Prediction of Performance of Rotameter with Different Fluids Using CFD

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Abstract

Rotameter is a variable area flow meter in which the position of the float indicates the flow rate of the fluid. Normally rotameter is calibrated with standard fluids (water and air). However when this meter is used with other fluids correction factors are applied to account for the change in the density of the fluid. In the present study a rotameter existing in the institute has been modelled and flow is analysed using the CFD software ANSYS FLUENT 14. The accuracy of CFD methodology is established for water flow by comparing the computed flow rate with the indicated flow rate over the entire range of the meter. Subsequently analyses have been carried out with four different fluids having different density and viscosity. It was observed that not only density of the fluid but also the viscosity of the fluid affects the performances of the rotameter. I t is concluded that if the viscosity of the fluid is higher than that of a standard fluid , the actual flow rate by the meter will be lower than the indicated flow rate by the meter even after applying the correction factor for density. The reverse is true for lower viscosity. A parametric study has been carried out by systematically varying density and viscosity of the fluid. It is concluded that for the rotameter analysed , the accuracy of measurement(after applying standard density correction factor)will be within ±2% as long as the density and viscosity of the fluid are within -20% to +15% and -25% to +35% of the corresponding properties of the standard fluid respectively.

Keywords: Rotameter, Drag force, ANSYS,CFD,Density correction factor

1. INTRODUCTION

Rotameter is a Variable area type of flow meter which is a simple, economical and accurate flow measuring instrument. It consists of a tapered tube and a metallic float within the tube which is free to move up and down within the tube. The metering tube is mounted vertically in the fluid stream with its smaller diameter at the bottom.The fluid whose flow rate to be measured enters at the bottom of the tube, passes upward around the float (annulus area), and exits out from the top. When there is no flow through the meter, the float rests at the bottom of the metering tube where the maximum diameter of the float is approximately same as the bore of the tube. When fluid enters the metering tube, the buoyant effect of the fluid tends to lift the float, but since the float has higher density than the liquid the float remains in its initial position and the passage around the float remains blocked. The fluid pressure increases until it, plus buoyant effect is greater than the weight of the float and the float starts to rise in the tube. With upward movement of float towards the larger end of the tapered tube, the annular opening between tube and the float increases. As area increases, the pressure differential across the float decreases. The float assumes a position when it is in dynamic equilibrium. This happens when the drag force due to the fluid flow on the float plus the buoyancy effect balances the weight of the float. Any further increase in flow rate causes the float to rise higher in the tube; a decrease in flow causes the float to drop to a lower position.Every float position corresponds to one particular flow rate. Graduated markings are provided for different flow rates on a calibration scale on the outer surface of the tube and flow rate can be determined by direct observation of the position of float in the metering tube.

1.1Working principle of rotameter

Consider a rotameter shown in Fig1.1. The various forces that are acting on the float at any given position are shown in Fig 1.2 and are as follows:-

1.The weight of the float (W) which is acting vertically downwards
2.The buoyant force (FB) acting vertically upwards
3.The drag force (FD) due to fluid flow.

When the above 3 forces are balanced the float comes to equilibrium. It is to be noted that the first two forces namely W and FB are constant for a given meter. However, the drag force FD is dependent on several parameters like the properties of the fluid, flow rate, position of the float etc. Normally the drag force consists of pressure drag (form drag) and viscous drag. Since the float is a bluff body, the pressure drag dominates the viscous drag. However the drag force on the float is also dependent on the extent of annulus area available for flow between the float and divergent tube. Thus computation of FD and its dependence will be very complex.The governing equation relating the position of the float with the volumetric flow rate has been derived in our previous work [1]

1.2 Density correction factor

The Rotameter used to measure the flow rates of liquids, are usually calibrated with water, which has a nominal density of 1000 kg/m3 and viscosity of 0.001003 Pa-s. When flow rates of fluids other than calibrated fluid is to be measured using this rotameter then the indicated flow rate must be multiplied by the correction factor obtained from standard density correction formulae.The formulae is derived assuming that the variation of viscosity has negligible effect on the actual flow rate and the drag coefficient is constant for both the fluids and at all flow rates it is given by

$$Q_{L,act} = \sqrt{\frac{(\rho_F - \rho_{oil})\rho_W}{(\rho_F - \rho_W)\rho_{oil}}} \times Q_W \ m^3/s \ldots\ldots\ldots\ldots(2)$$

Where QL,actis the actual volumetric flow rate of the fluid, m3/s
ρ_oilis the density of fluid other than water, kg/m
Density correction factor for liquids

$$(C_S) = \sqrt{\frac{(\rho_F - \rho_{oil})\rho_W}{(\rho_F - \rho_W)\rho_{oil}}} \ldots\ldots\ldots\ldots (3)$$

2. Literature survey

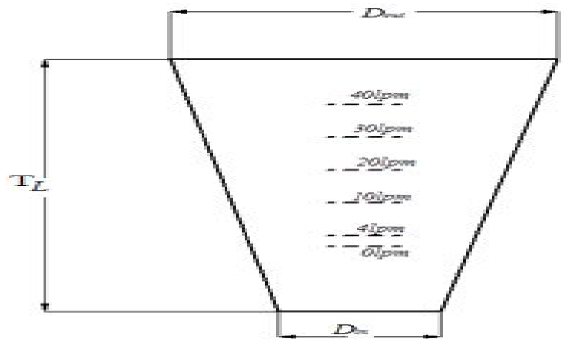
Pavan kumar et.al[1] havereported Analysis of flow through a rotameter available in the laboratory using CFD. Here the drag force on the float at various positions in the tapering tube has been calculated. On the basis of the analysis the flow rates at which the float comes to equilibrium at various locations have been calculated. A comparison between the computed (CFD) flow rate and the flow rate indicated by the meter has been done and the results showed excellent agreement.Rakesh Joshi et.al [2] studied the effect of Rotameter float design on the performance characteristics of Rotameter. Gambit and ANSYS fluent software were used for geometry modeling and analysis of Rotameter respectively.Buckle et.al [3] conducted an investigation on the flow through rotameter. They have used Laser Doppler anemometry (LDA) and CFD analysis for visualization of the flow around the float for different flow rates, different density of the float material and two heights of the float in the tube.BogdanStoyanov et.al [4]conducted a study to determine the flow rate of different fluid through rotameter.Using correction factor equations the flow rate of ammonia, oxygen, carbon dioxide, argon and Chlorine has been calculated theoretically and compared with the calibrated fluid flow rates at different position of float.

Objective of the present study is to use CFD to establish the performance characteristics of a rotameter when it is used to measure fluids of varying density and viscosity. As a first step, the accuracy of the CFD methodology is established by comparing the computed flow rates with the indicated flow rate for a rotameter available in the institute. Then analysis have been carried out with four different fluids namely Gasoline (a), Gasoline (c), Diesel-2D, Kerosene. It is proposed to establish the validity of the standard density correction factor used in industries. Aparametric study by systematically varying the density and viscosity of the fluid will be carried out to establish the range of variation of these two properties within which the accuracy of the measurement by a rotameter is not affected.

2.1 Details of the rotameter analyzed

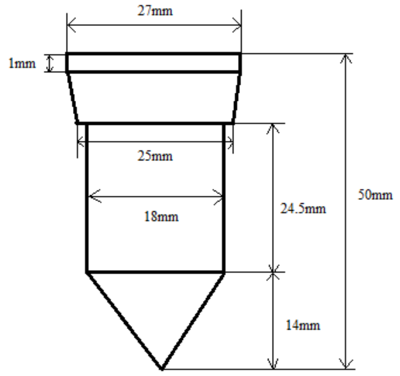
The rotameter used in the analysis is designed for the measurement of flow rate of water in the range 0 – 40 lpm. It consists of a vertical diverging tube (see Fig.5.10) in which a stainless steel float can move freely. The shape of the float is shown in Fig 1. The various dimension details are as follows:

a) Dimensions of the Tapered Tube:



Inlet diameter = Din = 25.48mm
Outlet diameter = Dout = 36.85mm
Vertical height of the tube = TL= 260mm
Half Taper angle = θ= 1˚ 12˚.

b) Dimensions of the float:



Float Material = stainless steel
Material Density = ρ_F= 7850 kg/m3
Volume of float= VF = 12584.46 mm3
Drag force FD when the float is in equilibrium is calculated using the formulae,
FD =$[(\rho_F - \rho_W) \times V_F \times g]$=[(7850 - 1000) ×12584.46× 10-9 ×9.81]= 0.8456 N
This FD is constant at all positions when the float is in equilibrium since it depends only on density of float material and fluid and volume of the float.
The heights of each marking from the inlet have been measured and the ratio of diameter of the float and diameter of the tapered tube at float position are tabulated in Table 1

TABLE – 1 :Height of markings from Inlet (Float Height)for different Flow rates and Diameter ratio at that position

Q_{ind} (lpm)	H (mm)	$\frac{D_F}{D_t}$
4	57.5	0.96
10	86.5	0.92
20	129	0.87
30	166	0.82
40	199	0.79

3. Performance of rotameter when used with different fluids:

In the present analysis to study the accuracy of rotameter when it is used to measure the flow rate of fluids other than water, four different types of fluids namely Diesel- 2D, Gasoline (a), Gasoline(c), and Kerosene have been considered. The properties of these fluids [10] at room temperature and the density correction factors (CS) calculated from standard density correction formulae are given in the Table 2

TABLE -2: Properties of different fluids and Density correction factor			
FLUIDS	DENSITY , kg/m3	VISCOSITY, Pa-s	CS
Kerosene	780	2.1138e-3	1.1503
Diesel-2D	820	1.64e-3	1.1187
Water	1000	1.003e-3	1
Gasoline (a)	740	6.512e-4	1.1843
Gasoline (c)	680	3.128e-4	1.24068

For the above fluids computations has been made for 5 different float positions corresponding to 4,10,20,30 and 40 lpm markings. The properties of the fluid are fed as an input and initially the velocity corresponding to the marked flow rate is given as a boundary condition at the inlet of the tube. Since this does not give the desired drag force for dynamic equilibrium the value of velocity at the inlet is iterated so that dynamic equilibrium is achieved. This velocity is given as UCFD and flow rate corresponding to this velocity is termed as QCFD. Further the flow rate of the oil (Q_{oil}) after applying density correction factor (CS) is also calculated. Ideally these two values (Q_{CFD} and Q_{oil}) should be in agreement if the assumption of constant drag coefficient (CD) is valid. It is to be noted that Qoil takes care of only density variation however the viscosity variation is not accounted for. The results are tabulated in Table 3.

Table 3: Results of performance of rotameter with different fluids						
KEROSINE						
Q, lpm	H, mm	U_{CFD}, m/s	Q_{CFD}	Q_{oil}	Re	Error (%)
4	57.5	0.13338	4.113	4.601	1329	+10.6
10	86.5	0.343	10.576	11.503	3417	+8.1
20	129	0.6891	21.248	23.006	6866	+7.6
30	166	1.02868	31.718	34.509	10249	+8.1
40	199	1.363	42.027	46.013	13580	+8.7
DIESEL – 2D						
4	57.5	0.13508	4.165	4.475	1824	+6.9
10	86.5	0.343	10.576	11.187	4631	+5.4
20	129	0.68475	21.113	22.374	9244	+5.6
30	166	1.01884	31.415	33.562	13754	+6.4
40	199	1.3543	41.758	44.749	18283	+6.7
GASOLINE (a)						
4	57.5	0.1548	4.773	4.737	4750	-0.7
10	86.5	0.391	12.056	11.843	11997	-1.8
20	129	0.77103	23.774	23.687	23657	-0.4
30	166	1.14916	35.433	35.529	35258	+0.3
40	199	1.526	47.053	47.373	46820	+0.7
GASOLINE (c)						
4	57.5	0.172	5.303	4.963	10096	-6.9
10	86.5	0.4206	12.969	12.407	24687	-4.5
20	129	0.82789	25.527	24.814	48593	-2.9
30	166	1.2323	37.997	37.220	72331	-2.1
40	199	1.6341	50.386	49.627	95914	-1.5

It is observed in the tabulated values that for kerosene, the correction factor gives an error in the range +7.6% to +10.6%. Calculated values of flow rate are in excess of actual flow rates in this case. This is due to the fact that viscosity of Kerosene is higher than that of water (about $2.1\times\mu_w$).For Diesel-2D the correction factor gives an error in the range +5.4% to +6.9%. Calculated values of flow rate are in excess of actual flow rates in this case. This is due to the fact that viscosity of Diesel-2D is higher than that of water (about $1.64\times\mu_w$).For Gasoline (a) the correction factor gives an error in the range -0.7% to +0.7%. The calculated values of flow rate are in good agreement with that of

values obtained from CFD.This is due to the fact that viscosity of Gasoline – A is fairly close to that of water ($0.65\times\mu_w$).For Gasoline (c) the correction factor gives an error in the range -6.9% to -2.1%. The calculated values of flow rate are lesser than that of actual flow rates in this case. This is due to the fact that the viscosity of Gasoline(c) is lower than that of water ($0.31\times\mu_w$).
It can be concluded from this analysis that whenever the viscosity of the fluid is less than that of the calibrating fluid (here it is water) the computed values of flow rates using density correction factor are less than the actual flow rate and when the viscosity is higher the computed values of flow rates using density correction factor are higher than the actual flow rate

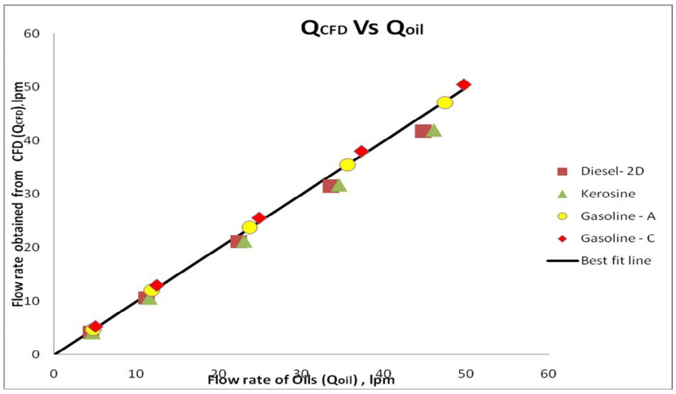


CHART 1: Plot showing the variation of Q_{CFD} and Qoil for different fluids

Above chart shows the graph showing the variation of flow rate obtained from CFD with respect to the flow rate obtained by applying density correction factor equation.
From the graph it can be observed that the values of Q_{oil} for Diesel–2D and Kerosene are higher than the actual flow rates. The values corresponding to Gasoline (a) are almost coinciding with best fit line. In the case Gasoline (c) the values of Q_{oil} are lower than the actual flow rates. Hence density correction factor is valid for fluids having viscosity not very much different from the standard fluid viscosity. Thus it can be concluded that if the viscosity of the fluid differs substantially from that of the standard fluid the rotameter will give erroneous results even after applying density correction factor and the error will be positive if the viscosity is higher and error will be negative if viscosity is lower.

4. Conclusions

The performance of rotameter calibrated with water when used to measure the flow rates of different fluids has been analyzed using CFD. Four fluids [(namely Diesel – 2D, Kerosene, Gasoline (a), and Gasoline(c)] having different density and viscosity values are used in the analysis.The computed flow rates are compared with indicated flow rates (after applying density correction factor).The study has shown that as long as density and viscosity of the fluid is with a certain range of the corresponding values of the calibrating fluid, the accuracy of the flow measurement can be ensured.

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