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MODIFICATION OF GATE VALVE SEALING ELEMENT TO ENHANCE THE WEAR RESISTANCE

Jamaladdin ASLANOV[1], Khalig MAMMADOV [1,*]
[1]Azerbaijan State Oil and Industry University, Baku, Azerbaijan
*Corresponding author: khalig.mammadov1993@gmail.com

Abstract: *This study illustrates the optimization in gate valve constructions by improving wear resistance, friction control, and pressure distribution within hermetic sealing elements. Gate valves, essential for fluid control systems, often suffer from excessive wear and frictional degradation, particularly in high-pressure and abrasive environments which is specific for the valves being used in different environments as well as in oil and gas industry. The research focuses on selecting optimal materials and improved design configurations to enhance the longevity and reliability of sealing components by focusing on enhancement of wear resistance. Using ST 20X and ST 40X steel grades, experimental investigations were conducted with a vertical universal wear-testing machine, evaluating circular and triangular hermetic elements under controlled load and time intervals. Several environmental factors are considered while the experiment run in order to define the new designed hermetic elements and their respective materials resistance level to wear. The findings indicate that moderate hardness differentials between gate and saddle materials improve durability, whereas excessive disparities accelerate tribological wear. Furthermore, incorporating triangular and trapezoidal elements optimized pressure distribution, reduced deformation, and minimized frictional resistance, leading to enhanced sealing efficiency in gate valves. To validate these findings, relevant simulations were performed, analysing pressure and velocity variations over the improved valve design. The simulations demonstrated that structural modifications lead to more uniform stress distribution, reducing erosion, turbulence, and friction-induced material degradation. By applying the proposed configuration of the hermetic element pairs, reliability of gate valve constructions could be considered as extended for the continuous operations. The research highlights that integrating tribological principles, optimized material selection, and geometric refinements is a viable strategy for minimizing wear, mitigating friction, and extending service life in industrial gate valves. These findings provide a foundation for further enhancements in tribological nodes, ensuring superior performance and reliability in demanding fluid control applications.*

Keywords: *wear, tribological nodes; friction; hermetic elements; improved gate valve; steel;*

1. INTRODUCTION

The advancement of modern technology across various industries increasingly depends on extending the service life of critical components, particularly sealing structures. These components are essential for maintaining the efficiency and reliability of operations in sectors such as oil and gas, power generation, and other industrial applications. Ensuring their durability requires extensive research to enhance their performance under demanding operating conditions [1-3]. Among these essential sealing system components, valves play a crucial role due to their widespread use in regulating fluid flow across varying pressure levels. While designed to endure diverse operational challenges, valves subjected to high pressures are particularly susceptible to frequent malfunctions, potentially compromising entire systems [4].

Despite significant advancements, challenges related to valve reliability remain unresolved. Friction between valve components, wear on sealing surfaces, and the impact of environmental and operational stresses continue to degrade these critical systems [5-6].

Beyond frictional wear, valve components are exposed to various damage mechanisms, including corrosion, erosion, and hydro-abrasive wear. Hydro-abrasive wear, which is particularly severe, occurs when transported fluids contain sand or other abrasive particles. These particles accumulate in the small clearances between the wedge and valve body, causing scratches and progressive degradation of the sealing material during operation [7]. Over time, this process leads to the formation of narrow gaps between sealing surfaces, resulting in fluid leakage. High fluid velocities and turbulence accelerate this damage, with initial surface abrasions developing into extensive wear zones. Although repairs may be possible in some cases, damage often goes unnoticed until it becomes irreparable. When valves fail to fully open or close, uncontrolled fluid flow exacerbates internal deterioration and reduces overall system efficiency [8-9].

The persistent challenges associated with valve seating and sealing surfaces highlight the urgent need for further research and innovation. This study seeks to address these issues by improving the durability and reliability of valves, specifically by reducing wear on sealing surfaces such as saddles and gates that are in constant contact. Optimizing structural design and mitigating wear are well-documented strategies for significantly extending the lifespan of industrial equipment. Experimental findings from this research underscore the importance of carefully selecting the mechanical properties of valve components—particularly material strength and hardness—to enhance performance [10].

Furthermore, research conducted at NEFTGAZMASH OJSC demonstrates that when the hardness of pressurized components is significantly higher than that of the opposing elements, the softer materials wear out more rapidly, reducing their operational lifespan. Studies on ZMS and ZMAD valve types confirm this effect, highlighting the need for a balanced approach to material selection [11-13].

Structural design is another key factor influencing pressure distribution across contact surfaces. Uneven pressure distribution accelerates wear and diminishes efficiency. Addressing this issue requires strategic material selection and optimized hardness properties, supported by rigorous research and experimental validation [14]. In this study, we focus on identifying optimal hardness levels for hermetic elements and refining structural designs to enhance reliability and extend service life.

2. GATE VALVE CONSTRUCTION AND CHALLENGES IN HERMETIC ELEMENT PERFORMANCE

Gate valves are among the most commonly used valve types, particularly in demanding environments, due to their robust performance and reliable sealing capabilities at high system pressures. Figure 1 presents a cross-sectional view of a gate valve with a solid wedge, illustrating its structural components. This detailed view highlights the key elements that constitute the valve unit. The sealing components, which play a crucial role in maintaining operational integrity, are subjected to significant pressure and are among the most vulnerable to frequent failures. The primary functional elements of a gate valve are its hermetic components, which operate under harsh conditions and are prone to wear and rejection over time. These hermetic elements consist of two main subcomponents: the gate (or wedge) and the saddle (or seat ring). During valve operation, these elements function in pairs, making them particularly susceptible to wear and failure. One of the leading causes of failure in these components is the unequal distribution of pressure across the sealing surfaces. Additionally, material incompatibility between the paired elements often contributes to valve rejection during operation, typically due to inadequate material selection during manufacturing.

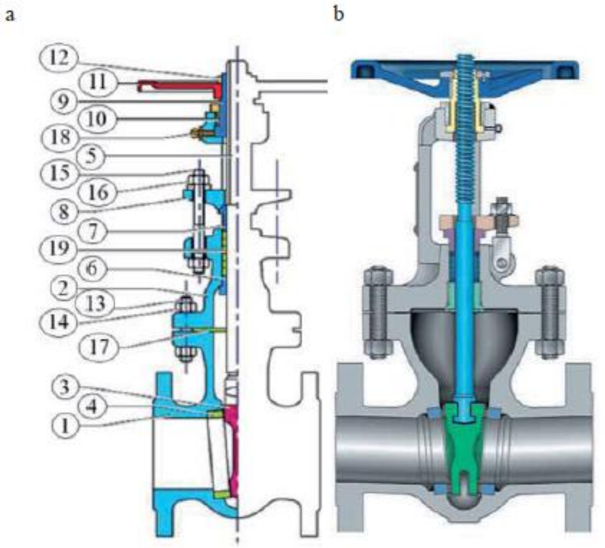

Figure 1. Gate valve
a – cross-section (1 – body, 2 – bonnet, 3 – solid wedge, 4 – body seats, 5 – stem, 6 – back seat, 7 – gland follower, 8 – gland flange, 9 – stem nut, 10 – yoke nut, 11 – handwheel, 12 – handwheel nut, 13 – stud bolts, 14 – nuts, 15 – stud bolts, 16 – nuts, 17 – bonnet gasket, 18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

Pressure distribution across the hermetic elements is predominantly compressive due to the nature of the fluids passing through the valve, which often contain abrasive particles. These particles accumulate on sealing surfaces, causing progressive damage during operation. As a result, the intended even distribution of pressure across the gate-saddle interface is disrupted, leading to premature failure, often before the expected operational lifespan of the valve is reached [19-20].

These challenges significantly reduce the overall efficiency of the valve unit and accelerate structural deterioration, particularly in applications where aggressive liquids and gases are present. The inability to maintain uniform pressure distribution and material compatibility within the hermetic components remains a critical issue, necessitating further research to improve valve design and enhance durability.

3. METHODS AND MATERIAL

The presence of abrasive and mechanical particles within valve systems, coupled with the effects of corrosion from metal-to-metal contact, significantly contributes to efficiency loss and potential failures. Uneven pressure distribution across working surfaces accelerates wear as the hermetic elements move forward and backward during the opening and closing of the valve. This process also deteriorates metal-to-metal contact surfaces over time. Since extracted fluids from wells frequently contain abrasive particles, they gradually degrade the performance of the gate and saddle components, eventually rendering them unusable. Experimental analysis identified material selection as a key factor influencing valve wear. As previously noted, friction corrosion is a predominant issue in gate-saddle interactions [15-16]. Accordingly, this study investigates the friction-corrosion mechanisms that arise when different steel materials interact under operational conditions [17-18]. Findings confirmed that the primary friction and wear occur at the gate-saddle interface. To analyse this phenomenon in detail, test samples were prepared using two steel grades: ST 20X and ST 40X. The wear and friction characteristics of these materials were systematically examined.

The experiments were conducted in the Oil and Gas Equipment Laboratory at Azerbaijan State Oil and Industry University using an MKS-10 MMW-1 vertical universal wear-testing machine, manufactured by Jinan Fangyuan Testing Machine Co. Ltd., as depicted in Figure 2.

The experimental setup involved preparing both cylindrical and circular steel samples. A circular sample was securely clamped onto the stationary seat of the testing apparatus, while a cylindrical rod was attached to the upper rotating assembly. A controlled load was applied to the stationary sample following a predefined schedule with varying time intervals.

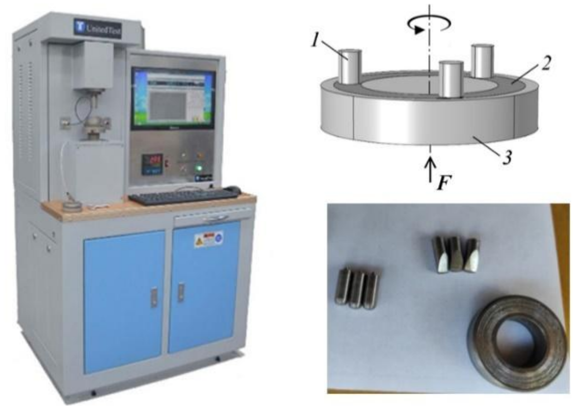

Figure 2. Jinan Fangyuan Testing Machine CO.Ltd MKS-10 MMW-1 vertical-universal wearing machine and sample preparation for the experiment

A similar procedure was followed for triangular samples, where they were securely fixed to the stationary seat while the rod construction was connected to the upper assembly of the testing equipment. The load was applied according to a structured time schedule, allowing for comparative analysis.

For both cases, friction-corrosion phenomena occurring at the metal interface were evaluated, and the collected data were used to generate graphical representations. The results were compared based on hardness variations over time, and the tested materials' performance was benchmarked against an alternative steel structure—specifically, a three-layer packing element commonly used in valve construction.

The experimental findings presented aim to inform modifications to hermetic elements and the reconstruction of their seating interfaces within the valve. To achieve this, material hardness variations were analysed and validated. Achieving this goal necessitates several approaches, including reducing force loss within the system, optimizing the design of hermetic elements, refining the valve seat structure to align with the improved geometric parameters of hermetic elements, and selecting materials with hardness variations that enable smooth and efficient interaction.

Typically, hermetic elements in valves consist of rubber and metal rectangular rings, which ensure a tight seal. However, rubber seals are frequently subjected to cutting stresses caused by uneven pressure distribution within the hermetic assembly. These stresses lead to deformation, compromising sealing efficiency due to excessive compression of the packing components. Addressing this issue is critical to enhancing the durability of hermetic elements.

To mitigate these stresses, it is recommended to redesign the rectangular hermetic element into two distinct components: triangular and trapezoidal flat elements. This adjustment aims to resolve the issue of uneven pressure distribution. The trapezoidal element functions as the core structural component, while the triangular element serves as the primary deformable component under working pressure. The triangular element absorbs the initial stress, thereby reducing the stress experienced by the trapezoidal element. Consequently, the two components compress against each other along their contact surfaces, ensuring a more uniform pressure distribution within the hermetic assembly. This structural modification significantly enhances the reliability and longevity of the sealing mechanism.

The selection of materials for valve construction is largely determined by application-specific requirements and compliance with industry standards. Experimental analysis of various steel structures emphasizes the importance of selecting materials based on the operating conditions and industry demands where the valve will be deployed.

Figure 3 illustrates the influence of time on the interaction between two materials in motion against each other. The graph, titled "Load-Time Curve," represents the variation of the applied load over time and its effect on the friction coefficient. The measurements are presented in SI units, with time in seconds (s) and load in newtons (N). In this study, the materials under investigation are ST 20X and ST 40X. The experiment involved a circular sample made from ST 20X steel, which was securely fixed onto the stationary seat of the testing equipment using a small clamp. This sample was positioned on the sample table, while a cylindrical rod made from ST 40X steel was attached to the upper rotating assembly. During the test, the rotating assembly applied a load onto the stationary sample according to a predefined schedule with varying time intervals.

Test Number	1-20	Sample name	POLAD
Test Result			
Load	33.54 N	Rotate speed	534.2r/min
Time	200 s	Temperature	159.2℃

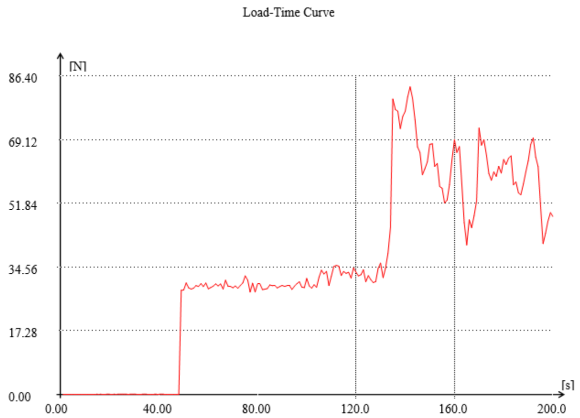

Figure 3. Experimental Setup for Circular-Shaped ST 20X – ST 40X Element

The Load-Time Curve illustrates the distribution of load and frictional behaviour over time. During the initial phase (0–40 seconds), the applied load remains at 0 N, indicating no significant contact between the materials. At 40 seconds, the load initiation phase begins, with a gradual increase stabilizing at 34.56 N, showing minimal fluctuations. By 120 seconds, the peak load phase is reached at 86.40 N, suggesting changes in frictional behaviour or surface contact. After 160 seconds, the fluctuation phase begins, with the load oscillating between 69.12 N and 51.84 N, indicating potential wear affecting material interaction.

Figure 4 illustrates the time-dependent effects on material interaction, highlighting how variations in applied load influence the friction coefficient. These findings provide valuable insights into material wear behavior and frictional dynamics, aiding in the optimization of valve component designs.

Test Number	@Test Number@	Sample name	@Sample name@
Test Result			
Load	45.69 N	Rotate speed	1482.0r/min
Time	200 s	Temperature	159.2℃

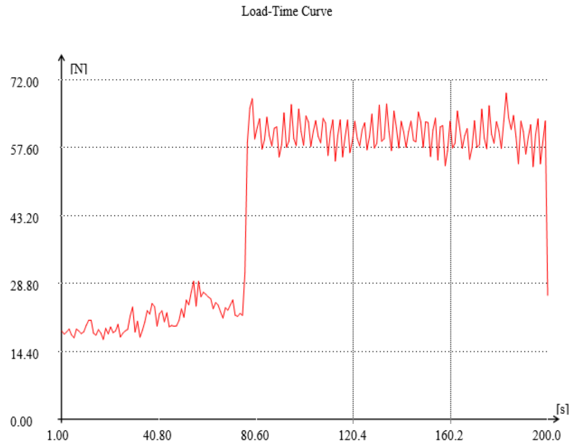

Figure 4. Processing of the experiment on triangular shaped element for ST 20X-ST 40X

The Load-Time Curve presents the applied load variations over time and their impact on friction. Measured in SI units (seconds and newtons), the experiment involved a circular ST 20X steel sample, securely clamped to the stationary seat, while a cylindrical ST 40X rod was attached to the rotating assembly. The assembly applied a controlled load, following a predefined schedule with variable time intervals. During the initial phase (0–40 seconds), the load starts at a minimal level and gradually increases, maintaining a stable distribution and consistent frictional interaction. In the transition phase (40–80 seconds), the load continues rising, with fluctuations becoming more pronounced, indicating shifts in material contact. By the third stage (80–120 seconds), the load reaches a plateau between 57 N and 72 N, reflecting changes in frictional behavior due to evolving surface conditions. During the peak phase (120–160 seconds), the load oscillates within this range, suggesting surface adaptation before potential structural changes. In the final phase (160–200 seconds), despite temporary stabilization, the load ultimately reaches a rupture point, indicating failure due to accumulated stress and uneven distribution.

This analysis demonstrates the dynamic behaviour of materials under variable load conditions, emphasizing the necessity of understanding load distribution and material properties to predict performance and potential failure in similar engineering applications.

2.1 Comparative Analysis of Friction and Wear in ST 20X and ST 40X Steel Interactions. Simulation of the new proposed model

The interaction of different steel materials under varying load conditions is heavily influenced by material selection and component geometry, both of which must align with operational requirements. The study examined the wear behaviour of ST 20X and ST 40X steel samples, emphasizing the impact of shape and material properties on frictional resistance.

A comparison of Figures 3 and 4 highlights distinct differences in load-time behaviour. In Figure 3, where ST 20X moved against ST 40X, the load remained at zero for the first 40 seconds before gradually increasing to a stable 34.56 N. After 120 seconds, a sharp rise to 86.40 N was observed, followed by fluctuations between 69.12 N and 51.84 N, indicating material wear. The system ultimately stabilized, maintaining a functional state despite wear effects. In Figure 4, where ST 40X moved against ST 20X, load application began immediately, increasing steadily. Unlike Figure 3, this experiment exhibited sharper fluctuations between 40–80 seconds, reaching a plateau at 57–72 N. In the final phase (160–200 seconds), the load persisted but culminated in a sudden rupture, suggesting premature material failure. Comparatively, Figure 3 demonstrated a higher peak load and greater stability, whereas Figure 4 showed an earlier engagement, sharper fluctuations, and lower endurance.

The results emphasize that the gate material should be significantly harder than the saddle in gate valve construction, but not excessively so, to maintain compatibility. Careful selection of material properties, shape optimization, and load distribution are crucial to improving wear resistance and extending the service life of valve components. The study confirms that uneven pressure distribution and frictional forces at the gate-saddle interface are primary contributors to material degradation, reinforcing the need for improved design strategies in valve and this could be achievable by replacing the cross-sectional area of the pair used to seal gate valve construction.

Simulation has been set up in order to proceed with pressure disturbance over the hermetic elements of the improved valve.

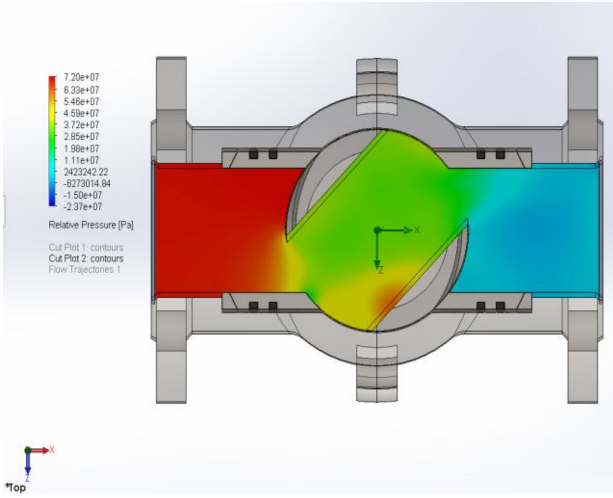

Figure 5. distribution of pressure on improved valve hermetic elements

Figure 5 illustrates simulation of a gate valve, relative pressure distribution as fluid flows from left to right. The color gradient highlights different pressure regions, with the red area on the left indicating high-pressure fluid entering the valve, while the blue region on the right represents the lower-pressure outlet after the fluid passes through the gate mechanism. The transition from high to low pressure, visible through the green and yellow gradients, reflects the pressure drop caused by the restriction and turbulence generated by the partially open gate. The diagonal gate structure in the centre partially obstructs the flow path, leading to variations in pressure and velocity. This obstruction results in a noticeable pressure drop across the valve, as the fluid accelerates through the reduced cross-sectional area. The asymmetry in pressure contours suggests turbulence and potential vortex formation, which could contribute to erosion and wear over time. Additionally, the streamlines in the image indicate how the fluid navigates around the gate, with noticeable transitions between high and low-pressure regions, pointing to possible flow separation and energy losses.

Another simulation run for the valve is the velocity over the hermetic elements based on the new design provided.

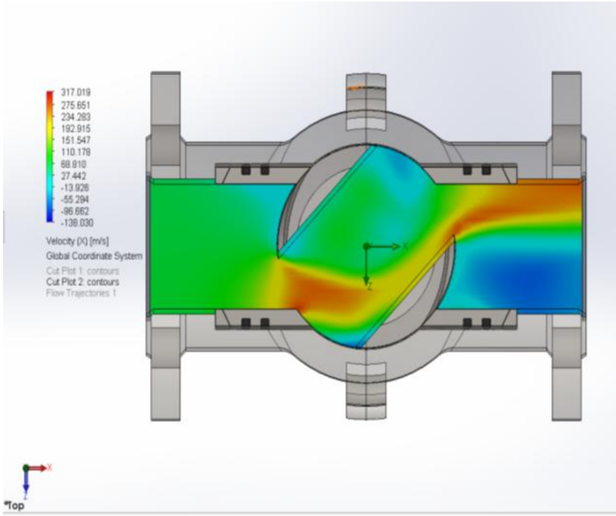

Figure 6. velocity over the hermetic elements of the improved gate valve

Figure 6 illustrates the velocity distribution of fluid flow. The color gradient highlights variations in velocity, with green indicating uniform flow at the inlet, transitioning to red and orange near the gate due to increased velocity as the fluid passes through the restricted section. The right side shows lower-velocity blue and green regions, suggesting flow expansion and turbulence. The high-velocity zones near the gate indicate shear stress and potential erosion, while turbulence at the outlet suggests pressure drops and energy losses. These factors can contribute to cavitation, wear on sealing surfaces, and structural fatigue over time. Optimizing valve design and material selection is essential to ensure even pressure distribution, reduce turbulence, and enhance durability. This analysis underscores the importance of fluid dynamics in improving valve efficiency and longevity in industrial applications.

4. CONCLUSION

This study provides a comprehensive analysis of gate valve sealing elements, emphasizing the interdependence of wear resistance, friction behaviour, and pressure distribution. Experimental results using ST 20X and ST 40X steel grades confirmed that wear and friction performance are directly influenced by material hardness differentials and geometric configurations of hermetic components. The introduction of triangular and trapezoidal elements significantly improved load distribution, reducing deformation, tribological wear, and excessive frictional resistance. Comparative Load-Time Curve analysis highlighted distinct wear patterns and frictional stability across different configurations, demonstrating that optimized tribological nodes contribute to prolonged durability and enhanced sealing efficiency. CFD simulations further validated that modifications in hermetic element geometry ensure uniform pressure distribution, minimizing energy losses, turbulence, and erosion-induced wear over time.

Ultimately, this research underscores necessity of integrating advanced tribological principles with material and structural optimizations to improve wear resistance, reduce friction, and enhance reliability of gate valves in high-pressure and abrasive conditions. The findings serve a critical reference for future advancements in tribology-driven valve design, ensuring long-term durability and operational efficiency across industries such as oil and gas, power generation, and fluid control systems.

ORCID iDs

Jamaladdin ASLANOV 0000-0001-8008-9532
Khalig MAMMADOV 0000-0002-6023-2810

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