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EXPERIMENTAL INVESTIGATION FOR THE MEASUREMENT OF PRESSURE AND DISCHARGE THROUGH MODIFIED GATE VALVE

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ABSTRACT

The rate of discharge in pipelines can be controlled using a gate valve. A wheel located at the top of a stem that features a round disc (called the gate) at its top can turn the gate. Each time the wheel rotates, a distinct linear disc movement is produced, which modifies the flow region. An experiment is presented in this paper that details the transition of the gate valve from a device that controls flow to one that measures flow. The experiment is conducted on a regular gate valve as well as a gate valve that has a rubber sleeve. The CFD analysis of a standard gate valve and one that has been altered is explained, and the results of the experimental investigation are utilised to support the findings of the CFD study. The experimental investigation demonstrated that the modified gate valve has the ability to function as a flow metre by incorporating a piezometer at both ends of the valve for the purpose of pressure monitoring. The findings that were obtained point to a substantial advance in the correlation that exists between disc orientation (angle) and discharge. With the help of computational fluid dynamics software, the flow through a gate valve with and without a rubber sleeve was analysed. The results of the CFD tests conducted without the rubber sleeve demonstrate that the flow rate variations are, in large part, the result of the establishment of variable separation zones on each side of the gate. In this study, the disagreement between the experimental data and the CFD findings has been analyzed, and a solution to the problem is suggested.

Keywords: Gate valve, pressure, flow measuring device, rubber sleeve, CFD.

INTRODUCTION

Flow metres are instruments that are used to determine the speed of a fluid or gas that is travelling through a pipe, while piezometers are instruments that are used to determine the pressure that is present at both ends of the valve. The monitoring of mass flow can be helpful in a variety of situations, including those that include the movement of water. A gate valve has a wide variety of applications, both in the home and in the business world. In industrial applications, many processes require accurate flow management in order to function properly. The flow of liquid can be controlled directly by the gate valve. The inaccuracy of the flow regulation achieved through the measurement of the pressure difference necessitates the utilisation of a flow measuring device that is distinct from the original (Achour et al., 2022). The gate valve, complete with piezometers on both sides, can be shown in Fig. 1. In this investigation, a gate valve was put through its paces as a device for accurately measuring flow under a single set of working conditions, and a piezometer was used to establish a correlation between the discharge and the pressure differential. This can be accomplished by utilising the gate valve in conjunction with a flow-measuring instrument such as a Venturi metre or an orifice metre. The combination of these two tools will allow the desired results to be obtained. The objective of the present study is to measure the pressure difference and investigate its relations with discharge so that it is correlated with the discharge given by the modified gate valve.

Turning the wheel of the gate valve in either direction causes the gate to move linearly in either the forward or the reverse direction. The wheel is attached to the disc of the gate valve via the stem. As a result of the establishment of fluctuating separation zones on either side of the gate in the studies that were carried out by Bhilare and Hinge (2020) using a 65 mm gate valve, it was claimed that an accurate relation could not be established between the rotation angle of the wheel and the discharge. These experiments were carried out using a 65 mm gate valve.(Bhilare Hinge, 2020)

The outflow is heavily influenced by the opening angle of double-stage flap valves. Streamline, homogeneity, and outlet culvert head loss were examined under four different operating circumstances. A decrease in resistance was seen along the outlet culvert as the angle of opening decreased. When the opening angle is increased, the head loss is decreased and the flow patterns are enhanced (Xi et al., 2022).

In order to calculate discharge, hydraulic turbines rely heavily on the pressure-time approach. It has evolved over time with enhancements including a friction factor that varies with time and a new maximum integration value. The accuracy has been demonstrated in the lab (Dunca et al., 2014). An experimental study compared standard and customised gate valves for use in pipelines. The findings validated the efficacy of the modified gate valve as a flow metre by strengthening the correlation between disc position and discharge. The CFD study showed, however, that flow rate discrepancies are heavily influenced by separation zones that shift on either side of the gate. Better flow control and adaptable membrane technology are proposed as solutions in the study.(Bhilare et al., 2021)

This work explores the dynamics of fluid flow via a pipeline with sectionalized gate valves and their free, undamped vibration. Flow velocity profiles and pressure fields are analysed with modal analysis that is based on finite element analysis (FEA) and computational fluid dynamics (CFD). From what we can see from CFD, a gate valve's sectionalized design causes a lot of pressure drop and fluid vorticity(Sozinando et al., 2023).

When considering the flow of liquid through a safety valve, it is important to note that the discharge coefficient CD differs significantly from the more common coefficient KD. Discharge coefficient CDn for the nozzle and loss coefficient Kbn for the body are proposed for a safety valve model in this work, along with their relation to one another (Morris, 1996).

Ball valves are tested at high pressure to see how they fare in a compressible flow environment. It takes readings of the flow's pressure and temperature to calculate the flow and heat loss efficiencies. Pressure and fluid velocity are required to calculate the flow coefficient and the loss coefficient. The flow coefficient decreases with decreasing pressure. When the pressure is lowered, the valve loss coefficient decreases more quickly than the discharge rate.(Iravani Toghraie, 2020)

The pressure drop (DP) via a 1¼″ ball and gate valve is studied for vertical upflows. As the valve is opened, the pressure loss increases, yet the valve coefficient grows. The pressure drop in a two-phase flow rises as the opening size decreases, peaking at 20% and 19% openings. At completely opening conditions, the two-phase flow multiplier is very close to 1, but it drops off when liquid is held back.(Zeghloul et al., 2020)

A standard American National Standards Institute (ANSI) globe valve was used for the research. The flow coefficient is found to be influenced by the shape and opening of the valve in addition to the Reynolds number. Flow coefficients tend to be constant until the Reynolds number is high enough. Within a range of 10 nominal diameters, the study also compares pressures at various locations.(Nguyen et al., 2020)

The solenoid valve's response properties are analysed using computational fluid dynamics and the FLUENT programme. Aerodynamic parameters are determined by flow field analysis. Comparisons are made between the results of computer simulations and those of mathematical models. It is found that the response characteristics are irrelevant once a certain operating frequency is reached. The open switching time decreases when the inlet pressure and driving voltage are increased, but the close switching time increases with the three variables. (Zhang et al., 2019)

The effect of throat length on cavity shedding during cavitation in active fields is investigated using Venturi geometries. When comparing the two venturi geometries (with and without a neck), there is a significant difference in the outcomes. High-speed imaging, high-frequency sound pressure, and dynamic pressure changes are all diagnostic tools. Based on the data, it can be shown that condensation shocks and re-entrant jets occur in the venturi with a throat length of 23 mm as the cavitation number drops, while the opposite occurs in the venturi with a throat length of zero. This diversity in cavitation mechanisms is due to the thickness of the cavity and the magnitude of the pressure gradient.(Ullas et al., 2023)

Irrigation canals benefit from radial gates because they regulate flow and increase discharge. In subterranean flow, precise discharge measurement is very challenging. This study focuses on the radial gate contraction and velocity coefficients in both free and submerged flow conditions. Discharge characteristics were enhanced by altering the gate exit geometry to include a quarter-elliptical lip and a moderate increase in the contraction coefficient.(Menon Mudgal, 2018)

Achour, Amara, Mehta, et al., 2022 considers the potential of installing a broad-crested sill to shorten the length of a rectangular hydraulic jump stilling basin. All of the study's findings are derived from controlled laboratory testing with a purpose-built hydraulic system. (Achour, Amara, & Mehta, 2022a) presented the study for addition something new by incorporating a very wide range of the relative position X/h_2 of the sill - 15 values of this parameter are considered—through the design and implementation of an acceptable hydraulic system. To make the problem applicable to any flow state, this quantitative supplement was helpful.

Umrigar et al., 2023 evaluated the EFR in the lower stretch of the Tapi River using the Tennant, Tessman, variable monthly flow (VMF), and Smakhtin methods. The investigation started with daily data measured in three-gauge stations (Ukai, Motinaroli, Ghala).

Discharge varies for a given gate location because, as illustrated in Fig. 1, the separation zones on either side of the gate tend to shift with time, influencing the coefficient of discharge.

Experiments conducted on a 65 mm gate valve in the laboratory for fluid mechanics revealed an imperfect link between the rotation angle of the wheel and discharge, prompting the suggestion of using a rubber sleeve inside the gate valve to monitor flow. In both the case of the rubber sleeve and the case of the traditional pipe, piezometers are put on both sides of the valve to determine the pressure differential.

Both conventional and modified valves are tested experimentally, compared, and subjected to a computational fluid dynamics (CFD) analysis to ensure that no flow separation occurs. Both CFD analysis and experiments are used to verify the pressure difference.

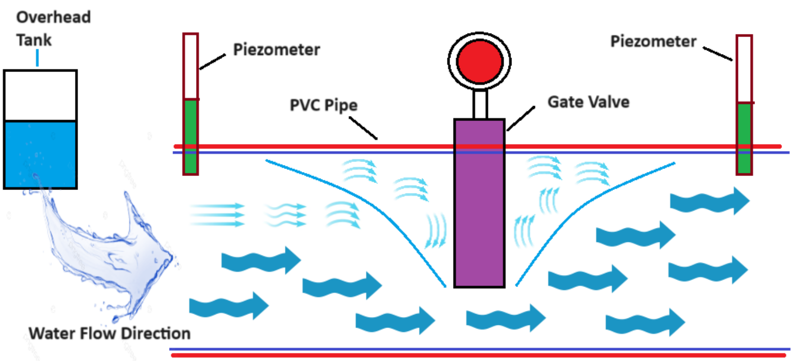


Figure 1: Representation of separation zones with piezometer on both side of gate valve for pressure measurement

EXPERIMENTAL INVESTIGATION

Discharge through Existing gate valve

An existing gate valve was set up in the recirculation pipeline to regulate the intake from the overhead tank, which was maintained at a constant head of 1.83 m. Discharge was measured using a piezometer at the same gate position of the valve with varying pressures, and the resulting rotation angles were recorded. Different separation zones were seen during testing with a standard gate valve, and the discharge volume was measured. The customised gate valve has dual applications in the laboratory for flow measurement and in the manufacturing sector for flow regulation. Standard and modified gate valves with piezometers attached to both ends of the valve are illustrated in Fig. 2 as part of experimental setups.

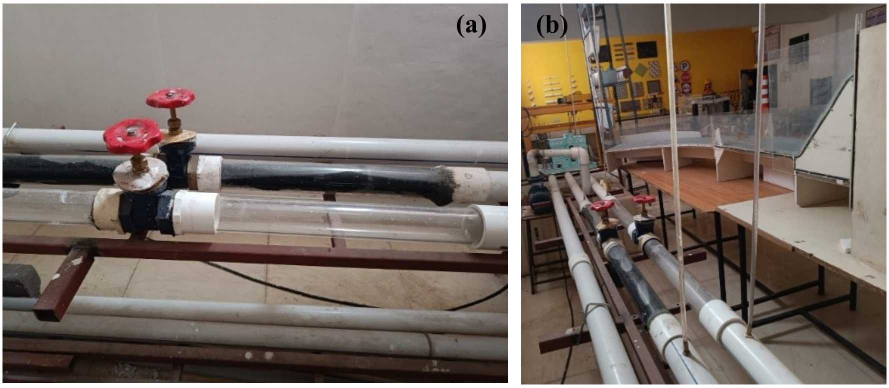


Figure 2: Experimental setup (a) with and without rubber sleeve and (b) piezometer at both end of valve

In the standard design, a metal gate valve with a 65 mm diameter is used, and it takes 13 spins of the wheel to completely close (for a total of 46800 radians). An acrylic pipe of the same length as the flow development length (650 mm) is inserted on either side of the valve, and the bonnet of the valve is marked with points at 900 mm intervals to facilitate its installation.

We first measured the discharge with the valve fully open at the beginning of each experiment. The valve was then closed in increments of up to eight full rotations anticlockwise, each time traversing an angular interval of 90 degrees. The discharge from a standard gate valve at a 900 interval in both the clockwise and anticlockwise directions is depicted in Fig. 3.

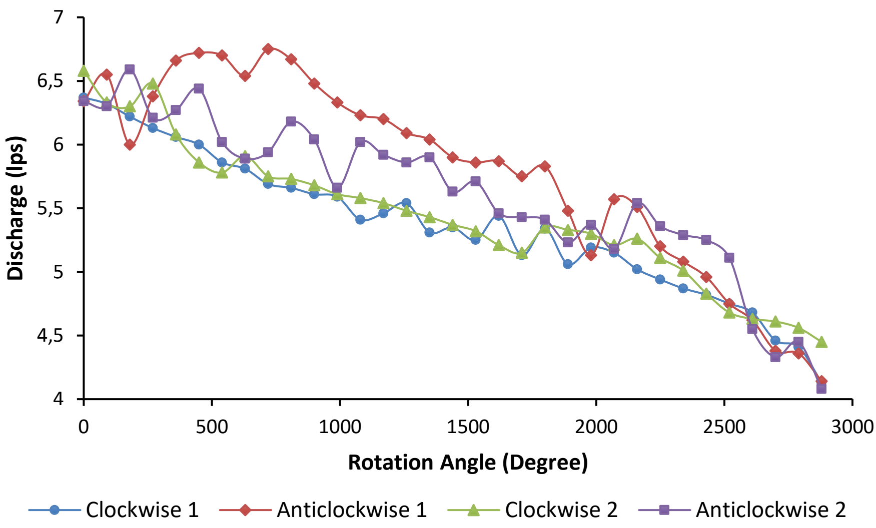


Figure 3: Discharge vs rotation angle for two sets of rotation through existing gate valve

Discharge through Modified Gate valve with Rubber sleeve

As can be seen in Fig. 2, a second model with the same parameters was fabricated by inserting a rubber sleeve inside the gate valve. This was done so that the pipe's shape would change in response to the gate's position, thereby preventing the formation of separation zones. This setup was used in the experiment shown in Fig. 2.

Each end of the 650-millimeter-long acrylic pipe in this system is fitted with a 65-millimeter gate valve for controlling the flow of liquid; the pipe itself is made of the same rubberized material found in car floor mats.

Length of rubber sleeve was = Flow development length on either side + length of valve=(650 + 650) +228.6 =1528.6 mm

As a result, a rubber sleeve with a length of 1550 millimetres was chosen as the optimal option. At first, the pipes made of clear acrylic were joined together on either side of the gate valve. After that, the rubber sleeve was slipped inside of this assembly, and at this point, there was a protrusion of fifty millimetres of it coming out of the ends of the acrylic pipes. Following the application of the solution, this additional length was carefully wrapped around the PVC pipe in order to create a watertight seal.

Fig. 4 depicts two sets of data obtained in a clockwise and anticlockwise manner, indicating that the discharge is almost constant throughout all locations of the gate valve. This is similar to the scenario that was presented in Fig. 3 which displayed two sets of readings taken in the clockwise and anticlockwise directions.

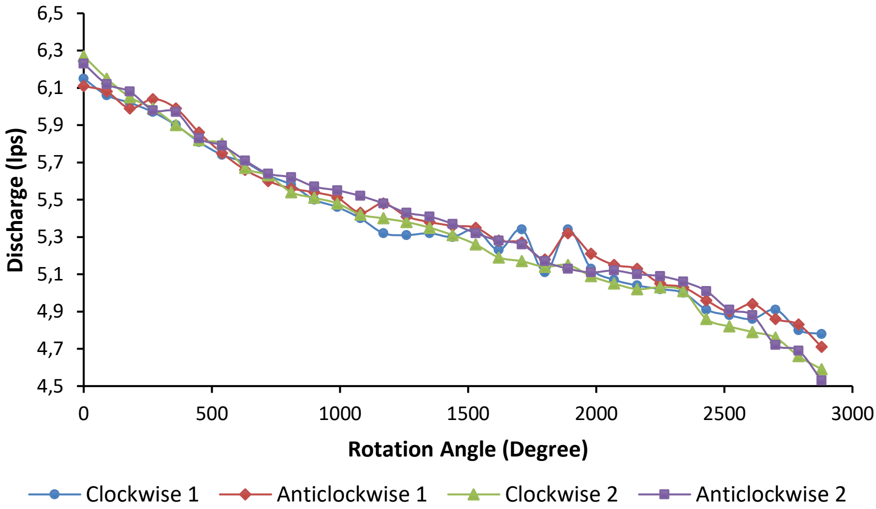


Figure 4: Discharge vs rotation angle for two sets of rotation through modified gate valve

Experimentation using Piezometer to check Pressure difference

In order to make sense of the data, graphs were generated for each set of observations. The degree of wheel rotation was shown along the X axis, and the discharge rate, measured in litres per second, was plotted along the Y axis. Because of the formation of different separation zones, the discharge from a standard gate valve changed with each measurement. However, in the case of a gate valve equipped with a rubber sleeve, the pattern observed was close together, which indicated that a correlation between gate position and discharge could be established. Fig. 3 and 4 illustrate a comparison of discharge vs wheel rotation angle for conventional and modified valves, respectively. There are two sets of readings depicted in these figures namely the first cycle of clockwise and anticlockwise running and the second cycle of clockwise and anticlockwise running. These readings were taken after two cycles of clockwise and anticlockwise running. A gate valve that was already installed demonstrated a substantial variance in discharge during both cycles, although having the same rotation angle.

After conducting an in-depth analysis of the data, it became abundantly evident that the installation of a pipe bend resulted in a significant improvement in the accuracy of the gate valve when used in the capacity of a flow metre. There was a good agreement between the mathematical models and the experimental models, with the maximum discharge variation in the case of an existing gate valve being observed to be 12% and the error between estimated discharge by equation and experiment being less than 2%. This indicates that the mathematical models and the experimental models are both accurate representations of reality.

It is also necessary to check the pressure at the inlet and outlet of the gate valve and its pressure difference while modifying the gate valve using rubber sleeve. Hence, the piezometer has been installed at both ends of the valve at equal distance, and the pressure has been recorded with the discharge. First, the discharge has been recorded for a existing gate valve with a pressure difference, and it has been observed that the discharge gradually decreases while increasing the pressure difference, as shown in Fig. 5. In the other case, a modified gate valve with rubber sleeve, as shown in Fig. 6, it has been observed that the discharge has no relevance to the pressure difference and is volatile while increasing the pressure difference. Hence, it can be concluded from the experimental trials with the modified gate valve that even though the flow is smooth with no separation zone, the pressure difference is not proportional to discharge, and it may be due to the pressure fluctuation dampening. Hence, there is no specific relation between the pressure difference in either the gate valve or the flow through the gate valve, and hence all the relations with the modified gate valve are proposed without any concern for the pressure difference. The flow and discharge are connected with the rotation of the wheel in clockwise and anticlockwise directions only.

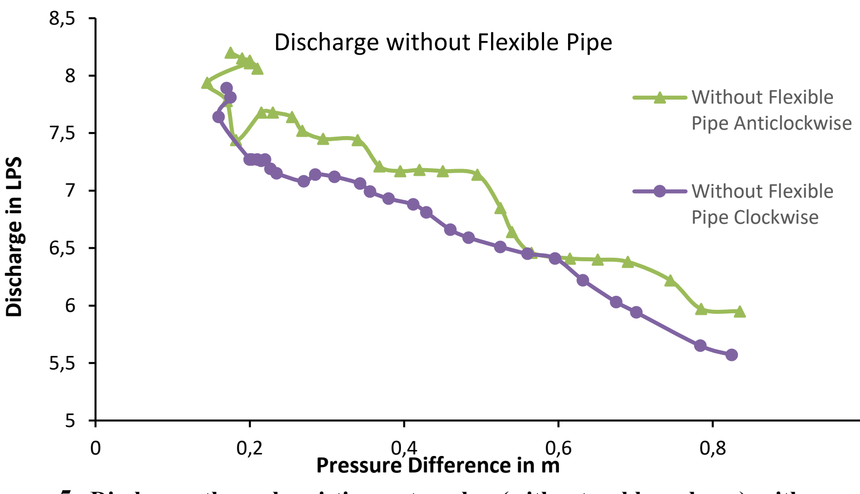


Figure 5: Discharge through existing gate valve (without rubber sleeve) with respect to pressure difference in clockwise and anticlockwise direction.

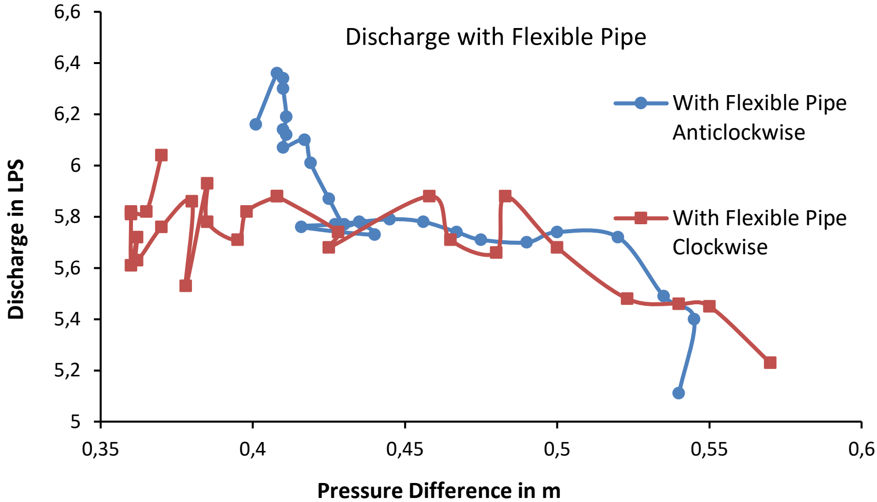


Figure 6: Discharge through modified gate valve (with rubber sleeve) with respect to pressure difference in clockwise and anticlockwise direction

CFD ANALYSIS FOR PRESSURE MEASUREMENT AT BOTH END OF GATE VALVE

The flow through a pipe equipped with a gate valve has been the subject of a computational fluid dynamics (CFD) analysis, and the results have been validated with experimental results. For the purpose of measuring the pressure at both ends of a gate valve, a total of four different situations have been taken into consideration. These cases include flow through a pipe with a gate valve that is either 70% open, 55% open, 40% open, or 25% open for both standard and modified gate valves.

For the purpose of conducting a CFD analysis of flow through a pipe with a gate valve having dimensions of 2 metres in length and 65 millimetres in diameter, the model is meshed with SOLID 186 hexahedral elements, which have 67891 nodes and 20753 elements, and the maximum and total volumes of the mesh are considered to be 2.35887510-6 m3 and 6.52702410-3 m3, respectively. Fig. 7 shows a three-dimensional illustration of the pipe, and Fig. 8 shows a three-dimensional mesh model of the pipe that incorporates a liquid domain. The remaining problems are being resolved with the use of multizone meshing, and the hexahedral element sweep meshing has been applied to every open pipe segment. The inputs that can be utilised for the CFD analyses are detailed in Table 1.

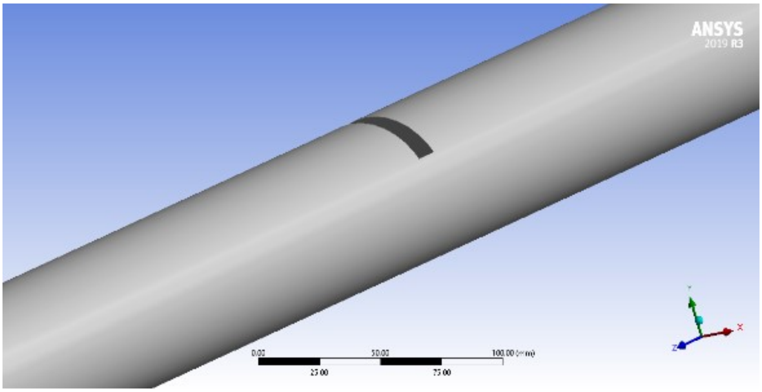


Figure 7: CAD modelling of pipe shows gate valve at center

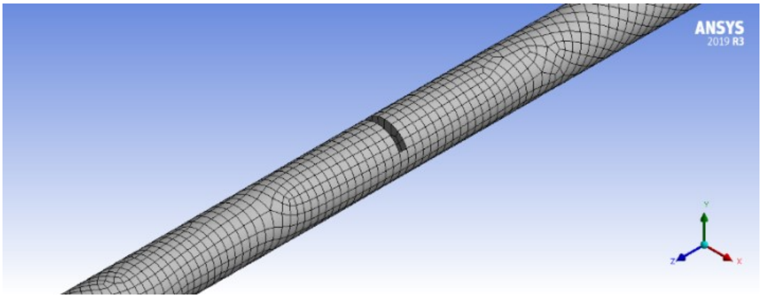


Figure 8: Meshing of pipe using hexahedral element

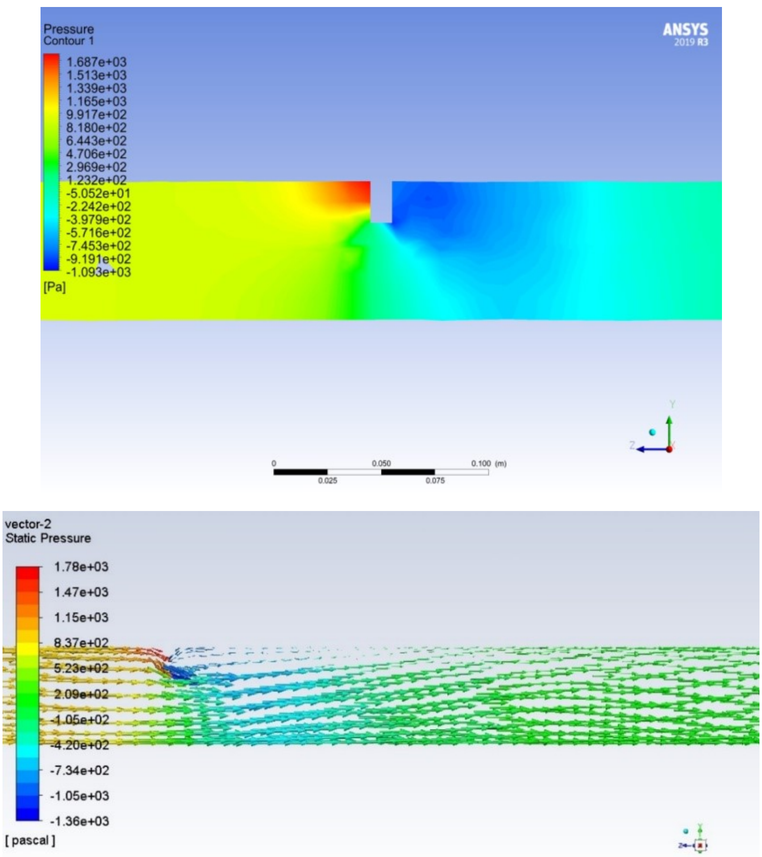
Table 1: Parameters as an input for CFD analysis of water flow through gate valve with difference rotation angle

Gate valve Opening	Rotation Angle (Degree)	Velocity (m/s)	Mass Flow Rate (lps)
100%	0	1.93	6.41
70%	1440	1.675	5.56
55%	2160	1.606	5.33
40%	2880	1.265	4.2
25%	3510	1.073	3.56

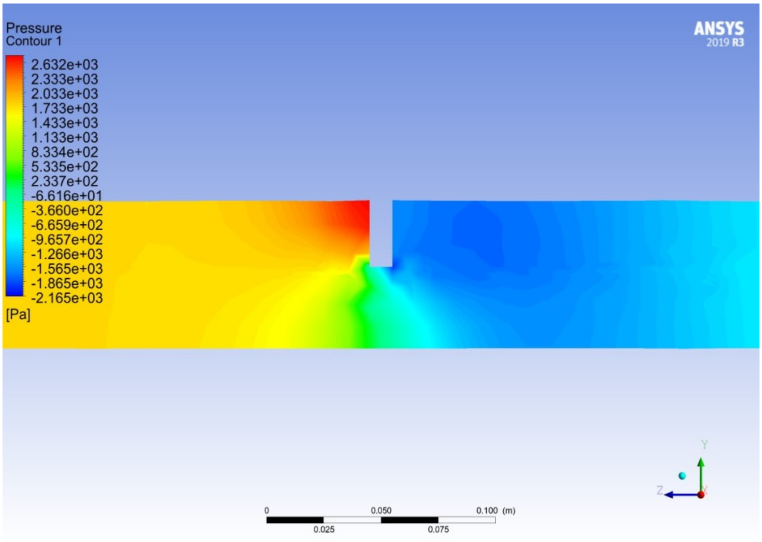
The SST k-omega turbulence model requires a mass flow rate to be specified at the inlet and validated at the outlet of the pipe. Pressure contour plots and pressure vectors for both the standard and modified gate valves are displayed in Fig. 9 and 10, respectively, for a range of opening sizes. Both sides of the valve have had pressure readings taken using a piezometer at 1, 1.5, and 2 feet away. With the gate valve fully open, the analysis shows that linear flow occurs in the pipe. The water flow changes direction when the gate is just half closed.

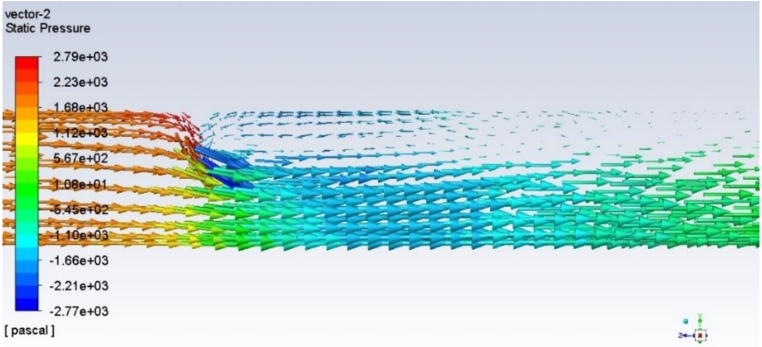
Existing gate valve

After going through the gate valve, it can be seen that the water flows backwards. After 30–40 iterations, it's also clear that the mass flow rate is stable and equal at the inlet and outlet. The revised gate valve also undergoes a similar study. Fig. 9 displays the flow pattern in the form of pressure contour and vector, for existing gate valve s (without rubber sleeve) at 70%, 55%, 40% and 25% gate valve openings. The velocity is gradually increasing at oulet and pressure is gradually increasing at inlet of the pipe for the valve opening of 70%, 55%, 40%. The results get also validated with the experimental results for the same opening. 25% is the minimum opening of the gate valve which is not considered while experimentation but considered during CFD analysis to check the flow pattern and pressure distribution for conventional and modified gate valve. It has been observed that the separation zone occurs at the outlet of existing gate valve for the gate valve opening of 25% and also velocity and pressure at 25% opening is very high. From Fig. 9 (d), it is observed that the pressure at inlet and outlet is also maximum i.e. about 40 bar.

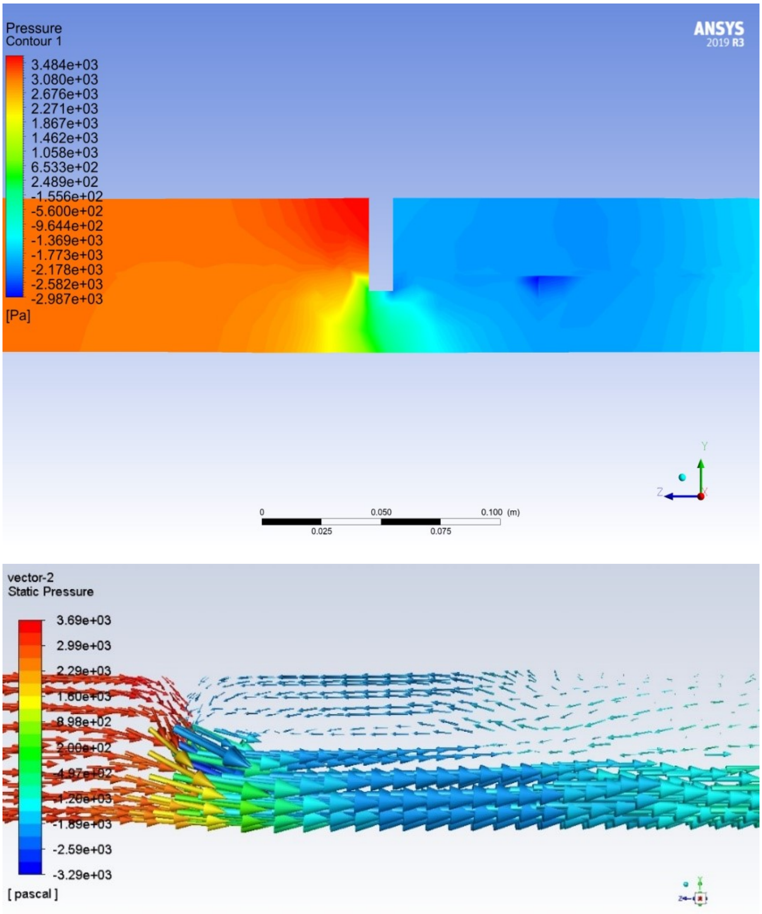


(a) Pressure contour and vector for 70% opening of existing gate valve (45.5 mm)

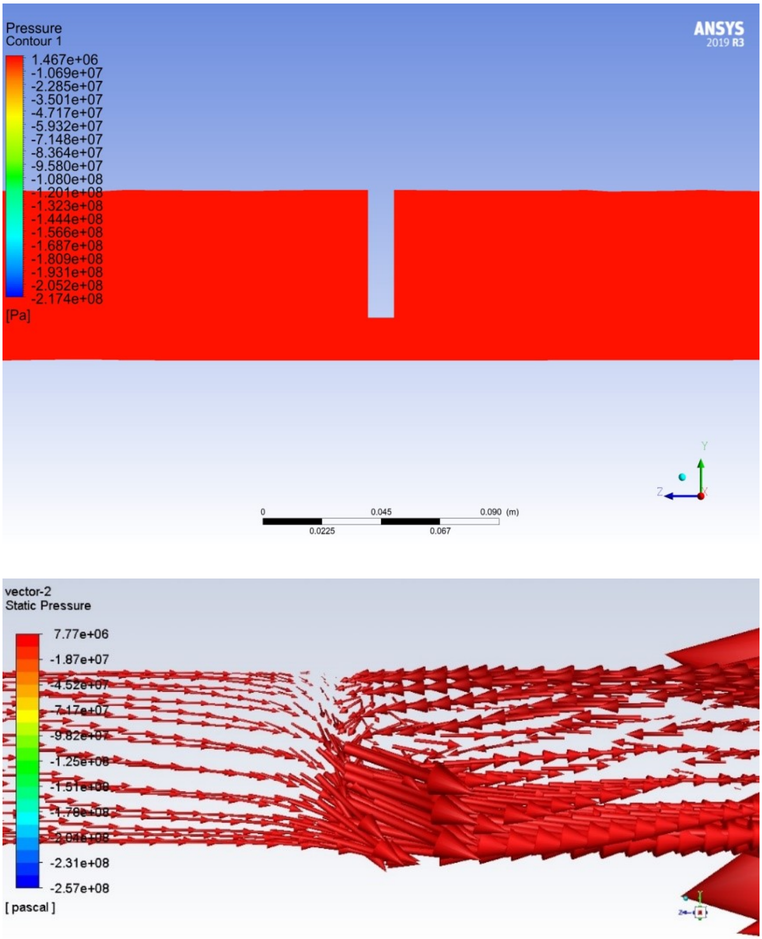




(b) Pressure contour and vector for 55% opening of existing gate valve (36.75 mm)



(c) Pressure contour and vector for 40% opening of existing gate valve (26 mm)



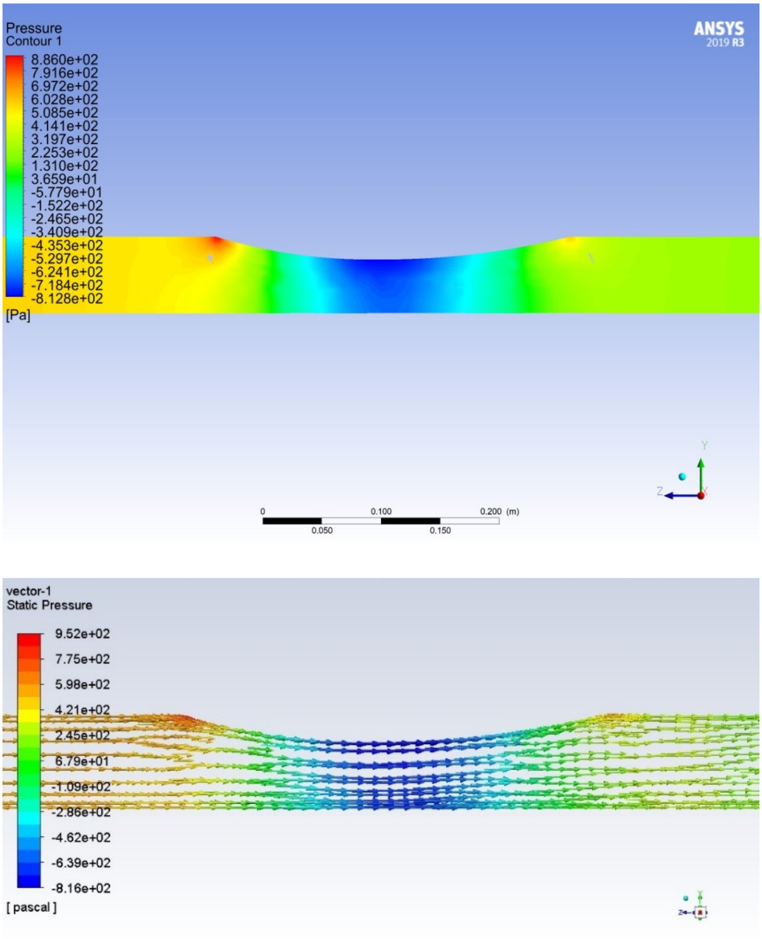
(d) Pressure contour and vector for 25% opening of existing gate valve

Figure 9. Pressure contour plot and vector reprensetation over the existing gate valve opening of 70%, 55%, 40% and 25%

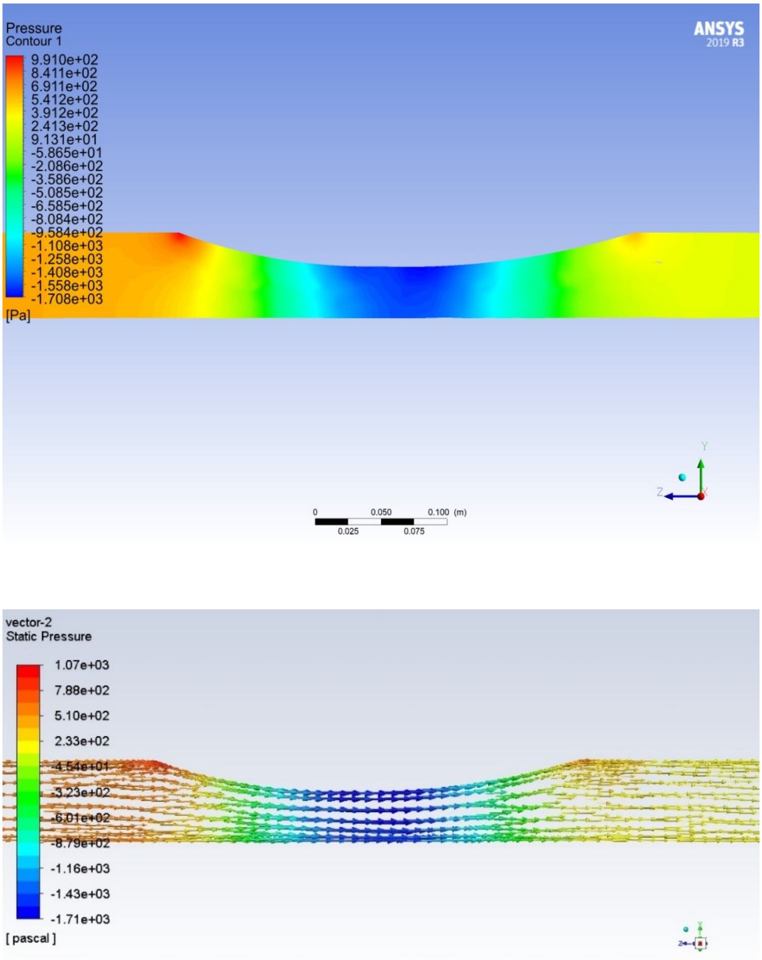
Modified Gate Valve (with rubber sleeve)

A rubber sleeve has been installed inside of a gate valve in order to measure the discharge. Water flow via a conventional and modified gate valve has been experimentally analysed, and the results show that the mass flow rate from the modified gate valve is linear and can be utilised as a flow measurement device. The pressure differential between the inlet and output of the modified gate valve must also be verified via CFD analysis. At 70%, 55%, and 40% valve opening, the pressure differential for the modified gate valve is detected using CFD analysis, and it is found to be reduced from 0.3 bar to 0.1 bar at the

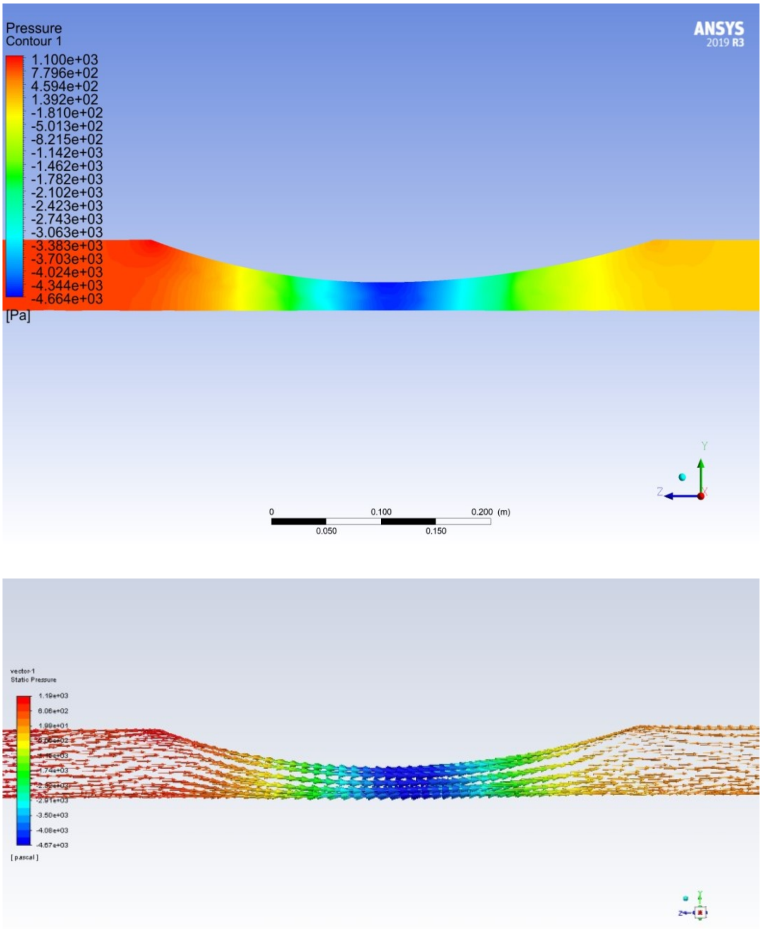
40% opening. The pressure drops dramatically from 41 bar to 0.03 bar at the output with a minimum valve opening of 25% in a modified gate valve. Additionally, with a valve opening of 25%, the modified gate valve has no separating zone. Fig. 10 depicts the pressure and velocity vectors of water flowing through a pipe with a modified gate valve (with a rubber sleeve) at four different valve openings: 70%, 55%, 40%, and 25%.



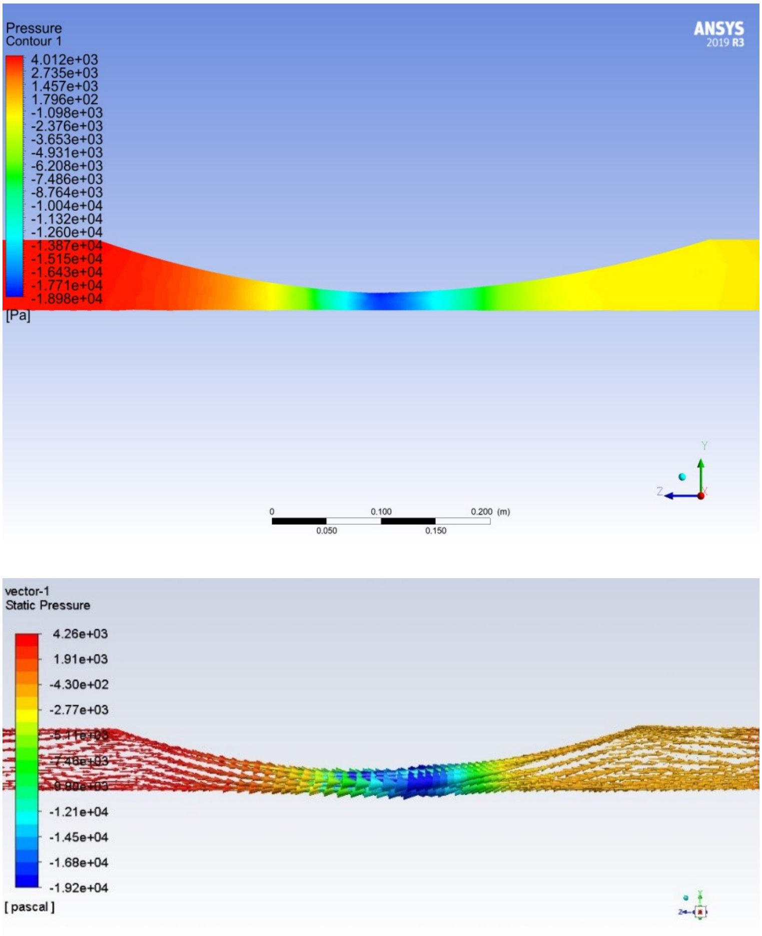
(a) Pressure contour and vector for 70% opening of modified gate valve (45.5 mm)



(b) Pressure contour and vector for 55% opening of modified gate valve (36.75 mm)



(c) Pressure contour and vector for opening of 40% modified gate valve (26 mm)



(d) Pressure contour and vector for opening of 25% modified gate valve

Figure 10: Pressure contour plot and vector reprensetation over the modified gate valve opening of 70%, 55%, 40% and 25%.

RESULT AND DISCUSSION

The flow of fluid through a conventional gate valve is depicted in Fig. 4 under a variety of different rotational angles. The flow rate and pressure are both uniform when the valve is fully open (rotation angle = 0^{o}), but as the rotation angle increases, fluid separation and the production of eddies in the downstream zone of the valve between the pipe and the valve contact region cause the discharge to become non-uniform. When the valve is fully open (rotation angle = 90^{o}), the flow rate and pressure are both uniform.

For existing gate valve

The results of experimental analysis performed on the currently installed gate valve demonstrate that the pressure measurement using piezometer at both end of the valve has steadily grown while reducing the valve opening, and the pressure has been recorded at both the ends of the valve. The valve opening was reduced from 100% to 40%, which resulted in a progressive increase in pressure.

The computational fluid dynamics (CFD) analysis shows that streamlines are straight and that the fluid velocity remains constant during the whole opening of a conventional gate valve. The speed of the fluid moving in the pipe's core is significantly higher than the velocity of the fluid going along the pipe wall. However, as the valve opening is reduced, the fluid's velocity suddenly increases at the valve, which results in fluid separation and eddy currents for a length of pipe both upstream and downstream of the valve.

As the valve opening is decreased, frictional head loss occurs as a result of fluid separation that takes place downstream of the valve over a specific length of pipe. This occurs for a particular amount of pipe. The intake of a pipe that has a valve that is fully open will have the highest pressure of any point along the pipe, while the outlet will have the lowest pressure.

For modified gate valve

When the modified gate valve is only partially closed, the upper half of the rubber tube will bend and operate as a nozzle. This will cause the fluid's velocity to gradually increase at the inlet, reach a peak at the gate valve region, and then gradually decline at the exit.

Fig. 11 and 12 depict the analysis of fluid flow and the distribution of pressure at the end of a conventional and modified gate valve, respectively. As seen in Fig. 11, the pressure at the intake remains high even after the opening is reduced from 100% to 40% with a standard valve. Fig. 11 shows how replacing a standard valve with a modified gate valve equipped with a rubber sleeve can reduce pressure by a factor of three. Straight streamlines and a steady flow rate are both characteristics of a fully open existing gate valve. However, fluid separation and eddy currents occur for a limited distance upstream and downstream of the valve when the valve opening is reduced, because the velocity of the fluid at the valve grows exponentially. The high outlet pressure shown in Fig. 12 suggests that a standard gate valve would not function well at a 25% opening. However, the pressure at a modified gate valve is only slightly higher than that at a 40% opening, and the flow is smooth throughout. As a result, the redesigned gate valve can be operated at an opening of 25%.

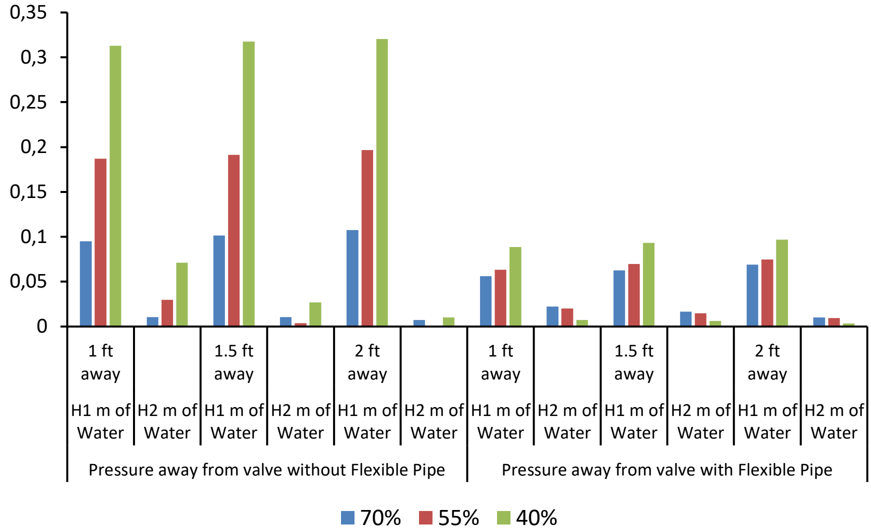


Figure 11: Comparison of pressure drop at 40%, 55% and 70% valve opening for with and without rubber sleeve away 1 feet, 1.5 feet and 2 feet from both side of valve

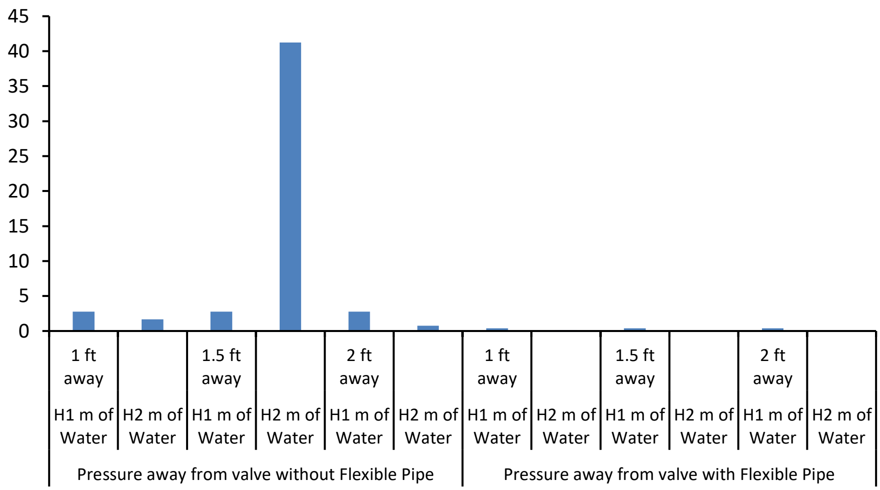


Figure 12: Comparison of pressure drop at 25% valve opening for with and without rubber sleeve away 1 feet, 1.5 feet and 2 feet from both side of valve

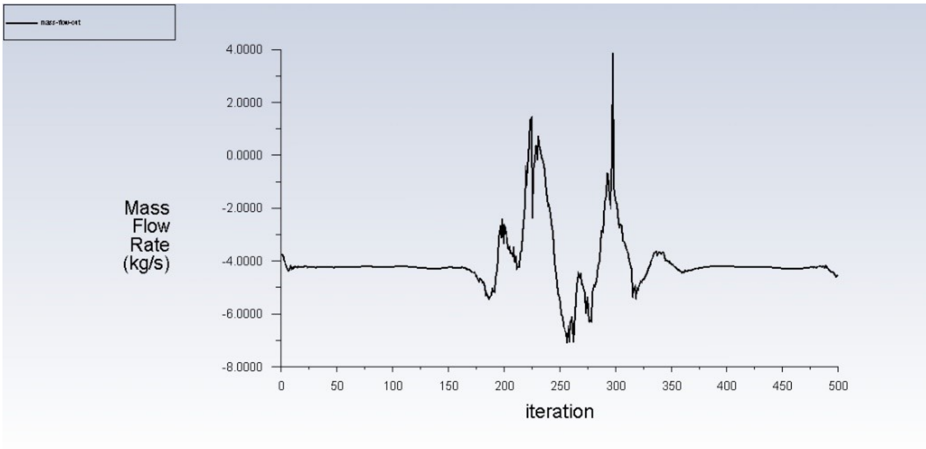


Figure 13: Mass flow rate for existing gate valve (without rubber sleeve) at critical valve opening of 25%

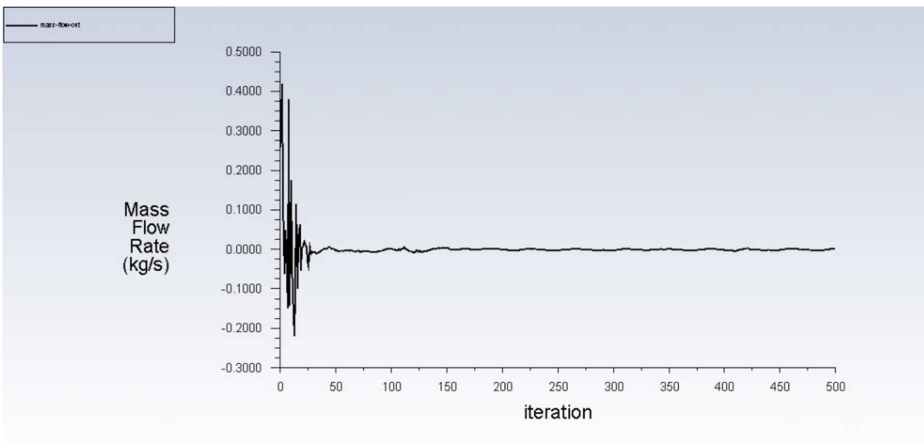


Figure 14: Mass flow rate for modified gate valve (with rubber sleeve) at critical valve opening of 25%

CONCLUSION

Because the discharge obtained from an existing gate valve for the same disc position and at different times varies due to the formation of fluctuating separation zones and eddies, adding a rubber sleeve inside the gate valve has improved its performance and transformed it into a flow measuring device. This is because the discharge obtained from an existing gate valve for the same disc position and at different times. Additionally, during the process of experimental validation, the concept of flow development length was taken into consideration in order to comprehend the velocity distribution and pressure distribution that varies in this portion of the pipe and may tend to generate different readings of pressure and velocity. This was done in order to understand the flow development length. Since there will be fewer instances of measurement mistakes, the flow development duration of the modified valve will be able to be cut even more during the commercial manufacturing process.

The modified gate valve's pressure difference and discharge rate were the primary foci of the research. The data demonstrated that an existing gate valve 's discharge varies between measurements because of spatial discontinuities. In contrast, the discharge pattern from a gate valve with a rubber sleeve was clustered closely together. The gate valve's efficacy as a flow metre was enhanced by the installation of a pipe elbow. When the pressure difference increased, the discharge from a standard gate valve dropped, but the discharge from a modified gate valve was unpredictable and not at all related to the pressure difference. According to the results, the direction of the wheel's rotation has an effect on the flow and discharge.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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