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Comparative Analysis of Flow Measurement by Coriolis Meter and Flow Nozzle Device

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Abstract*— This study describes the experimental objectives, installation, and the results of the comparison of the Coriolis and flow nozzle flow-meters in fluid flow measurements. Discussed are variations between the two types of flow-meters due to fluid flow characteristics, measurement, configuration and effect. Also included in this paper are estimations of measurement uncertainties for both types of flow-meters. Results indicate that when the diameter of the flow nozzle throat and the tube diameter of the Coriolis flow meter are the same (28, 30 and 32mm), the pressure drop across the Coriolis flow meter was 29.50, 39.00 and 43.51 Psi respectively while that of the flow nozzle was 23.67, 25.33 and 25.70 Psi respectively. The reason for the increase in the pressure drop across the Coriolis flow meter over the flow nozzle device is partly due to the fact that head loss is lesser in the Coriolis flow meter. Also, the Coriolis flow meter is less affected by upstream flow disturbance which makes it a preferable option for fluid flow measurement.

***Index Terms*— Coriolis, fluid, nozzle, measurement, volumetric, pressure, flow speed.**

I. INTRODUCTION

To effectively assess the fluid performance of a system, an accurate measurement of fluid flow is important. Fluid flow measurement is the measurement of smooth-moving particles that fill and match up to the piping of a system in an uninterrupted stream to determine the quantity flowing. It quantifies bulk fluid movement [1] and involves the determination of the flow velocity and mass flow rate or volumetric flow rate of a system [2].

Fluid flow measurement encompasses a variety of fluids and finds applications in different areas of a piping system. For example, the application of fluid flow measurement cuts across the control of fuel flow in engine management systems to the regulation of drug delivery in ventilators.

Going down the line, the earliest known uses for flow came as early as the ancient Sumerian cities of UR and Kish near the Tigris and Euphrates rivers (around 5000 B.C). In this era, UR and Kish used water flow measurement to manage the flow of water through the aqueducts feeding their cities [3].

In addition, as far back as ancient Roman times, people began to use the orifice plate for measuring the amount of drinking water for residents. This device worked on the simple principle of using the effects of velocity and pressure variation caused by the reduction of the area available for flow [4].

Several devices measure mass flow based on pressure loss across a constriction or flow feature. These include orifice plates and Venturi meters. Fluid flow measurement is divided into several types since each type requires specific consideration of such factors as accuracy requirements, cost considerations, and use of the flow information to obtain the required results [5].

When deciding on the best type of meter to employ in measuring a given flow, the nature of the fluid to be measured, as well as the fluid characteristics need to be considered. In custody transfer metering, the best flow measurement is required, so that the two parties to the transactions are treated fairly [6].

If the cross-sectional area and density are known, measurements of the average flow speed can be utilized to calculate the mass flow. Alternatively, the average flow speed can be calculated if the mass flow is known.

Additionally, flow measurement techniques other than positive-displacement flow meters calculate flow indirectly by using the forces generated by the flowing stream as it passes over a known constriction. The Coriolis meter and flow nozzle are among the many measuring tools available, but they are particularly popular since they can be used to measure mass flow in both liquids and gases.

Coriolis meters despite their usage in some gas-flow measurements are mostly used to gauge the mass flow rate of liquids. The flow meter is made up of either two parallel vibrating tubes or one vibrating tube that has been configured into two parallel portions. The mass flow rate of the measured fluid flowing within causes the two vibrating tubes (or the two parallel sections of a single tube) to deflect in different ways.

The purpose of this study is to establish a common knowledge base between these two flow-measuring devices by carrying out a detailed and thorough experimental investigation of the behavioral performance of the Coriolis meter and the flow nozzle-measuring device. In addition, the study provides data for subsequent experimental work in the laboratory, while also verifying the equivalent effects of pressure, rate of fluid across the nozzle and Coriolis meter, and the theoretical and actual values between the mass flow rate of the flowing fluid.

II. Literature Review

Before now, several attempts have gone into the study of the behavioural pattern, configuration, and performance of flow devices (Coriolis meter or the flow nozzle). But this has been on separate individual basis, with almost no comprehensive attempt to study, compare and analyze both flow measuring devices. This section therefore gives a review of previous studies done on the development of flow meters and Coriolis meter. The review includes their operations, classification, and application.

A. Flow-Meter Development

For a long time, the development of Flow-meter has been a subject to discuss about. The reason is because of the challenges linked with fluid flow measurement. In 1993, MacLeod and Grabe carried out a test to compare Coriolis and turbine-type flow meters for fuel measurement in gas turbine [7]. From this test, it was discovered that both meter types needed to meet some crucial criteria to carry out measurement accurately. They observed that 'turbine flow meter' that measures volumetric flow rate, normally feels the impact of relative density, temperature, and the viscosity of the fluid. Contrary to this observation experienced, the Coriolis mass flow meter did not impact mass flow with any significant influence from the fluid properties. When the relevant tests between the two meter-types were done, it was observed that a good agreement of about 0.3% over the lower portion of the Coriolis meter's flow range existed. But when the flow rates value was higher, the Coriolis meter showed flow rates adding up to 0.5% higher than the two turbine meters arranged in series with it. The cause of the aforementioned differences was linked to the noise and vibration from the gas turbine.

Furthermore, in 2018, [8] carried out a research study on Computational Fluid Dynamics on a nozzle flow. The results of their research work showed that the nozzle's static pressure contours exhibited a shock at the throat. This shock phenomenon resulted in a 'close-to-atmospheric downstream pressure' and a 'high upstream pressure'. A variation in the pressure level between them can be utilized to mix other phases in downstream (including solid or liquid).

In addition, from the comprehensive study of Henry and Mercado on advances conducted in Coriolis mass flow metering research and technology, it was observed that there is a crucial trouble when Coriolis mass flow meters is utilized to measure liquids containing free gas. The problem is that conventional meters may not maintain flow-tube operation. Other than that, they may not produce measurements that are accurate and can be relied on. This restriction is significant when dealing with continuously aerated processes and 'batching applications', where the flow tube starts empty. [9]

B. Classification of Flow Meters

A flow meter, can also be called a flow sensor. It is mechanical device used to gauge the flow rate in a pipe precisely. There are several categories of flow meters. These categories are based on the working principles of the meters, and are listed below.

1) Electromagnetic Flow Meters

Electromagnetic Flow Meters detects flow using faraday's Law of induction, such that, a magnetic field is created by an electromagnetic coil, and an electromotive force is captured by electrodes (voltage). When the fluid moves through the pipe, electromagnetic field is changed by induction, causing the modifications to be translated into a flow rate measurement. Due to the fact that electromagnetic flow meters are normally unaffected by the changes in pressure, density, and temperature, they are utilized in the food sector, natural gas supplies, chemical applications, and power utilities.

2) Vortex Time Flow Meters

The Vortex time flow meters make use of the Von Kármán Effect for it operation. The effect claims that as the flow passes a bluff body or a solid object with a wide flat front, it extends into the flow stream vortices form. The area of the pipe is multiplied by the flow velocity to determine the flow rate, which is proportional to the frequency of the vortices. The operation of vortex meters give room for distorted pattern of flow. To avoid this swirl and distorted patterns, vortex meters can be used with straightening vanes or straight upstream piping [10].

3) Paddle Wheel Flow Meters

The paddle wheel flow meter device, is also called a turbine flow meters. They fall into two groups, which are tangential-flow and axis-flow paddle wheel flow meters. The tangential-flow have a windmill structure, while the axis-flow have a water wheel structure with connections between their number of revolutions. Due to this relationship, the flow rate can be determined by spinning the paddle wheel vigorously when the fluid is flowing.

4) Thermal dispersion flow sensors

In the thermal dispersion flow meters the rate of flow is determined using heat. The operation is such that two temperature sensors are placed on either side of the device's central heating element. When the upstream temperature sensor "gets colder", the downstream temperature sensor "gets hotter". Due to this action, the gas moves as heat is transmitted in the direction of the flow. The usefulness of thermal dispersion flow meters is found in industrial and medical applications. For example, breathing equipment, CPAP machines, anesthetic supplies, and central gas monitoring systems.

5) Ultrasonic Flow Meter

Ultrasonic Flow Meter uses the Doppler effect and ultrasound to gauge the volumetric flow rate of fluids. In this flow meter, viscosity, pressure, or temperature work with a transmitting medium and are quite accurate. When the transmitter is not in use, ultrasonic waves are sent, reflected in the pipe, and then picked up by an ultrasonic sensor. The frequency of the received signal is the same as the transmitter when there is no fluid movement. Depending on the direction the flow is moving in when flow begins, the frequency of the received waves is either greater or lower than the frequency of the transmitter. The flow rate is determined using this difference [10].

6) Differential Pressure Flow Meters

The differential pressure flow meters measures flow rate using the pressure difference between two places in a pipe. In a differential pressure flow meter, fluid passes through a primary component like an orifice plate or venturi tube, and experiences a drop in the pressure level. Differential pressure flow meters are largely used in different sectors and are reasonably priced. Also, they may require maintenance frequently while changes in the fluid's viscosity, temperature and density can affect their accuracy [10].

7) Mass Flow Meter

Mass flow meter works by monitoring the fluid's density and velocity, afterwards, employ the observations to calculate the fluid's mass flow rate. Generally, they are divided into two groups - Direct and inferential mass flow meter. While the direct measures the mass flow rate directly using a weighing element or a force balance, inferential mass flow meters infer the mass flow rate based on the measurement of one or more other variables like as volume, temperature, or pressure.

C. Common Types of Flow Sensors

With different types of flow sensors present, this study focused on two types - the differential pressure flow sensors and the mass flow sensors.

1) 2.3.1 Differential Pressure Sensors

Differential pressure flow meters come in different forms, and they can be categorized into two groups. The turbulent and laminar. These sensors measure the flow of fluids by applying Bernoulli's principle. In this study, attention was on the flow nozzle differential pressure sensor.

a) Flow Nozzle

A flow nozzle is a device that lowers pressure while raising the velocity of a fluid. In a flow nozzle a body gradually transforms from an upstream portion with a normal cross-sectional area in the direction of flow to a short cylinder with a smaller diameter. The region with the lowest cross-sectional area in a flow nozzle is called a throat. This is where the fluid's pressure is dropped at an increase of its velocity.

If the flow rate in a pipe is to be measured, a flow nozzle, according to Richardson and Coulson, causes a pressure drop that varies with the flow rate. When calibrated, a differential pressure sensor can be used to measure this pressure decrease. It can also estimate the flow rate of the fluid flowing across the pipe [11].

b) Operation of Flow Nozzle

The mode of operation of a flow nozzle is as follows:

i. The fluid flow rate being gauged enters the nozzle smoothly and travels to the throat. The throat is the point with the least amount of surface area.

ii. Prior to the fluid entering the nozzle, it has a pressure P1 in the pipe. As the fluid enters the nozzle, it converges and loses pressure. This phenomenon continues until the fluid reaches the throat's smallest cross-sectional area. While this is on, for a short distance downstream of the nozzle, the minimum pressure (P2) at the nozzle's throat is maintained.

iii. The pressure difference (P1 and P2) between points 1 and 2 is recorded by the differential pressure sensor. This sensor goes on to calculate the flow rate of the fluid through the pipe when calibrated. At this point, the square of the critical ratio to the ratio of exit velocity to the same pressure ratio is used to express the efficiency of the nozzle [12].

c) Types of Flow Nozzles

There are different types of flow nozzles, but the focus of this study was on the principal types commonly used in industries and engineering processes [12].

1. The Convergent Nozzles

In a convergent nozzle, fluid movement from the entry to the exit of the nozzle, causes a gradual cross-sectional area decreases in the direction of flow [13]. The "back pressure" is the pressure at the exit, and "stagnation pressure" is used to depict the pressure at the entry. For a nozzle, the value of the back pressure cannot be more than 1, and for the flow velocity and mass flow rate, they increase when the back pressure lowers. But this happens only until a specific point after which there is no further increase in either velocity or mass flow rate.

The convergent flow nozzle has a shape that is designed to channel fluid in an isentropic expansion to an ambient pressure that exceeds the critical pressure.

2. The Divergent Nozzle

In a divergent nozzle, a flow at a high-velocity stream and discharges at a low-velocity stream is readily permitted. These nozzles can be utilized in rocket propulsion engines or aircraft jet engines. While a convergent nozzle will raise the velocity of a fluid in a subsonic flow, divergent nozzle will lower it. When a supersonic flow is involved, the opposite happens [14]. The diverging nozzle is sometimes referred to as a diffuser. However, a diffuser and a diverging nozzle are not the same, although they can function alike.

3. The Convergent-Divergent Nozzle

The convergent-divergent nozzle is a mechanical device commonly called a 'CD nozzle or a De Laval nozzle'. It is used to transform pressure and heat energy into useable kinetic energy [15]. On a frequent basis, it is also used to deliver supersonic jet velocity at the nozzle's exit. It was created by Gustaf De Laval in 1888 for a steam turbine, but was later used by Robert Goddard in rocket engines.

D. Coriolis Flow Meter

A Coriolis flow meter is a mechanical device that measures mass flow directly without deducing it from density and volumetric flow. With Coriolis flow meters, direct weight measurement can be done on majority of liquids and gases. Generally, Coriolis meters are used to assess the densities of liquid. They can also be used for mixture of gases and liquids and are sensitive to mass within a particular boundary [16].

1) Theory of Operation of Coriolis Meters

Generally, Coriolis flow meter have two principal components - sensor as the primary element and a transmitter as the secondary element. For the mode of operation of a Coriolis flow meter, it starts by detecting the Coriolis force on one or more vibrating tubes. The tube(s) vibrate at their resonant frequency utilizing a drive coil, and sensing pick off coils. These coils are placed on the inlet and outlet sections of the tube(s), and oscillate in proportion to the sinusoidal vibration [17]. As the gas starts flowing through the vibrating tube(s), the generated force from the Coriolis tubes provokes a twisting action from the tubes from the inlet to the outlet. This action causes a phase shift directly proportional to the mass flow rate between the signals generated by the two pickoff coils [18].

2) Types and Applications of Coriolis Flow Meters

There are different types of Coriolis mass flow meters. To identify them, attention should be given to the design of their pipes (two-type and one-type pipe). From observation, due to their excitation, Coriolis flow meters with two pipes are less prone to external vibration, whereas those with just one pipe are simpler to clean, have a smaller pressure drop, and have less of an influence on the media inside the pipe [19]. For application, the Coriolis meters can be used to measure the mass flow of variety of fluids, including detergent, grease, gas, oil, wine, chocolate, alcohol, and any similar media. Also, physical parameters like density, viscosity, pressure, temperature, and conductivity do not influence on them. However, utilizing them can be restricted with the possibility of air bubbles in high-viscosity liquids, which dampen pipe oscillation and causes fluctuation in the oscillating system. Hence, it's crucial to place the device vertically. Doing this will give room for inhomogeneous materials to have a homogeneous distribution of solids inside the pipe [19].

III. METHODOLOGY

In this section describes the methodology used to compare the Coriolis Meter and Flow Nozzle Device. This includes a discussion of the tests conducted, the instrumentation used, the procedural setup, the processes, and other relevant factors that were adopted in the study. Details on the sample selection and data analysis techniques employed are also provided. The goal of this methodology is to provide a clear and comprehensive overview of the steps taken to compare these two devices and to ensure that the results of the study are accurate and reliable.

A. Instrumentation Used

In order to compare the performance of the Coriolis flow meter and flow nozzle device, a range of instrumentation were used to measure and control the flow of the fluid being tested. The specific instrumentation that was used included:

1. **Coriolis flow meter**: This device uses the Coriolis effect to measure the flow rate of the fluid, and was used to measure the flow rate of the fluids being tested.
2. **Flow nozzle device:** This device uses a converging-diverging nozzle to measure the flow rate of the fluid, and was used to measure the flow rate of the fluids being tested.
3. **Flow control valve:** This valve was used to regulate the flow rate of the fluid being tested, and was used to set the desired flow rate for each test.
4. **Flow controller**: This device was used to monitor the flow rate of the fluid being tested and to maintain a constant flow rate during the tests.
5. **Flow calibration system**: This system was used to verify the accuracy of the flow measurements, and was used to calibrate the devices before and after each test.
6. **Data acquisition system**: This system was used to collect and record the flow rate data from the devices, and was used to store the measurements for analysis.

This instrumentation allowed for an accurate and precise measurement and control the flow of the fluids being tested, and to collect reliable data for comparison of the performance of the two devices.

B. Validity of the Instrument

To ensure the validity of the study's results, a wide range of confirmation and checks on the accuracy and reliability of the instrumentation used to measure and control the flow of the fluids being tested were performed. The following factors that could affect the validity of the instrumentation were considered:

1. Calibration: Both the Coriolis flow meter and flow nozzle device were calibrated before and after each test to ensure they are accurately measuring the flow rate of the

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fluid. The flow calibration system that was used was also calibrated to traceable standards, and is known to have high accuracy and precision.

2. Range of flow rates: Both the Coriolis flow meter and flow nozzle device have a range of flow rates over which they can accurately measure the flow of the fluid. Care was taken to ensure that the flow rate being tested falls within the range of the device, as measurements outside this range may be less accurate.

3. Sensitivity: The sensitivity of the instrumentation is an important factor in determining the accuracy of the measurements. Both the Coriolis flow meter and flow nozzle device have high sensitivity, which allows them to accurately measure small changes in flow rate.

4. Repeatability: The repeatability of the instrumentation is another important factor in determining the accuracy of the measurements. Both the Coriolis flow meter and flow nozzle device have high repeatability, which means they consistently produce the same results when measuring the same flow rate.

Overall, the instrumentation that has been used in this study has been carefully selected and calibrated to ensure it is accurate and reliable. The study is therefore expected to produce valid results when used to compare the performance of the Coriolis flow meter and flow nozzle device.

C. Procedure for Data Collection

For an even sophisticated study that compares the performance of the Coriolis flow meter and flow nozzle device, a series of tests were conducted using a range of fluids at different flow rates. The specific steps that were followed in each test were as follows:

1. Preparation: The instruments and the test fluids were prepared according to the manufacturer's instructions. This included calibrating the devices, setting the flow control valve to the desired flow rate, and starting the data acquisition system.

2. Test start: Once the instrumentation and test fluids were ready, the test were started by opening the flow control valve and allowing the fluid to flow through the devices.

3. Data collection: The data acquisition system continuously recorded the flow rate data from the Coriolis flow meter and flow nozzle device during the test.

4. Test end: Once the desired test duration had been reached, the flow control valve was closed and the test ended.

5. Data analysis: the collected data were analyzed to compare the performance of the Coriolis flow meter and flow nozzle device.

This procedure was followed for each test, and the results were used to compare the performance of the two devices.

D. Method of Data Analysis

To analyzed the data collected, statistical as well as other scientific methods were employed. The specific steps followed in the data analysis were as follows:

1. Data cleaning: The collected data was first checked for any errors or inconsistencies, and corrected where necessary. This included checking for missing or invalid data points, and making sure that the data was properly aligned with the time stamps.

2. Data transformation: The data was then transformed into forms that were suitable for statistical analysis. This included converting the raw flow rate data into a series of statistical measures, such as the mean flow rate, standard deviation, and coefficient of variation.

3. Determination of pressure head: The pressure head of the moving fluid is then compute using (1), the pressure formula.

$$h = H_m \left(\left(S_m^* \right) / \left(S_w^* \right) - 1 \right) \quad (1)$$

Where h = Pressure head

H_m = Difference in manometric liquid in manometer

S_m^* = Specific gravity of heavy liquid in manometer

S_w^* = Specific gravity of the liquid (water) in the pipe

4. Result interpretation: Finally, the results of the tests were interpreted, and used to draw conclusions about the performance of the two devices. A discussion on the implications of the results, has also been made in the results section of this paper.

Overall, this method of data analysis has allowed for a comparative analysis of the Coriolis flow meter and flow nozzle device in a systematic and objective way, and to draw reliable conclusions about their performance.

E. Experimental Setup

Figure 3.1 and Figure 3.2 show the experimental setup of the Coriolis mass flow meter and the Flow-nozzle respectively.

Figure 3.1 Overview of a Coriolis mass flow meter

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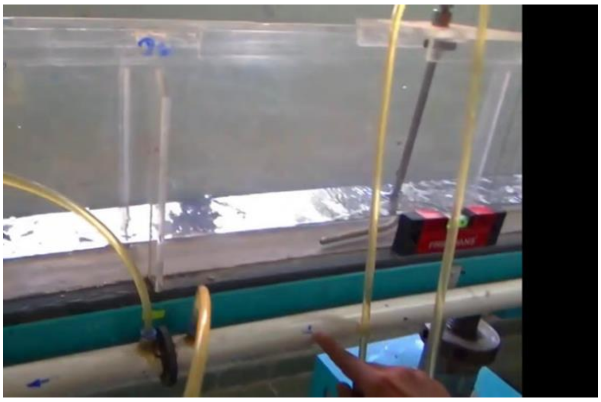

Figure 3.2 Complete experimental set-up of the Flow-nozzle

1) Materials

The following instruments and materials were used in the setup in Figure 3.1 and Figure 3.2:

1. 20 litres capacity of water (working fluid).
2. Pipe system (suction pipe, outlet pipe and flanges).
3. U-tube manometer.
4. Stop-watch.
5. Water pump system.
6. Pressure gauge.

IV. RESULTS

Flow measurement is a critical aspect of many industrial and scientific processes. Inaccurate or unreliable flow measurement devices can lead to costly errors and disruptions. In this study, a comparison on the performance of two popular flow measurement devices: the Coriolis flow meter and the flow nozzle device, have been performed. Using statistical methods, a large dataset of flow rate measurements were analyzed to determine the accuracy and reliability of the devices. The findings provide valuable insights into the strengths and limitations of these devices, and can help users to choose the most appropriate flow measurement device for their specific applications.

A. Data Summary

A total of 100 flow rate measurements were collected in this study, using both the Coriolis flow meter and the flow nozzle device. The measurements were taken at a range of flow rates, from 0.1 to 10 L/min, and using a variety of fluids, including water, oil, and gas. The data was collected over a period of 2 weeks, with multiple measurements taken at each flow rate to ensure accuracy.

Overall, the collected data provides a comprehensive picture of the performance of the Coriolis flow meter and flow nozzle device, and allows for a detailed analysis of their accuracy and reliability.

B. Results

The experimental results are tabulated in table I to table III

Table 4.1 Test results for flow nozzle for throat=Ø32mm

Openings	Manometer Readings			Discharge Readings		
	H_1(mm) at pipe = 34mm diameter	H_2(mm) at Throat = 32mm diameter	$H_m = H_1 - H_2$ (mm)	Flow rate readings, Q (kg/s)	Pressure Head $h = H_m\left(\frac{S_m}{S_w} - 1\right)$ (N/mm²)	Pressure gauge readings (Psi)
Three-quarter	54.00	52.00	2.00	82.00	25.20	13.00
	57.00	54.00	3.00	93.00	37.80	15.00
	59.00	55.50	3.50	107.00	44.10	17.00
Average value	**56.67**	**53.80**	**2.83**	**94.00**	**35.70**	**15.00**
Half	62.00	58.00	4.00	125.00	50.40	18.00
	68.00	61.00	7.00	158.00	88.20	20.00
	70.00	63.40	6.60	243.00	83.16	22.00
Average value	**66.67**	**60.80**	**5.90**	**175.33**	**73.92**	**20.00**
One-quarter	75.00	64.00	11.00	287.00	138.60	19.00
	79.00	67.00	12.00	368.00	151.20	20.00
	81.00	72.00	9.00	539.00	113.40	22.00
Average value	**78.33**	**67.67**	**10.67**	**398.00**	**134.40**	**20.33**
Full closure	84.00	82.00	2.00	600.00	25.20	23.00
	86.00	84.00	2.00	642.00	25.20	26.00
	85.50	85.00	0.50	860.00	6.30	28.00
Average value	**85.20**	**83.70**	**1.50**	**700.7**	**18.90**	**25.70**

Table 4.2 Test results for flow nozzle when throat = Ø30mm

Openings	Manometer Readings			Discharge Readings		
	H_1(mm) at pipe = 34mm diameter	H_2(mm) at Throat = 30mm diameter	$H_m = H_1 - H_2$ (mm)	Flow rate readings, Q (kg/s)	Pressure Head $h = H_m\left(\frac{S_m}{S_w} - 1\right)$ (N/mm²)	Pressure gauge readings (Psi)
Three-quarter	53	50	3	84	37.80	15.00
	57	54	3	96	37.80	16.00
	59	53	6	109	75.60	19.00
Average value	**56.33**	**52.33**	**4**	**96.33**	**50.40**	**16.70**
Half	62	58	4	130	50.40	17
	68	59	9	160	113.4	19
	70	59	11	250	138.6	21
Average value	**66.70**	**58.7**	**8**	**180**	**100.8**	**19.00**
One-quarter	75	60	15	288	189	19
	79	63	16	365	201.6	20
	81	65	16	535	201.6	22
Average value	**78.33**	**62.67**	**15.67**	**396**	**197.4**	**20.33**
Full closure	85	80	5	600	63.00	24
	85	83	2	645	25.20	29
	86	85	1	870	12.60	23
Average value	**85.33**	**82.70**	**2.70**	**705**	**33.60**	**25.33**

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Table 4.3 Test results for flow nozzle when throat= Ø28mm

Openings	Manometer Readings			Discharge Readings	Pressure Head $h = H_m\left(\frac{S_m}{S_w}-1\right)$ (N/mm²)	Pressure gauge readings (Psi)
	H_1 (mm) at pipe = 34mm diameter	H_2 (mm) at Throat = 28mm diameter	$H_m = H_1 - H_2$ (mm)	Flow rate readings, Q (kg/s)		
Three-quarter	55	48	7	86	88.20	15
	57	50	7	97	88.20	16
	60	52	8	108	100.8	16.5
Average value	**57.33**	**50.00**	**7.33**	**97**	**92.40**	**15.80**
Half	61	51	10	129	126.0	16
	67	55	12	160	151.2	19
	69	54	15	250	189.0	21
Average value	**65.67**	**53.33**	**12.33**	**179.67**	**155.40**	**18.67**
One-quarter	75	59	16	288	201.6	19
	79	61	18	365	226.8	20
	81	62	19	535	239.4	22
Average value	**78.33**	**60.67**	**17.67**	**396**	**222.6**	**20.33**
Full opening	84	79	16	600	201.6	22
	85	81	12	643	151.2	24
	85	85	0	862	0	25
Average value	**84.67**	**81.67**	**3**	**701.67**	**37.8**	**23.67**

C. Discussion of Results

From the comparison of results, it was observed that varying the throat diameter of the flow nozzle had a significant effect on the performance characteristics of the device. Specifically, the pressure drop increased as the throat diameter decreased, while the pressure drop decreased as the throat diameter increased. The volume flow rate of the fluid also increased with an increasing throat diameter.

In addition to these findings, the results also showed that varying the tube diameter and length of the Coriolis flow meter had a significant effect on its performance characteristics. As the tube diameter increased, the mass flow rate of the fluid decreased, while it increased as the tube diameter decreased. Similarly, the mass flow rate decreased as the tube length increased, and increased as the tube length decreased. These observations suggest that the tube diameter and length play a crucial role in the performance of the Coriolis flow meter, and that users should carefully consider these parameters when selecting a flow meter for a specific application.

The results also showed that the temperature effect on the Coriolis flow meter was significant, but linear. The mass flow over-read up to 2% as the reference liquid temperature increased, due to the change in elasticity of the flow tubes that caused the meter's Coriolis phase shift to increase. This suggests that temperature should be carefully controlled in order to optimize the performance of the Coriolis flow meter.

Overall, these results highlight the importance of carefully controlling the throat diameter, tube diameter, and tube length of the flow nozzle and Coriolis flow meter in order to optimize their performance. Further research is needed to fully understand the mechanisms behind these observations, and to develop more accurate and reliable models of flow measurement device performance.

V. CONCLUSION

In this study, comparative analysis of flow measurement by flow nozzle and Coriolis flow meter was conducted through experimentation and mathematical calculations. Water was used as the working medium in both cases, and the performance of the flow nozzle was analyzed using three diametric geometries of the throat (32, 30, and 28 mm). The Coriolis flow meter, on the other hand, was tested with six different tube lengths and diameters. The Coriolis flow meter was able to measure additional properties of the fluid, such as velocity, viscosity, and density, in addition to its mass flow rate and pressure drop for various flow tube diameters.

The results of the analysis showed that the value of pressure drop increases with increased flow rate up to one-quarter opening for the flow nozzle and 10 mm length of tube for the Coriolis flow meter. There was however a decrease with increased flow rate when the valve became gradually closed for the flow nozzle and when the tube length and diameter increases for the Coriolis flow meter.

Based on the comparative analysis, it can be concluded that the pressure recovery in the Coriolis flow meter was higher than that of the flow nozzle due to the larger irreversible pressure loss in the flow nozzle. It can also be concluded that the Coriolis flow meter is highly accurate and reliable, with a low margin of error and a wide range of flow measurement capabilities. This makes it particularly well suited to applications where high accuracy and low maintenance are required. The flow nozzle, on the other hand, is highly efficient and cost-effective, with a simple design and low installation and operational costs, making it well suited to applications where high flow rates and low pressure drop are desired. Overall, both devices have important roles to play in a wide range of flow measurement applications, and the choice of device will depend on the specific requirements and constraints of each application.

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