Effect of wedge shape and pressure tap locations on the characteristics of a wedge flowmeter

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Performance characteristics of a wedge flowmeter with $H/D = 0.5$ has been experimentally evaluated to study the variation of discharge coefficient with Reynolds number. Three geometrical parameters of the meter namely wedge tip radius, wedge tip angle and pressure tap locations have been systematically varied to establish their effects. Results show that the discharge coefficient remains constant over the range of Reynolds number tested for all wedge element shapes and pressure tap locations. The highest value of discharge coefficient is obtained for a rounded wedge element with an angle of 90° and differential pressure measuring locations at $2D - D$.

Measurement of flow rate is one of the oldest art in the field of scientific instrumentation and its history extends back at least to the great hydraulic and public engineering works of the Romans. Flow measurement is very important in industries which deal with any kind of fluid flow. The applications could range from measurement of blood flow in arteries to fuel gas in rockets. Fluid engineers have been continuously striving to develop high quality flow rate measuring devices to meet the specialized needs of various industrial applications and cover a very wide range of flow rates which can be as high as 100:1. Attempts have also been made to develop devices which work for different types of fluids such as highly viscous fluids, non-Newtonian slurries, two phase flows, etc. It is well established that obstruction type of flowmeters are versatile although they have some limitations. Performance characteristics of conventional type of obstruction flowmeters like orifice, nozzle and venturi meter, are well documented. However, these devices cannot be used in all applications. For example, orifice plates cannot be used to meter the flows when the fluid is dirty and/or mixed with solid particles. This is due to the fact that solid particles in the flow tend to get deposited on the upstream face of the orifice plate and alter the flow coefficient of the meter. Also, it is well established that at smaller Reynolds number (less than $10^4$), the flow coefficient of conventional obstruction flow meters becomes strongly dependent on the actual value of Reynolds number thereby altering the well established square root relationship between flow rate and pressure drop. The wedge element is a differential producer that takes the name from the special V shaped restriction (Fig. 1) which creates the differential pressure. It has been reported that wedge element conforms to the square root relationship between flow and differential pressure over an extremely wide range of Reynolds number from as low as 1000 to values greater than 40,000 where as other obstruction type flow meters start showing deviations below 10,000. The other important feature is that it does not have any wear sensitive surfaces like an orifice plate and it can handle difficult fluids that are viscous, corrosive/erosive. A wedge element can also be used to monitor flows of solid liquid mixtures since the problem of choking is not encountered. This is due to the fact that the wedge is located at the top of the pipeline spanning across the cross section. Fig. 1b shows the streamline pattern in a wedge flow meter. It is seen that below the wedge the flow accelerates which will prevent the settling of solid particles at the bottom of the pipeline. Since at the bottom side of pipeline, there is no obstruction to the flow, a wedge element can be used to monitor flow in a slurry pipeline. Studies on the characteristics of wedge flow meters are scanty and most of the data is of confidential nature and is only available with the manufactures.

In the present study, effort has been made to establish the effect of tip angle and tip radius on the discharge coefficient of a wedge flowmeter in a 50 mm NB pipe. Attempt has also been made to suggest the selection of optimum pressure tap loc-
Pressure taps to multilube manometer

Fig. 1a—Wedge flow element

Flow accelerations

Fig. 1b—Expected stream line pattern

Table 1—Parameters of wedge element investigated

<table>
<thead>
<tr>
<th>Pressure tap locations</th>
<th>Wedge angle</th>
<th>Wedge shape</th>
<th>Fluid</th>
<th>Test Pipe diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>2D–2D</td>
<td>60°/90°</td>
<td>Sharp/round</td>
<td>Air/water</td>
<td>50 mm NB</td>
</tr>
<tr>
<td>2D–D</td>
<td>60°/90°</td>
<td>Sharp/round</td>
<td>Air/water</td>
<td>50 mm NB</td>
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<td>D–D</td>
<td>60°/90°</td>
<td>Sharp/round</td>
<td>Air/water</td>
<td>50 mm NB</td>
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</table>

Experiments on these flowmeters were conducted to evaluate the performance in terms of variation of discharge coefficient with Reynolds number using two fluids, namely, water and air. Different experimental rigs were fabricated for the two fluids and are described below.

**Experimental set-up for air flow**—The schematic diagram of the experimental set-up used for air flow is shown in Fig. 2 and it consists of centrifugal blower, pipe of 60 diameter length, wedge flowmeter and pitot static tube for measuring flow rate. Air was supplied from the blower having a capacity of 0.57 m$^3$/s at 67 cm of water column. Air from the blower flows through 50 mm NB pipe having 60 diameter length. The wedge flowmeters were fitted at this end and then it was followed by another pipe piece of 15 diameter length which had a gate valve at the end to control the flow rate. A bypass line with a valve is also provided near the blower outlet to be used as an auxiliary device for flow control. A pitot static tube was used to measure actual flow rate by mounting it at the centre axis of the pipe at a distance of 50 diameters from the blower exit. Pressure differential indicated by the Pitot static tube was measured using a BETZ micromanometer having a resolution of 0.1 mm water column. The measurement of the centre line velocity allows evaluation of flow rate within ± 1% using standard correlations available in literature. The flowmeter was mounted 10 pipe diameters downstream of the Pitot static tube. This distance is sufficient to ensure the absence of interference effects for achieving a constant value of discharge coefficient over as wide a range of Reynolds numbers as possible. Table 1 gives the range of parameters investigated in the present study. The results from this study can be used in the design of wedge flow meters for special applications.

**Experimental Procedure**

**Wedge flowmeter**—Four wedge Flowmeters of 50 mm NB with $H/D=0.5$ were fabricated with different wedge element shapes. Two wedge elements had sharp wedge tips with included angles of 60° and 90°. The other two wedge elements had rounded tip with 3 mm radius of curvature with same included angles. Each flowmeter was provided with two sets of pressure taps of 3 mm diameter on both sides of the wedge element at distances of $D$ and $2D$ from the centre of the wedge element to sense the differential pressure across the wedge element in 3 combinations namely $2D–2D$, $2D–D$ and $D–D$. The salient dimensions of the wedge flowmeters are as follows.

- Opening to diameter ratio ($H/D$) = 0.5
- Pipe diameter (ID) = 54 mm
- Flowmeter length = 400 mm
- Flange diameter = 63 mm
since it corresponds to a length of over 200 times
the diameter of the pitot static tube. The pressure
difference across the wedge was measured using an
inclined tube bank manometer.

For a particular setting of the flow rate, the fol-
lowing measurements were taken: (i) velocity head
indicated by Pitot static tube, (ii) static pressure at
the pitot static tube, (iii) pressure differential ac-
ross the wedge flowmeter for three combinations
of Pressure tap locations, namely, 2D−2D,
2D−D, and D−D, (iv) temperature of the air, and
(v) atmospheric pressure in mm of Hg.

From these measurements, the actual flow rate
through the meter is accurately calculated follow-
ing standard procedure. The ratio of centreline
velocity to the average fluid velocity in the fully
developed turbulent flow through a pipe is a weak
function of Reynolds number. This relationship is
available in standard textbooks. The measured
centreline velocity is converted to average velocity
using this relationship and hence actual flow rate
is calculated. Using this flow rate and the pressure
differential across wedge flowmeter, the wedge
flow coefficient $C$ is evaluated using the well
known equation for obstruction flow rate measur-
ing devices given below

$$m = \rho Q_v = CA_0 F_a Y \sqrt{2 \Delta \rho}$$

... (1)

In the present case since $\Delta p/p < 1$, the expan-
sibility factor was assumed to be equal to unity.

This procedure was repeated at different flow
rates to cover the total range of flow rates avail-
able from the blower.

**Experimental set-up for water**—Fig. 3 shows the
schematic diagram of the experimental set-up used
for studies with water as the fluid. It consists of an
overhead tank where head was maintained con-
stant, 50 mm pipe line, wedge flowmeter, weighing
machine and collecting tank.

The supply of water was obtained from a large
sized overhead tank located at an elevation of 15
m above the ground level. The level of water in
this tank was maintained constant using the pumps
located in the basement of the laboratory. The ex-
cess water flowed back to the pump though an
over flow pipe. Water from the overhead tank
flows through the meter and empties into the col-
lecting tank. The flow rate through the meter is
regulated by the gate valve downstream of the me-
ter. The flow rate in this case is measured gravimeti-
cally. The measuring tank is placed on a
beam type of balance which is fitted with an opto-
electronic type of sensing device for switching on
and off the electronic timer. For each measure-
ment, 400 kg of water was collected which result-
ed in an accuracy of ±0.2% for flow rate determi-
nation. The pressure differential was measured using mercury manometer and inverted U tube water manometer. Using these quantities, wedge flow coefficient $C$ is obtained by the wedge meter Eq. (1) [$Y=1$, for incompressible fluids].

The values of $C$ for different wedge flow meters are calculated over a wide range of flow rates. Accuracy in determination of $C$ is of the order of ±0.5%.

Results and Discussion

Figs 4-6 present the variation of wedge coefficient as a function of wedge shape and pressure tap location at various Reynolds numbers in the range of 10,000-280,000. The results for both air and water have been presented on the same plots and it is seen that results overlap and no variation is seen in wedge coefficient for the two fluids which is as expected.

Effect of wedge angle—Fig. 4 shows the variation of wedge coefficient for two wedge angles, namely, 60° and 90°. It is seen that for 60° angle

![Fig. 5—Variation of wedge coefficient for rounded edge wedge element (a) 60° Round edge wedge element, and (b) 90° Round edge wedge element](image)

...Combination of pressure tap location...

![Fig. 6—Effect of pressure tap location on wedge coefficient](image)
Table 2—Effect of geometrical parameters on wedge coefficient

<table>
<thead>
<tr>
<th>Sl No</th>
<th>Fluid</th>
<th>Wedge degree</th>
<th>Tip shape</th>
<th>Pressure tap</th>
<th>Wedge coefficient</th>
<th>Reynolds number range</th>
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<tbody>
<tr>
<td>1</td>
<td>Air</td>
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<td>2D–2D</td>
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<td>D–D</td>
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<td>Round</td>
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</table>

Effect of tip rounding of wedge element—Fig. 5 depicts the effect of rounding the wedge tip for the two wedge elements of 60° and 90°. It is seen that rounding has drastic effect on wedge coefficient. For 60° wedge with rounded edge (Fig. 5a), the losses have reduced due to reduced wake size and probably due to shifting of vena contracta towards the tip. The value of wedge coefficient for a given combination of pressure locations is higher by about 17%. Similar effect is seen for 90° wedge angle (Fig. 5b) but the effect seems to be not that pronounced because flow has already been partially streamlined due to increased angle. The increase in this case is only by about 8%. Rounding of wedge tip is attempted because it is well known that sharp edges are subject to more wear in slurry flows. Increase in wedge coefficient has also shown that rounding of the tip gives an additional advantage in terms of pressure loss.

Effect of pressure tap location—Fig. 6 presents the variation of average discharge coefficient for the 4 wedge flowmeters as a function of differential pressure tap locations. For D–D and 2D–D combination of pressure taps locations, there is no significant change in the value of average wedge coefficient but for 2D–2D the value changes abruptly. This is due to location of the downstream pressure tap which may or may not be in the zone of separation downstream of the wedge element. Therefore, to avoid this change due to change in element shape, downstream pressure tap location could be only at a distance of one diameter (ID). During experimentation and also from the graphs (Figs 4 and 5) one sees that for D–D, the
scatter of experimental points is more and hence $2D-D$ can be taken as an optimum combination.

All of the above results have been summarised in Table 2 and give a comparative analysis of the effect of different geometrical parameters.

**Permanent pressure loss**—Pressure loss has been measured over a 15 diameter length of the pipe with and without the wedge flowmeter. From these measurements, permanent pressure loss created by the wedge meter has been evaluated. This experiment has been done for rounded 60° and 90° wedge elements only since sharp wedges are rarely used in commercial applications of two phase flows. Permanent pressure loss has been normalized by pressure drop across the wedge with $2D-D$ pressure taps. Permanent pressure loss as a function of Reynolds number is presented in Fig. 7. It is seen that permanent pressure loss for 90° is less than that for 60° which can be attributed to better guidance of the flow. Another important feature seen is that permanent pressure loss increases with Reynolds number. This effect could be identified with the elongation of the wake bubble with Reynolds number and enhanced mixing which allows faster pressure recovery close to the wedge.

**Conclusion**

Two wedge elements namely 60° and 90° with sharp and rounded tips have been experimentally investigated for their performance. It has been found that rounded wedge elements with higher included angle give better performance with $2D-D$ pressure tap locations. Analysis of permanent pressure loss has shown that this instrument has higher pressure loss compared to concentric orifice plate of equivalent diameter ratio. Additional investigations are needed to be carried out to establish the authenticity of the above results for different geometrical and dynamical conditions. Based on the present study, the following specific conclusions can be drawn.

1. 90° wedge angle has higher value of wedge coefficient which further increases due to rounding of the wedge tip due to better guidance of the flow.

2. $2D-D$ is the optimum pressure tap location as this gives minimum scatter of data points over the range of Reynolds numbers tested.

3. The permanent pressure loss in a wedge flowmeter is somewhat larger than orifice or nozzle meter which could be attributed to the asymmetry in the flow in the case of wedge.

4. The wedge coefficient remains independent of Reynolds number over the range tested. Currently, investigations are planned to establish this phenomenon in two phase flows also.

5. Measurements with two fluids, namely, air and water have shown the validity of Reynolds number similarity for the flow through the wedge element.

**References**


**Nomenclature**

- $A_0$ = area of cross section at wedge tip
- $C$ = wedge coefficient
- $D$ = pipe diameter, m
- $F_a$ = coefficient of thermal expansion of device
- $H$ = height of opening, m
- $m$ = mass flow rate, kg/s
- $P$ = upstream pressure, N/m²
- $\Delta p$ = pressure differential, N/m²
- $Q_v$ = volumetric flow rate, m³/s
- $Y$ = expansibility factor
- $\rho$ = density of fluid (kg/m³) at upstream conditions