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Hydraulic analysis of gate valve using computational fluid dynamics (CFD)

Key words: gate valve, hydrodynamic analysis, CFD, Ansys Workbench software package

Introduction

The water supply network consists of a number of interdependent elements, one of which is a gate valve. They represent machine elements commonly used to control fluid flow because they provide positive seal at high liquid and gas pressures (Fig. 1). They are used in various industries such as refineries, petrochemical plants, power stations, hydroelectric power plants, nuclear power plants, etc. High flow velocities with partial opening of the valve can lead to erosion of its walls, vibrations and noise (Banko, 2019). They are most commonly used for drinking water and wastewater in the temperature range from –20 to +70°C and can withstand flow velocities of up to 5 $m \cdot s^{-1}$ and pressures of up to 16 bar. Their main disadvantage is the large required number of turns of the valve opening/closing handwheel.

During the opening or closing of the gate valves, considerable forces are exerted on the valve construction due to the leakage of the flow. The hydrodynamic forces caused by the high flow velocities under the gate valve result in a vertical force downwards. As the gate valve opens, the velocities increase non--linearly in relation to the degree of opening. Most flow changes occur near the valve at a relatively high flow velocity and cause wear on the valve walls and bearings. High flow velocities in partially opened valves can cause erosion of the valve discs and the bearings themselves, and vibrations can cause damage to the partially opened disc (Quimby, 2007). When the gate valve is lowered to reduce the flow (e.g. by closing), the pressure on the lower surface of the valve decreases due to the high flow velocity, a b

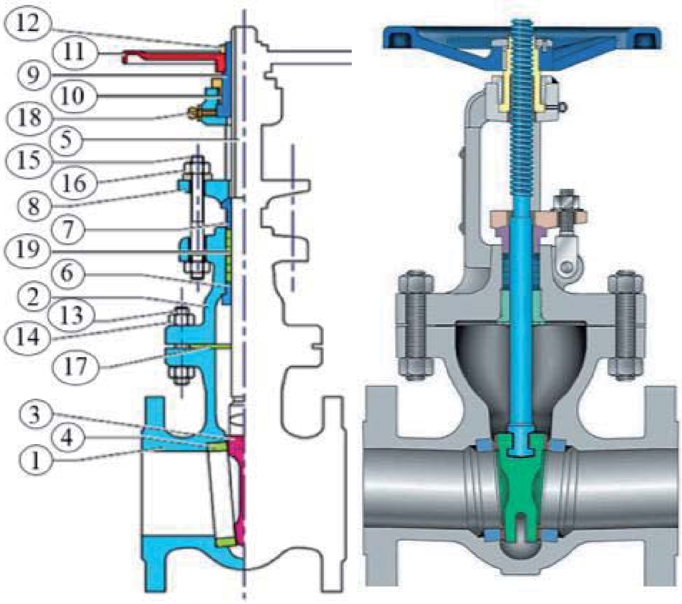


FIGURE 1. Gate valve: a – cross-section (1 – body, 2 – bonnet, 3 – solid wedge, 4 – body seats, 5 – stem, 6 – back seat, 7 – gland follower, 8 – gland flange, 9 – stem nut, 10 – yoke nut, 11 – handwheel, 12 – handwheel nut, 13 – stud bolts, 14 – nuts, 15 – stud bolts, 16 – nuts, 17 – bonnet gasket, 18 – lubricator, 19 – packing); b – model with solid wedge (Banko, 2019)

while the pressure on the upper surface of the valve changes only slightly relative to the static regime. The aim of this paper is to apply computational fluid dynamics (CFD) to gain insights into the physical quantities for gate valve models within a pipe at characteristic opening degrees. By comparing the results of models with different degrees of opening of the gate valve, a more accurate and better quality of the observed pipeline components can be guaranteed.

Previous research

Numerous studies have been carried out on gate valves, only some of which are listed below. Jatkar and Dhanwe (2013) carry out stress analyses on critical components of gate valves using the FEA technique. The modelling of valve components was performed in the CATIA V5R17 software and analysed with the FEM method in the ANSYS-11 software. The validation of the software results is analytically supported by a stress analysis using the classical theory of solid mechanics. Patil and Gambhire (2014) provide a basic methodology for the design of gate valve bodies using a CAD technology where structural FEM analysis is applied at maximum operating pressure. The work involved static, dynamic, thermal, harmonic and electromagnetic analyses on a valve using CATIA and Ansys Fluent software. The work of Wang (2014) is based on the CAD/CAE system. The influence of factors such as fluid flow, flow velocity, wall thickness of the valve body and transverse installation was investigated in the paper. Pujari and Joshi (2016) carried out the analysis and optimization of the design of gate valve bodies using the FEA technique and stress analysis. Katkar, Kulkarni, Patil and Katkar (2017) analysed the critical components of a gate valve. The paper gives a detailed overview of the different techniques used in the design of gate valves (developed in CATIA software) and the analysis in the ANSYS Workbench software package using the FEM technique.

Application of numerical models

For the calculation and hydraulic analysis in this paper the Ansys CFX 19.1 and Ansys Fluent 19.1 software within the Ansys Workbench software package was used (Ansys CFX 15.0, 2015, Žic, 2019). The following part describes the design of a numerical model of a gate valve using the Ansys CFX 19.1 software and the definition of the water supply pipe and the valve around which the fluid flows. The water supply pipe and the 3D geometric model of the gate valve were created in the AutoCAD 2016 software for a starting position of 20% pipe closure. The water supply pipe has a diameter of 100 mm, while the thickness of the pipe and valve flange is 1 mm. Defining and importing the pipe system geometry is done in the SpaceClaim and DesignModeler software packages within the software Ansys Workbench package (Banko, 2019). For the initial model with a 20% of the valve opening a pipe length of 820 mm was taken (300 mm in front of the valve and 520 mm behind the valve), because the changes are larger and longer in the span behind the gate valve. The DesignModeler software was used to generate the network model of the gate valve. After mesh generation, it is necessary to check the quality of the numerical mesh to ensure that a meaningful result is obtained during processing (Žic, 2019). It is also necessary to define all the contour elements of the future model (e.g. inlet and outlet profile, pipe walls, valve, etc.). The network consists of 101,205 nodes and 502,984 elements. In addition to checking the quality of the numerical grid, the quality of the elements was also checked by checking the aspect ratios for the triangle, prism and tetrahedron, the Jacobian ratio or "Jacobian", the twist factor, the characteristic length of the element, etc. For processing, it is necessary to define physical parameters for a given numerical model/submodel, including the definition of the input variables and their values, the definition of a model type, the definition of the dynamic and kinematic viscosity and the initial and boundary conditions. A single-phase problem is selected, which means that only one fluid is defined in the problem (water at 25°C). For the hydrodynamic analysis, a stationary flow regime with a reference pressure of 101,325 Pa without heat transfer within the model and the so-called k–ε turbulence model with standard wall function was chosen. The first variable (k) represents the turbulent kinetic energy and the second transport variable (ε) refers to the dissipation rate of the turbulent kinetic energy. The transport equation for k is described by the expression (1) and the transport equation for ε by the expression (2) (Ansys CFX 15.0, 2015):

$$\rho\frac{Dk}{Dt}=\mu_t\left(\frac{\partial U_j}{\partial x_i}+\frac{\partial U_i}{\partial x_j}\right)\frac{\partial U_j}{\partial x_i}+ \\ +\frac{\partial}{\partial x_i}\left\{(\mu+\mu_t/\sigma_k)\frac{\partial k}{\partial x_i}\right\}-\rho\varepsilon+G_b-Y_M+S_k \tag{1}$$

$$\rho\frac{D\varepsilon}{Dt}=C_{1\varepsilon}\left(\frac{\varepsilon}{k}\right)\left[\mu_t\left(\frac{\partial U_j}{\partial x_i}+\frac{\partial U_i}{\partial x_j}\right)\frac{\partial U_j}{\partial x_i}+C_{3\varepsilon}G_b\right]+ \\ +\frac{\partial}{\partial x_i}\left\{(\mu+\mu_t/\sigma_\varepsilon)\frac{\partial \varepsilon}{\partial x_i}\right\}-C_{2\varepsilon}\rho\left(\frac{\varepsilon^2}{k}\right)+S_\varepsilon \tag{2}$$

The turbulent viscosity μ_t is defined by the expression $\mu_t=\rho C_\mu\frac{k^2}{\varepsilon}$ where ρ is the density of the liquid. The velocities U_i and U_j define the velocities in the longitudinal and transverse cross section of the flow. The coefficients σ_k, σ_b, $C_{1\varepsilon}$, $C_{2\varepsilon}$, $C_{3\varepsilon}$ and C_μ are the empirically defined constants. With the marks G_b, Y_M, S_k and S_ε within the expressions (1) and (2) are presented the values of the variables with which we can model the turbulence. The compressibility effects are denoted by Y_M, the buoyancy force by G_b and user-defined sources by S_k and S_ε. The compressibility effects are mainly due to large changes in the properties and characteristics of the fluid. Their influence is described by the coefficients β_c and β^*_c as a function of the Mach number by the following expressions (Decaix & Goncalvès da Silva, 2013):

$$\beta_c^*=\beta^*(1+\xi^*F(M_t)) \tag{3}$$

$$\beta_c=\beta-\beta^*\xi^*F(M_t) \tag{4}$$

$$F(M_t)=(M_t^2-M_{t0}^2)H(M_t-M_{t0}) \tag{5}$$

for the values M_{t0} = 0.25 and ξ^* = 1.5. An initial inlet flow velocity of 1.0 m·s^{-1} is defined for the inlet profile on the surface of the entire inlet profile, while a relative pressure of 0 Pa is defined on the outlet profile. This means that at the last profile of the water supply pipe the pressure is equal to the pressure outside the pipe (atmospheric pressure). In the post-processing part of the numerical modelling, arbitrary transverse and longitudinal profiles are selected, on the basis of which changes of certain physical quantities within the obtained model can be represented. The gate valve was analysed by four positions: 20, 40, 60 and 80% of the valve closed. For each of these submodels a hydrodynamic analysis of the fluid flow around the valve at an inflow velocity of 1.0 and 1.5 m·s^{-1} was performed.

Hydrodynamic analysis and research results

The processed variants were compared for each physical quantity, namely flow velocity (v), relative pressure (p) and turbulence kinetic energy (k). Each of the physical quantities is calculated using the same eight transverse (Fig. 2) and nine longitudinal profiles. The transverse profiles are arranged in such a way that the first one is halfway between the start of the pipe and the valve, the second one directly in front of the valve, the fourth profile runs through the middle of the valve, the next three profiles are di-

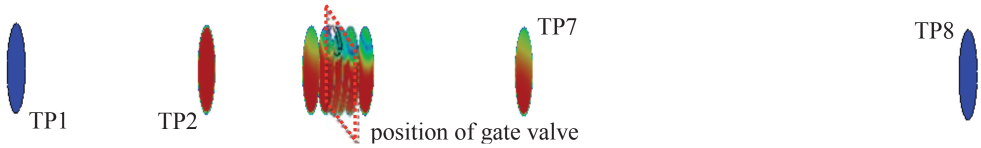


FIGURE 2. Arrangement of the transverse profiles (TP) in relation to the gate valve

rectly behind the valve and the last one halfway between the valve and the end of the pipe. The longitudinal profiles are positioned so that the middle fifth profile is in the middle of the pipe and the four longitudinal profiles are symmetrically arranged at equal distances on both sides.

Fluid flow velocity

Figure 3 shows a longitudinal view of the gate valve model at various degrees of opening based on the 150 streamlines. The first four models show models with an inlet velocity of 1.0 m·s^{-1} and the last four models with an inlet velocity of 1.5 m·s^{-1}.

The figure shows that a vortex flow is observed in the area behind the gate valve at 80% closure, which is a consequence of the abrupt narrowing of the flow cross-section under the valve, which also causes the greatest increase in flow velocity (red colour in Fig. 3). The streamlines of each model are shown at local values, i.e. the colours are not universal and are not the same on each of the models, therefore the flow velocities on the model cannot be compared with each other depending on the colour tones, but only individually (the legends given in Fig. 3 refer to a gate valve with a

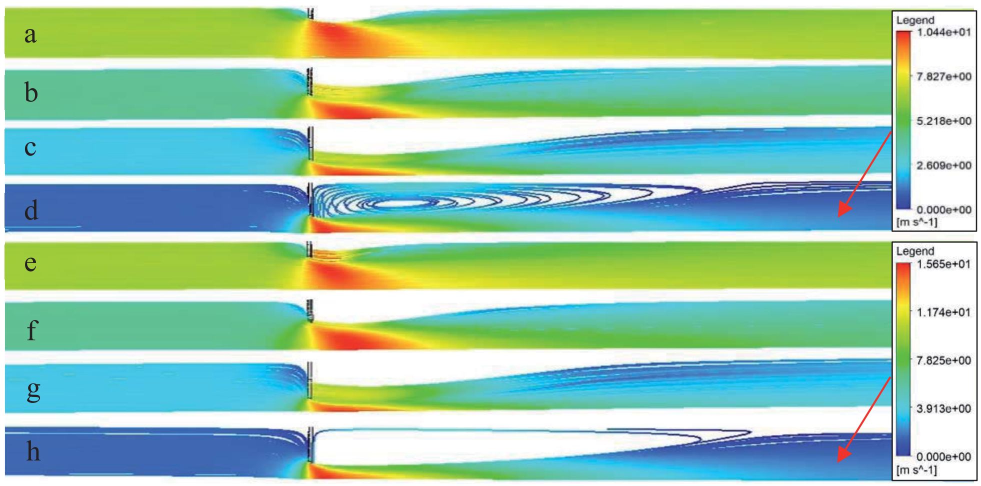


FIGURE 3. Model view of gate valves with streamlines: a – model with 20% gate closure (inlet velocity v = 1 m·s^{-1}); b – 40% closure (v = 1 m·s^{-1}); c – 60% closure (v = 1 m·s^{-1}); d – 80% closure (v = 1 m·s^{-1}); e – 20% closure (v = 1.5 m·s^{-1}); f – 40% closure (v = 1.5 m·s^{-1}); g – 60% closure (v = 1.5 m·s^{-1}); h – 80% closure (v = 1.5 m·s^{-1})

valve closing degree of 80% at velocities of 1.0 and 1.5 m·s^{-1}). The maximum, minimum and average values of flow velocities for each of the submodels and both inlet flow velocities are shown in Table 1. The average and maximum flow velocities within the model increase exponentially as a function of the percentage closure of the gate valve. The increment percentages coincide with the second decimal place and are 115.5% from 20 to 40% closed, 133% from 40 to 60% closed and 175% from 60 to 80% closed valve for the average values. The percentages for increasing the maximum values of the flow velocities are in the same order: 162, 175 and 240%. Table 2 shows the maximum (bold values) and average values of flow velocities for all positions of valve closure with inlet velocities of 1.0 and 1.5 m·s^{-1} up to eight transverse profiles (Fig. 2). The positions of the largest maximum and average flow velocity values vary depending on the percentage of valve closure.

velocity of 1.0 m·s^{-1} the average valve flow velocity is 1.03 m·s^{-1}, for models with 40% closure 1.40 m·s^{-1}, with 60% closure 2.39 m·s^{-1} and with 80% closure the value is 6.50 m·s^{-1}. The maximum flow velocity of 10.4 m·s^{-1} occurs at the fifth profile (directly behind the valve) for models with an inlet velocity of 1.0 m·s^{-1} and 15.6 m·s^{-1} for models with an inlet velocity of 1.5 m·s^{-1}. Maximum flow velocities with lower valve closure occur at a greater distance behind the valve, while models with a higher valve closing percentage have maximum values of flow velocity closer to the valve due to the abrupt narrowing of the flow area. The nine longitudinal profiles are defined at regular intervals, starting from the centre of the pipe towards the edges (the centre of the fifth profile intersects the centre of the valve, seen perpendicular to the valve). They show most clearly the change in flow velocity along the pipe and the transient flow velocity from the beginning of the pipe system through

TABLE 1. View of the maximum, minimum and average values of the flow velocities [m·s^{-1}] for each of the gate valve models

Percentage of gate valve closure [%]	v = 1.0 m·s^{-1}			v = 1.5 m·s^{-1}		
	max	min	avg	max	min	avg
20	1.564	0.007	1.035	2.337	0.021	1.553
40	2.533	0.003	1.195	3.797	0.004	1.795
60	4.415	0.004	1.594	6.633	0.003	2.390
80	10.585	0.002	2.780	15.884	0.004	4.220

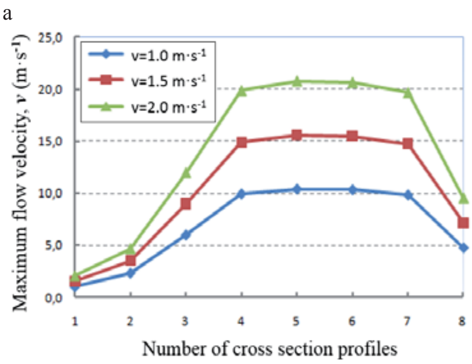
It is also noticeable that the values of maximum and average flow velocities for all profiles in the immediate vicinity of the valve increase exponentially with the percentage of closure. For models with 20% closure and an inlet flow

the valve to the recovery of the flow velocity at a certain distance behind the valve. Table 3 shows the maximum and average flow velocities for all positions of valve closure with inlet velocities of 1.0 and 1.5 m·s^{-1} for nine randomly selected

TABLE 2. View of the maximum and average values of the flow velocities [m·s^{-1}] at a gate valve on the corresponding transverse profiles

Cross section profile	20% valve closure		40% valve closure		60% valve closure		80% valve closure	
	max	avg	max	avg	max	avg	max	avg
1	1.03	1.00	1.03	0.99	1.03	0.99	1.03	0.99
2	1.15	0.99	1.37	1.02	1.72	1.08	2.34	1.14
3	1.29	1.01	1.77	1.25	2.76	1.64	5.99	2.40
4	1.45	1.03	2.13	1.40	3.75	**2.39**	9.93	**6.49**
5	1.53	1.02	2.28	1.20	4.03	1.59	**10.40**	2.68
6	**1.56**	**1.17**	2.43	1.40	4.26	1.80	10.34	2.62
7	1.51	1.16	**2.53**	**1.57**	**4.41**	1.97	9.84	2.81
8	1.16	0.98	1.59	0.97	2.51	1.14	4.78	2.04
Cross section profile	20% valve closure		40% valve closure		60% valve closure		80% valve closure	
	max	avg	max	avg	max	avg	max	avg
1	1.54	1.49	1.54	1.48	1.54	1.48	1.54	1.48
2	1.73	1.49	2.05	1.54	2.59	1.62	3.51	1.72
3	1.92	1.51	2.64	1.87	4.13	2.46	8.99	3.60
4	2.17	1.54	3.20	2.10	5.63	**3.58**	14.91	**9.75**
5	2.28	1.51	3.43	1.80	6.04	2.39	**15.59**	4.02
6	**2.34**	**1.73**	3.65	2.12	6.39	2.71	15.50	3.93
7	2.26	1.72	**3.79**	**2.37**	**6.63**	2.96	14.76	4.22
8	1.74	1.48	2.39	1.46	3.79	1.71	7.14	3.02

longitudinal profiles. The maximum average flow velocities on the defined longitudinal profiles are 1.79 m·s^{-1} for the model with an inflow velocity of 1.0 and 2.67 m·s^{-1} for the model with an inflow velocity of 1.5 m·s^{-1}. Figure 4a shows



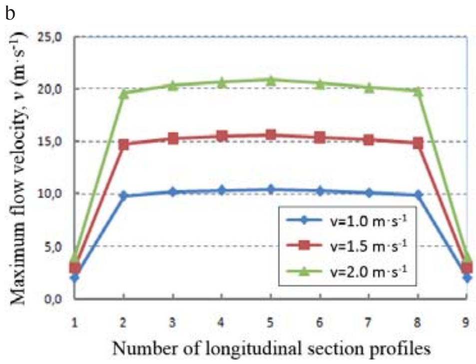


FIGURE 4. Graphical view of the maximum flow velocities for a gate valve model with 80% closure based on transverse profiles (a) and longitudinal profiles (b)

TABLE 3. View of the maximum and average values of flow velocities [$m \cdot s^{-1}$] at a gate valve at the corresponding longitudinal profiles

Longitudinal profile	20% valve closure		40% valve closure		60% valve closure		80% valve closure	
	max	avg	max	avg	max	avg	max	avg
1	1.561	1.015	2.378	1.019	3.806	0.994	2.021	0.976
2	1.559	1.002	2.522	1.027	4.160	1.110	9.816	1.325
3	1.549	0.982	**2.532**	1.040	4.356	1.195	10.198	1.635
4	1.551	0.981	2.529	1.042	4.383	1.208	10.347	1.702
5	1.549	0.981	2.529	**1.052**	**4.413**	**1.243**	**10.437**	**1.787**
6	1.545	0.981	2.528	1.044	4.390	1.213	10.264	1.700
7	1.547	0.986	1.527	1.035	4.333	1.182	10.098	1.566
8	1.553	1.002	2.521	1.027	4.160	1.116	9.911	1.337
9	**1.563**	**1.016**	2.405	1.026	3.946	0.997	2.022	0.971
Longitudinal profile	20% valve closure		40% valve closure		60% valve closure		80% valve closure	
	max	avg	max	avg	max	avg	max	avg
1	2.333	1.529	3.584	1.541	5.712	1.497	2.963	1.453
2	2.326	1.505	3.787	1.546	6.245	1.668	14.730	1.970
3	2.309	1.472	**3.796**	1.562	6.540	1.793	15.295	2.438
4	2.311	1.470	3.793	1.565	6.582	1.813	15.517	2.541
5	2.308	1.469	3.788	**1.578**	**6.627**	**1.864**	**15.650**	**2.670**
6	2.302	1.470	3.792	1.565	6.592	1.819	15.390	2.541
7	2.306	1.479	3.792	1.553	6.506	1.773	15.146	2.339
8	2.318	1.506	3.788	1.542	6.248	1.674	14.871	1.998
9	**2.336**	**1.530**	3.617	1.539	5.918	1.498	2.987	1.456

a graphical representation of the flow velocities for a gate valve model with 80% closure at an inflow velocity of 2.0 $m \cdot s^{-1}$, compared with the same model with an inflow velocity of 1.0 and 1.5 $m \cdot s^{-1}$. The maximum velocity value on the fifth profile at an inlet velocity of 2.0 $m \cdot s^{-1}$ is 20.80 $m \cdot s^{-1}$. Figure 4b shows the values of maximum flow velocities per longitudinal profile for the model with 80% valve closure for inlet velocities of 1.0, 1.5 and 2.0 $m \cdot s^{-1}$.

Relative pressure

The maximum, minimum and average values of relative pressures [Pa] for all submodels of gate valves based on the k–ε turbulent model are shown in Table 4. The maximum, minimum and average relative pressure values increase exponentially when the valve is closed. The average relative pressure of a valve 80% closed is approximately 75 times higher than in the case of a valve 20%

TABLE 4. View of maximum, minimum and average relative pressures [Pa] for each of the gate valve submodels

Percentage of gate valve closure [%]	v = 1.0 m·s^{-1}			v = 1.5 m·s^{-1}		
	max	min	avg	max	min	avg
20	895	–1 053	171	1 983	–2 501	355
40	1 989	–2 689	407	4 433	–6 057	886
60	7 223	–8 209	1 897	16 195	–18 347	4 228
80	56 948	–46 156	12 890	127 831	–103 401	29 080

closed. The values to be analysed when dimensioning the valve as a function of pressure are maximum and minimum pressures, since extreme maximum and minimum pressures can cause the pipe itself to expand or twist, which can lead to its damage and cracking. The upper row in Figure 5 shows the changes in relative pressures at the first four transverse profiles (a), b), (c) and (d) and the bottom row shows the changes in relative pressures at the last four transverse profiles (e), (f), (g) and (h) for the gate valve submodel at 80% closed (at 1.0 m·s^{-1}).

Table 5 shows the maximum, minimum and average values of the relative pressures at the transverse profiles for all submodels of gate valves and both inlet velocities. The highest relative pressures and the lowest negative pressures occur at both inlet flow velocity variants for the same profiles. The maximum relative pressure values are 56,942 Pa for the inlet velocity of 1.0 m·s^{-1} and 127,817 Pa for the inlet velocity of 1.5 m·s^{-1}, which occur for partial models with 80% valve closure on the third profile 7 cm in front of the disc surface of gate valve, seen in the direction of flow. The lowest negative pressures also occur in submodels with 80% valve closure on the fourth profile, which is located at the back of the valve disc.

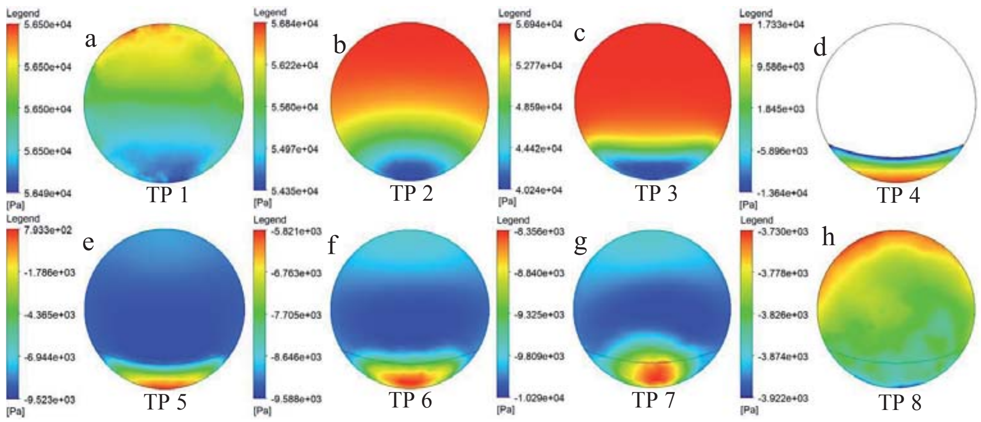


FIGURE 5. Distribution of the relative pressures on transverse profiles of gate valve submodels with 80% of valve closure and inflow velocity of 1.0 m·s^{-1}

TABLE 5. The view of maximum, minimum and average values of the relative pressures [Pa] at the transverse profiles TP1 to TP8 in gate valve model

Cross section profile	$v = 1.0$ m·s^{-1}											
	20% valve closure			40% valve closure			60% valve closure			80% valve closure		
	max	min	avg	max	min	avg	max	min	avg	max	min	avg
1	443	**439**	**441**	1 538	**1 534**	**1 536**	6 773	**6 769**	**6 671**	**56 499**	**56 495**	**56 497**
2	665	261	403	1 836	1 076	1 446	7 103	5 769	6 583	56 844	54 647	56 160
3	**870**	123	–367	**1 978**	517	1 137	**7 216**	3 526	5 546	56 942	40 241	52 472
4	48	–58.2	–230	178	–1 548	–791	1 834	–3 759	–1 782	17 326	**–13 637**	–3 976
5	–21	–623	–343	–185	–1 430	–1 035	141	–3 221	–2 530	793	–9 522	–7 905
6	–110	**–838**	**–443**	–674	–1 602	–1 272	–1 736	–2 412	–2 970	–5 821	–9 588	–8 699
7	**–174**	–591	–373	**–1 185**	**–1 844**	**–1 589**	**–3 098**	**–3 822**	**–3 579**	**–8 856**	–10 293	**–9 819**
8	97	90	94	–39	–68	–54	–669	–735	–69	–3 730	–3 922	–3 807
Cross section profile	$v = 1.5$ m·s^{-1}											
	20% valve closure			40% valve closure			60% valve closure			80% valve closure		
	max	min	avg	max	min	avg	max	min	avg	max	min	avg
1	951	**944**	**949**	3 406	**3 398**	**3 402**	15 170	**15 160**	**15 165**	126 880	**126 850**	**126 850**
2	1 459	552	869	4 084	2 375	3 208	15 919	12 920	14 750	127 593	121 977	126 100
3	**1 924**	245	789	**4 407**	1 119	2 492	**16 178**	7 837	12 420	**127 817**	90 249	117 820
4	81	–1 377	–568	335	–3 549	–1 827	4 067	–8 558	–40 71	38 779	**–30 978**	–9 124
5	–74	–1 435	–804	–461	–3 254	–2 375	–259	–7 321	–5 755	1 715	–21 557	–17 870
6	–269	**–1 830**	**–993**	–1 563	–3 682	–2 925	–3 962	–7 750	–6 749	–13 093	–21 718	–19 650
7	**–415**	–1 298	–843	**–2 698**	**–4 244**	**–3 636**	**–7 016**	**–8 658**	**–8 111**	**–18 727**	–23 214	**–22 110**
8	188	171	180	–188	–122	–154	–1 538	–1 686	–1 599	–8 267	–8 721	–8 446

Cavitation can occur on the part of the pipe behind the gate valve due to negative pressures. The highest average relative pressures are much higher in submodels with higher closure percentages (60 and 80%) than 20% closure valve. The value of the highest average relative pressure at 80% closed valve is almost 120 times higher than the 20% closed valve submodel. As the inlet velocity and the valve closure percentage increase, an additional increase in relative pressures can be expected up to a certain closure percentage when the maximum pressure value decreases from that of the previous valve closure percentage. For processed submodels, the maximum absolute pressure to be expected within the pipeline is 2.29 bar at 80% closure and an inlet velocity of 1.5 $m \cdot s^{-1}$, which is a fully acceptable pressure for water pipes. The maximum relative pressure for both flow velocities occur at the middle profile and have values of 56,948 Pa for the inlet velocity of 1.0 $m \cdot s^{-1}$ and 127,831 Pa for the inlet velocity of 1.5 $m \cdot s^{-1}$ (submodel with 80% of valve closure). The highest pressures occur in the vicinity of the second and penultimate longitudinal profile, which are 15 mm from the pipe wall.

Turbulent kinetic energy

In fluid dynamics, the turbulent kinetic energy – TKE (*k*) is a measure of the kinetic energy per unit mass associated with eddy currents in turbulent flows. According to the RANS equations (Reynolds-averaged Navier–Stokes equations), the turbulent kinetic energy can be calculated according to the turbulence model. It is generally calculated as half the sum of the variance (the square of the standard deviations) of the velocity components. Figure 6 shows the values of the turbulent kinetic energy on the cross profiles of the submodels at 80% valve closure and an inflow velocity of 1.5 $m \cdot s^{-1}$. The upper part of Figure 6 shows three profiles in front of valve (a), b), (c) and one at valve (d), and the lower part of the figure shows profiles (e), (f), (g), (h), which are located behind the gate valve. The figure shows that the maximum values of the turbulent kinetic energy occur at the valve itself and beyond, extending from the bottom of the valve wall to the upper half of the pipe along the flow behind the valve. The maximum value that appears is 2.66 $m^2 \cdot s^{-2}$ on the last cross-sectional profile. The maximum value of the turbulent kinetic energy of 5.52 $m^2 \cdot s^{-2}$ does not appear on any user-defined profile, but directly behind the last profile (*h*). Table 6 shows the maximum (values in bold), minimum and average values of the turbulent kinetic energy [$m^2 \cdot s^{-2}$] on the transverse profiles for all numerical submodels and both input velocities of 1.0 and 1.5 $m \cdot s^{-1}$.

With the increase of the valve closure degree, the maximum values of the turbulent kinetic energy move further away from the valve. This is due to the increase in the variations in flow velocities caused by moving away from the valve in submodels with a smaller closing degree compared to a larger closing degree (e.g. 60% of the valve closing degree). For this reason, the maximum values for submodels with higher closure percentages occur behind the last user-defined cross-section profile in the direction of water flow.

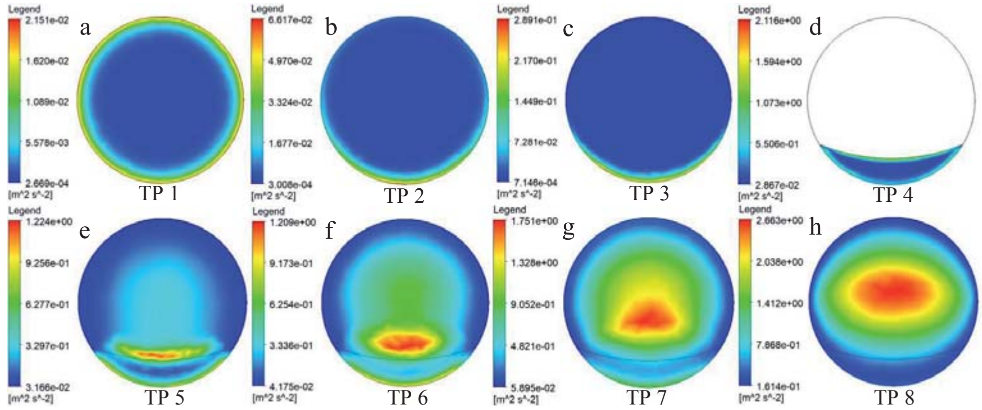


FIGURE 6. Distribution of turbulent kinetic energy at transverse profiles of a gate valve submodel with 80% of valve closure and an inlet flow velocity of 1.5 m·s^{-1}

Conclusions

In this paper a hydraulic analysis of gate valve models was performed using the commercial softwares Ansys CFX 19.1 and Ansys Fluent 19.1. The analyses were performed for 4° of opening of the gate valve with inlet velocities of 1.0 and 1.5 m·s^{-1}. After the hydrodynamic analysis it was found that all models show vortices in the area behind the gate valve, especially at smaller opening degrees. The appearance of the vortex and its movement along the pipe is clearly visible on the given central longitudinal profiles of the pipe system. In the case of the gate valve with 40% closing degree and an inlet flow velocity of 1.0 m·s^{-1}, the maximum velocity occurring is 2.53 m·s^{-1}, whereas for the same model and an inlet flow velocity of 1.5 m·s^{-1} it is 3.80 m·s^{-1}. The analysis shows that maximum values of velocities, pressures and other physical quantities occur in models with a lower valve opening degree. The maximum values of the physical quantities in the analysed models occur mainly in the valve area or behind it. This paper shows that the implementation of hydrodynamic analysis is possible for different forms of valve geometry. Correct numerical modelling through CFD technology allows the obtained results to be used to improve the valve characteristics in its design and operation.

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TABLE 6. The view of the maximum, minimum and average values of turbulent kinetic energy [$m^2 \cdot s^{-2}$] on the transverse profiles TP1 to TP8 of a gate valve

Cross section profile	$v = 1.0\ m \cdot s^{-1}$											
	20% valve closure			40% valve closure			60% valve closure			80% valve closure		
	max	min	avg	max	min	avg	max	min	avg	max	min	avg
1	0.01144	0.00014	0.00311	0.01051	0.00014	0.00314	0.01081	0.00014	0.00313	0.01089	0.00014	0.00314
2	0.01356	0.00010	0.00308	0.01716	0.00011	0.00322	0.02147	0.00012	0.00350	0.03406	0.00014	0.00378
3	0.01497	0.00011	0.00243	0.02404	0.00016	0.00273	0.04333	0.00034	0.00384	0.14914	0.00033	0.00949
4	0.02208	0.00011	**0.00565**	0.05912	0.00022	0.01691	0.16759	0.00092	0.03915	0.88934	0.01319	0.21620
5	0.01968	0.00013	0.00347	0.05966	0.00033	0.01707	0.13125	0.00206	0.03468	0.53885	0.01338	0.10860
6	0.02064	0.00015	0.00482	0.09068	0.00094	0.02597	0.17000	0.00644	0.05021	0.53124	0.01730	0.13810
7	**0.02233**	**0.00021**	0.00503	**0.18801**	0.00256	**0.04415**	**0.29017**	0.01401	**0.08991**	0.69996	0.02282	0.20790
8	0.01337	0.00012	0.00317	0.03227	**0.00321**	0.01127	0.20445	**0.01421**	0.06462	**1.14978**	**0.06886**	**0.35820**
Cross section profile	$v = 1.5\ m \cdot s^{-1}$											
	20% valve closure			40% valve closure			60% valve closure			80% valve closure		
	max	min	avg	max	min	avg	max	min	avg	max	min	avg
1	0.02268	0.00027	0.00623	0.02073	0.00027	0.00628	0.02135	0.00027	0.00626	0.02151	0.00027	0.00628
2	0.02666	0.00021	0.00617	0.03358	0.00024	0.00642	0.04186	0.00027	0.00698	0.06617	0.00030	0.00751
3	0.02969	0.00023	0.00489	0.04692	0.00035	0.00546	0.08415	0.00074	0.00762	0.28910	0.00071	0.01871
4	0.06786	0.00025	0.01495	0.12699	0.00048	0.03366	0.33137	0.00200	0.08358	2.11641	0.02867	0.47990
5	0.06669	0.00028	0.01783	0.13641	0.00070	0.03853	0.30955	0.00449	0.08088	1.22364	0.03166	0.26990
6	**0.13371**	0.00040	0.02447	0.19733	0.00206	0.05792	0.40030	0.01428	0.11610	1.20911	0.04175	0.34190
7	0.12998	0.00075	**0.02473**	**0.40703**	0.00555	**0.09827**	**0.68619**	**0.03434**	**0.21010**	1.75139	0.05895	0.52140
8	0.02658	**0.00087**	0.00666	0.07491	**0.00718**	0.02506	0.47935	0.03283	0.15270	**2.66295**	**0.16141**	**0.84520**

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Summary

Hydraulic analysis of gate valve using computational fluid dynamics (CFD). As a very important element of most water supply systems, valves are exposed to the effects of strong hydrodynamic forces. When exposed to large physical quantities, the valve and piping can be damaged, which could endanger the performance of a water supply system. This is the main reason why it is necessary to foresee and determine the maximum values of velocity, pressure and other physical quantities that can occur in the system under certain conditions. Predicting extreme conditions allows us to correctly size the valve for the expected conditions to which the valve might be exposed, which is also the main objective of this paper. One of the methods for predicting and determining extreme values on a valve is to perform a simulation with computational fluid dynamics (CFD). This is exactly the method used in the preparation of this paper with the aim of gaining insight into the physical magnitudes for models of gate valves positioned inside a pipe under characteristic degrees of valve closure. The Ansys CFX 19.1 and Ansys Fluent 19.1 software was used to simulate the hydrodynamic analysis and obtain the required results. The hydrodynamic analysis was performed for four opening degrees of gate valve.

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