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Design and Analysis of A New Check Valve on Water Hammer Performance by using SolidWork Flow Simulation

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Abstract: Basically, a check valve permits stream one way and naturally forestalls reverse (turn around stream) during a liquid in the line inverts heading. These check valves consist of an openings disc and two-port valves, purposely for the liquid to enter and leave. Water hammer occurs in check valves, involves the jack forces on the disc and it happens during the disc is shut while the fluid still flows into the valves. This phenomenon had triggers feared as violent damage to the disc of check valves by creating a hammering sound and increase the wear and tear rate onto the disc. This study is conducted to find the optimum design to reduce the water hammer impact on the disc. In this study, three new design disc is introduced whereby the analysis and performance were validated by a simulation through SolidWorks Flow Simulation. Steady-state water flows with an inlet velocity of 2 m/s, 1 bar gauge pressure, opening angle 0 °, 22.5 °, 45 ° and 67.5 ° were specified as the boundary condition. The hydrodynamic, torque and velocity acting in the valve were applied as the critical parameter and used to select the best disc design. From this research, the contour analysis for pressure and velocity for standard and design 2 shows a better result in terms of uniform flow distributions. Based on all critical parameters, disc 3 shows the lowest performance among all the check valves. This is due to pressure and velocity drop in almost all angles of the opening disc. Design 2 satisfy the optimum performance at boundary condition of pressure, velocity and hydrodynamic. In this framework, check valve design 2 shows the increment of performance in terms of velocity and pressure distribution in the check valve compared to the other check valves.

Keywords: Check Valve Disc, Water Hammer, Hydrodynamic, Torque, Velocity

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1. Introduction

Basically, a check valve permits stream one way and naturally forestalls reverse (turn around stream) when liquid in the line inverts heading. They are one of only a handful scarcely any self-robotized valves that don't expect help to open and close. In contrast to different valves, they keep on working regardless of whether the plant office loses air, power, or the individual that may physically cycle them. Check valves are found all over, including the home. In the event that you have a sump siphon in the storm cellar, a check valve is most likely in the release line of the siphon. Outside the home, they are found in for all intents and purposes each industry where a siphon is found [1].

Check valves are two-port valves, which means they have two openings in the body, one for the liquid to enter and the other for the liquid to leave. There are different sorts of check valves utilized in a wide assortment of utilization. Check valves are frequently part of regular family unit things. Despite the fact that they are accessible in a wide scope of sizes and costs, check valves, for the most part, are extremely little, straightforward, or economical. Check valves work consequently and most are not constrained by an individual or any outer control; in like manner, most don't have any valve handle or stem [2].

Water sledge can result from ill-advised valve determination, ill-advised valve area and once in a while poor support rehearses. Certain valves, for example, swing check valves, tilting plate checks and twofold entryway check valves likewise can add to water hammer issues. These check valves are inclined to pummeling in light of the fact that they depend on switching stream and back pressure to push the plate back onto the seat so the valve closes. On the off chance that the converse stream is mighty, as, on account of a vertical line with typical stream upwards, the circle is probably going to pummel with a lot of power. The subsequent stun can harm the arrangement of the plate so it no longer makes full, 360-degree contact with the seat. This prompts releases that, in the best case, sabotage the proficiency of the framework. In the most pessimistic scenario, this could harm other channeling framework segments. Restricted, sudden weight drops are an inconvenience in any event and a significant issue

The design check valve is expected to enhance by minimizing the impact of the water hammer at the optimum operating condition. Therefore, the purpose of this study is to define the effect of disc design, opening angle and fluids velocity on hydrodynamics, torque and velocity performance. By comparing these works finding to the literature, it is expected to define critical information regarding disc design and opening angle effect for further optimization from a practical viewpoint.

2. Literature Review

Valves are mechanical devices that help to regulate the flow or pressure of fluid in a fluid flow or pressure system. This also applies to the start and stopping of flow, control flow rate, prevent backflow, divert flow, control pressure, or pressure relief. Valves can suffer from unexpected wear and tear, depending on the type of fluid used, which may lead to an inadvertent failure [3]. Performance of piping system depends largely on good selection and location of the valve in order to control and regulate fluids flow to other connected equipment in the system. There are many designs of valve that suit it specific function.

2.1 Water Hammer

Figure 1 shows the water hammer or also known as a hydraulic shock is momentum or pressure transient in one closed system that was caused by a sudden change in the velocity of a fluid. It can be classified due to a cause of change in velocity. It can occur in any thermal-hydraulic system and can be very dangerous for the thermal-hydraulic system because if the pressure exceeds a range of pressure of pipe from the manufacturer, it could lead to pipeline failure [4].

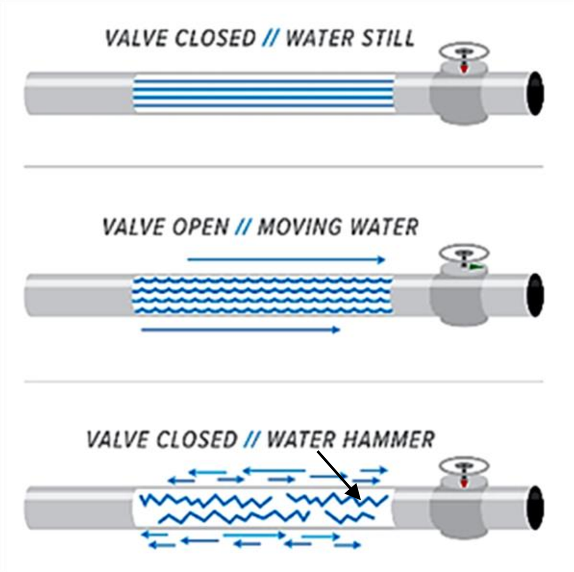


Figure 1: Water hammer in valves [4]

Fluid in a pipeline is not compressible. Under some velocity during moving, fluids can generate some amount of force when fluid motion suddenly stops. Water hammer can lead to pipeline noise and vibration. However, the impact of water can also cause shock waves to propagate at the speed of sound in between the valve and next equipment such as elbow in a piping system or within the water column after the pump [4].

2.2 Modelling of check valves

In order to avoid water hammers, it is important to properly design a system to meet our specific needs. There are ways to help lower the fluid velocity in the pipe such as use a shorter pipe length branch, short straight pipe length, add elbows and expansion to the piping system process and arrange major pipes in loops that supply shorter, smaller runt out branches of pipe [5].

2.2.1 Equation of Motion

In a moving disc behavior, there are various related forces and corresponding forces. Newton’s second law of motion states that a body of mass that is affected by an external force, F will undergo acceleration in the same direction of a force. Magnitude is proportional to force and inversely proportional to mass as shown as in Equation 1. The equation of Newton’s second law when applying to a rotational motion equation becomes Where T is torque, I is rotational inertia and ω is angular velocity as in Equation 2 [6].

$$F = ma = m\frac{dU}{dt} \qquad \textit{Eq. 1}$$

$$T = I\frac{d\omega}{dt} \qquad \textit{Eq. 2}$$

2.3 Mitigating check valve slamming and subsequent water hammer events for PPFS using MOC

The evaluation check valve-induced water hammer behavior at Parallel Pumps Feedwater System (PPFS) as shown in Equation 2 during the process of alternate startup. Due to water hammer-induced pipe breakage and abruption of pipe support system, the nuclear power reactor plant was forced to shut down. The method of characteristics (MOC) was selected in order to solve the water hammer problem because of its feasibility and advantages in solving a complex system problem. Characteristics of water hammer are greatly influenced by the geometry of test facility, layout and thermal physical property of working fluid. In this study, check valve motion is evaluated based on inertia valve mode [7].

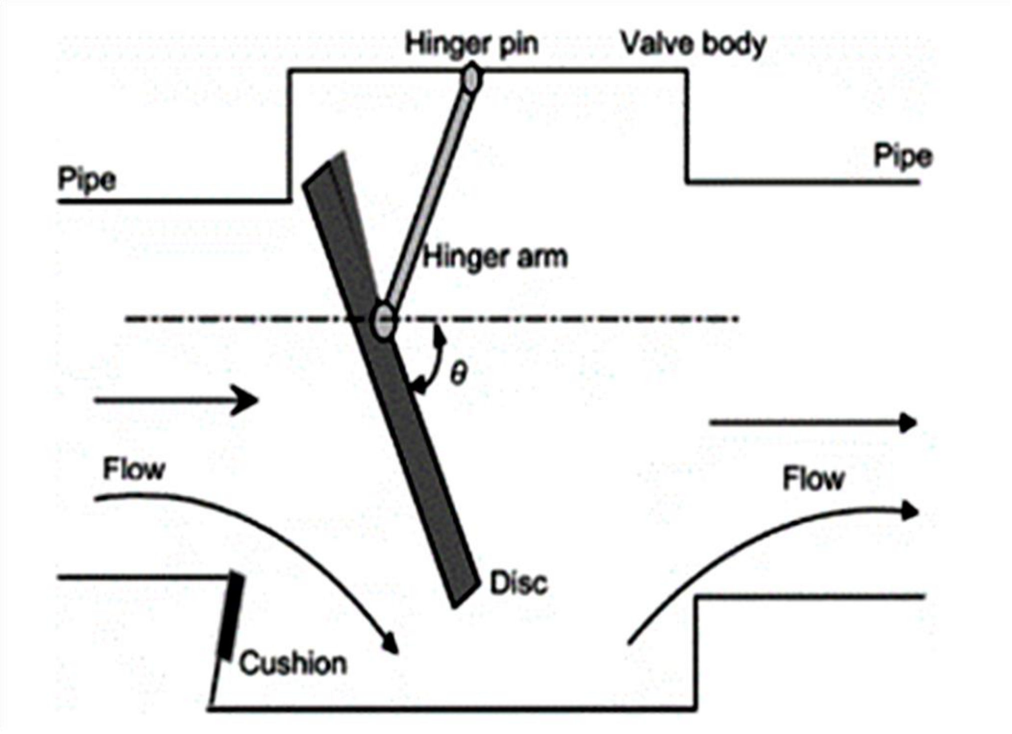


Figure 2: Sketch diagram of the check valve [3]

2.4 SolidWorks flow simulation analysis (SWFS)

The fluid flow across the valve disc during closing at different disc positions is modeled using CFD package SOLIDWORKS Flow Simulation, (SWFS). The internal design geometry of the check valve disc will be modified in order to reduce drag on the moving disc and thus the force causes its slam. Now the original model is drawn and imported into the CAD software, modifications that are used for drag reduction in external flow problems are applied willing to reduce fluid force acting on the disc [8].

The add-in to Flow-Simulation is focused on the computational fluid dynamics. CFD is a fluid dynamic branch that uses digital analytic and algorithms to analyze and visualize the fluid flow. CFD simulates liquid that moves through or around an object. The flow simulation performs calculations according to Navier-Stokes equations in order to simulate the interaction between fluids and surfaces [8].

3. Methodology

3.1 New disc design

Figure 3 shows a cross-sectional of a check valve. For this research, the check valves were designed to follow the ASME specifications and the disc was altered into new three designs. The first step in designing the check valves is collecting all the information of the model from the previous research. This includes the diameter, length, and dimension of the new disc at the check valve. The conceptual design involves for each concept was improvise and consists of aspect details as it would able to reduce water hammer in the check valves.

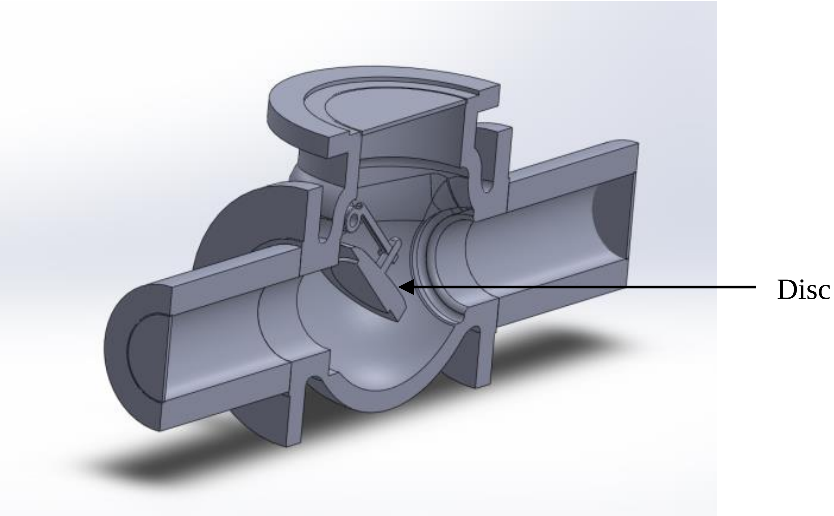
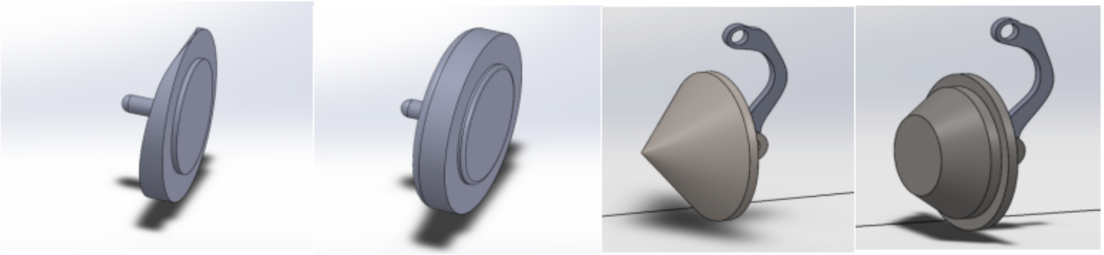


Figure 3: Cross-sectional of a check valve

3.2 Design specification

In the process of designing, the four different check valves with different designs of the disc have been designed in detail so that the project produces a result as expected. Figure 4 described the design specification of the check valve disc which covering height, radius, density, mass and volume. Moreover, Figure 4 shows the design of the standard check valve with no modifications is at the standard disc which simulates the real-industry valve used while the other shows the modification that is focusing on shape, dimension and design that could disperse the pressure and hydrodynamic inside the valve structure. However, disc design 1, 2 and 3 is the new disc design to undergo the simulation by using SWFS and the specification is illustrated in Figure 4.



Standard Disc	Disc 1	Disc 2	Disc 3
Design	Design	Design	Design
Height, mm = 35.70	Height, mm = 80	Height, mm = 80	Height, mm = 60
Radius, mm^2 = 43.86	Radius, mm^2 = 78.11	Radius, mm^2 = 78.11	Radius, mm^2 = 48.22
Density,g/mm = 0.01	Density,g/mm = 0.01	Density,g/mm = 0.01	Density,g/mm = 0.01
Mass, g = 7105.63	Mass, g = 8152.43	Mass, g = 8152.43	Mass, g = 8105.40
Volume, mm^3 = 428104.21	Volume, mm^3 = 1019053.24	Volume, mm^3 = 1019053.24	Volume, mm^3 = 1013174.44

Figure 4: Design of a new check valve

3.3 SolidWorks Flow Simulation (SWFS)

SWFS is an important instrument for fluid machinery design. It helps to describe fluid flow physics by governing equations that are based on conservation law of physics which is the conservation of energy.

Implementing this into the governing equations, the so-called Navier Stokes Equations are obtained as in Equation 3, treating the time-dependent three-dimensional fluid flow and heat transfer of an incompressible Newtonian fluid. Navier-Stokes equations can be express as below:

$$\rho \frac{\delta v}{\delta t} = - \nabla p + \rho g + \mu \nabla 2v \qquad \textit{Eq. 3}$$

Where;

ρ = fluid density

v = fluid flow velocity

p = fluid pressure

μ = fluid dynamic viscosity

∇ = del operator

3.5 Mesh

In order to solve the governing differential equations, the fluid domain is divided into smaller subdomains by a grid, called Mesh, representing the geometry. Then the equations are discretized and solved within every cell, fulfilling continuity over cell faces shared by the subdomains. Cell faces that are not shared with another cell is boundary and need a boundary condition in order to close the equations. Cells can have different geometrical shapes where some common 3D types of mesh cells are tetrahedral, hexahedral and a more and more commonly used cell type polyhedral.

3.6 Boundary Conditions

This simulation of the check valve design and investigation under the same operating conditions as shown in Table 1.

Table 1: Boundary condition

No	Parameter	Value
1	Velocity	2 m/s
2	Pressure	1 bar
3	Mesh @ no of cell	21330 to 27879 @ (0.01 and 0.001)
4	The opening angle of the check valve disc	0°, 22.5°, 45° and 65.7°

4. Results and Discussion

4.1 Velocity and pressure contour at standard design

Figure 5 shows the velocity and pressure contour flow of the check valve at every different angle that has been set in the simulation. In the simulation of this project, the flow direction of the water that flows in the check valve is from the left to right side of the valve. Hence, in the velocity contours of the simulation is indicated that the color of the contour of the check valve is varied. The highest velocity that existed in the check valves is different in every opening angle. The smaller the opening angles of the ball valve, the higher the velocity that forms at the outlet of the check valve. However, as for the opening angle of 22.5 °,45.0 °, and 67.5 °, it shows that velocity contours on the right side of the ball valves higher than the left side. The maximum pressure in each of the valves indicated a different value at every opening angle. At all opening angle, we could observe that the pressure distribution at the outlet is steadily distributed.

4.2 Velocity and pressure contour at disc 2

Based on Figure 6, the velocity and pressure contour start to flow at optimum when the opening angle of the disc is at 22.50 °. Among the other of the check valve, this check valve started to have good velocity distribution at the minimum opening angle. also It can be seen at the pressure distribution with the same opening angle. This condition can be seen in all of the minimum opening angle, which the pressure are higher at the inlet and start decreasing after the disc area.

4.3 Velocity and pressure contour at disc 3

Based on Figure 7, the velocity and pressure contour is concluded. The velocity of the fluid that flows inside the check valves is proportional to the opening angle. The comparison has been made on each type of opening angle of the check valve disc. The result also indicates the recirculation of fluid behind the disc thus it dominates the pressure from the inlet of the check valves at 22.50 °.

4.4 Velocity and pressure contour at disc 4

Figure 8 shows the velocity and pressure contour is inversely proportional to the valve opening and the experimental data are fitted by an equation. As we can conclude, when the opening angle of the check valve disc is increasing, the velocity is increased. Based on Figure 8, the velocity contour at an opening angle of 67.50 ° is the highest. However, the pressure contour shows that at 0.00 ° the inlet is at high pressure and at 65.70 ° the pressure become steadily flows through the check valve. The disc design indicates that this check valve is relevant to use even at an angle of 67.50 °.

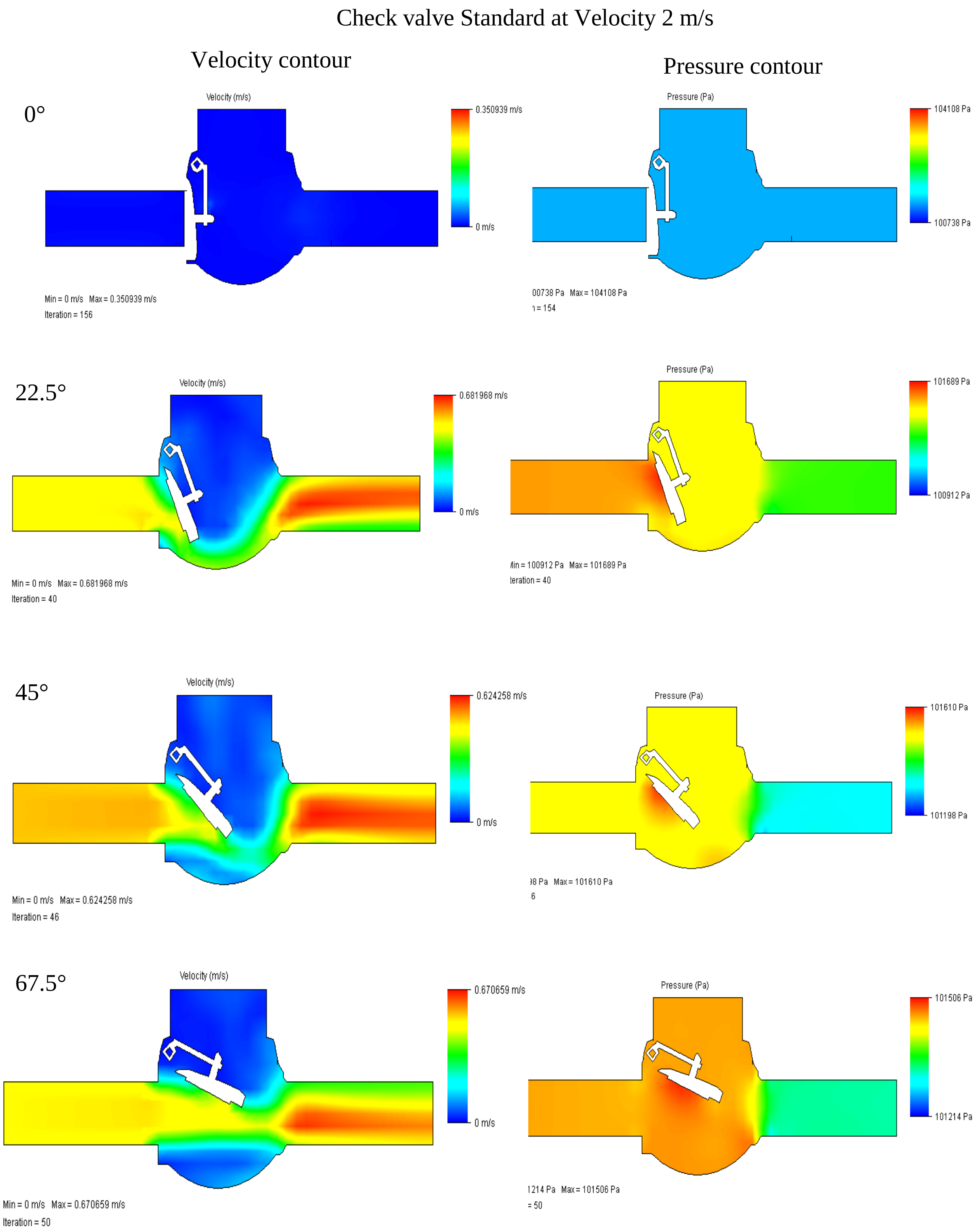


Figure 5: Velocity and pressure contour of standard design

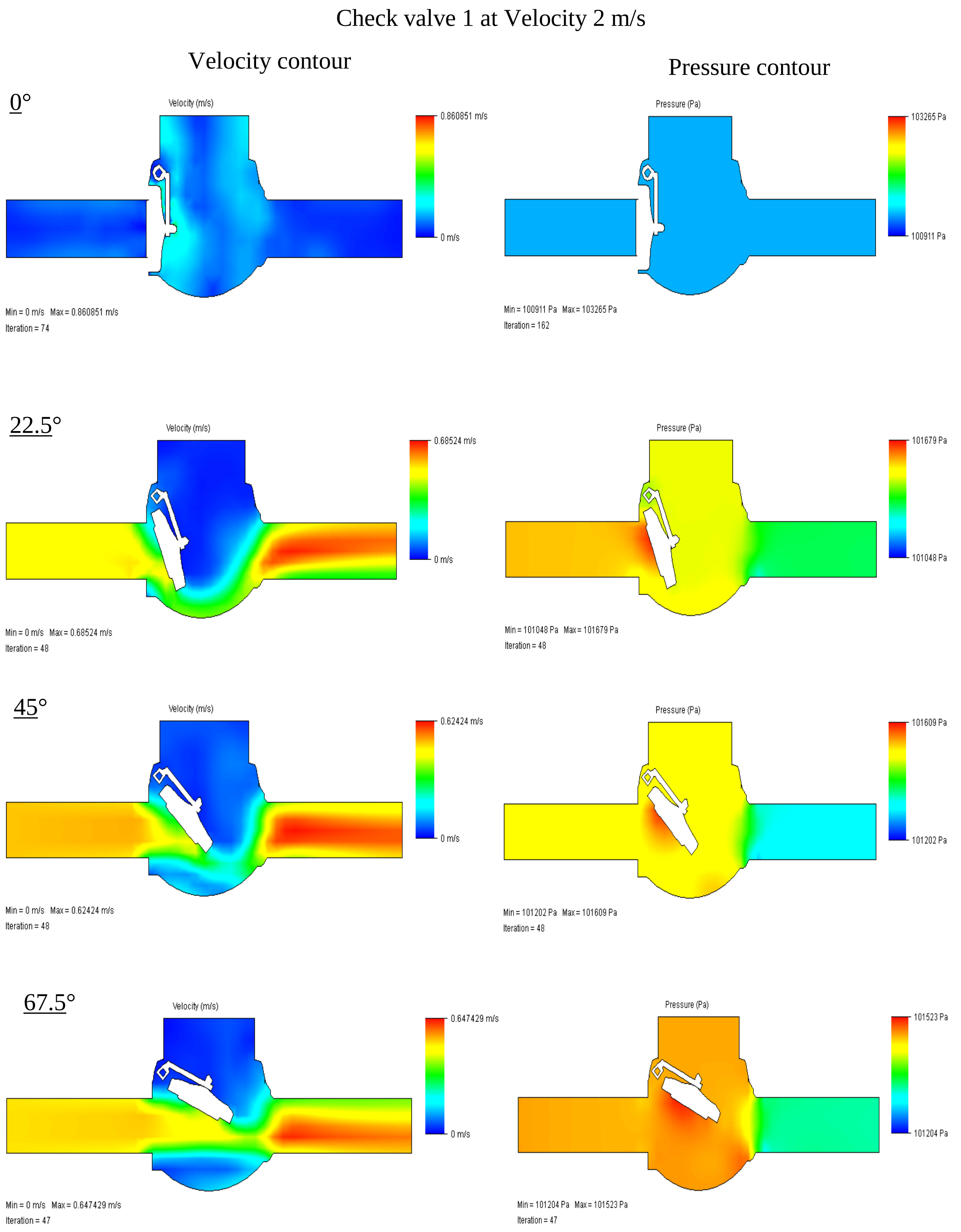


Figure 6: Velocity and pressure contour of design 1

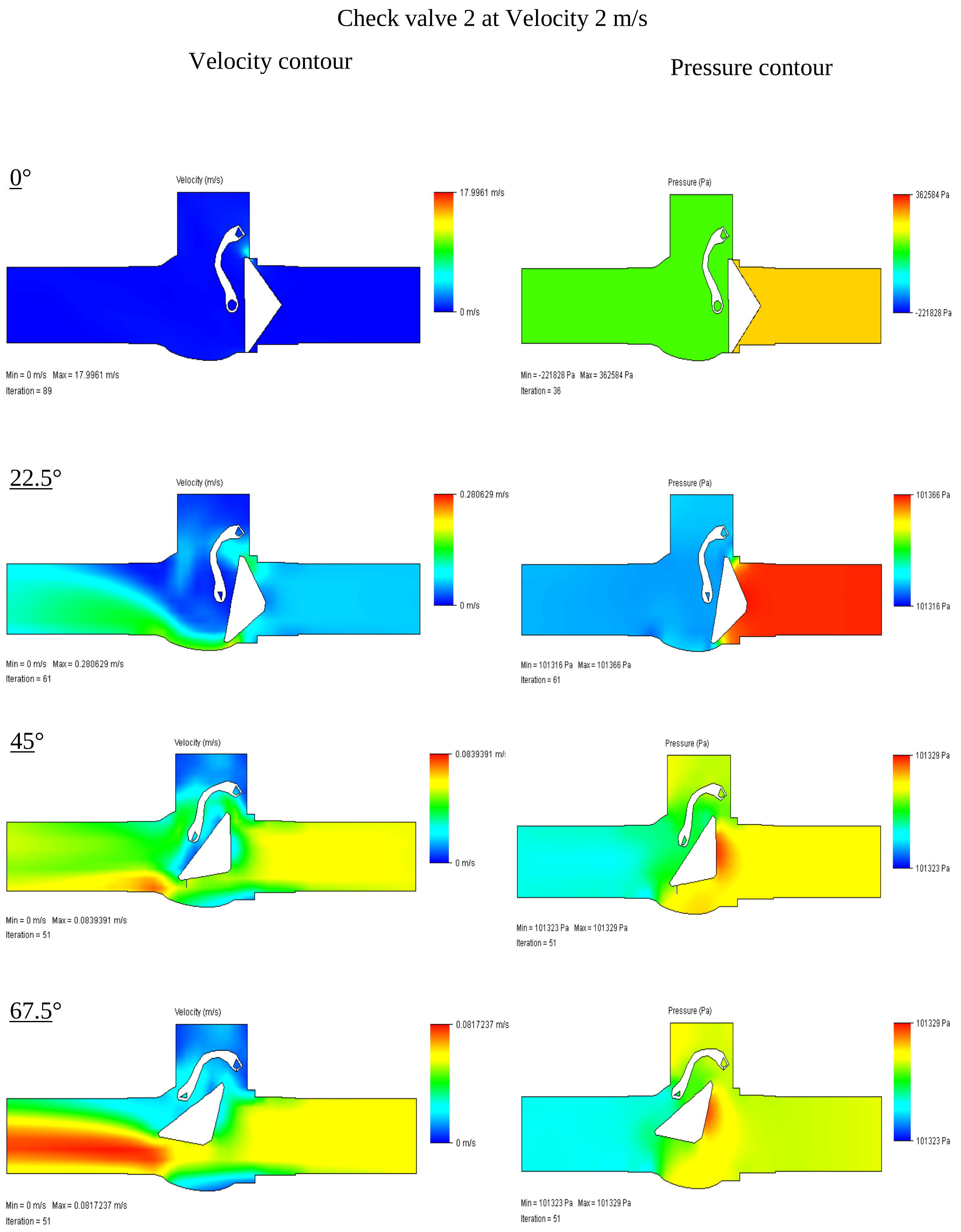


Figure 7: Velocity and pressure contour of design 2

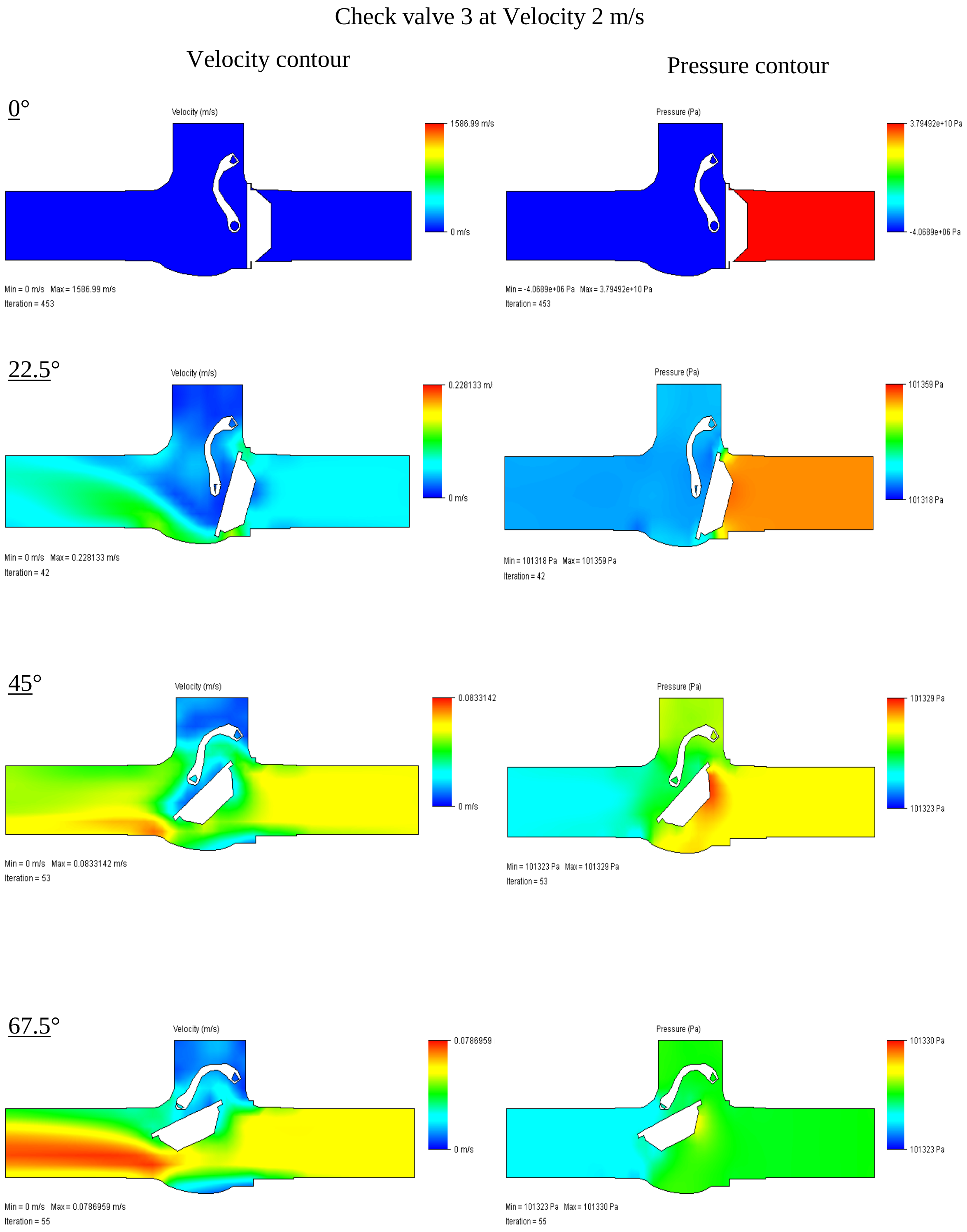


Figure 8: Velocity and pressure contour of design 3

4.5 Hydrodynamics

Figure 9 indicates the relationship between the opening angle of each check valve and the hydrodynamic force. The different starting point of hydrodynamic force is observed. As the disc opens at an angle of 22.50 ° the hydrodynamic force is started to flow at a constant rate. The constant index with respect to the valve opening indicates the same value for hydrodynamic flow. Figure 9 shows that the hydrodynamic value on check valve 3 is the lowest at 0.00 °. However, check valve disc 2 is simply the highest value of hydrodynamic based on this project simulation at 0.00 °. In the opening angle aspect, the check valve disc design 1 produces the best results which are constant when the disc is opened at 0°.

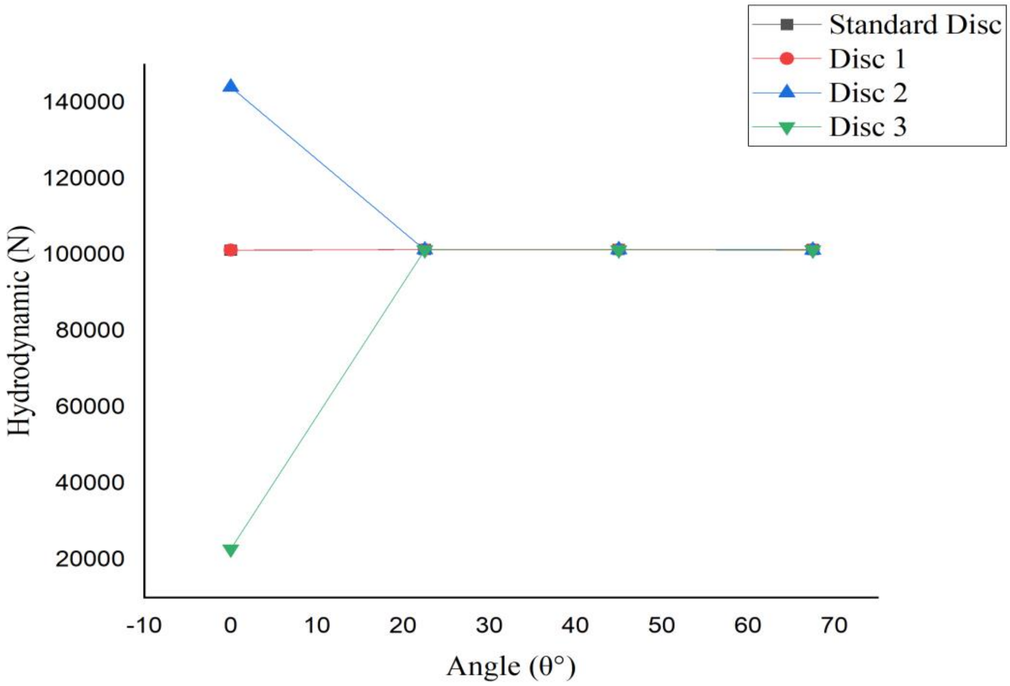


Figure 9: Relationship between opening angle and hydrodynamic force

4.6 Torque

Figure 10 shows that the lowest value of torque among all the check valves is at 0.00 ° with the value of 0.00005 Nm. However, check valve disc design 3 shows the highest value among all of the check valve However when all the disc of the check valve was opened at the angle of 22.50 ° all the values of torque start to plot as a constant value. This indicates that 22.50 ° is the most optimum opening angle for all check valve to perform at their finest due to the reading of torque is almost the same.

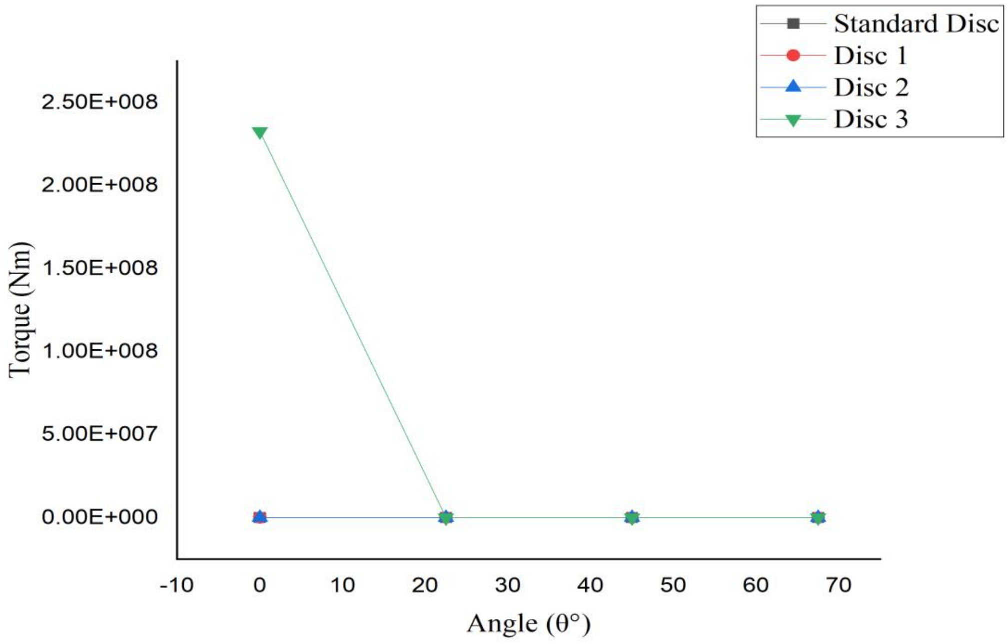


Figure 10: Relationship between ppening angle and torque

4.7 Velocity

In Figure 11 shows the relationship between the opening angles of check valve disc 1, disc 2, disc 3 and disc 4 versus the velocity acting in the valve. Based on the Figure 11, we can see that disc 1 has the highest velocity acting in it at 22.50 ° compared to the other disc of a check valve. The check valve disc 4 gives the lowest velocity acting in the valve resulted when the ball valve is operated at all opening angle due the disc design has a narrow surface distribution to flow.

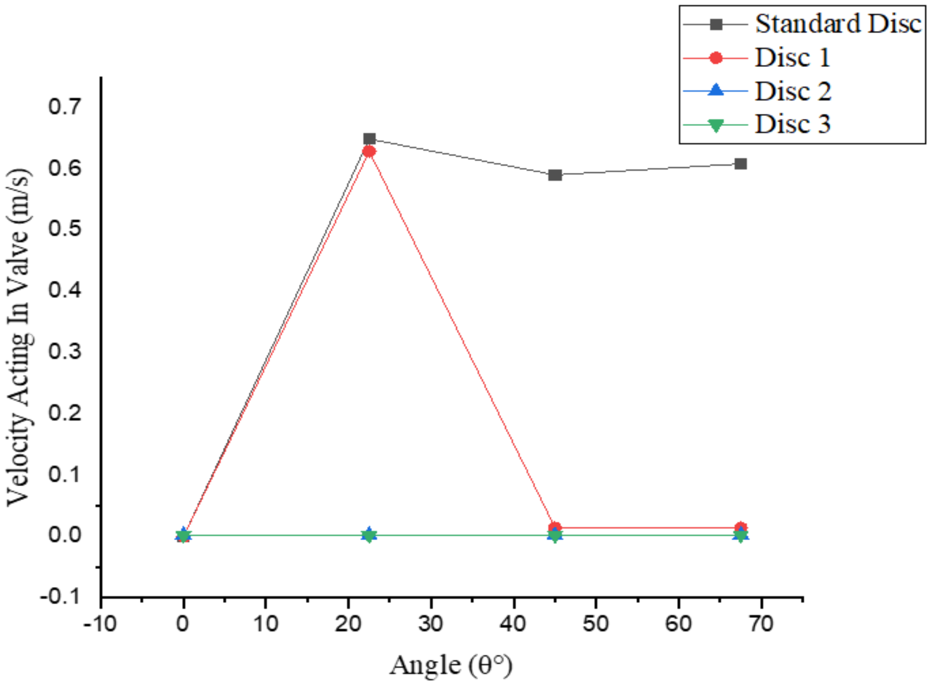


Figure 11: Relationship between the opening angle and velocity acting in valve

5. Conclusion

A flow simulation by using SWFS at specific boundary conditions.in order to come out with optimum boundary condition for valve flow velocity and visualization. These check valves were designed by using Solid work, and the standard design was from a real-industry check valve to get the likely similar dimension so that this study would result in a reliable and valid study. The discs were then modified, and the simulation run to the different opening angle of disc, which are 0.00 °, 25.50 °, 45.00 °, and 67.50 °. Afterward, the models were then analyzed in SWFS at a constant velocity of 2 m/s, and the outcome was acquired. The result was then analyzed in terms of velocity, pressure and torque distribution inside the check valves. It can be concluded that based on the critical parameter which is hydrodynamic, design 2 performed as the optimum design. Meanwhile, the opening angle for most all boundary condition parameters, opening angle 22.50 ° showed the most stable at the velocity, hydrodynamic and pressure. This proved that at that specific angle the flow of the forces is at optimum flow. Based on the simulation resulted that design 2 satisfy the optimum performance at boundary condition of pressure, velocity and hydrodynamic. In this framework, check valve design 2 shows the increment of performance in terms of velocity and pressure distribution in the check valve compared to the other check valves. Further researcher could investigate the slam in different location with different opening angle of check valve disc. Next is to analyse with the presence of longer inlet pipe to compare the reliability of this study to a real-industrial situation due to the presence of the longer pipe will affect the result differently and this will greatly help researchers to come out with a better and reliable research.

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