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Comparing Dual Plate and Swing Check Valves and the Importance of Minimum Flow for Dual Plate Check Valves

Karan Sotoodeh*

[1]Piping Engineering, Aker Solutions, Oslo, Norway
*Corresponding author: Karan Sotoodeh, Karan_sqi@yahoo.com

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Abstract Check valves are automatic valves that open with forward flow and close against reverse flow. The main function of a check valve is to protect mechanical equipment in a piping system by preventing fluid reversal. A swing check valve is an economic type of check valve, but it has a high slamming effect. Dual plate check valves are more popular than swing check valves in Norwegian offshore industry [16] because they have a low slamming effect. Additionally, the total cost of a dual plate check valve—initial cost, maintenance cost, and energy cost—is less than a swing check valve. In fact, swing check valve makes more pressure drop and energy consumption in pumping system. However, the minimum flow capacity may not produce enough pressure during the usage of dual plate check valves, which results in two operational problems. The valve loses more pressure when it is not in a fully open position, and in addition to a rise in energy consumption, insufficient flow velocity can wear the valve. A case study of minimum flow capacity and velocity calculation for fully opening a 22Cr duplex dual plate check valve in ASME pressure class 300 is discussed in this paper. The minimum flow in the example is lower than minimum critical flow required to fully open the valve. Thus, to avoid operational problems, it is recommended to not operate the valve with minimum flow. The other recommendation is to avoid installing the valve on the vertical line. Reducing the size of the valve and spring torque behind the disk are two other solutions to mitigate operational risks due to a minimum flow condition.

Keywords: *check valves, minimum flow, velocity, oil and gas industry, offshore*

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1. Introduction

1.1. Dual Plate vs. Swing Check Valve

Check valves are automatic valves that open with forward flow and close against reverse flow. The different groups of check valves include swing check valves, lift check valves, dual plate check valves, etc. [1]. The main function of a check valve is to protect the mechanical equipment in a piping system by preventing fluid reversal. Additionally, the function of a check valve is to stop massive backflow when a pipe breaks and prevent backflow toward lower pressure [2]. Generally speaking, a check valve has no requirement for operators and the valve is operated automatically through fluid flow or flow reversal.

In a swing check valve, the closure member swings around the hinge, which is mounted in the seat [1]. Figure 1 shows a swing check valve with the disk moving away from the seat by the force of the water to keep the valve open.

Figure 1. Swing check valve

A swing check valve is an economic option of check valve with a high slamming effect [3]. Although slamming is a common problem associated with check valves, not much information has been published about how to prevent and predict its occurrence. Check valve slam occurs after pump stoppage when the forward flow reverses and flows back toward the pump before the check valve is fully closed. The reverse flow is stopped by closing the valve, causing slamming and water hammering [4]. BALLUN (2007) believes that the noise associated with the slam is not the impact of the disk into the seat, but instead, it is related to rapid reverse flow [4].

On the other hand, manufacturers such as AVK believe that not only the return flow, but also the weight of the disk, has an impact on slamming, hammering, and shutoff characteristics of the valve [5]. Research conducted to understand the slamming and closing characteristics of check valves has described the check valve slam as a two-step process. First, after pump stoppage, the flow reverses and may flow backward through the check valve before it can fully close. The second step happens when the closure member stops the reverse flow suddenly [6].

It was suggested that a check valve must close either very rapidly before reverse flow occurs, or very slowly once reverse flow has begun [7]. Therefore, it was suggested that one way to close the disk rapidly is to assist the motion of the disk with a spring [8]. Dual plate check valves use a spring for closing the check valve disk, so dual plate check valves are more popular than swing check valves because they have a low slamming effect [9]. Additionally, a dual plate check valve can be designed to be more compact than a swing check valve in a wafer (flangeless) design [6,10]. Figure 2 compares the closing action of dual plate and swing check valves closing actions. The slamming effect is much higher in a swing check valve, which is closed through the disk weight force. In a dual plate check valve, slamming the disks on the seat is lower than swing check valve due to spring force assistance in closing the plates rather than the weight of the plates. In addition, the disk weight in a dual plate check valve is distributed between two parts rather than one.

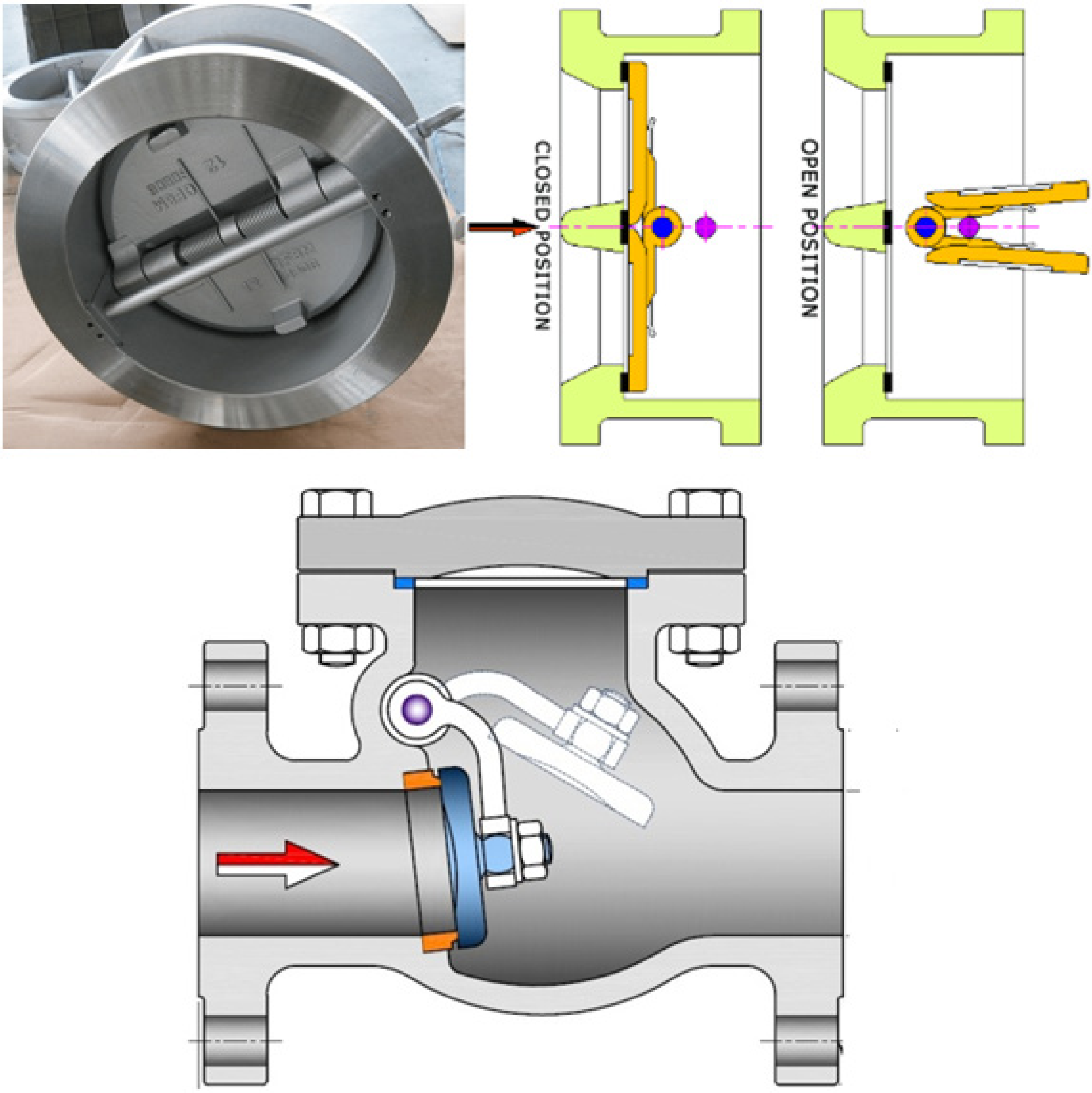

Figure 2. Comparison between swing and dual plate check valve

Table 1. 12” swing and dual plate check valve comparison over 40 years

Type of Check Valve	Installed Cost	Energy Cost	Maintenance Cost	Total Cost
Dual plate	$2000 USD	$22,400 USD	$6,000 USD	$31,200USD
Swing	$8500 USD	$30,800 USD	$24,000 USD	$63,300USD

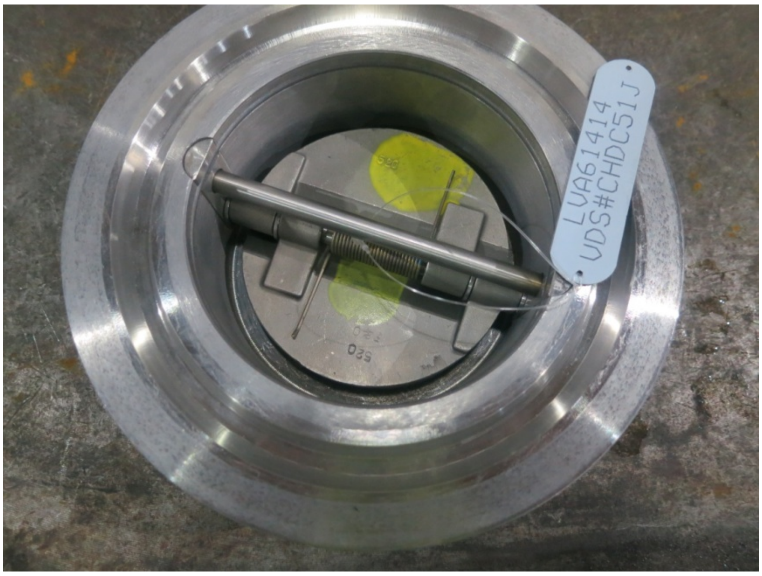

Figure 3. Dual plate check valve carbon steel body and class 600 for offshore use

The advantages of a dual plate check valve compared to a swing check valve are not limited to space saving and lower slamming rate. The total cost of a dual plate check valve including the sum of initial cost, maintenance cost, and energy cost, is less than a swing check valve. Table 1 compares the total cost of 12” swing and dual plate check valves over 40 years. The table shows that the swing check valve is almost twice as expensive based on the research done by Val-Matic Valve and Manufacturing Corp [6]. Swing check valve has more pressure drop compared to dual plate check so that will increase the energy cost. Additionally, relatively weak connection of the disk of the swing check valve to body increases the chance of disk dismantling during the operation and higher maintenance cost.

Figure 3 shows a dual plate check valve in class 600 (equal to 100Barg) [11] and carbon steel material that is used in the offshore industry.

2. Minimum Flow Operational Risks in Dual Plate Check Valves

The minimum flow capacity may not produce enough pressure during the usage of dual plate check valves, which results in two operational problems. A lower flow capacity causes the valve to lose more pressure than it does in a fully open position. In addition to a rise in energy consumption, an insufficient amount of flow or flow velocity can wear the valve. When the flow quantity is sufficient, the disk of the valve is constantly pushed and can be opened fully. If the flow capacity reduces to minimum, the disk begins to vibrate, which results in repeated slams on the body. The slamming can wear the valve and increase wear on the shaft bearing. Consequently, unscheduled maintenance work may need to be carried out or the valve may need to be replaced [12]. The other disadvantage of insufficient flow rate is that the flow cannot produce the flow capacity (Cv) value that the valve is capable of [13]. Cv is a relative measure of valve efficiency to permit the fluid flow. Mathematically, the Cv rating of valve can be expressed as equation 1:

$$C_v = Q\sqrt{\frac{SG}{\Delta P}} \quad (1)$$

Where:
Q: rate of flow (expressed in US gallons per minute)
SG: specific gravity of the fluid. This value is 1 for water.
ΔP: Pressure drop across the valve in psi

Figure 4 shows a dual plate check valve in closed and fully open positions.

Figure 4. Dual plate check valve in closed and fully open positions

3. Case Study

A dual plate check valve in 12” and Class 300 and 22Cr Duplex material has been selected for gas services with a design temperature of 100°C. The minimum and maximum flow capacities through the valve are

954.4 m^3/h and 7818.45m^3/h, respectively based on valve manufacturer data. The first step is to calculate the minimum and maximum velocity in the pipe. Velocity of fluid in pipe is not uniform across section area. Therefore a mean velocity is used and it is calculated by equation 2. Velocity of the fluid depends on the area of the pipe or channel and the liquid flow rate, as per equation 2:

$$Q = AxV \quad (2)$$

Where:

Q=liquid flow rate $\left(\frac{m^3}{s}\right)$

A=area of the pipe or channel (m^2)

V= Mean fluid velocity $\left(\frac{m}{s}\right)$.

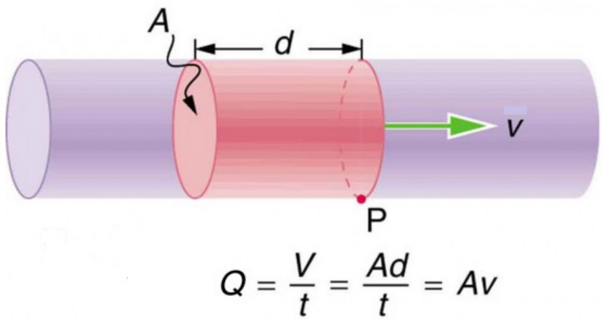

Figure 5. Velocity of the fluid in the pipe

The area of the pipe (A) is calculated using equation number 3:

$$A = \pi\left(\frac{ID}{2}\right)^2 \quad (3)$$

Where:
ID = internal diameter of the pipe (mm).

The internal diameter of the pipe is calculated using equation number 4:

$$ID = OD - 2xt \quad (4)$$

OD= outside diameter of the pipe (mm)
t= piping wall thickness (mm).

The piping wall thickness is calculated as per equation 5:

$$t = \frac{PD}{2(PY + SE)} \quad (5)\ [14]$$

Where:
t= thickness (inch)
P=design pressure (psi)
D = pipe outside diameter (inch)
Y= 0.4 (material coefficient)
S= allowable stress (psi)
E= joint efficiency =1.

The valve is in 22Cr duplex and pressure class of 300 equal to 50.7 Barg at 100° C design temperature [11]. The outside diameter of a 12” pipe is 12.750”, according to ASME B36.19 standard [15]. Allowable stress for a 22Cr duplex pipe at 100°C is 30.000 psi as per ASME B31.3. [14]

Using equation 5:

$$t = \frac{50.7x14,5x12.750}{2(50.7x14.5x0.4 + 30000)}$$

$$= \frac{9373.1625}{60588.12} = 0.1547 \text{ inch} = 3934\text{mm}.$$

A mill tolerance of 12.5% should be added to the calculated pipe thickness of the pipe to mitigate the risk of pipe thickness reduction during the production [14,16]. Adding 12.5% gives a thickness value of 4.426mm. The calculated thickness after adding 12.5% is not a standard thickness, so the thickness should be calculated to the next standard thickness that is Schedule 10 equal to 4.57mm. Schedule 10 provides just 0.15mm extra thickness compared to the basic thickness after adding 12.5% mill tolerance. Thus, the next standard schedule based on the ASME B36.19 standard that is schedule 20 equal to 6.35mm is selected as the final piping wall thickness. Now it is possible to calculate the ID of the pipe using equation 4. Afterward, the area of the pipe will be calculated using equation 3.

Equation 4)
ID=12.750(inch) x 25.4 (mm/inch) –2x (6.35) = 311.15 mm
Equation 3)

$$A = \pi\left(\frac{311.15}{2}\right)^2 = 76035.5 \text{ mm}^2 = 0.07603\text{m}^2$$

The next step is to calculate minimum and maximum flow velocity using equation 2:

954.4 m^3/h = 0.07603m^2 X minimum velocity -> minimum velocity = 12553 m/h= 3.487 m/s

7818.45 m^3/h = 0.07603m^2 X maximum velocity -> maximum velocity = 102834 m/h= 28.56 m/s

The minimum flow to fully open a swing check valve is calculated using equation 6 [13]. It is assumed that this formula is also applicable for a dual plate check valve:

$$V_{min} = 55x\sqrt{\frac{1}{\rho}} \quad (6)$$

Where:
V_{min} : Minimum flow velocity (ft/s)
ρ : Fluid density (lb/ft3).
The fluid is gas with a density of 11kg/m^3.

ρ = 11 kg/m^3 = 0.6867 lb/ft3 -> $V_{min} = 55\ x\ \sqrt{\frac{1}{0.6867}}$

= 55 x $\sqrt{1.456}$=66.37ft/s = 20.22 m/s

It is also possible to calculate the minimum required flow to keep a check valve fully open using equation 2:

$$Q_{min} = 0.07603\text{m}2\text{X}20.22\text{m}/\text{s}$$

$$= 1.537\ \text{m}^3/\text{s} = 5534\text{m}^3/\text{h x}11\ \text{Kg}/\text{m}^3$$

$$= 60{,}874\ \text{kg}/\text{h}.$$

4. Data Analysis and Recommendation

1. The minimum flow in the 12” Class 300 dual plate check valve based on process data is 954.4 m^3/h, whereas the minimum flow to fully open the valve (critical flow) is 5534 m^3/h.

2. A check valve will open at any flow. However, below the critical flow the valve will not be fully open. In this condition the flow through the valve maybe unstable and cause wearing and tearing. Therefore, it is not recommended to use the valve below 5534 m^3/h except for short periods of time.
3. The preferred valve direction of installation is horizontal. Vertical installation of the check valve with the downward fluid can keep the valve always open. Vertical installation of the valve with the upward fluid makes the opening of the valve difficult, especially in flow conditions below critical flow.
4. Reducing the size of the valve facilitates easier opening of the disk and may solve the minimum flow operational problems.
5. Reducing the torque of the springs which are installed behind the disk can also solve the minimum flow operational problems.

5. Conclusion

Minimum flow capacity may not produce enough pressure during the usage of dual plate check valves, and this can create operational problems. The valve may lose more pressure than it would in a fully open position. In addition to a rise in energy consumption, an insufficient amount of flow velocity can wear the valve. If the velocity is not sufficient, the disk will start vibrating and result in frequent slamming on the body of the valve. This slamming damages the valve disk and body contact surfaces with the disk, and unscheduled maintenance may be required or the valve may need to be replaced. This paper discussed a case study performed to calculate the minimum flow rate as well as the flow velocity for a 12" class 300 dual plate check valve in 22Cr duplex material. The calculated minimum flow to fully open the valve was 5534 m^3/h, whereas the minimum flow in the valve was 954.4 m^3/h. Therefore, the valve will not be fully open below the 5534 m/h (critical flow). Thus, it is not recommended to use the valve below the critical flow for a long period of time. Reducing the size of the valve and/or spring torque are solutions that can help avoid operational problems in this case. It is important for process engineers to size valves properly and avoid oversizing the disk check valves. Oversizing a check valve prevents full opening of the valve during minimum flow or even normal flow conditions. Detail discussions on alternative solutions such as avoiding oversizing of the check valve or using lower spring torque is not a part of this paper and requires further research.

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