# Experimental Research on Flow Coefficient of Flow Equation of Metal Rotameter

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**Abstract** On the basis of analyzing flow equation for rotameter, using the flow standard device with master meter method, the rotameter with one type of floater chosen from two different floaters in shape and metal tube from 25mm caliber to 100mm caliber had been calibrated. After calculating and analyzing curve between flow coefficient and Reynolds Number ($\alpha \sim \mathrm{Re}$) of metal rotameter, some laws are founded. Within the upper limit flow rate of metal rotameter, flow coefficient does not tend towards a constant number. Under the double logarithmic coordinate, relation curve of large capacity metal rotameter between flow coefficient and Reynolds Number ($\alpha \sim \mathrm{Re}$) is near to linearity, and the approximate expression reflecting this kind of relationship is deduced.

**Keywords**: metal rotameter; flow equation; flow coefficient; Reynolds number

## 1. Introduction

Rotameter is a kind of traditional float type variable area flowmeter with the advantages of simple structure, little pressure loss, stabilization and the ability of measuring low velocity fluid. There are two kinds of rotameters, glass rotameter and metal rotameter, according to the material of which Rotometer is made. And metal rotameter is used widely for measuring high temperature, high pressure and corrosive fluid. At present, the maximal pressure of metal rotameter is 100Mpa; the resistance of elevated temperature is up to 300□.

The flow equation of metal rotameter, which is very important in the engineering design, is decided by the correct determination of flow coefficient in the flow equation. Therefore the study on the flow coefficient is significant for designing the metal rotameter.

## 2. Basic fundamentals

In the Fig.1, a floater was placed in the upright tapered measuring tube. When flow goes through the measuring tube in the direct of it, it gives the floater an upward force because of the difference of pressure caused by the throttle location of floater. At the meantime, the floater gets another hydrodynamic force produced by viscosity of water. The floater will go up when the buoyancy force and viscous force are bigger than the weight of floater. Then the area between the floater and measuring tube becomes large, and the flow velocity through that annularity slows down. The total force on floater becomes small. When all the forces are under the balance, the floater will take up a defined height in the measuring tube. The pressure on the floater will keep constant, no matter how height it is. Therefore rotameter is called as constant pressure flowmeter.
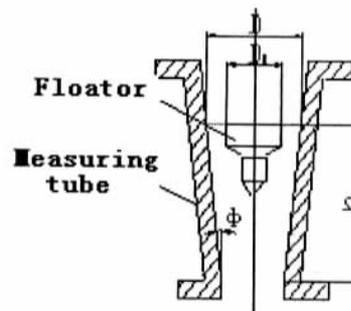


Fig.1   Structural sketch plan of metal rotameter

Flow equation was studied from the research of D.S.Plumb, but the balance of force on the floater is not considered by Whitwell and Plumb, Therefore the flow equation can not show the characteristic of flow and floater together. After that, R.W.Miller thought the balance of forces on the operating floater, and obtained the function between the flow volume and floater height on the base of Bernoulli and balance of forces[1] [2]. The flow equation of metal rotameter is showed in the following equation:

$$Q_v = \alpha\pi[D_0 h \tan\phi + (h\tan\phi)^2]\sqrt{\frac{2gV_f}{A_f}(\frac{p_f - p}{p})}$$

(1)

$Q_v$ --Flow rate

$\alpha$ ---Flow coefficient

$D_0$ --Diameter of the inlet area of measuring tube

$h$ ----Floater height

$\Phi$ ---Cone angle of measuring tube

$V_f$ -- Volume of floater

$\rho_f$ --Density of floater

$\rho$ ---Density of fluid

$A_f$ --The biggest area of floater in the direct of flow

Flow coefficient $\alpha$ is a very important parameter in the flow equation, which is decided by floater's shape and inlet Reynolds number. For the metal Rotameter, the structures of measuring tube and material with the roughness degree also give the assignable effect on the determination of flow coefficient $\alpha$.

The research on the flow coefficient in the literatures is very few. The most common description on the characteristic of the rotameter in the literatures is showed in the Fig.2 [3]. As Reynolds number is greater than one certain value, flow coefficient will keep invariant as a constant. In the Fig.2, the flow coefficient of floater of type A is 0.96, the flow

coefficient of floater of type B is 0.76, the flow coefficient of floater of type C is 0.61. And the most common type operated is spherical floater whose flow coefficient is 0.99. However, the experimental condition, the type of rotameter and range of flow rate are not mentioned in the result of above research. In this paper, metal rotameter from 25mm caliber to 100mm caliber have been studied on the flow coefficient in order to help designing for metal rotameter.
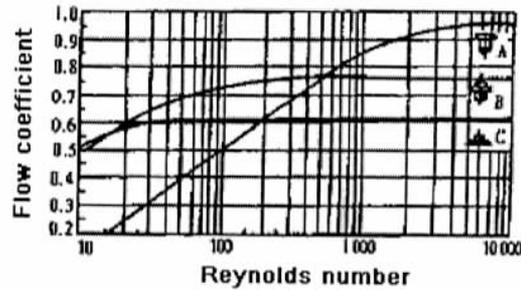


Fig.2    Relation curve between flow coefficient and Reynolds number

## 2.  Experimental equipment

Experimental medium is the water with the density of    $998.0 kg/m^3$    and    the    viscosity of $1.002E - 3kg/m\cdot s$. The metal rotameter used in the experiment is showed in the following figure.
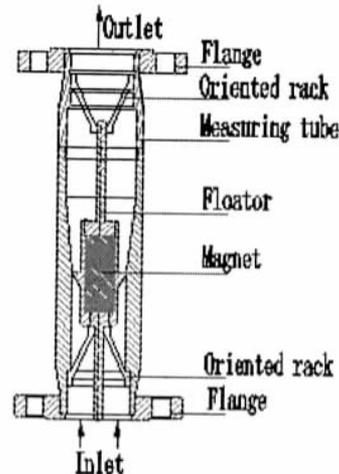


Fig. 3    Metal rotameter used in the experiment

Two types of the floater, floater of CF and floater of DF showed in fig.4, are used in this experiment. The metal rotameters with different ranges of flow rate are made up with the one from two types of floater and the different measuring tube.
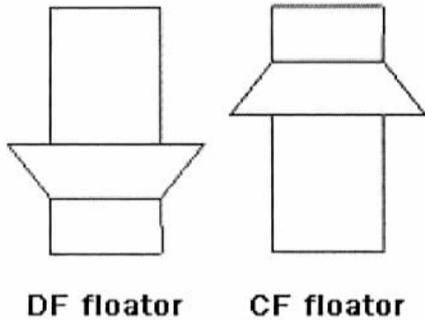


**DF floater     CF floater**

**Fig. 4**  Schematic plan of DF floater and CF floater

The calibration equipment used in this experiment is showed in the Fig.5. The static weighing method and the standard meter method can be employed in this equipment. In this experiment, standard meter method is adopted to calibrate the metal rotameter. The metal rotameters with the calibers of 25mm, 50mm, 80mm and 100mm are calibrated individually. According to the flow rate range, 11 flow points, each one of which is calibrated twice in the forward and reverse, are set as the calibration points equally with the flow rate increment of $0.1 Q_{max}$.
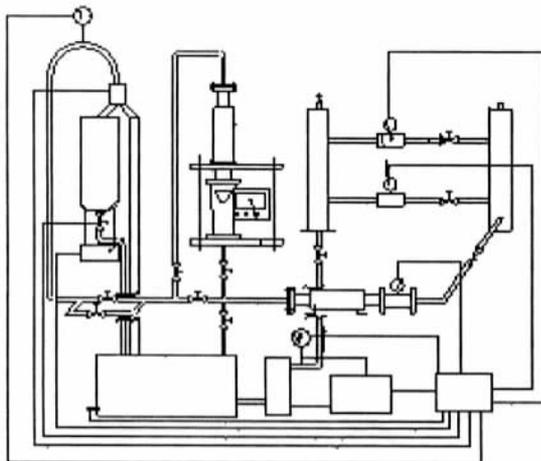


**Fig.5**  Experimental equipment for calibration

## 4. Experimental result and analysis

1.  The $\alpha - Re$ curves of metal rotameters with the caliber from DN25 to DN100 are displayed in the following graphs from Fig.6 to Fig.9.
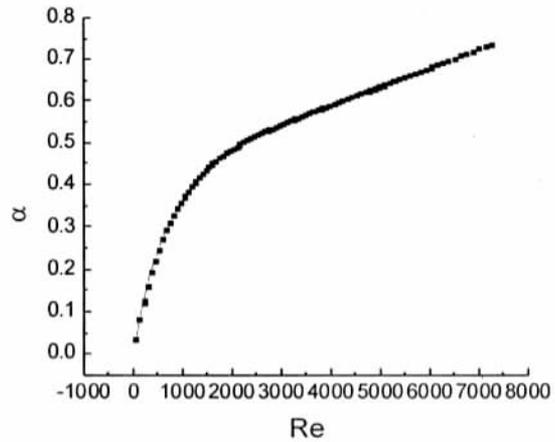


**Fig.6**  $\alpha - Re$ curve of DN25 metal rotameter with the CF floater in the flow range from $0.063 m^3$ to $0.63 m^3$
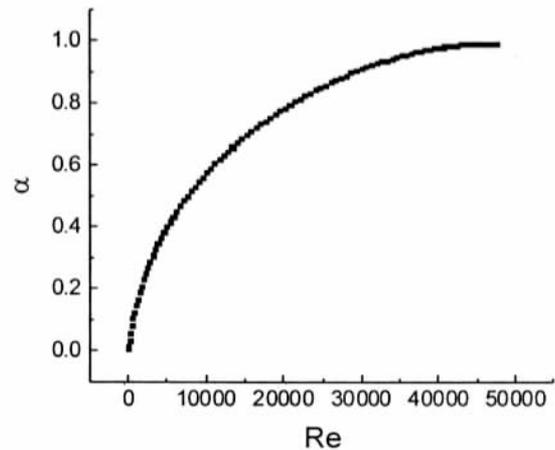


**Fig.7**  $\alpha - Re$ curve of DN50 metal rotameter with the CF floater in the flow range from to $0.63 m^3$ to $6.3 m^3$
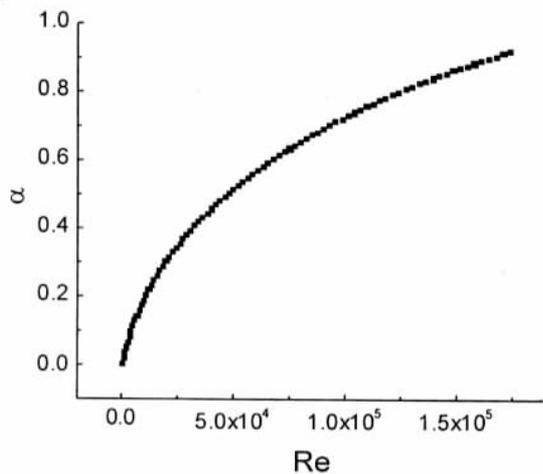
**Fig.8** $\alpha - \mathrm{Re}$ curve of DN80 metal rotameter with the floater of DF in the flow range from $4.0 m^3$ to $40 m^3$
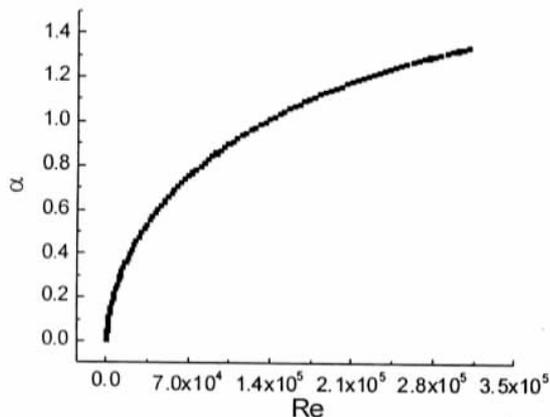


**Fig.9** $\alpha - \mathrm{Re}$ curve of DN100 metal rotameter with the floater of DF in the flow range from $6.3 m^3$ to $63 m^3$

Relational curves $a - \mathrm{Re}$ of the metal rotameters with different measuring tubes and floaters are not exactly same each other from Fig.6 to Fig.9. But the trend that value of flow coefficient will go up and approach to a constant with the Reynolds number increasing can be found in all the figures, which demonstrates that metal rotameter has the same trend with the rotameter showed in Fig.2.

The value of flow coefficient and the flow rate are relationship of direct proportion according to the formula $\mathrm{Re} = \rho \dfrac{UD}{\mu}$. Therefore the maximal flow rate corresponds to the maximal flow coefficient. Though the curve of flow coefficient will approach

to a constant in the range of $\mathrm{Re} \leq \mathrm{Re}_{UpFlowRate}$

( $\mathrm{Re}_{UpFlowRate}$ is the Reynolds number that corresponds to maximal flow rate), it is hard to find a value of Reynolds number $\mathrm{Re}_0$ in this range to satisfy that $\dfrac{d\alpha}{d\mathrm{Re}} \approx 0$ when $\mathrm{Re} > \mathrm{Re}_0$. At the meantime, flow coefficients of three types of floaters in the graph of Fig.2 equal to a constant value at Reynolds number of 40, 800 and 6000 individually. In this experiment, a constant value will be obtained after Re=8000 even for the flow coefficient of metal rotameter of minimal flow rate.

The result of experiment above is decided not only by the value of Reynolds number and the material of metal rotameter, but also by the shapes of measuring tube and floater of meter rotameter. In the experiment, the metal rotameter is employed with short-tube rotameter with the total height of 250mm and floater flight of 65mm. Full of vortices are produced by the disturb of narrow structural room of metal rotameter, which makes the floater in unstable situation. Therefore flow coefficient of metal rotameter can not approach to a constant value easily in the range flow rate.

In all the metal rotameter of this experiment, only the Reynolds number of DN50 metal rotameter with the flow rate of $0.063m^3 - 0.63m^3$ comes to a constant value at the maximal flow rate. The flow coefficient of DN50 metal rotameter, which is 0.988, has great gap from 0.76, the flow coefficient of rotameter with type B in the Fig.2.

The flow coefficients of meter rotameters with other caliber are not constant at the maximal flow rate. So only the flow coefficient corresponding to the maximal Reynolds number can be obtained. The flow coefficient of DN25 metal rotameter with CF floater is 0.732. The flow coefficient of DN80 rotameter with DF floater is 0.920. The flow coefficient of DN100 rotameter with DF floater is 1.33.

From the discussion above, the flow coefficient is

hardly decided only by the shape of floater. And the shape of metal rotameter, material of rotameter and the value of Reynolds number, etc should also be considered. The flow coefficent of metal rotameter consisted with different measuring tubes and different floaters have to be determined in the calibration equipment. But obtaining a constant flow coefficient is not unrealistic in the range of flow rate.

2. Under the double logarithmic coordinate, the $\alpha - Re$ curves of metal rotameters with the calibers from DN25 to DN100 are displayed in the following graphs from Fig10 to Fig13.
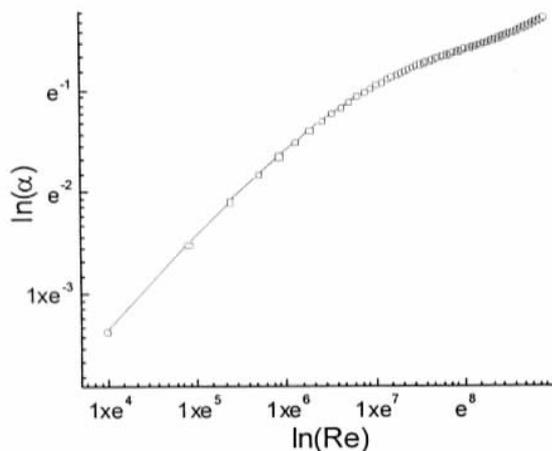


**Fig.10** $\alpha - Re$ curve under the double logarithmic coordinate for DN25 metal rotameter with floater of CF in the flow range from $0.063\,m^3$ to $0.63\,m^3$
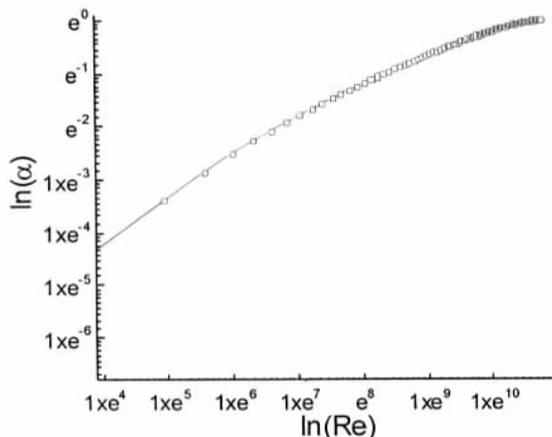


**Fig.11** $\alpha - Re$ curve under the double logarithmic coordinate for DN50 metal rotameter with the floater of CF in the flow range from $0.63\,m^3$ to $6.3\,m^3$



**Fig.12** $\alpha - Re$ curve under the double logarithmic coordinate for DN80 metal rotameter with the floater of DF in the flow range from $4.0\,m^3$ to $40\,m^3$



**Fig.13** $\alpha - Re$ curve under the double logarithmic coordinate for DN100 metal rotameter with the floater of DF in the flow range from $6.3\,m^3$ to $63\,m^3$
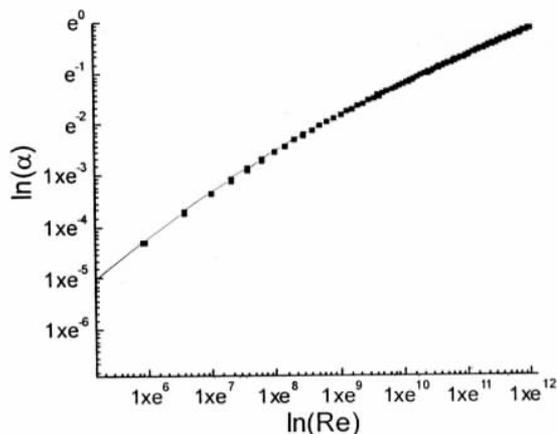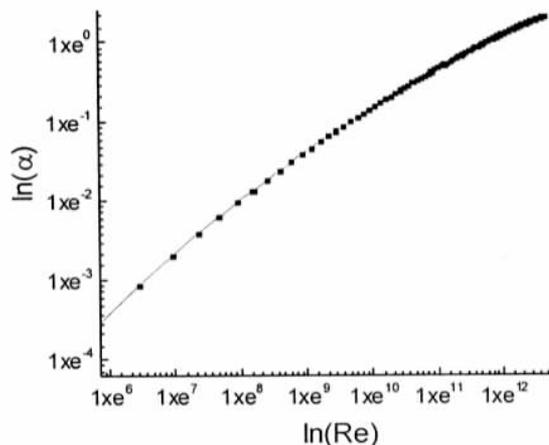
From the graphs above, it can be seen that the $\alpha - Re$ curves under the double logarithmic coordinate tend toward linearity from small caliber metal rotameter to large caliber metal rotameter. And this trend shows that under the double logarithmic coordinate, the $\alpha - Re$ curve of meter rotameter with large caliber or large flow rate can be regard as linearity. Therefore the approximate equation of $\alpha - Re$ curve of large caliber metal rotameter can be established.

$$\log \alpha = a \log Re + b \qquad (2)$$

By exponential transform:

$$\alpha = c \, \mathrm{Re}^{a} \tag{3}$$

Where $c = e^{b}$

For verifying the result of derivation, the two points of $(\mathrm{Re}, \alpha)$ on the $\alpha - \mathrm{Re}$ curve of DN100 metal rotameter with flow rate of $6.3 m^{3}$ —$63 m^{3}$ are substituted into the equation3. With the solution of coefficient a and coefficient c, equation of $\alpha \sim \mathrm{Re}$ curve of that metal rotameter can be obtained:

$$\alpha = 0.026959 \times \mathrm{Re}^{0.3134653} \tag{4}$$

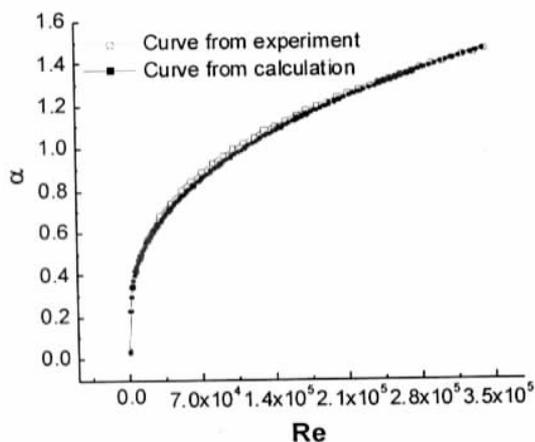In Fig.14, the curve plotted according to equate4 is compared with the one obtained from the experiment.



Fig.14  Comparison between the $a \sim \mathrm{Re}$ curve from calculation and $a \sim \mathrm{Re}$ curve from experiment

The result above shows that the evolution of $a \sim \mathrm{Re}$ curve of metal rotameter with large capacity has the form of power function, see equation 3. From this law, a brevity equation expressing $a \sim \mathrm{Re}$ curve of metal rotameter for large capacity is obtained just by calibrating two flow points. This method will simplify the process to decide the value of flow coefficient.

## 5. Conclusion

1. The trend that flow coefficient will go up and approach to a constant value with the increment of Reynolds number in the $\alpha - \mathrm{Re}$ curve of metal rotameter. It is hard to find a value of Reynolds number $\mathrm{Re}_{0}$ in the range of flow rate to satisfy that $\dfrac{d\alpha}{d\mathrm{Re}} \approx 0$ when $\mathrm{Re} > \mathrm{Re}_{0}$.

2. Under the double logarithmic coordinate, $\alpha - \mathrm{Re}$ curve of metal rotameter will approach to linearity from small flow rate to large flow rate. And approximate equation for the metal rotameter of large capacity is created as following equation:

$$\alpha = c \, \mathrm{Re}^{a}$$

Through the comparison, this approximate function is coincident with the experimental result very well.

## Reference

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