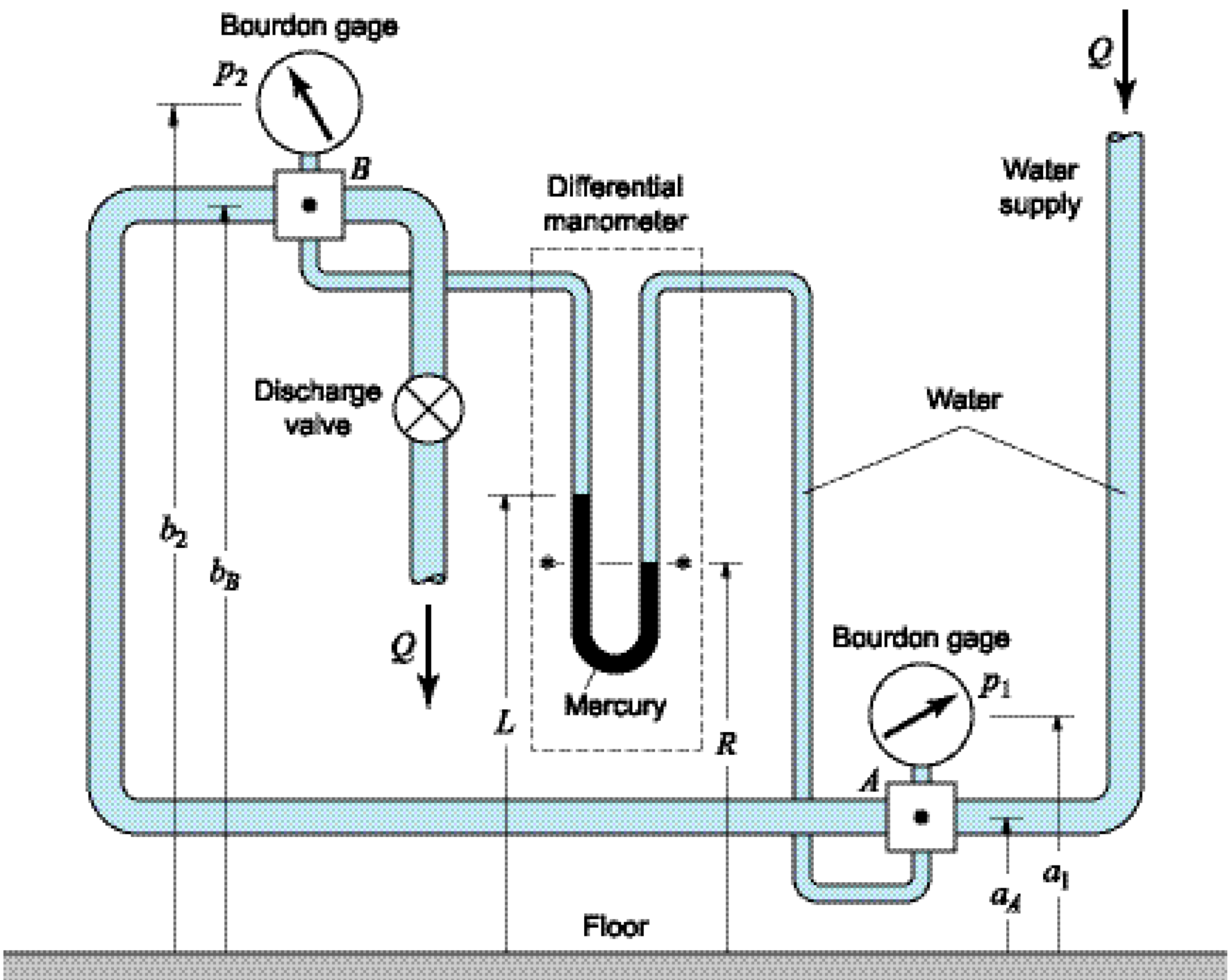
Lab 1 – Elementary Lab Procedures



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Section ABH, Monday 3–5 pm

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I. Introduction

Fluid mechanics plays a pivotal role in various engineering disciplines, providing the fundamental understanding necessary for the design and operation of countless systems. The ability to accurately measure flow rates and pressure differences within fluid systems is crucial for engineers and scientists alike. This document focuses primarily on determining the steady flow rate using a stopwatch and weighing tank and determining a pressure difference in a pipe using Bourdon pressure gages and a differential manometer. These measurement methods assist in understanding the underlying fluid theory by demonstrating the relationships between the measured values and the flow rate/pressure difference. The ability to measure and evaluate the two values form the foundation upon which more advanced experiments and analyses are built. Furthermore, the comparison between the two pressure difference measurement methods, Bourdon pressure gages and differential manometer, is made.

II. Method

a. Procedure

The measurement of steady, volume flow rate (ΔQ) and pressure difference (Δp) between two points (A and B) is done as water flows through the apparatus specified in Figure 1. The flow rate from the water supply is set to the maximum setting (100%) with the drain in the tank open for the first measurement of flow rate and pressure difference. The pressure readings from both Bourdon gages and the height readings on the differential manometer are recorded for the calculation of Δp.

The water discharged through the discharge valve flows into a weighing tank. In order to calculate the mass flow rate $\dot{M}$ (and thereby volumetric flow rate), the weight gain in the tank (W) over time (Δt) is recorded using a scale (Figure 2) and stopwatch. First, steady flow from the discharge pipe is confirmed, the cursor setting on the scale is slid to a slight overbalance (scale hits bottom stop), and the stopwatch is set to zero. The drain in the tank is then closed and when the scale hits the top stop (weight of the water in the tank is equal to the weight of the scale), a weight marker (equivalent to 100 pounds) is added, and the stopwatch is started. Once the scale hits the top stop again (the weight gain of the water in the tank is equal to 100 pounds), the stopwatch is stopped, and the value is recorded.

The above process is repeated for different flow rates (80%, 60%, 40%, 20%, and 0%). The flow rates are set using the pressure difference from differential manometer and the correlation

$$\Delta P \sim Q^2 \rightarrow \Delta P \sim \rho g \Delta h_{max} \rightarrow \Delta h_{max} \sim {Q_{max}}^2 \tag{1}$$

Therefore, for each following trial, the water flow from the water supply is adjusted until the pressure difference and therefore the height difference reading on the differential manometer is 64%, 36%, 16%, 4%, and 0% of the maximum pressure difference.

b. Equipment

The weight–time measurement of steady, volumetric flow rate requires the following equipment to accurately capture fluid flow:

- Weighing Tank: A tank mounted on a beam scale is used to capture the entire flow. This tank is equipped with a drain that can be opened and closed. A pipe situated directly above empties into the tank.
- Scale: The scale is used to measure the weight of the tank. The movement of the scale represents the mass flow rate, where the scale balances out once the tank reaches a desired weight. A balance beam mechanism is used so that small weight markers can be compared to a fraction of the tank weight. The scale rebalances when the additional weight added to the tank is equal to the weight chosen. The entire scale is demonstrated in Figure 1.
- Stopwatch: A stopwatch starts when the scale reaching equilibrium with one weight marker. At this time, another weight marker is added and the stopwatch is stopped when the scale reaches equilibrium again. The recorded value is used to calculate the volumetric flow rate.

III. Results

The data obtained from volumetric flow rate pressure measurements from Bourdon gages, and height measurements from differential manometer is collated by trial in Table 1. For each trial, the mass flow rate is

$$\dot{M} = \frac{W}{g\Delta t} \quad (2)$$

and corresponding volumetric flow rate is

$$Q = \frac{\dot{M}}{\rho} = \frac{W}{\rho g \Delta t} = \frac{W}{\gamma_w \Delta t} \quad (3)$$

where ρ is the mass density of water, g is the gravitational constant, and the specific weight of water $\gamma_w = \rho g$. Then, for the pressures measured at the Bourdon gages at points A and B, the Bernoulli and pressure equations are used and the measured pressure is subtracted by the atmospheric pressure:

$$p_A = p_1 + \gamma_w(a_1 - a_A) \quad (4)$$

$$p_B = p_2 + \gamma_w(b_1 - b_B) \quad (5)$$

Therefore, the pressure difference using Bourdon gages is

$$\Delta p = p_A - p_B \quad (6)$$

Similarly, the absolute heights of the left and right readings of the differential manometer is used to calculate the pressure on each side:

$$p_R = p_A + \gamma_w(R - a_A) \quad (7)$$

$$p_L = p_B + \gamma_w(b_B - L) + \gamma_{Hg}(L - R) \quad (8)$$

where the left height reading $h_L = R - h_0$ and the right height reading $h_R = R - h_0$ can be substituted. Therefore the pressure difference using the differential manometer is

$$p_L - p_R = \gamma_w(b_B - a_A) + (\gamma_{Hg} - \gamma_w)(h_L - h_R) \quad (9)$$

The graph of the pressure difference determined by the Bourdon gage method as a function of the pressure difference determined by the differential manometer method is charted in Figure 3.

The graph of the pressure differences calculated by both methods as functions of the volumetric flow rate is charted in Figure 4.

IV. Discussion

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V. Conclusions

This report entails not only the method for measuring volumetric flow rate and pressure differences at different points in a pipe system, but also the significance of using different measuring methods affecting the accuracy of derived values.

VI. References

Keane, Phillips, *Manual: Elementary Laboratory Procedures*, 2020

VII. Appendix

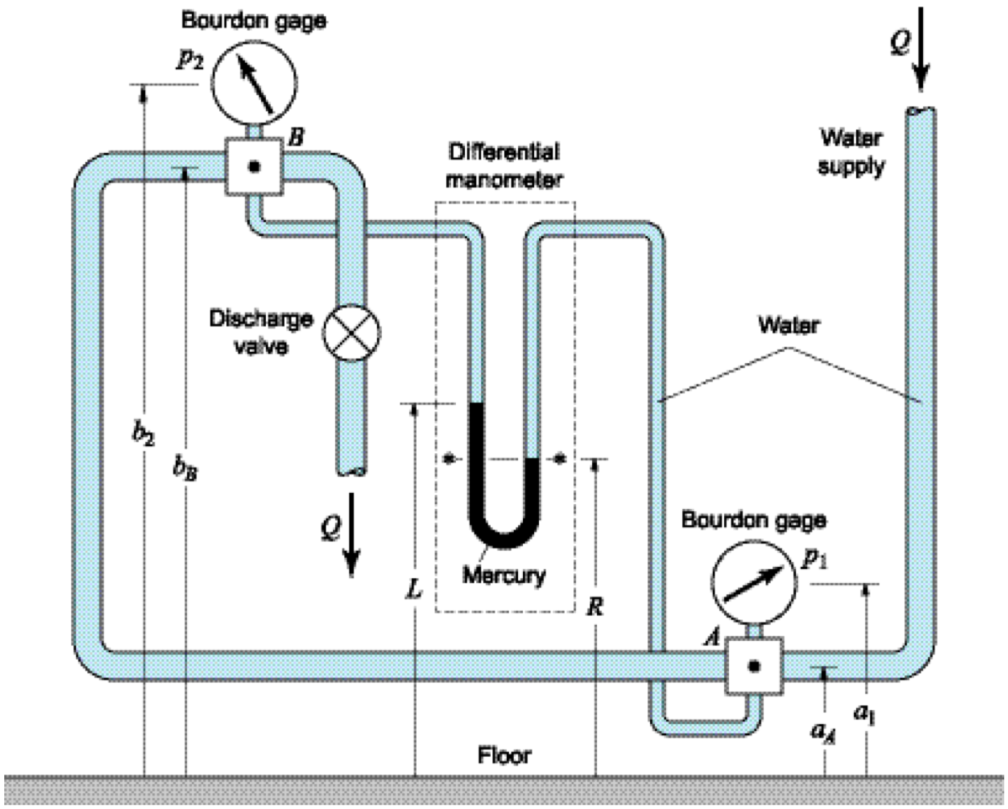


Figure 1: The apparatus for flow control and differential pressure measurements.

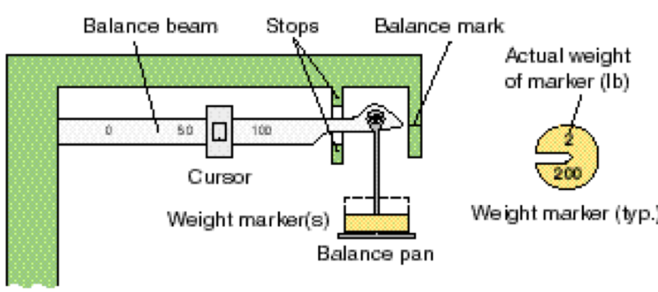
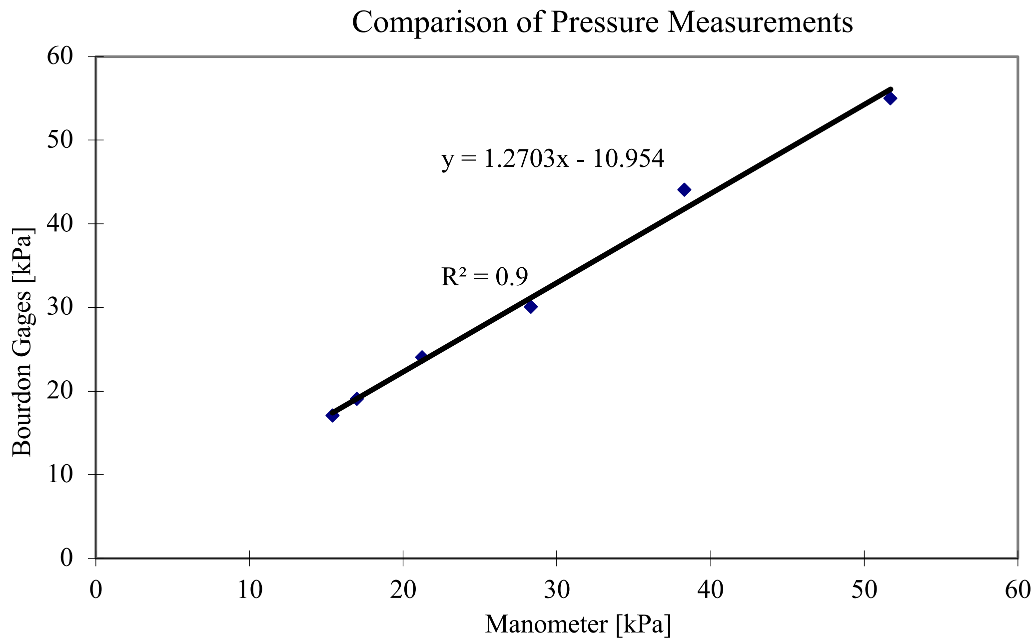


Figure 2: Tank scale mechanism



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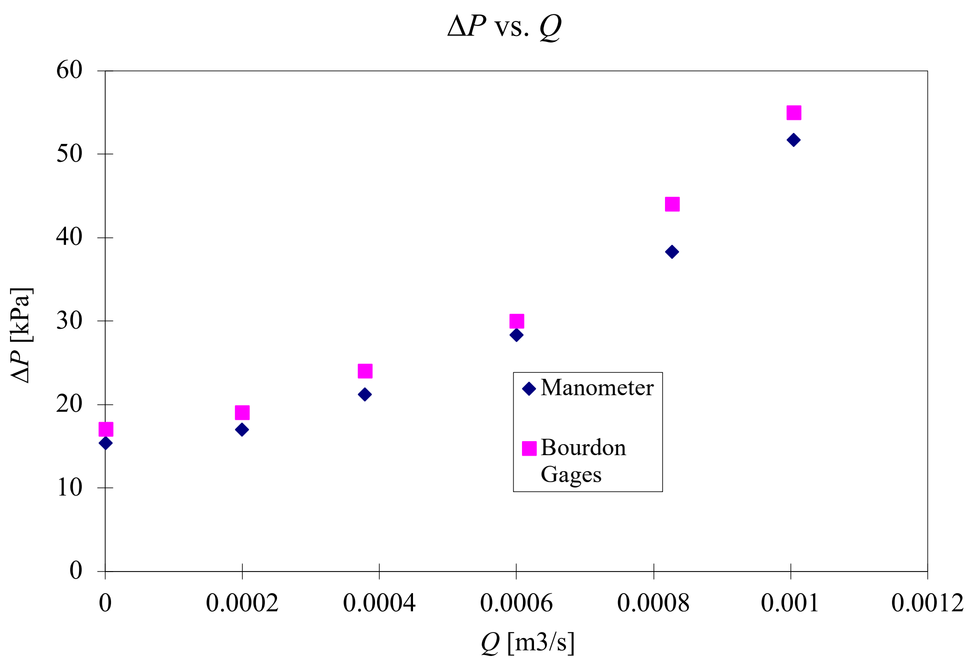

Figure 1: The apparatus for flow control and differential pressure measurements.

Table 1. Data table with measured parameters

Run no.	Volumetric flow rate				Bourdon gages			Manometer			$Q\%$
	W	Δt	Q		p_1	p_2	$p_A - p_B$	h_L	h_R	$p_A - p_B$	
---	lb	sec	ft^3/s	m^3/s	kPa	kPa	kPa	cm	cm	kPa	---
1	100	45.2060	0.03545	0.00100397	70	15	55.0392	14	-15.5	51.7206	100
2	100	54.90	0.02919	0.00082676	102	58	44.0392	8.6	-10	38.301	80
3	100	75.63	0.02119	0.00060012	118	88	30.0392	4.6	-5.9	28.3288	60
4	100	119.91	0.013365	0.00037849	134	110	24.0392	1.75	-3	21.2497	40
5	100	227.59	0.007041	0.00019942	142	123	19.0392	0.2	-1.1	17.0022	20
6	100	---	---	---	145	128	17.0392	---	---	15.4017	0