head, m

ANALYSIS AND DISSCUSION

1. Comment on the validity of the Bernoulli equation for convergent flow and divergent flow?

2. Comment on the comparison of the total heads obtained by the 2 methods you have carried out?

The velocity increases as a fluid flows to wider pipe to a narrow. This shown in all result which is the velocity of water flows in the tapered duct increases as the duct area decreases This experiment was based on the Bernoulli's theorem. . From section 5 to 6, there was a big drop in the total head reading and it increased slightly from the 4 until 6, there was a decreased immediately. The graph 1.1 showed the trend of the total head along the venturi is decreasing slightly as it moves from section 1 to 4. Based on the theory, t**he pressure would decrease if there is an increase in velocity**, which explained the big drop from section 1 to 4 because the cross sectional area from section 1 to 4 decrease a lot, making the velocity of the fluid to increase thus the pressure will decrease to balance the total head constant. The flow rates of the fluid vary along the venturi. This variation was expected as the velocity of the fluid increased at certain points which contribute to the increasing of the flow rates.

Besides, the graphs showed the static head measured (experimental) and static head calculated (theoretical) have a same type of the curve graph. At the section 1 to 4, that decreased slowly and smooth but at section 5, the slope of the both static head are suddenly drop and it increased again at the section 6 (it form a slightly concave at graph 1.1 and obvious concave at graph 1.2 and 1.3 on the section 5). From the graph, the value of the static head measured (experimental) is lower than the static head calculated (theoretical).

From the graphs, when the area of the duct from wider getting to narrower, this is called convergent while the area of the duct from smaller to bigger which is called divergent. This proved that convergent flow and divergent flow where convergent flow is the static head calculated (theoretical) is decreased as the area of the duct is become smaller (Section 1 to 5) while the divergent flow is the static head calculated (theoretical) is increase as the area of duct is become larger can be refer at Section 5 to 6

B y conclusion flat slope of the data points in the converging section shows a low frictional head loss there. While there are not multiple data points in the diverging section for this configuration, it still can be seen that most of the head loss is in the diverging section. Specifically, most of the losses are between section 5 and 6, which shows that the larger loss is experienced in the expansion portion of the conduit.

Others, that estimated is total head measured, m (h_1) which is the higher value in each water flow rate the total head experimental (constant). For another method is calculated through the Bernoulli equation, (total head calculated, m). From these two methods, the total head theoretical is decreased as the flow from section 1 to section 6. That because some of the energy is used in the flow with some phenomena effect in flow.There are no big different compare to the experimental result to the theoretical result. For an instance, we calculate the difference between theoretical and experimental of velocity, the biggest different just is 0.0302.

CONCLUSION

The duct with bigger diameter, the speed of the air flow is lower and increase the velocity and dynamic head. This increase in dynamic head explains why the theoretical dynamic head is less. Therefore the pressure is highest if compare with part with smaller diameter. The highest speed occurs where the pressure is lowest, and the lowest speed occurs where the pressure is highest.There also have both type of flow which are convergent flow and divergent flow. Based on the Bernoulli equation, the velocity is inversely proportional to the area of duct while the total head is constant which mean the velocity will increases at convergent flow while it will decrease when at divergent flow depend with the shape of the pipes. Besides, we know the head loss is most in the diverging section than converging section cause the slope of the graph of the total head. Furthermore, the static head is become lower as the converging section occurs which is the area of the duct is become smaller, at the same time, the velocity head will increasing cause the total head is constant (combine of elevation, velocity and static head).

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2. Web document

Theory Part refer to(PG 3-5)

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