Design and development of primary orifice plate flowmeter

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Abstract: Accurate and stable gas flows are very important in different applications like, the performance study of vacuum pumps, gauge calibration, leak detection and advance research in low pressure physics. Primary Orifice Plate Flowmeter (OPF) has been designed and developed indigenously. This flowmeter consists of two orifice plates. Orifice-1 (O_1) acts as a flow restriction, while orifice-2 (O_2) enables continuous pumping mode. By varying upstream pressure P_1, a change in downstream pressure P_2 is recorded, and the flow-rate is calculated from the conductance "C" of the orifice O_1 and pressure difference by the relation $Q = C(P_1 - P_2)$. Main feature of this primary OPF is that it is very simple and compact. A stable and reproducible flow-rate has been achieved in the range of 10^{-5} to 10^{-6} mbar.l/s. A variation in Q has been observed with a change in temperature of orifice and orifice diameter.

1. Introduction

Accurate measurement of the transport of gas molecules from low vacuum to high vacuum has been greatly emphasized throughout the history. Small gas flows occur at very low rate, but its impact bring significant changes in sophisticated and complex manufacturing processes and research work, like mixing of gases in different ratios, gauge calibration, fusion and particle accelerators, in electronic devices manufacturing labs and leak testing laboratories. Measurement of such micro-flow is very crucial and fluctuations in gas flow may result in errors.

In last couple of decades, rapid industrialization has taken place in Pakistan. During this period, the understanding of vacuum technology has improved remarkably. A large number of industries and research laboratories in Pakistan are using vacuum technology because of the increasing demand of innovations in industrial products. A primary flowmeter for the calibration of leak was demanded by industries and research laboratories, which motivated us to initiate a step towards the development ofa Primary Orifice Plate Flowmeter (OPF).

In the present work design parameters, performance and results of this OPF are discussed in detail. A detail of flowmeter designs is discussed comprehensively in literature [1]. OPF is a constant volume flowmeter and flow-rate for Nitrogen gas with high purity (99.99%) generated through this

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flowmeter is presented in this paper. The compact design of OPF ensures minimum out gassing rate. Due to compact design with minimum surface to volume ratio of the OPF alongwith conflate flanges ensures minimum outgassing rate.

2. Experimental setup

A schematic diagram of the OPF is shown in figure 1. It consists of two small volumes with upstream and downstream pressure sides separated by a specially designed orifice plate "O_1". Upstream pressure side P_1 is installed with a Pirani gauge, whereas downstream side P_2 is monitored by cold cathode gauge. Both the gauges were calibrated on primary standard before installation on the OPF. Upstream side is connected with a buffer through a fine needle valve. It adjusts reference pressure in the upstream side which varies from 10^{-2} to 10^{-1} mbar. The buffer is further connected to the gas cylinder through a regulated valve.

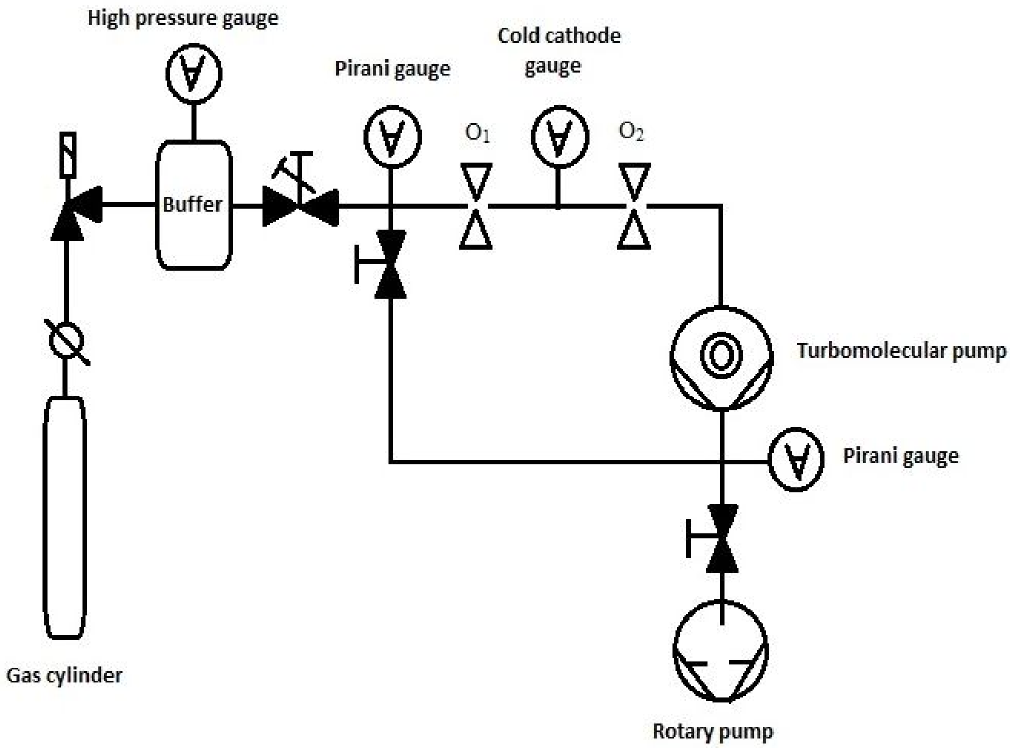

Figure 1. Schematic diagram of Orifice Plate Flowmeter.

The arrangement, shown in figure 1, helps in maintaining a desirable upstream pressure P_1. Downstream side is pumped by turbo molecular pump backed by rotary vane pump. A second orifice "O_2" of 1.7 mm diameter is installed between "P_2" side and turbo molecular pump to maintain a dynamic flow. The idea of two orifices is also reported in literature [2,3]. The flowmeter is designed such that the conductance of orifice "O_1" is kept smaller than that of the "O_2", and the conductance of "O_2" is in turn smaller to that of the pumping speed of turbo molecular pump. To minimize outgassing, orifice plates are sandwiched between conflate flanges. Two different orifice plates of orifice diameter 110μm (O_a) and 130μm (O_b) respectively have been employed at "O_1" position. These plates were specially designed for OPF. Stainless steel sheet was electron beam welded in copper seal as shown in figure 2.

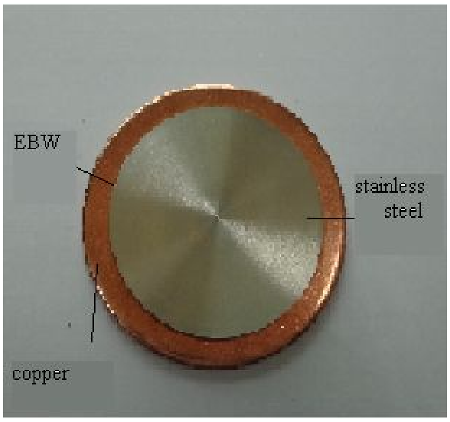

Figure 2. Orifice plate used in experiment.

Flow-rate Q of the flowmeter was calculated by the following equation (2.1) [4]:

$$Q = C(P_1 - P_2) \tag{2.1}$$

Where C is conductance of the orifice O_1 and P_1 and P_2 are upstream and downstream pressures respectively. The conductance C of orifice in the molecular regime is given by equation (2.2) [4]:

$$C = 3.64A\sqrt{\frac{T}{M}} \tag{2.2}$$

Here T is temperature, M is molecular weight of the gas and A is area of the orifice. The main objective of current work was to study the behavior of flow-rate with different orifice diameters and to study the effect of temperature on the flow-rate.

3. Results and discussions

The objective of the present work was to study the behavior of flow-rate with different orifice plates O_a & O_b. The flowmeter consists of CF flanges, CF cross, ionization gauges and copper seals with orifice plates. The whole assembly (all metal) was leak tested at 5×10^{-9} mbar.l/s and baked at high temperature (150 ^{o}C) that is more than the experimental temperatures (75 ^{o}C). Figure 3 shows a plot of flow-rate Q vs upstream pressure P_1 at three different temperatures 25 ^{o}C, 50 ^{o}C and 75 ^{o}C for orifice plate O_a. The variation in upstream pressure from 2×10^{-2} to 2×10^{-1} mbar was kept same for all the three temperatures. Results show that flow-rate Q increases linearly with an increase in upstream pressure P_1 and temperature effect is also prominent as shown in figure 3. A variation in flow-rate has been observed when temperature was raised from 25 ^{o}C to 75 ^{o}C as shown in figure 4. Figure 3 also shows plot of flow-rate Q vs upstream pressure P_1 at three different temperatures 25 ^{o}C, 50 ^{o}C and 75 ^{o}C for orifice plate O_b. Here, again a linear behavior of flow-rate against upstream pressure was observed as in case of orifice plate O_a.

A comparison of the flow-rate results obtained from plate O_a & O_b is shown in figure 3. The minimum flow-rate Q_a recorded for orifice "O_a" was 3.22×10^{-6} mbar.l/s, whereas flow-rate Q_b for orifice "O_b" was 4.63×10^{-6} mbar.l/s.

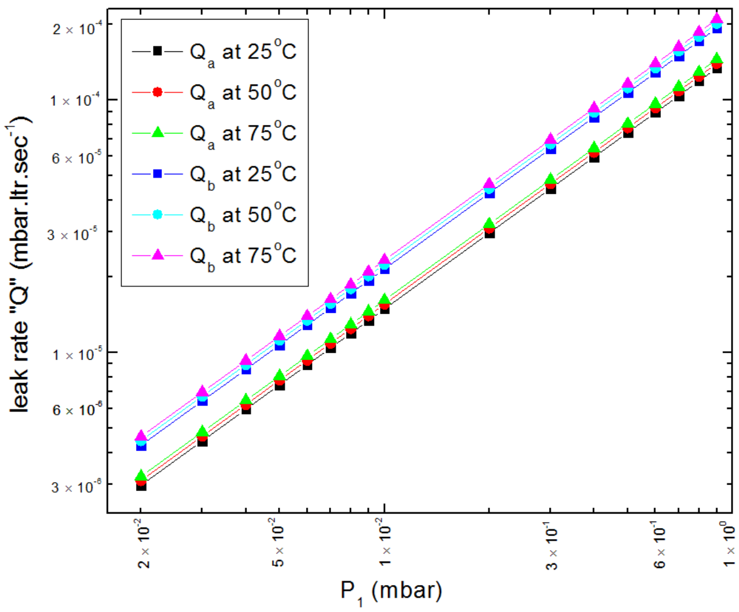

Figure 3. Flow-rate Q vs upstream pressure P_1 for "O_a" and "O_b".

Similarly, the maximum Q_a observed for orifice "O_a" was 2.97×10^{-5} mbar.l/s and Q_b for orifice "O_b" was 4.28×10^{-5} mbar.l/s.

The behavior of flow-rate with the increase in temperature has also been analyzed. It is found that the flow-rate increases linearly by 0.16% with per degree rise in temperature of orifice plate. Thus, a total of 8% rise in flow-rate is observed with an increase in temperature from 25°C to 75°C.

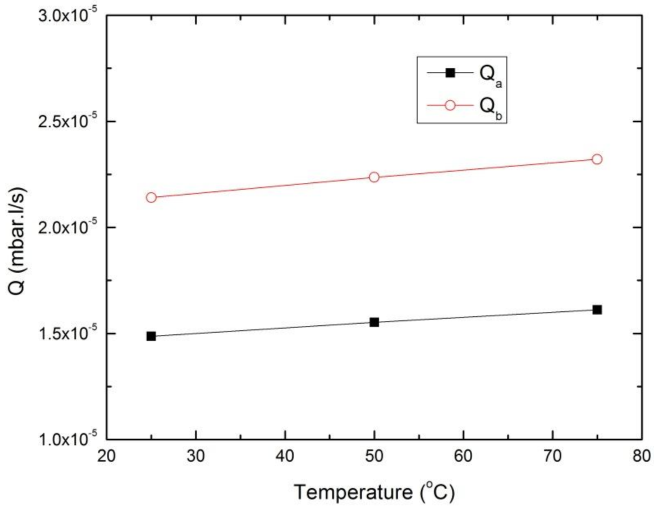

Figure 4. Flow-rate Q vs temperature for "O_a" and "O_b" at the upstream pressure of 1×10^{-1} mbar.

4. Uncertainty

Uncertainties of the different factors effecting flow-rate Q are evaluated by deriving standard deviation of all the parameters (pressure, temperature and hole diameter) and the expanded uncertainty using equations 4.1, 4.2 and 4.3 which shows an increase with the increase in temperature as shown in figure 5.

$$\sigma = \sqrt{\frac{1}{N-1}\sum(x-\bar{x})^2} \qquad (4.1)$$

$$U_c = \frac{\sigma}{\sqrt{N}} \qquad (4.2)$$

$$U = kU_c \qquad (4.3)$$

Where,

σ is the standard deviation, N is the number of trials, x is the sample data, $\bar{x}$ is the mean value, U_c is the combined uncertainty, U is the expanded uncertainty and k is the confidence level which is 95% with k = 2.

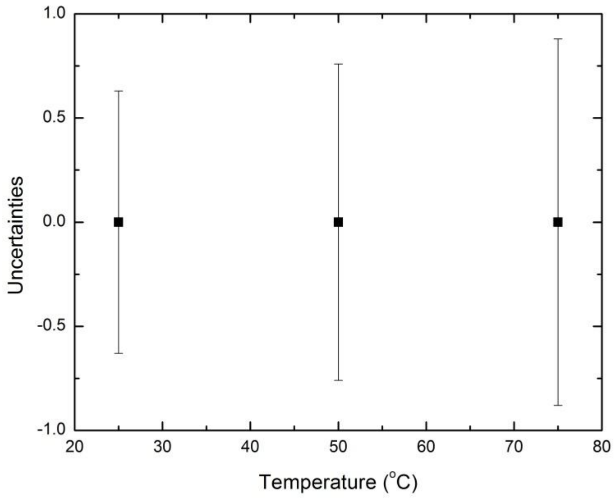

Figure 5. Uncertainties of the factors effecting Q.

5. Conclusions

In the present study it is found that, an increase of 20μm in orifice diameter results in an increase of 44% in flow-rate. Hence a minimum flow-rate can be obtained by using orifice of smaller diameter in the upstream pressure "P_1" range of 2.0×10^{-2} to 2.0×10^{-1} mbar. Also, a variation of 8% in flow-rate has been observed when temperature was raised from 25^{o}C to 75^{o}C. Hence 0.16% increase in flow-rate has been observed per degree rise in temperature of orifice.

References

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