7 Singapore has enjoyed good quality tap water for more than five decades as a result of sound watershed management, effective water treatment processes and continued investments in Research & Development. Our tap water is well within the World Health Organization drinking water guidelines, and is suitable for drinking without any further filtration.

Raw water from various sources is conveyed by pipelines to the waterworks where it is chemically treated, filtered and disinfected. To ensure that the tap water is clean and safe, water samples are regularly collected and analysed chemically and bacteriologically at the Water Testing Laboratory. Samples of water at various stages of treatment at all waterworks, raw water from all sources, treated water from all service reservoirs and selected points in the distribution network are collected for daily or periodic analysis.

In these water treatment plants, it is important to monitor the water flow rates at the different stages of treatment so that the water pressures are kept at a safe acceptable level. One common way to monitor flow rate is to use the orifice meter.

An orifice meter is a piece of equipment used to measure the flow rate of a gas or a fluid. It mainly consists of an orifice plate, an orifice plate housing, and a meter tube. Fundamentally, it works on the Differential Pressure Measurement principle. The liquid or gas whose flow rate is to be determined is passed through the orifice plate. This creates a pressure drop across the orifice plate, which varies with the flow rate, resulting in a differential pressure between the outlet and inlet segments. This pressure drop is measured and used to calculate the flow rate of the fluid or gas.

There are several advantages of using the orifice meter. Firstly, it is cost-effective and quite easy to use. It occupies less space, making it ideal for space-constrained applications. It can be used to determine flow rates in small and large pipes. On top of that, it can be installed in the horizontal or vertical positions.

Fig. 7.1 shows a side view of an orifice meter, which consists of a thin orifice plate with a circular hole through it. There is a pressure tap upstream from the orifice plate and another just downstream. Both pressure taps are connected to a manometer. As a liquid passes through the orifice constriction, it experiences a drop in pressure across the orifice. The pressure drop is then used to measure the volume flow rate of the liquid. A front view of the orifice plate is included on the left for easy reference.

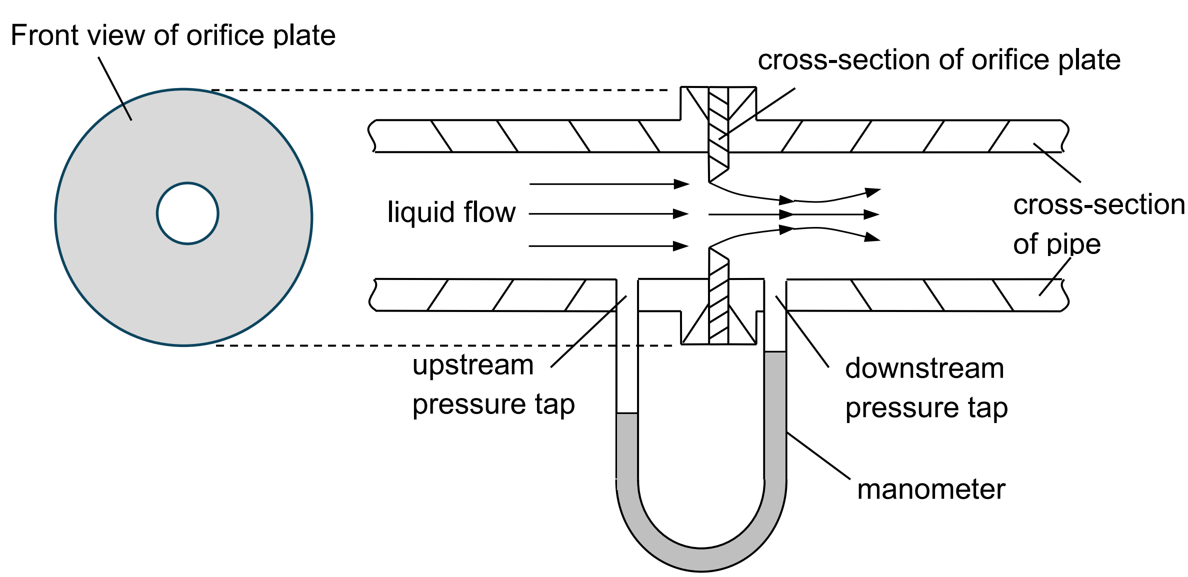

Fig. 7.1

The volume flow rate and pressure drop across the orifice plate are Q and Δp respectively. The variation with Q of Δp is shown in Fig. 7.2.

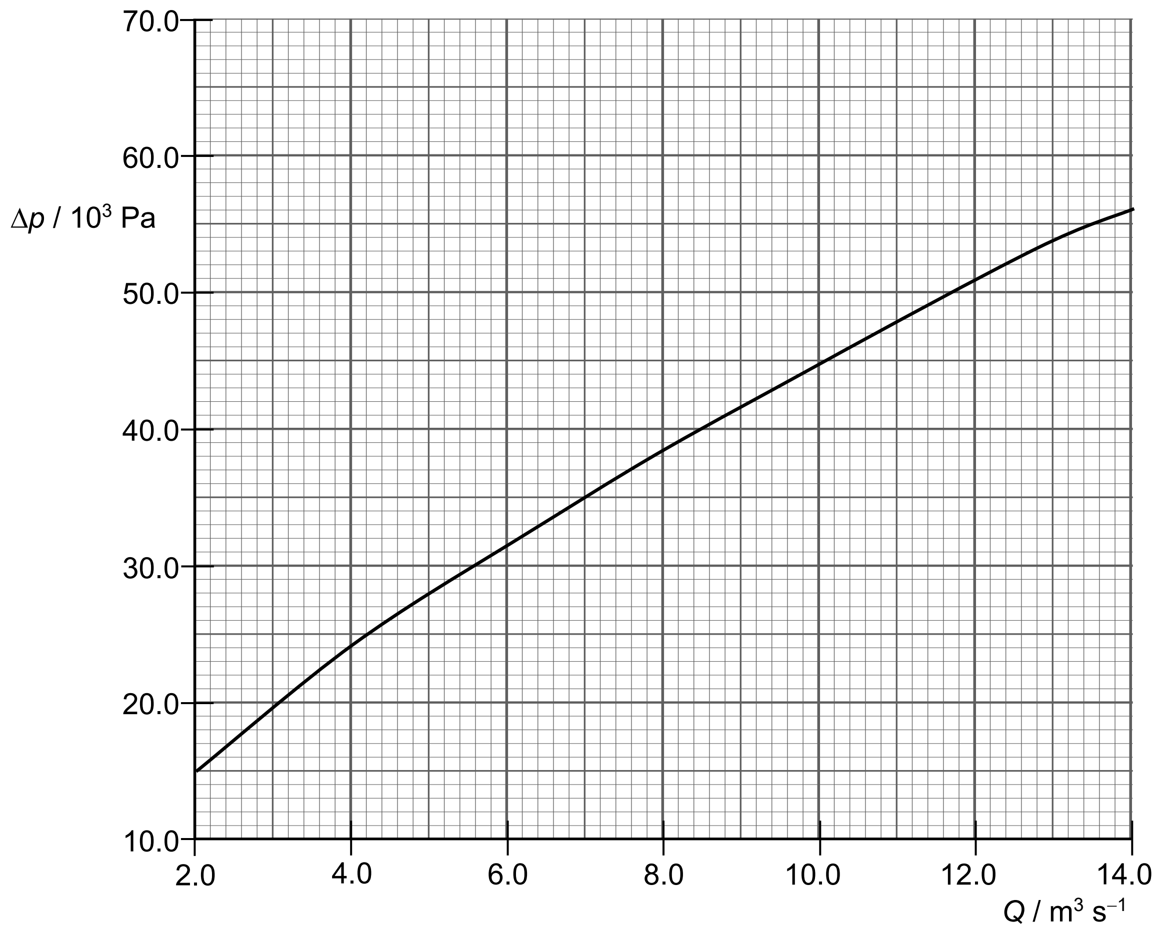

Fig. 7.2

(a) Describe, without calculation, the variation with Q of Δp.

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....[2]

(b) Suggest why there is a pressure difference between the upstream pressure and downstream pressure during a uniform water flow process.

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....[2]

(c) Suggest whether the pressure difference will be affected if the orifice meter is installed in a vertical position, instead of the horizontal position.

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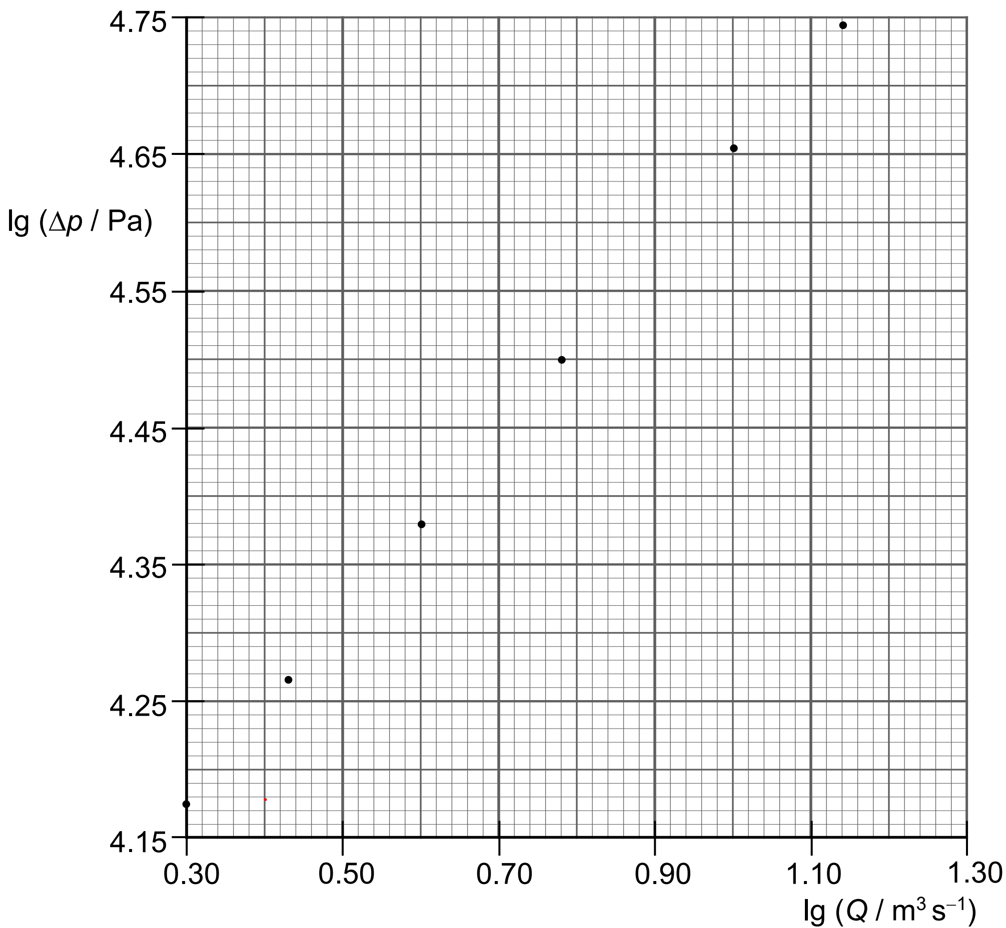
....[2]

(d) The relation between Δp and Q is thought to follow the expression

$$\Delta p = kQ^n ,$$

where k and n are constants.

Data from Fig. 7.2 are used to obtain values of lg (Δp / Pa) and lg (Q / m^3 s^{-1}). These are plotted on the graph of Fig. 7.3.



(i) Use Fig. 7.2 to determine lg (Δp / Pa) for $Q = 8.0\ m^3\ s^{-1}$.

lg (Δp / Pa) = ……………………… [2]

(ii) On Fig. 7.3,

1. plot the point corresponding to $Q = 8.0\ m^3\ s^{-1}$,

2. draw the best fit line for all the points. [2]

(iii) Determine the gradient of the line drawn in **(ii) 2**.

gradient = ……………………… [2]

(iv) Using your answer in **(iii)**, determine the magnitude of k.

magnitude of k = ……………………… [2]

(v) Determine the SI base units for k.

SI base units = ……………………… [2]

(e) Theory suggests that k is given by the expression

$$k = \frac{\rho}{1.2\,A_o^2},$$

where A_o is the area of the circular hole in the orifice plate and ρ is the density of the liquid used.

(i) Use your answer in **(d)(iv)** to determine the radius r of the hole if the liquid used is water of density 1000 kg m^{-3}.

r = ……………………… m [2]

(ii) On Fig. 7.3, sketch a second graph to represent the results for oil, instead of water.

[1]

(iii) On Fig. 7.2, sketch a second graph to represent the results for oil, instead of water.

[1]

(iv) Hence, state and explain how the design of the manometer needs to be different for the measurement of the volume flow rate of oil, instead of water.

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