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Research Article

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Taguchi Analysis for the Coefficient of Discharge in a Venturimeter

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Abstract

For measuring the rate of flow in the pipeline for both incompressible and compressible fluids, the device venturimeter is used. The rate of fluid flow is known as discharge. The ratio of the actual discharge to the theoretical discharge is known as the coefficient of discharge. In this paper the value of the coefficient of discharge is found out by experimental work and thereafter the Taguchi analysis is applied on the venturimeter results outcome. The main effects plot for signal to noise (SN) ratios, data ratio for mean of SN ratios and mean of means are drawn. After performing the Taguchi analysis, the three ranks are obtained for both the SN ratios and means. It is clear that the rank will be dependent on the value of delta. The coefficient of discharge of venturimeter lies in between the 0.92 to 0.98.

Keywords

Venturimeter, Coefficient of discharge, Taguchi analysis

Introduction

The rate of fluid flow is known as discharge. The discharge is the total quantity (volume) of fluid per unit time that passes a given cross-section. Its unit is m^3/s. It is denoted by Q. venturimeter is used basically for measuring the discharge through pipeline. The ratio of the actual discharge to the theoretical discharge is known as the coefficient of discharge. It is denoted by C_d. For measuring the rate of flow in the pipeline for both incompressible and compressible fluids, the device venturimeter is used. It is the most practice applications of Bernoulli's theorem.

Hutagalung found the maximal value of discharge coefficient was 0.983 observed by the experimental results [1]. Whereas the value of coefficient of discharge lies between 0.92 to 0.98 depends on the size of the instruments and other various factors. Jahith et al. studied the various features which were exploring theory of venturimeter, and data calculated through Bernoulli's equation [2]. Khayat and Afarideh developed the three-phase flow which required phase behavior identification in various conditions [3]. Wrasse et al. developed a flow meter to observe the discharge in gas-liquid flows in venturimeter. A simple algebraic approach added pressure variations of the venturimeter to calculate the liquid flow rate [4]. He et al. researched on the cone meter for cryogenic fluid measurement through numerical simulation [5]. V-Cone meter in low pressure wet gas measurement and the over-reading of the V-Cone meter was researched by He et al. [6]. Dayev improved the flow measurement methods. The discharge coefficient was the main characteristic of differential pressure flowmeter. There are various studies for designing this flow meter; these were implemented with artificial neural networks. So, they change the conventional equation of discharge coefficient in ANN [7].

Essien et al. experimental research on discharge coefficient was done for high viscosity fluid by nozzle. They also compared the data from study and published data to improve the correlation on discharge coefficient [8]. Mubarok et al. used ANSYS for simulation of two-phase geothermal fluid flows by solving computational fluid dynamics models [9]. Stauffer used multiple taps on venturimeter to minimize the errors [10]. Nasiruddin et al. proved that the vertex tip radius had no effect on performance of flowmeter [11]. Pan et al. used the venturimeter technique for measurement of gas flow rate. A linear correlation was improved to forecast the gas flow rate with void fractions from 0 to 95% [12]. Some research performed on the experimental modelling and analysis of fluid-structure interaction using critical statistical tools and Taguchi tool [13-21]. Whereas we used Taguchi analysis for finding the optimum results for venturimeter.

Venturimeter is used for measuring the discharge. It works on the principle of Bernoulli's theorem. It consists of three parts.

(a) Convergent section

(b) Throat

(c) Divergent section

A manometer is attached with inlet as first pressure point and the throat as second pressure point. The coefficient of discharge equation of venturimeter is:

$$C_d = \frac{Qactual}{Qtheortical}$$

$$Qactual = A_t \text{ x } \frac{H_t}{T}$$

$$Qtheortical = \frac{A.a\sqrt{2gh}}{\sqrt{A^2 - a^2}}$$

Where, C_d = coefficient of discharge, A = Cross sectional area of inlet, a = Cross sectional area of throat A_t = Cross sectional area of tank, $\frac{H_t}{T}$ = Height of the tank in T seconds, and $h = \frac{X}{S_1}(S_2 - S_1)$, Where, S_1 = Specific gravity of flowing fluid, S_2 = Specific gravity of manometer fluid, and X = Difference in manometer reading.

Figure 1 shows the diagram of the venturimeter experiment. Specifications for this venturimeter which is used for experimental work are given below:

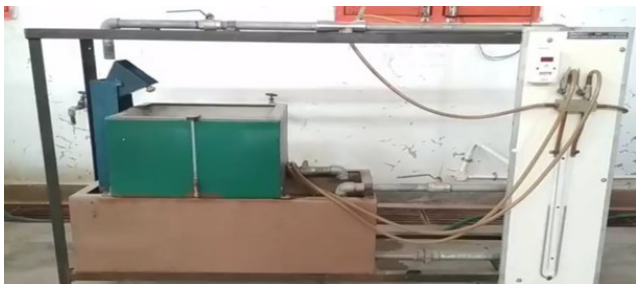

Figure 1: Diagram of the venturimeter.

Area of tank (A_T) = 2000 cm^2

Diameter at inlet D = 2.8 cm

Diameter at outlet/throat = 1.4 cm

Area at inlet (A) = $\frac{\pi}{4}D^2$ = 6.16 cm^2

Area at outlet/throat (a) = $\frac{\pi}{4}d^2$ = 1.54 cm^2

Results and Discussion

Experimental result of the venturimeter

The experimental work shows the working of the venturimeter with their formulae for finding the coefficient of discharge. Now the optimization result of the venturimeter for finding the coefficient of discharge.

For the experiment result of the venturimeter for measuring the discharge of actual the area of tank which is fixed 2000 cm^2 is taken.

Area of tank (A_T) = 2000 cm^2

Now every 10 seconds time interval the height of the tank is measured. For example, in first reading the height of the tank H_2 is 25.2 cm and after 10 seconds the height of the tank H_1 will increase up to 28 cm. So, the total increase of the height of the tank H_t is calculated.

$$H_t = H_1 - H_2$$

Now we calculate the actual discharge of flowing fluid with help of given formulae:

$$X = X_1 - X_2$$

Now calculate the difference in manometer reading (X) by differentiating the manometer reading.

$$X = X_1 - X_2$$

Now calculate the h. we know that:

$$h = \frac{X}{S_1}(S_2 - S_1)$$

Where, S_1 = Specific gravity of flowing fluid, S_2 = Specific gravity of manometer fluid, and X = Difference in manometer reading.

In venturimeter experiment the manometer fluid is mercury and flowing fluid is water used. So

S_1= Specific gravity of flowing fluid = 1 and S_2 = Specific gravity of manometer fluid = 13.6. So as per first reading h is calculated by this formula:

$$h = \frac{X}{S_1}(S_2 - S_1)$$

Now we have all the value for finding the theoretical discharge. So, calculate the theoretical discharge with help of the below formulae:

$$Qtheortical = \frac{A.a\sqrt{2gh}}{\sqrt{A^2 - a^2}}$$

Now calculate the coefficient discharge:

$$C_d = \frac{Qactual}{Qtheortical}$$

So further calculate the coefficient of discharge by repeating the same method.

Now all the venturimeter experiment readings are shown in figure 2 by a line diagram. And figure 3 also describes the reading of the actual discharge, theoretical discharge and also coefficient of discharge.

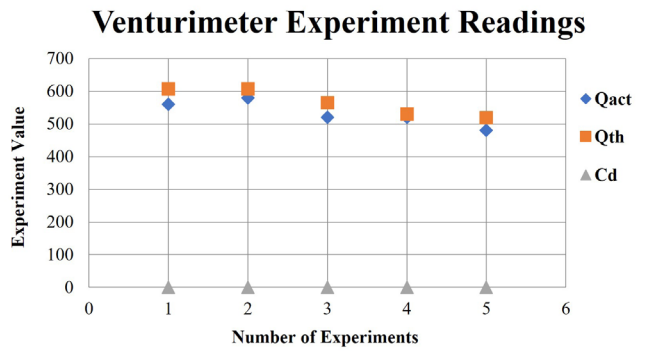

Figure 2: A line diagram of the venturimeter experiment readings.

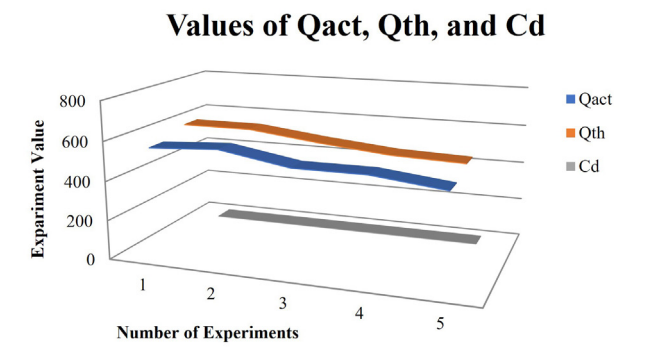

Figure 3: A 3D line diagram of the observed value of actual discharge, theoretical discharge and also coefficient of discharge.

Taguchi analysis

Now for the optimum solution of venturimeter results, the Taguchi tool is used in Minitab software. Here the three inputs are taken, and two outputs are calculated for obtaining the best results. The three inputs are: the total increase of the height of the tank H_t, the actual discharge of flowing fluid Q_{actual} and the Difference in manometer reading X taken. Whereas the two outputs are: theoretical discharge (Q_{th}) and coefficient of discharge (C_d) are taken. While analyzing the Taguchi design, SN ratio nominal is best taken for finding suitable results.

First in the Minitab software create the Taguchi design for the venturimeter performance by taking the above three outputs and then repeat the venturimeter experiments again on prescribed values given by software. Now these finding values of our outputs i.e., theoretical discharge (Q_{th}) and coefficient of discharge (C_d) are filled in software for analyzing the Taguchi method. After analyzing the Taguchi technique, the following results are obtained. The main effects plot for SN ratios data ratio for mean of SN ratios is shown in figure 4 and mean of means is shown in figure 5.

After performing the Taguchi analysis, the three ranks are obtained for both the SN ratios and means which are shown by table 1 and table 2. result obtained shown in figure 4 and figure 5 justify the Taguchi analysis result.

Taguchi analysis: Q_{th}, C_d versus H_t, Qactual, X

Nominal is best (10 × Log10 (Ybar^2/s^2))

The results obtained by the Taguchi method of coefficient of discharge for water are compared with the standard coefficient of discharge obtained by performing experiments are same i.e., 0.92 to 0.98. This coefficient of discharge water is fixed in every book so there is no need for referencing it.

Conclusion

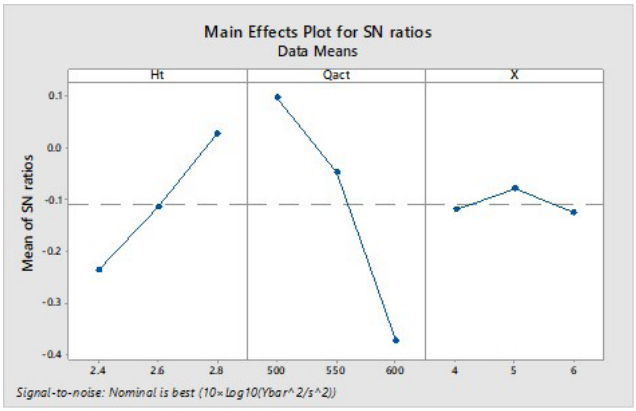

Figure 4: Ratio for mean of SN ratios.

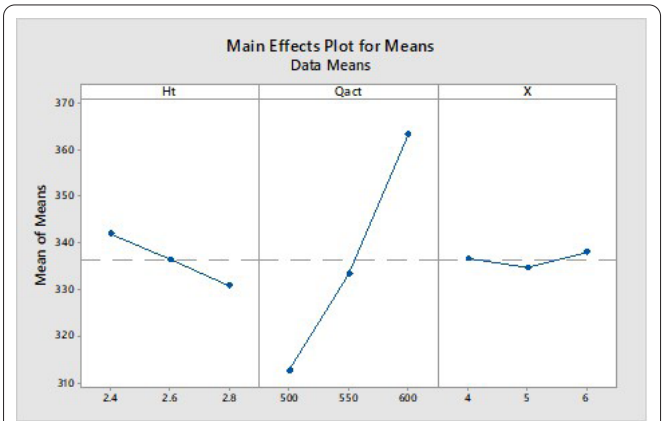

Figure 5: Ratio for mean of Means.

It is experimentally proved that the coefficient of discharge of venturimeter by both the way either experimentally or with help of software Taguchi, always less than 1. In this research it is experimentally found the coefficient of discharge for the

venturimeter, five readings of experiment is calculated. The result of coefficient of discharge is given in figure 2, which shows that always the value of coefficient of discharge for venturimeter is lies less than 1. Taguchi analysis is to be done on the venturimeter outcomes. The main effects plot for SN ratios data ratio for mean of SN ratios and mean of means shown in figure 3. After performing the Taguchi analysis, the three ranks are obtained for both the SN ratios and means are shown. It is clearly finding that the rank will be dependent on the value of delta. If the delta value is high, then the rank is 1 and lower the delta value the rank is continuously increased. The coefficient of discharge of venturimeter lies in between the 0.92 to 0.98.

Table 1: Response table for SN ratios.

Level	Ht	Qact	X
1	-0.23663	0.09777	-0.11914
2	-0.11470	-0.04669	-0.07855
3	0.02846	-0.37395	-0.12517
Delta	0.26510	0.47172	0.04662
Rank	2	1	3

Table 2: Response table for Means.

Level	Ht	Qact	X
1	342.0	312.7	336.7
2	336.5	333.3	334.7
3	330.8	363.3	338.0
Delta	11.2	50.7	3.3
Rank	2	1	3

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Conflict of Interest

The authors declare no conflict of interests that are relevant to the content of this article.

Credit Author Statement

Varun Kumar: Investigation, Formal analysis, Writing - original draft preparation; Rajesh: Conceptualization, Methodology, Resources; Jitender: ; K.K. Kataria: Writing - review and editing, Supervision. All the authors read and approved the manuscript.

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