Conversion of gate valve into a flow measuring device

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A gate valve is traditionally used for controlling discharge in pipes. It is operated by rotating a wheel provided on top of a stem which is connected to a circular disc (i.e. gate) on the other side. Every single rotation of the wheel produces specific linear movement of the disc, which in turn tends to change the area of flow. It is expected that for the same disc position discharge should be the same, but analysis showed that the discharge varied considerably. Further analysis revealed that it occurs on account of the fluctuating separation zones formed on either side of the disc. To address this issue, it is proposed to use a flexible membrane pipe inside the gate valve. This membrane will not allow the separation zones to form, as its shape will automatically adapt depending upon the disc position and intensity of discharge. It is similar to that of a venturimeter with dynamically changing convergent and divergent cones. With this novel adaption, an experimental set-up with 65 mm acrylic pipe was used. The results have shown good improvement in the relationship between disc position and discharge. Further, it has been calibrated with respect to rotation angle of the wheel. The experimental study has shown that the modified gate valve can also be used as a flow measuring device. This communication describes the conversion of a gate valve from flow control device to flow measuring device.

Keywords: Discharge, flow measuring device, gate valve, separation zone.

A gate valve is commonly used in many household and industrial applications. The industrial applications demand accurate flow control for various processes. In fact, the gate valve itself is a flow control device. However, on account of its inability to precisely control the flow, it needs to be supplemented with separate flow measuring device. Therefore gate valves, when used along with flow measuring devices like venturimeter or orifice meter, can act as a precise flow control device. Figure 1 shows a gate valve and its components.

The wheel of a gate valve is connected to a circular disc by means of a stem. The clockwise and anticlockwise movement of the wheel results into linear movement of the disc in the forward and backward direction respectively.

Gate valves are used for on/off service and are designed to operate when fully open or fully closed[1]. Due to excessive vibrations generated in partially closed gates, the valves are not intended for throttling or flow regulation.

Zakirnichnaya and Kulsharipov[2] have plotted the velocity vector graph on either side of the gate valve which shows formation of separation zones and reverse flow therein. Steele *et al.*[3] have measured the force exerted on the stem at different gate positions. They have also reported that this force keeps fluctuating continuously.

Sathe *et al.*[4] have carried out experiments with 25 mm gate valve to identify the relation between rotation angle of wheel and discharge. They reported that no exact relation could be established between these two parameters owing to formation of fluctuating separation zones on either side of the gate. The 25 mm gate valve was then modified by inserting a flexible pipe inside and a pilot study was carried out. The results of the modified gate valve indicated a proportionate relation between rotation angle and discharge. Hence the present study has been undertaken with a 65 mm gate valve to further confirm the above-mentioned relation and propose a mathematical equation for the same.

Figure 2 shows a schematic of the separation zones which tend to form on either side of the gate. Since the separation zones keep fluctuating, it affects the coefficient of discharge which also keeps changing over a period of time and results into variation in discharge for the same gate position.

To study the flow conditions, an experimental set-up with recirculation system was used. It includes two pipelines identical in all respects, with the only difference

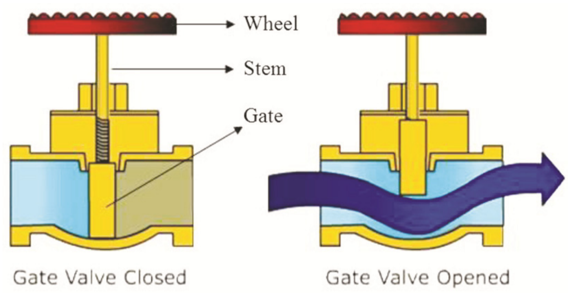

Figure 1. Gate valve.

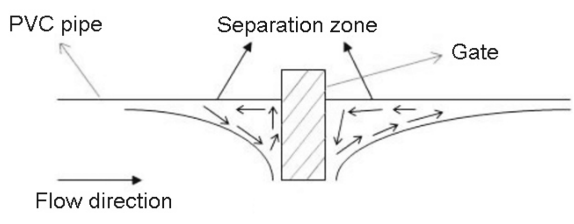

Figure 2. Schematic of separation zones on either side of the gate.

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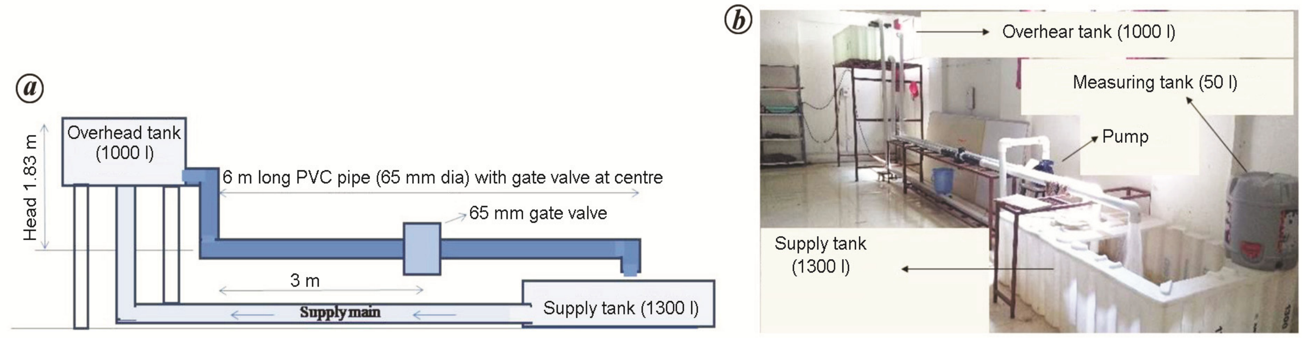

Figure 3. ***a***, Schematic of experimental set-up. ***b***, Experimental set-up of conventional and modified gate valve.

Table 1. Conventional gate valve readings

Rotation angle (°)	Discharge (l/s)				
	Clockwise 1	Anticlockwise 1	Clockwise 2	Anticlockwise 2	Average
0	**6.37**	**6.34**	**6.58**	**6.34**	**6.41**
90	6.32	6.55	6.33	6.30	6.38
180	6.22	6.00	6.30	6.59	6.28
270	6.13	6.38	6.48	6.21	6.30
360	**6.06**	**6.66**	**6.08**	**6.27**	**6.26**
450	6.00	6.72	5.86	6.44	6.26
540	5.86	6.70	5.78	6.02	6.09
630	5.81	6.54	5.91	5.89	6.04
720	**5.69**	**6.75**	**5.75**	**5.94**	**6.03**
810	5.66	6.67	5.73	6.18	6.06
900	5.61	6.48	5.68	6.04	5.95
990	5.59	6.33	5.61	5.66	5.80
1080	**5.41**	**6.23**	**5.58**	**6.02**	**5.81**
1170	5.46	6.20	5.54	5.92	5.78
1260	5.54	6.09	5.48	5.86	5.74
1350	5.31	6.04	5.43	5.90	5.67
1440	**5.35**	**5.90**	**5.37**	**5.63**	**5.56**
1530	5.25	5.86	5.32	5.71	5.54
1620	5.44	5.87	5.21	5.46	5.50
1710	5.13	5.75	5.15	5.43	5.37
1800	**5.34**	**5.83**	**5.35**	**5.41**	**5.48**
1890	5.06	5.48	5.33	5.23	5.27
1980	5.19	5.13	5.30	5.37	5.25
2070	5.15	5.57	5.21	5.18	5.28
2160	**5.02**	**5.51**	**5.26**	**5.54**	**5.33**
2250	4.94	5.20	5.11	5.36	5.15
2340	4.87	5.08	5.01	5.29	5.06
2430	4.82	4.96	4.83	5.25	4.96
2520	**4.75**	**4.75**	**4.68**	**5.11**	**4.82**
2610	4.68	4.62	4.63	4.55	4.62
2700	4.46	4.38	4.61	4.33	4.45
2790	4.41	4.36	4.56	4.45	4.45
2880	**4.13**	**4.14**	**4.45**	**4.08**	**4.20**

being that one had a traditional gate valve while the other had a flexible membrane pipe inside the gate valve. The length of the flexible membrane pipe was designed based on the consideration of flow development length. The inflow was taken from the overhead tank under a constant head of 1.83 m. For both the models various trials were conducted to measure discharge for the same gate position of the valve and the corresponding rotation angles were recorded. Using results of the model study with the flexible membrane pipe (i.e. modified gate valve), a mathematical equation for discharge was developed.

Figure 3 *a* shows a schematic of the experimental set-up and Figure 3 *b* shows the actual set-up with conventional and modified gate valves. The discharge was

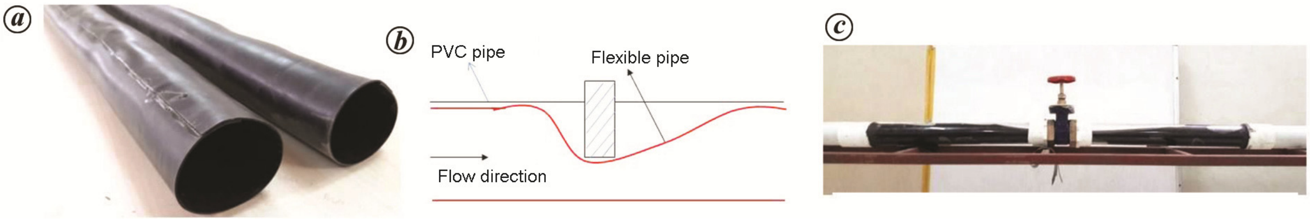

Figure 4. ***a***, Flexible membrane pipe. ***b***, Schematic of flexible pipe inside the gate valve. ***c***, Actual flexible membrane pipe inside the gate valve.

Table 2. Modified gate valve readings

	Discharge (l/s)				
Rotation angle (°)	Clockwise 1	Anticlockwise 1	Clockwise 2	Anticlockwise 2	Average
0	**6.15**	**6.11**	**6.27**	**6.23**	**6.19**
90	6.06	6.08	6.15	6.12	6.10
180	6.02	5.99	6.05	6.08	6.04
270	5.97	6.04	5.99	5.98	5.99
360	**5.90**	**5.99**	**5.90**	**5.97**	**5.94**
450	5.81	5.86	5.82	5.83	5.83
540	5.74	5.75	5.80	5.79	5.77
630	5.70	5.66	5.67	5.71	5.69
720	**5.63**	**5.60**	**5.63**	**5.64**	**5.62**
810	5.58	5.56	5.54	5.62	5.57
900	5.50	5.54	5.51	5.57	5.53
990	5.46	5.51	5.48	5.55	5.50
1080	**5.40**	**5.43**	**5.42**	**5.52**	**5.44**
1170	5.32	5.48	5.40	5.48	5.42
1260	5.31	5.41	5.38	5.43	5.38
1350	5.32	5.38	5.35	5.41	5.37
1440	**5.30**	**5.36**	**5.31**	**5.37**	**5.34**
1530	5.34	5.35	5.26	5.32	5.32
1620	5.23	5.28	5.19	5.28	5.25
1710	5.34	5.27	5.17	5.26	5.26
1800	**5.11**	**5.18**	**5.14**	**5.17**	**5.15**
1890	5.34	5.32	5.15	5.13	5.23
1980	5.13	5.21	5.09	5.11	5.13
2070	5.07	5.15	5.05	5.12	5.10
2160	**5.04**	**5.13**	**5.02**	**5.10**	**5.07**
2250	5.02	5.05	5.03	5.09	5.05
2340	5.00	5.03	5.01	5.06	5.02
2430	4.91	4.96	4.86	5.01	4.94
2520	**4.88**	**4.90**	**4.82**	**4.91**	**4.88**
2610	4.86	4.94	4.79	4.88	4.87
2700	4.91	4.86	4.76	4.72	4.81
2790	4.80	4.83	4.66	4.69	4.75
2880	**4.78**	**4.71**	**4.59**	**4.53**	**4.66**

measured on volumetric basis. While carrying out tests with the conventional gate valve, fluctuating separation zones were observed.

For the conventional model 65 mm metallic gate valve was used. Complete closing of this valve requires 13 rotation of the wheel which results into angular measure of 4680°. Before fixing the valve, points at 90° interval were marked along the periphery of the bonnet of the valve. On both sides of the valve, acrylic pipe of length equal to flow development length (i.e. 650 mm) was attached. Transparency of the acrylic pipe helped observe the flow conditions. For the remaining portion, a non-transparent PVC pipe was used. Hence total length of the horizontal pipe of experimental set-up was 6 m.

The experiment started with a completely open valve and the corresponding discharge was measured. Then the valve was partially closed by rotating it in a clockwise manner through an angular interval of 90°, and discharge was measured. The same procedure was repeated until the valve was closed up to eight rotations. Similarly, readings were taken while opening the valve at an interval of 90° by rotating the wheel in the anticlockwise direction. This completed one set of readings. Two-sets of such readings were taken (Table 1). It was observed that for same angular position of the wheel, discharge was not the same. This indicates the problem associated with traditional gate valves.

Another model with identical parameters was developed by using an additional flexible membrane pipe inside the gate valve (Figure 4 *a*). Figure 4 *b* shows a schematic of the modified shape of flexible pipe inside the gate valve in response to position of the gate. The flexible pipe was used to avoid formation of separation zones. Figure 4 *c* shows the actual experimental set-up.

This system consists of a 65 mm gate valve with acrylic pipes on either side having flow development length of 650 mm. This flexible pipe was made of rubber which is used in cars as mats. The length of the flexible pipe was calculated as follows:

Length of flexible pipe = Flow development length on either side + Length of valve
= (650 + 650) +228.6 mm = 1528.6 mm.

Therefore, a 1550 mm long flexible pipe was taken. Initially the transparent acrylic pipes were connected on either side of the gate valve. Then the flexible pipe was inserted inside this assembly. Due to the additional 100 mm length of the flexible pipe, this portion was gently wrapped around the PVC pipe and the solution was applied to make it water tight. Further, the acrylic pipes were connected to the PVC pipes.

The same procedure was followed for recording the readings. Similar to the previous case, two-sets of readings were taken both clockwise and anticlockwise (Table 2). It was observed that the discharge was almost same for the same position of the gate valve.

For each set of readings, graphs were drawn to analyse the results. On the x-axis Angle of rotation (deg) of the wheel was taken on the x-axis, while discharge (l/s) was taken on the y-axis.

The graphical presentation for conventional gate valve showed scattered pattern as the discharge varied due to formation of fluctuating separation zones. Whereas in case of gate valve with flexible pipe, a systematic pattern is observed. This showed that the relationship between gate position and discharge could be established.

Figure 5 shows the plot of discharge versus rotation angle of the wheel for total two sets of readings. For the same rotation angle, considerable variation in discharge was observed among the four values. These discharge fluctuations may be attributed to the fluctuating separation zones formed on either side of the gate. A similar graph for the modified gate valve Figure 6 shows that the discharge fluctuations are considerably damped.

A complete analysis of results revealed that use of flexible pipe has considerably improved the performance of the gate valve as a flow measuring device. The modified gate valve was calibrated and a linear equation was developed by the method of best fit as given below

$$y = 6.042 - 0.0005x,$$

where y is the discharge (l/s) and x is the angle of rotation (deg).

The error between discharge estimated by the mathematical equation and experiment was found to be less than ±2%. Thus good agreement was found between the mathematical and experimental models. Whereas maximum discharge variation in case of traditional gate valve was observed to be ±12%.

It is evident from the experimental study that in the traditional gate valve, for the same disc position and at different times, discharge obtained is not the same owing to formation of fluctuating separation zones. This can be avoided by providing a flexible membrane pipe inside the gate valve. Such modification has improved the performance of the gate valve and converted it into a flow measuring device. Further, the calibration equation is valid for a given held on upstream. The proposed modified gate valve has the potential to replace existing flow measuring

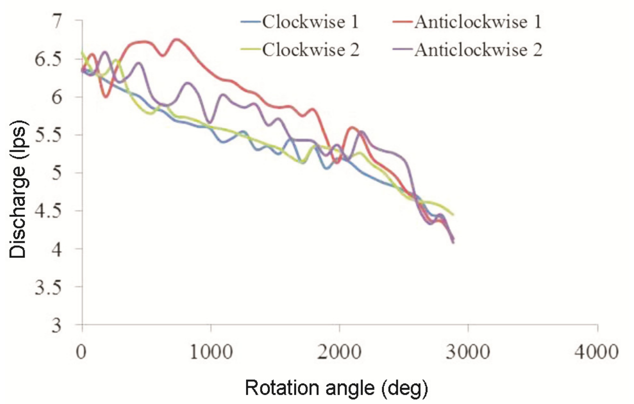

Figure 5. Graph of rotation angle versus discharge for conventional gate valve.

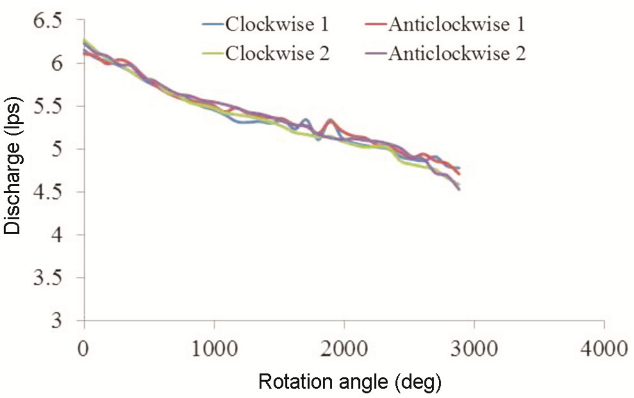

Figure 6. Graph of rotation angle versus discharge for modified gate valve.

devices, leading to considerable cost savings in various industrial applications.

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Optimization for single- and double-electrode high-tension separators using surface methodology to recover titanium minerals from Red Sediments, Odisha, India

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This study deals with the optimization of operating parameters of single- and double-electrode high tension electrostatic separators (HTS) using response surface methodology (RSM). The parametric optimization takes into account feed rate, temperature and drum speed as major operating variables. The objective is to recover titanium-bearing minerals such as ilmenite and rutile from red sediment deposits of badlands in Odisha, India, by optimizing the operating parameters of single- and double-electrode HTS. We predict titanium-bearing minerals recovery as a function of feed rate, temperature and drum speed. The optimized response was validated against data derived from both HTS test works comprising (i) mineral grade, (ii) mineral recovery and (iii) process yield. The study describes the optimization procedure using RSM and MATLAB. RSM was used for optimizing the criteria for separation of titanium-bearing minerals by varying feed rate, temperature and drum speed. It was observed that factors like maximum yield %, grade % and recovery % for ilmenite using double-electrode HTS method were better than single-electrode HTS method. Thus, it can be concluded on the basis of overall performance from both experimental and predicted values, that the double-electrode HTS method is better than the single-electrode HTS method, particularly from the grade and recovery point of view.

Keywords: Badlands topography, high-tension separator, red sediments, single and double electrodes, titanium-bearing minerals.

BADLANDS topography exists all along the east coast of India[1]. In general, these badlands are formed with red sediments which consist of placer minerals, including quartz, ilmenite, sillimanite, zircon, monazite, rutile and other minerals in small amounts. The general practice to recover heavy minerals involves scrubbing, desliming and gravity spirals. The heavy mineral concentrate output from the spiral operation is subjected to high-tension separation to recover ilmenite and rutile. However, the performance of the high-tension separator (HTS) depends on particle size, electrode position, drum speed, temperature of the feed and feed rate. In our experience, single-stage operation may not give high-grade titanium-bearing minerals at a higher recovery. Hence, it is necessary to optimize the process variables to recover maximum-grade titanium-bearing minerals using software to reduce the number of experiments for optimization of the process. The response surface methodology (RSM) with Box–Behnken design is one of the useful methods to optimize the process parameters. This method has already been applied for optimizing process parameters through RSM for grinding experiments of coal samples[2] as well as for producing graphite concentrates[3]. An optimization model for separation of titanium-bearing minerals from beach sand minerals was also developed using RSM[4–6].

This study aims to recover maximum-grade titanium-bearing minerals from red sediments using single-electrode and double-electrode HTS. The experimental results were analysed using software like Design expert 6.0.6 (RSM), ANOVA and MATLAB 8.1. The optimum

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