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# *DESIGN AND CALIBRATION OF A ROTAMETER SET FOR MEASUREMENT OF GAS FLOWS*

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***ABSTRACT :*** *This study discusses design and calibration of a rotameter set for measurement of gas flows. In this study, various gases (such as hydrogen, carbon dioxide, methane, nitrogen and argon) are used for calibration of the rotameter set. Each rotameter was calibrated with one or two gases and resulting gas flowrates through the rotameters (R1, R2 and R3) compared with each other according to their molecular weight.*
*The gases supplied from high pressure gas bottles and passed to each rotameters. Outlet of the rotameters are connected to needle valves (see Figure 1). With the needle valves, outlet gas flows of each rotameter were adjusted before passing to a bubble flowmeter . Each time, gas flows through the bubble flowmeter were monitored and residence time was recorded by using a stop watch.*

***KEYWORDS :*** *Rotameter, bubble flowmeter, design of rotameters*

# *GAZ AKIŞLARININ ÖLÇÜMÜ İÇİN BİR ROTAMETRE SETİNİN DİZAYNI VE KALİBRASYONU*

***ÖZET :*** *Bu çalışmada, gaz akışlarının ölçümü için bir rotametre setinin dizaynı ve kalibrasyonunu yapılmıştır. Bu çalışmada, farklı gazlar (örneğin, hidrojen, karbon dioksit, metan, azot ve argon), rotametre setinin kalibrasyonu için kullanıldı. Her bir rotametre bir yada iki gazla kalibre edildi ve rotametrelerden (R1, R2 ve R3) geçen gaz akışları molekül ağırlıklarına göre birbirleriyle karşılaştırıldı.*
*Gazlar yüksek basınçlı gaz silindirlerinden sağlandı ve herbir rotametreden geçirildi. Rotametre çıkışları iğne vanalarına birleştirildi (şekil 1'e bakınız). İğne(açma/kapama) vanalarıyle, her bir rotametrenin çıkış gaz debileri, bir kabarcıklı akışmetreye geçmeden önce ayarlandı.Her defasında, kabarcıklı akışmetreden geçen gaz akışları gözlendi ve gazların kabarcıklı akışmetreden geçiş süreleri bir kronometre yardımıyla kaydedildi.*

***ANAHTAR KELİMELER :*** *Rotametre, kabarcıklı akışmetre, rotametrelerin dizaynı*

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## *I. INTRODUCTION*

The main purpose of this study is to design and calibrate of an experimental flow system for measurement of feed gases of an analysis system, a reactor system and a diffusion cell.

A rotameter consists essentially of a solid float or plumb-bob shaped rotor which is free to move vertically in a transparent tapered tube. The fluid to be metered enters at the bottom, narrow end of the tube and moves upward, passing to some point through the annulus formed between the float and inside wall of the tube. As the flow increases the float rises, thereby providing a greater cross-sectional area of the annulus.

In order to keep the float centered in the fluid and sensitive to flow changes, small diagonal slots are usually provided under its head, which cause the float to rotate slowly. At any particular rate of flow the float assumes a definite position in the tube, its location being indicated by means of a graduated scale etched on the tube[1].

Since the tube is tapered, the annular cross-sectional area for flow is variable. Increasing flow rates do not, therefore, increase the pressure drop across the float but cause the float to take higher positions in the tube. The fluid flows vertically upward through the tapered rotameter tube, and the float comes to equilibrium at a point where the annular flow area is such that the velocity increase has produced the necessary pressure difference.

The pressure difference, $P_1 - P_2$, is found by making a force balance on the stationary float. The downward force caused by gravity is balanced by the upward buoyant force plus the force exerted by the pressure difference across the float caused by the velocity increase in the annular constriction.

Thus we write,

$$\rho_f V_f \frac{g}{g_c} = \rho V_f \frac{g}{g_c} + A_f (P_1 - P_2) \qquad (1)$$

and

$$P_1 - P_2 = \frac{V_f (\rho_f - \rho) g}{A_f g_c} \qquad (2)$$

Bernoulli's equation for the orifice meter is adapted to the rotameter by defining a coefficient $C_D$ by

$$U_{br} = C_D \sqrt{\frac{2\, g_c \left(P_1 - P_2\right)}{\rho}} \qquad (3)$$

$U_{br}$ is the velocity in the annular constriction. The substitution of Eq.(2) into Eq.(3) gives;

$$U_{br} = C_D \sqrt{\frac{2\, g\, V_f \left(\rho_f - \rho\right)}{A_f \cdot \rho}} \qquad (4)$$

If the area of the annulus between the float and tube is $A_2$ and the cross-sectional area of the tube is $A_1$, then equation (4) gives the mass flow G for a rotameter, hence[1,2,6,7,8];

$$G = C_D\, A_2 \sqrt{\frac{2\, g\, V_f \left(\rho_f - \rho_{rot}\right)}{A_f \left\{1 - \left[\frac{A_2}{A_1}\right]^2\right\}}} \qquad (5)$$

The Reynolds number is defined as;

$$R_e = \frac{\left(D - D_f\right) U_{br}\, \rho_{rot}}{\mu} \qquad (6)$$

If the rotameter is already calibrated for one gas, say at 760 mmHg and we wish to change the gas at a different pressure, then[3,4,5];

$$G_{ref} = C_D\, A_2 \sqrt{\frac{2\, g\, V_f \left(\rho_f - \rho_{ref}\right) \rho_{ref}}{A_f \left\{1 - \left[\frac{A_2}{A_1}\right]^2\right\}}} \qquad (7)$$

If the calibration is expressed as volume flow, $Q = G / \rho$, the division of Equation (5) by equation (7) gives;

$$\frac{G}{G_{ref}} = \sqrt{\frac{\rho_{rot}}{\rho_{ref}}} \qquad \text{only if} \quad \rho_{ref} \ll \rho_f \qquad (8)$$

For calibration, we wish to use a bubble flowmeter at temperature $T_a$ and gas pressure $P_b = P_{ambient} - P_{H_2O}$, where $P_{H_2O}$ is the pressure of water vapour in the laboratory. As the mass flow $G = Q\,\rho$, where $\rho$ is measured at $P_{bubble}$, $T_{ambient}$, then;

$$Q = Q_{ref} \times \frac{\rho_{ref}}{\rho_b}\sqrt{\frac{\rho_{rot}}{\rho_{ref}}} \qquad \text{or}$$

$$Q = Q_{ref} \times \sqrt{\frac{\rho_{ref}}{\rho_b} \times \frac{\rho_{rot}}{\rho_b}} \qquad (9)$$

The gas densities are proportional to the molecular weights, gas pressure and inversely proportional to the gas temperature. Therefore, Equation (9) can be written as follows[9]:

$$Q = Q_{ref} \times \sqrt{\frac{P_{ref}}{P_{bubb}} \times \frac{M_{ref}}{M_{bubb.}} \times \frac{T_{bubb}}{T_{ref}} \times \frac{P_{rot}}{P_{bubb.}}} \qquad (10)$$

### Calibration of Rotameters

The flow of gas through the rotameter is.

$$\left[Q_{BFMW} \times \frac{h_b - h_{H_2O}}{h_b}\right] \quad \text{and} \quad Q_{BFMD} = Q_{BFMW} \times \left[\frac{h_b - h_{H_2O}}{h_b}\right] \qquad (11)$$

We can plot $Q_{scale}$ of Rotameter against $Q_{BFMD}$ of the bubble flowmeter. The flow through the calibrated rotameter for a gas scale reading and temperature correction for the same gas may be calculated from the following equation [9]:

$$Q_{actual} = Q_{BFMD(calib)} \times \sqrt{\frac{(h_{md} + h_b)}{(h_b - h_{H_2O})_{bubb}} \times \frac{T_{bubb}}{T_{calib}}} \qquad (12)$$

## *II. TEST SET*

An experimental system was designed as Figure 1. Various gas flows from high pressure bottles (A) fed to a rotameter set (B). The flows of individual gases through each rotameter are regulated by means of needle valves (C). Then, flow of each gas at different experiments is passed to a bubble flowmeter (D) which having a soap reservior (E) and mounted on a support (F).

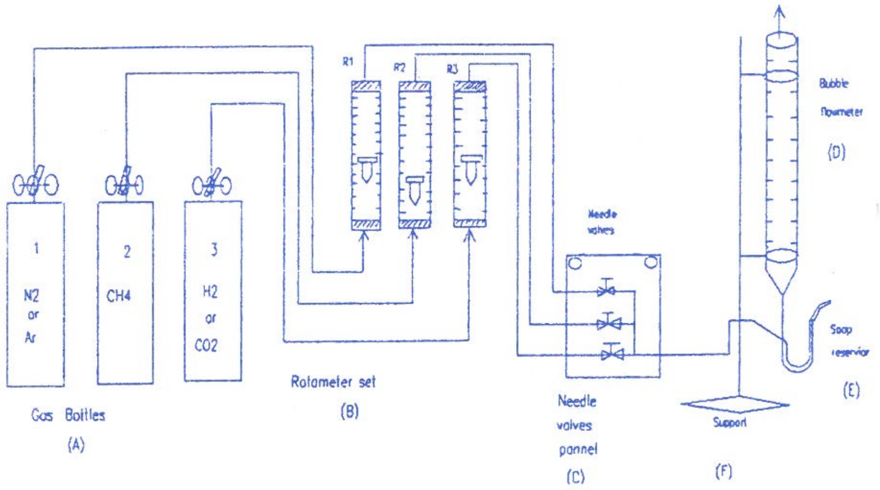


Figure 1. Schematic diagram of rotameter set.

The measurement of the wet gas flows were taken from the bubble flowmeter against each scale reading of the rotameters. The gas flow was gradually increased through each rotameter and corresponding wet gas flows were taken from the bubble meter. The wet gas flows, $Q_{BFMW}$ where then converted to dry gas flows, which is $Q_{BFMD}$. Then for each rotameter, the rotameter readings were drawn against $Q_{BFMD}$ values (see Figures 2 to 9).

## *III. DISCUSSION OF RESULTS*

This study is a typical practical study for applied chemistry , chemical engineering and other engineering areas. The designed experimental system can be used for measurements of feed gas flows of any reacting system without doing any further calibration studies for some particular reactions. By using this type of experimental systems, various gas flows can be regulated and measured efficiently before doing any diffusion, reaction and gas analysis studies.

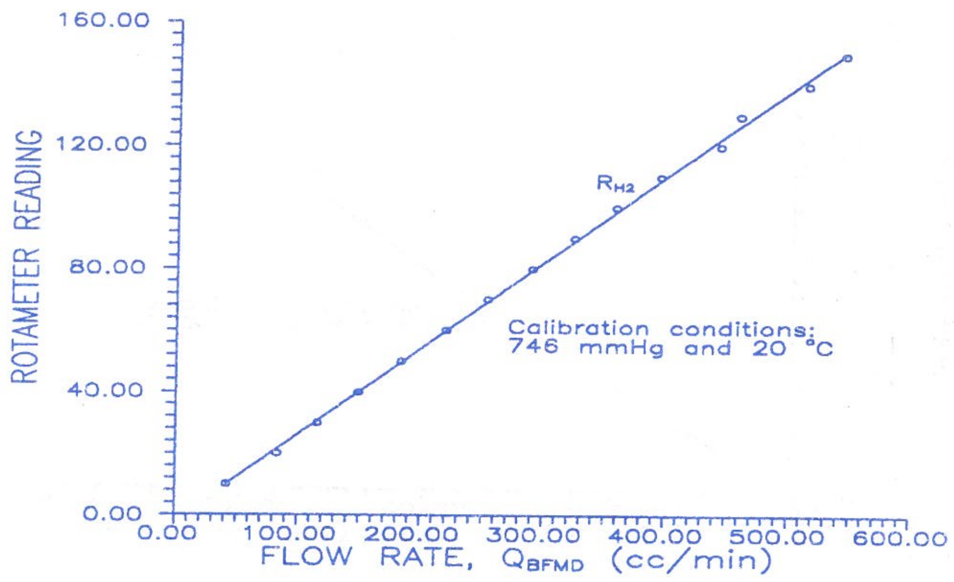


Figure 2. Calibration curve of the rotameter R3 for measurement of hydrogen flow.

According to Figure 2, the rotameter readings and dry gas ($Q_{BFMD}$) flowrates having a linear relation. The rotameter R3, having a scale range of 10 to150, and corresponding flow range of hydrogen at the bubble flowmeter is 42-545 cc/min. The measurement of very small gas flows was altered because the rotameter is suitable only for a certain range of gas flows. The calibration conditions of the rotameter for hydrogen were 746 mmHg abs, 20 °C (see Figure 2).

As shown on Figure 3, the rotameter readings and dry gas($Q_{BFMD}$) flowrates having an approximate linear relation as graph $R_{CH4}$. The calibration curve of the rotameter for methane shows a slight variation from linearity. From this curve, the gas flowrates of methane will be read against the rotameter scale readings. The measurement range of gas flows is 29 cc/min upto 364 cc/min and corresponding rotameter scale reading will be 10 to 150.The calibration conditions of rotameter R2 for methane were 746 mmHg.abs.and 20 °C.

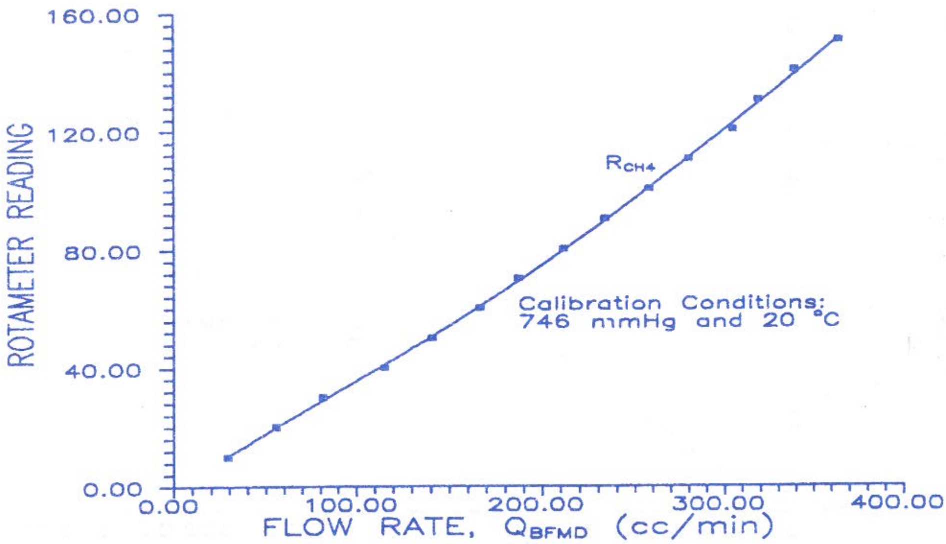


Figure 3. Calibration curve of the rotameter R2 for measurement of methane flow.

Figure 4 shows calibration curve of nitrogen for the rotameter R1. As seen on graph $R_{N2}$, the actual flowrate of nitrogen through the rotameter R1 is not greather than 200 cc/min for maximum rotameter scale reading of 200. On Figure 4, there is a linear relation between rotameter reading and actual flowrate of nitrogen. The molecular weight of nitrogen is heavier than the molecular weight of hydrogen and methane, so the flowrates of nitrogen through the rotameters will be less than both flowrates of hydrogen and methane.

Figure 5 shows rotameter readings against the carbon dioxide flowrates through the rotameter R3. The rotameter reading and the flowrate of $CO_2$ having an approximate linear relation this means that resulted calibration curve slightly differs from linearity as seen on graph $R_{CO2}$. From this curve, the flowrates of $CO_2$ through the same rotameter can be determined for the various experimental conditions of feature experimental studies.

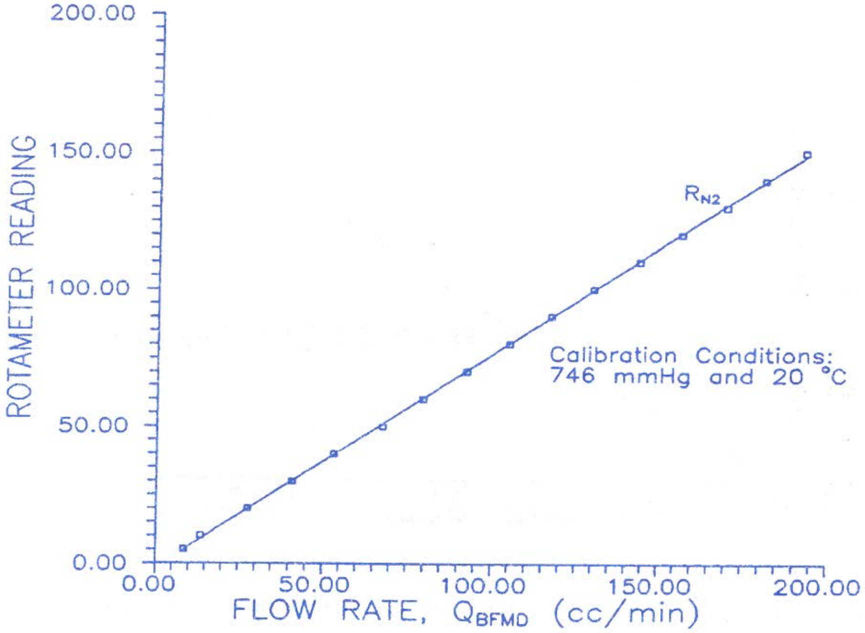


Figure 4. Calibration curve of the rotameter R1 for measurement of nitrogen flow.

On Figure 6 the calibration curve of argon gas was presented for the rotameter R1 as a function of flowrate. For a rotameter scale range of 0 to 160, a flowrate of 0 upto 200 cc/min of argon was passed through the rotameter R1.

The flowrates of nitrogen and argon through the rotameter R1 are presented on Figure 7. As seen on graphs $R1_{(N2)}$ and $R1_{(Ar)}$, the flowrates of nitrogen through rotameter R1 is higher than the flowrates of argon because the molecular weight of nitrogen is less than argon. The calibration conditions of the rotameter R1 for nitrogen and argon gases in this experiment are 746 mmHg and 20 °C.

Flowrates of carbon dioxide, methane and hydrogen through the rotameters R2 and R3 are represented on Figure 8. The flowrates of hydrogen is higher than the flowrates of methane and carbon dioxide for same rotameter scale readings. The calibration conditions for this experiment were 746 mmHg and 20 °C.

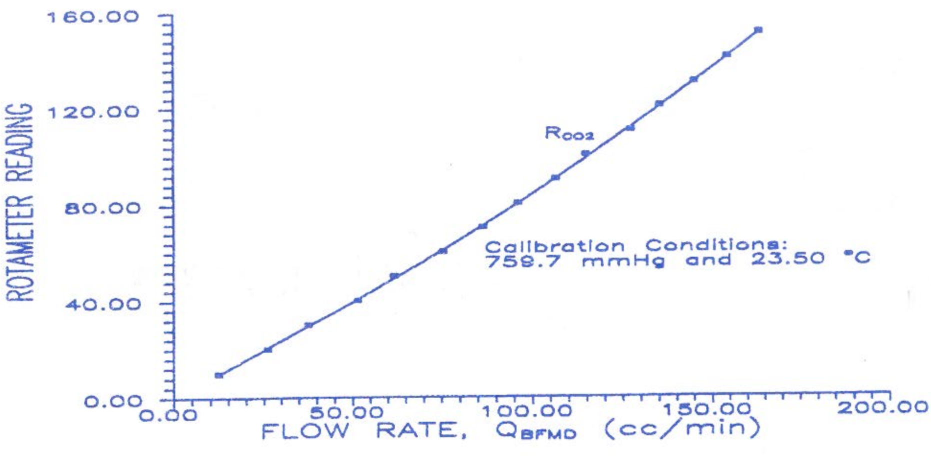


Figure 5. Calibration curve of the rotameter R3 for measurement of carbon dioxide flow.

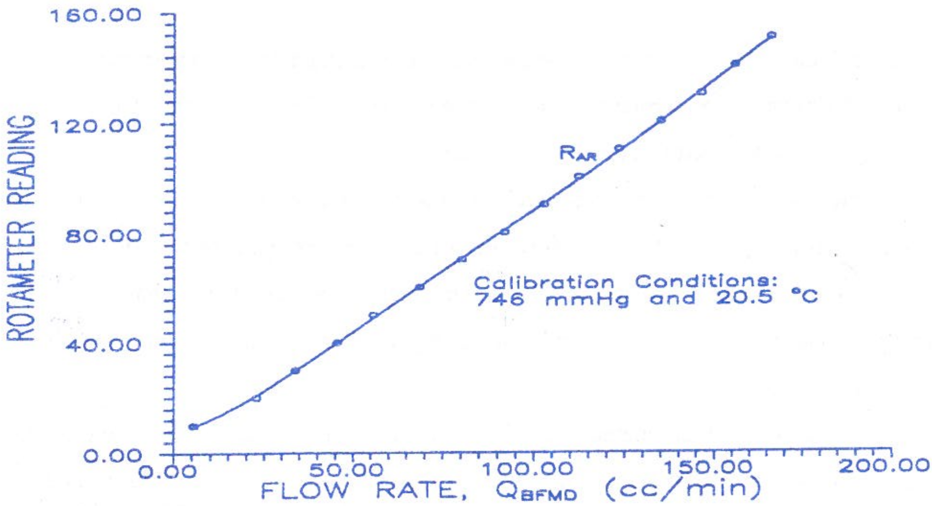


Figure 6. Calibration curve of the rotameter R1 for measurement of argon flow.

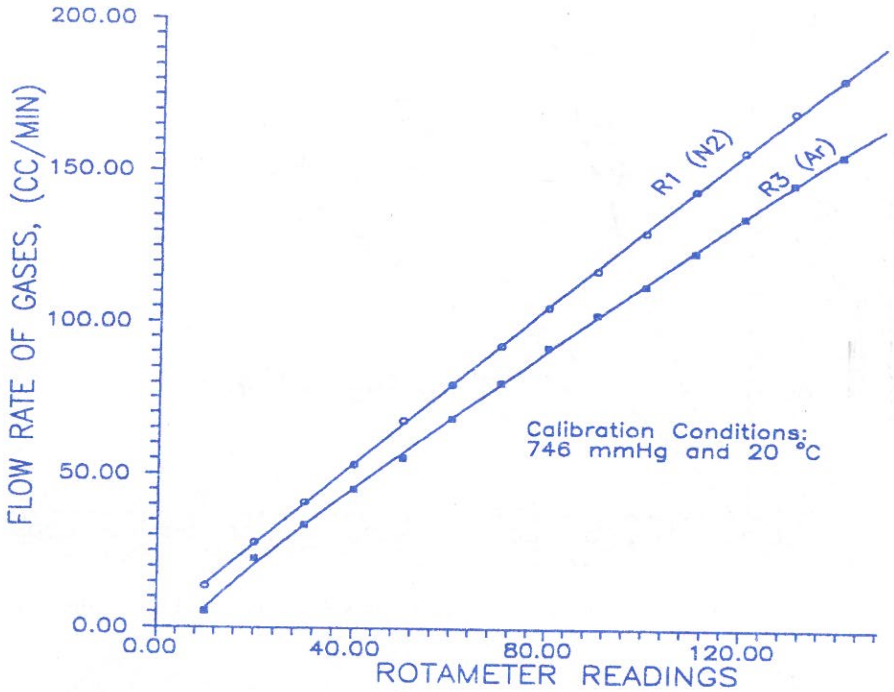


Figure 7. Calibration curves of the rotameters R1, R3 for measurement of nitrogen and argon flows.

Flowrates of hydrogen, methane, nitrogen, carbon dioxide and argon are represented against the rotameter readings of R1, R2 and R3 on Figure 9. Aş seen on graph, the flowrates of hydrogen through the rotameters are higher than flowrates of other four gases, because hydrogen is lighter than other gases. Flowrates of carbon dioxide and argon through the rotameters are less than flowrates of hydrogen, methane and nitrogen. The calibration conditions for this experiment were 756 mmHg and 20 °C.

The calibration curves of each gas will be quite useful for any experimental studies of gas analysis of a reacting system and a diffusion system with same gases and rotameter set in feature. In case of different experimental conditions with same rotameter set, there is no need to use the bubble flowmeter for measurements of each gas flow at the exit of each

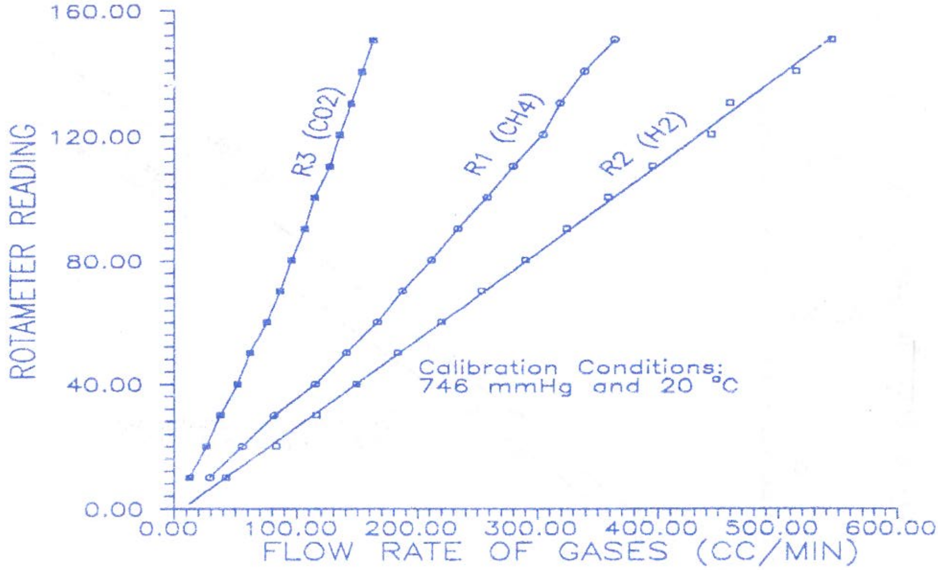


Figure 8. Calibration curves of the rotameters R1,R2 and R3 for measurements of carbon dioxide, methane and hydrogen flows.

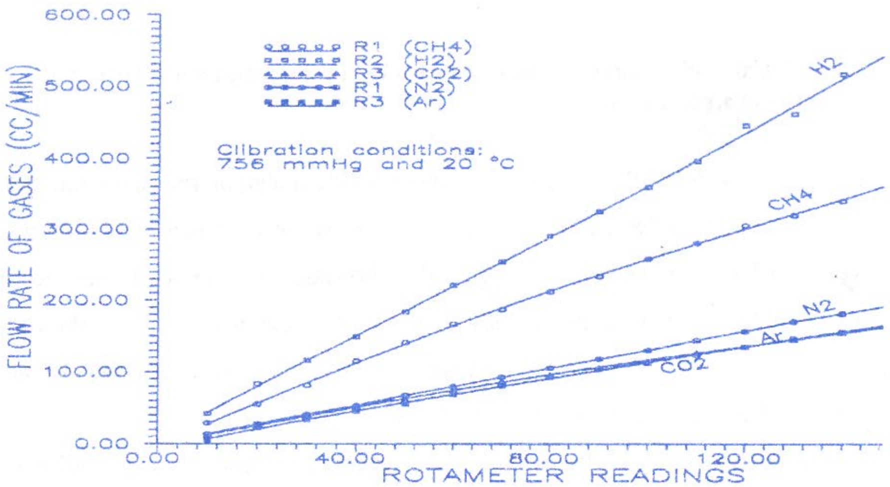


Figure 9. Calibration curves of the rotameters R1, R2 and R3 for measurements of hydrogen, methane, nitrogen, carbon dioxide and argon flows.

rotameter since gas flow rates will be found by aid of those calibration curves and rotameters scale readings.

## IV. CONCLUSIONS

So far, in this study, a rotameter set was designed and calibrated for measurements of gas flows. Gases supplied from high pressure bottles and passed through each rotameter at various times. During experimental study, each gas flowrates through the rotameters are read via a bubble flowmeter against rotameter scale reading. Then, from recorded wet gas flowrates, the actual dry gas flowrates are calculated. Finally, obtained actual gas flowrates are graphically represented as Figures 2 to 9.

## NOMENCLATURE

| | |
|---|---|
| $V_f$ | volume of float ($m^3$) |
| $\rho_f$ | density of float ($kg/m^3$) |
| $A_f$ | maximum cross-sectional area of float ($m^2$) |
| $A_2$ | area of the annulus between the float and tube ($m^2$) |
| $G$ | mass flow for a rotameter (kg/m.s) |
| $C_D$ | drag coefficient |
| $D$ | diameter of tube at level of float (m) |
| $D_f$ | maximum diameter of float (m) |
| $\rho_{rot}$ | density of gas at rotameter ($kg/m^3$) |
| $A_1$ | cross-sectional area of the tube ($m^2$) |
| $\rho_{ref}$ | density of reference gas ($kg/m^3$) |
| $P_{H2O}$ | pressure of water vapour in laboratory |
| $T_{ambient}$ | ambient temperature ($^oC$) |
| $P_{ref}$ | reference pressure (bar) |
| $P_{bubb}$ | gas pressure at the bubble meter (bar) |
| $M_{ref}$ | molecular weight of gases at the reference conditions (kg/kg.mol) |
| $M_{bubb}$ | molecular weight of gases at the bubble flowmeter conditions (kg/kg-mol) |
| $T_{bubb}$ | gas temperature at the bubble flowmeter conditions ($^oC$) |
| $T_{ref}$ | gas temperature at the reference conditions ($^oC$) |
| $P_{rot}$ | pressure of the gas in the rotameter (bar) |
| $Q_{BFMW}$ | volumetric flow of gas in the bubble flowmeter ($m^3/s$) |
| $Q_{BFMD}$ | corrected bubble flowmeter reading for corresponding water vapour ($m^3/s$) |
| $h_b$ | barometric pressure (bar) |
| $h_{mn}$ | gauge pressure of the rotameter (bar) |
| $h_{H2O}$ | water vapour pressure at laboratory temperature (bar) |
| $Q_{scale}$ | scale reading of gases in rotameter |
| $Q_{actual}$ | actual volumetric flow of gases through the rotameters ($m^3/s$) |

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