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Discharging Characterstics Of Venturimeter For Sediment Laden Flow

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Abstract: ***Measurement of flow is an important aspect in the field of hydraulic engineering. In case of pipe, various flowmeters are used for flow estimation, out of which venturimeter is most commonly used and conventional means. Pipe carrying sediment laden flow or slurry-water mixture is common in few industries. Suitability of flowmeters needs to be analyzed for sediment laden flow. Due to the presence of slurry or sediments, coefficient of discharge of flow varies with Reynolds number, sediment concentration and the size of sediment.***

In the present study, experiment has been conducted in two Venturimeters of sizes 2" x 1" and 3" x 1.5". At first readings were taken with clear water for both the venturimeters and then with sediment laden flow. Three different sizes of sediments such as Medium Sand (d_{avg} = 0.25 mm), Coarse Sand (d_{avg} = 0.8025 mm) and Very Coarse Sand (d_{avg} = 1.59 mm) have been used with four sediment concentrations – 1%, 2%, 3% and 5%.

Keywords: ***Venturimeter, Sediment laden flow, Coefficient of discharge.***

1. INTRODUCTION

In few industrial cases slurry flow (mixture of liquid and solid) measurement is to be taken through the pipeline carrying different concentration of sediments over a long distance. Solid transported through the pipe lines are mainly minerals, ores, silt and sand. Sediment laden flows generally create several problems in measurement of flow than liquid flow. Also the performance of pumps is affected by sediment present in fluid. In slurry transport the material is made to fine grain size and then mixed with liquid medium and then it is transported through pipelines to any location.

The present study is an experimental attempt to analyze the variation of coefficient of discharge of venturimeter with Reynolds number for different concentration of solids. The following aspects have been analyzed in the present study:

- Variation of coefficient of discharge with sediment concentration.
- Variation of coefficient of discharge with size of the sediment.

By developing a correlation of C_d with sediment size and concentration will be helpful for the analysis of flow rate and effectiveness of venturimeter.

2. Experimental setup and procedure

2.1 Laboratory set up

The experimental set up consists of two venturimeter of different sizes as shown in the Fig.1 given below. Dimension of the smaller venturimeter (V_1) is 5.04cm (2") × 2.54cm (1") while that of larger venturimeter (V_2) is 7.62cm (3") × 3.81cm (1.5"). The upstream length of smaller venturimeter and larger venturimeter was taken as 113 cm and 77 cm respectively. And downstream length was taken 96 cm and 144 cm for smaller venturimeter and larger venturimeter respectively.

Fig. 1 – Complete Setup in running condition

Venturimeter are installed according to IS 4477-2 (1975). The laboratory set up consists of two tanks, one mixing tank and another one is of the volumetric measuring tank as shown in the above figure. The mixing tank having the size of 99.5 cm × 100 cm × 100 cm and the measuring tank is of 91 cm × 91.5 cm × 80 cm. A closed single stage impeller centrifugal pump (driven by 5 hp, 3 phase electric motor with 2850 rpm) is attached to the mixing tank, which helps in circulation of clear water and sediment laden water in the system. The pump draws water from the mixing tank and throws it back to the measuring and mixing tank by means of 3” and 2” pipes attached to larger and smaller venturimeter respectively. The water is coming back to the mixing tank by means of the pump. Manual arrangement of mixing rods, ensure proper mixing of the sediment with clear water. Mixing of sediment was carried out manually. The flow rate is controlled by different valves attached in the system as shown in the Fig. 2. Valve-1 and Valve-2 are the opening valves for the smaller and larger venturimeters respectively. Valve-5 and Valve-6 control the flow into the mixing tank. The flow rate is varied by adjusting opening of these two valves for their respective venturimeter. Valve 3 and 4 are provided to avoid excess pressure development near the venturimeter taps, which may cause damage to the differential mercury manometer attached there as shown in the Fig. 2.

For the measurement of flow, there is a scale arrangement outside of the measuring tank which gives the depth of water present in the tank during a particular time interval. Time is measured by means of an electronic stop watch.

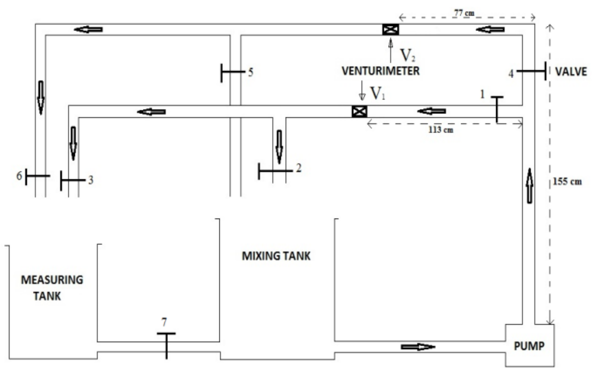

Fig. 2 – Schematic diagram of experimental setup

2.2 SEDIMENTS SELECTION

Three different sizes of sand samples have been chosen for mixing sediment with clear water and also for each sand size, concentration was varied from 1% to 3% and 5% by weight. For proper gradation of sediment samples sizes, hand sieving was done by means of four different sizes of sieves of size 2 mm, 1.18 mm, 0.425 mm and 0.075 mm, sieves.

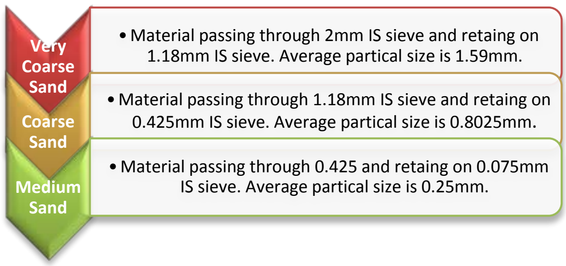

Fig. 3 – Diagram showing process of selection of sediment for the present study

The above classification of sediments is done according to AGU (American Geophysical Union). This is based on the Udden’s geometrical scale of sediment size and Wentworth’s modification. This is accepted by AGU, and widely used by hydraulic engineers

2.3 PROCEDURE

At first, the experiment was conducted with clear water in both smaller venturimeter (V_1) and larger venturimeter (V_2). Discharge or flow rate was varied 7 to 10 times and the corresponding theoretical discharge was measured from the U-tube differential manometer and the actual discharge was measured from the reading of the measuring tank. After taking the readings with clear water, experiment was conducted with sediment mixed water. At first, medium sand was mixed with clear water by varying the concentration as described above. For proper mixing of sand, water was continuously stirred by means of mixing rod. For each concentration of sediment, flow rate was varied 7 to 10 times and for each set theoretical and actual discharge were measured.

3. RESULTS AND DISCUSSION

3.1 TEST RESULTS FOR SMALLER VENTURIMETER – V_1 (2”×1”)

The test results for smaller venturimeter (V_1) have been presented in this section in the form of graphs. Results for very coarse sand (1.59 mm), coarse sand (0.8025 mm) and medium sand (0.25 mm) along with four different sediment concentrations (Cs = 1%, 2%, 3% and 5%) are also presented in this section.

3.1.1 Results for Medium Sand (d_{avg} = 0.25mm)

The coefficient of discharge versus Reynolds number on a semi log graph for the sediment laden flow with medium sand (d_{avg} = 0.25 mm) is shown in Fig. 4.

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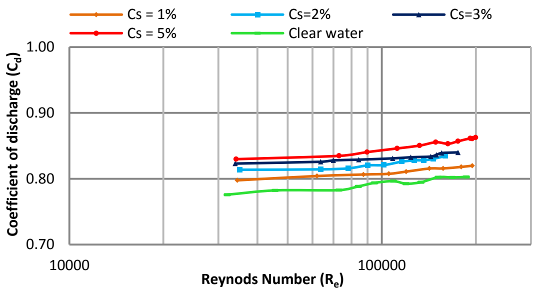

Fig. 4 – C_d versus Re for smaller venturimeter (V_1) with Medium sand

From the above Fig.4, it is clear that value of Coefficient of discharge (C_d) increases slowly with increase in Reynolds number. It is also clear that the value of C_d increases with increase in sediment concentrations i.e. from 1% to 5%. The variation C_d versus R_e for clear water is also shown in this Fig. 4, which shows that the values C_d is minimum for clear water and increases with increase of sediment concentration in sediment laden flow. It may be due to the decrease in turbulence intensity with the increase in sediment concentration.

3.1.2 Results of Coarse Sand (d_{avg} = 0.8025 mm) and Very Coarse Sand (d_{avg} = 1.59 mm)

The results of Coefficient of discharge versus Reynolds number for the sediment laden flow with coarse sand (d_{avg} = 0.8025 mm) are shown in Fig. 5 and for very coarse sand (d_{avg} = 1.59 mm) in Fig. 6.

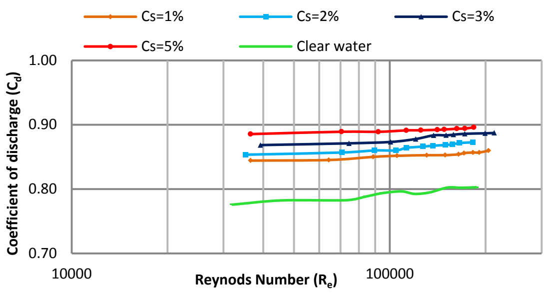

Fig.5 – C_d versus Re for smaller venturimeter with Coarse sand (d_{avg} = 0.8085 mm)

The trend of variation of Coefficient of discharge C_d versus Reynolds number R_e is similar to that for medium sand except that C_d for sediment laden flow is comparatively higher with respective to clear water flow

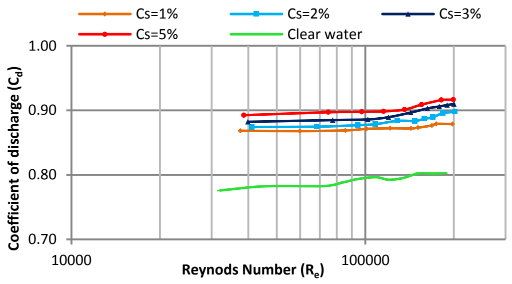

Fig. 6 – C_d versus R_e for smaller venturimeter with Very Coarse Sand (d_{avg} = 1.59 mm)

From the above Fig.6, it is also seen that the value of coefficient of discharge (C_d) increases slowly with increase in Reynolds number, it shows same trend as above two types of sediment. It is also clear that the value of C_d increases with increase in sediment concentrations i.e. from 1% to 5%. The reason of increase in C_d for sediment laden flow is same as that of previous case.

3.1.3 Development of Expression for C_d* for Venturimeter – V_1 (2”x1”)

- **Medium sand**

From Fig. 4, it can be observed that the value of Coefficient of discharge (C_d) increases with increases in concentration of medium sand and therefore, for different concentrations, different lines of C_d value have been obtained. To make these values fall in a single line, modified coefficient of discharge C_d* has been derived, which is given by

$$C_d^* = C_d / C_s^{n} \qquad (1)$$

In Eq. 1, Where C_s is the sediment concentration in percentage and n is the exponent to C_s.

For different values of exponent (n), C_d* has been calculated and corresponding values of correlation coefficient (R^2) are obtained for graphs drawn between corresponding C_d* and Reynolds number (R_e). The values of correlation coefficient (R^2) so obtained versus n have been given below. The value of exponent (n) is selected that corresponds to maximum value of R^2.

For smaller venturimeter with medium sand, value of n was found to be 0.026 for which R^2 is maximum i.e. 0.931. Therefore, equation (1) is reduced to:

$$C_d^* = C_d / C_s^{0.026} \qquad (2)$$

- **Coarse Sand and Very Coarse Sand**

The same procedure is followed to find the value of n for which R^2 is the maximum for coarse sand and very coarse sand. The value of n thus obtained is

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given below. Thus the value of n for coarse sand and very coarse sand was found to be 0.029 and 0.022 respectively.

The corresponding equations for coarse sand and very coarse sand are follows.

$C_d* = C_d / C_s^{0.029}$ (3)

$C^d* = C_d / C_s^{0.022}$ (4)

3.1.4 Development of expression for C_d for smaller venturimeter (2”×1”)**

In case of smaller venturimeter, for all the three types of sediments, a graph has been plotted between Reynolds number and the respective maximum C_d* (i.e. C_d* for a particular ‘n’ for which R^2 was found to be the maximum), which is obtained in the previous subsection and shown below in Fig. 7.

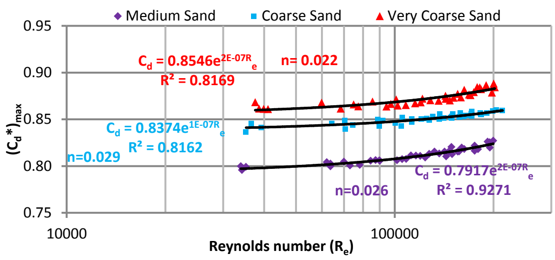

Fig. 7 $(C_d*)_{max}$ versus R_e for smaller venturimeter

From the above graph, it’s clear that for all the three types of sediments, three different curves are obtained. To make all these values fall on a single curve, another constant has been introduced by modifying C_d*, which is given below:

$C_d** = (C_d*)_{max} / d_{avg}^{m}$, (5)

Where d_{avg} is the average particle size diameter of the sediment.

For different values of m, graphs has been plotted between C_d** and Reynolds number for the smaller venturimeter. The value of m for which all the three lines became closest is found to be 0.039 as shown in Fig. 8. So the above equation (5) reduces to,

$C_d** = (C_d*)_{max} / d_{avg}^{0.039}$ (6)

The Fig. 8 represents the variation of C_d** versus Reynolds number for all the three types of sediment, for exponent m= 0.039. Values of all the three sediments are almost found to very closest for m=0.039, as shown in Fig. 8.

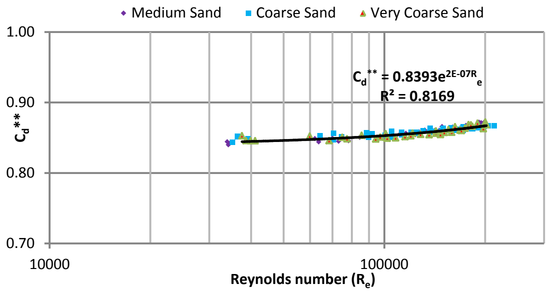

Fig. 8 - C_d** versus R_e for smaller venturimeter

3.2 TEST RESULTS FOR LARGER VENTURIMETER - V_2 (3”×1.5”)

The test results for larger venturimeter (V_2) have been presented in this section in the form of graphs. Results for very coarse sand (1.59 mm), coarse sand (0.8025 mm) and medium sand (0.25 mm) along with four different sediment concentration (Cs = 1%, 2%, 3% and 5%) are presented here.

Medium Sand (d_{avg} = 0.25 mm), Coarse Sand (d_{avg} = 0.8025 mm) and Very Coarse Sand (d_{avg} = 1.59 mm)

In Fig. 9 a graph has been plotted between C_d and Reynolds number, for the larger venturimeter (V_2) with sediment laden flow (d_{avg}=0.25 mm) on a semi log scale. From the graph, it’s clear that in case of the larger venturimeter (V_2) for medium sand (0.25 mm), as the concentration increases, value of coefficient of discharge (C_d) gradually increases i.e. from 1% to 5, but increases slowly with Reynolds number. The reason is behind this behavior is same as that for smaller venturimeter with medium sand as sediment.

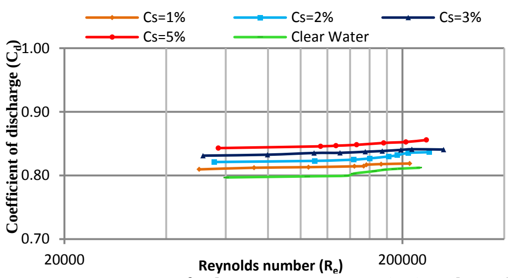

Fig. 9 – C_d versus R_e for larger venturimeter (V_2) with Medium sand as sediment

The variation of coefficient of discharge (C_d) with Reynolds number (R_e) and sediment concentration (C_s) is plotted in Fig.10 (for coarse sand) and in Fig.11 (for very coarse sand). Again the trend of variation and the reason behind this is same as that of previous case.

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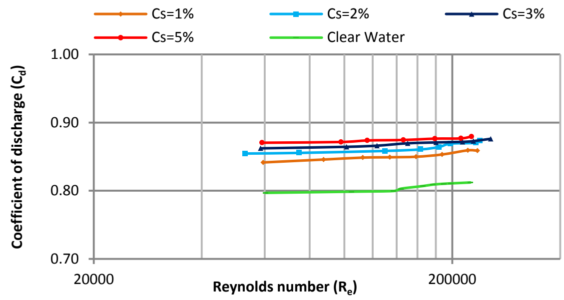

Fig. 10 – C_d versus R_e for larger venturimeter with coarse sand as sediment

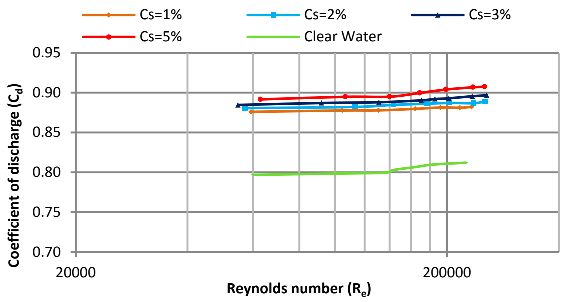

Fig. 11 – C_d versus R_e for upper venturimeter with very coarse sand as sediment

3.2.1 Development of expression for C_d* in case of larger venturimeter (V_2)

A similar procedure is adopted to find the value of exponent n for medium sand, coarse sand and very coarse sand. The corresponding equations for C_d** are given in Eq.7 to Eq.9. The correlation coefficients are also presented in this section. From the graph of medium sand, value of n is found to be 0.024, for which R^2 is maximum i.e. 0.837.

$$C_d^* = C_d / C_s^{0.024} \quad (7)$$

For coarse sand and very coarse sand, following equations (4.8) and (4.9) have been developed.

$$C_d^* = C_d / C_s^{0.017} \quad (8)$$

$$C_d^* = C_d / C_s^{0.022} \quad (9)$$

3.2.2 Development of expression for C_d** for larger venturimeter – V_2 (3”×1.5”)

In case of larger venturimeter, for all the three types of sediment, a graph has been plotted between Reynolds number and the respective maximum C_d* as shown below in Fig. 12 in the same way as in case of smaller venturimeter.

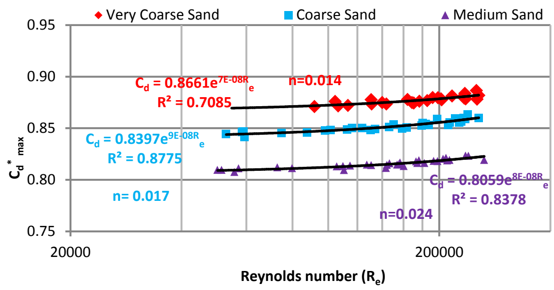

Fig. 12 - C_d* versus R_e for larger venturimeter

To obtain the C_d** for venturimeter V_2, for different values of m, graphs has been plotted between C_d** and Reynolds number for the larger venturimeter V_2. The value of m for which all the three lines became closest was found to be 0.039 as shown in Figure 13.

$$C_d^{**} = (C_d^*)_{max} / d_{avg}^{0.039} \quad (10)$$

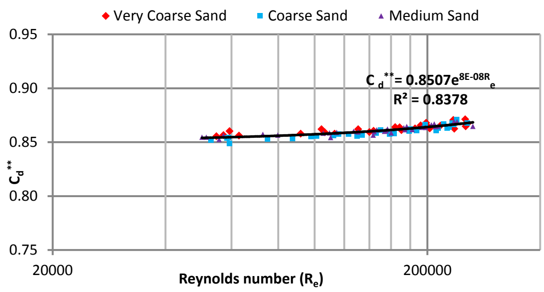

Fig. 13 - Cd** versus Re for upper venturimeter

The values of m for smaller and larger venturimeters are also tabulated in Table 4.2.

4. COMPARISON OF C_d** FOR BOTH THE VENTURIMETERS

In this section, a graph Fig. 14 has been plotted between C_d^{**} and Reynolds number for both the venturimeters. From the graph, it is clear that values of both the venturimeter almost fall in the same line, i.e. very close to each other. This may be due to the reason that, the diameter ratio of both the venturimeter is same i.e. 0.5.

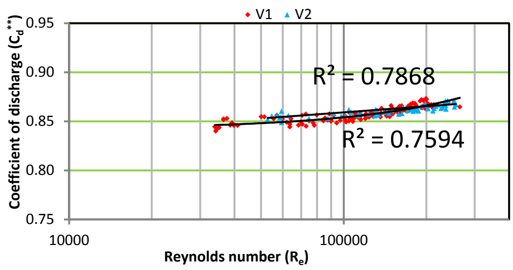

Fig. 14 – C_d** versus R_e for both venturimeters

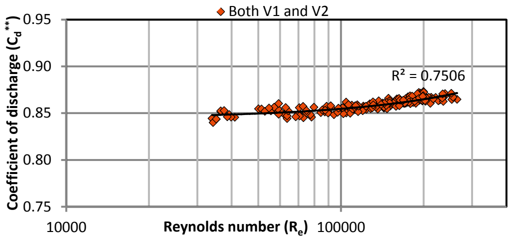

Fig. 15 – C_d^{**} versus R_e for both venturimeters

TABLE 4.1 THE VALUE OF EXPONENT 'n' FOR VENTURIMETER V_1 AND V_2

S. No.	Exponent 'n'			
	Venturimeter	Medium Sand	Coarse Sand	Very Coarse Sand
1	V_1	0.026	0.029	0.022
2	V_2	0.024	0.017	0.022

TABLE 4.2 THE VALUE OF EXPONENT 'm' FOR VENTURIMETER V_1 AND V_2

S. No.	Venturimeter	Exponent 'm'
1	V_1	0.039
2	V_2	0.039

5. CONCLUSIONS

From the experimental study carried out in the present work, following conclusions can be drawn for sediment laden flow:

i. The value of discharge coefficient (C_d) increases slowly with increase in Reynolds number (R_e) for all sediment concentrations for both the Venturimeters.

ii. The value of coefficient of discharge (C_d) of both Venturimeters increases with the sediment concentrations. The C_d for the sediment laden flow is higher as compared to that of clear water flow. This is due to the reason that the presence of sediment absorbs the turbulence in the flow system, thereby, increasing the value of C_d for sediment laden flow compared to clear water flow through Venturimeter.

iii. The modified coefficient of discharge (C_d*) has a unique relation with Reynolds number (R_e) which is independent of sediment concentration (C_s), but dependant of sediment size (d_{avg}).

iv. A unique expression (Eq.10) has been developed between further modified Coefficient of Discharge C_d** and Reynolds number (R_e) which is independent of sediment concentration (C_s) and size of sediment (d_{avg}).

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