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RESEARCH

Determination of the Optimum Angle for the Sealing Element of Improved Gate Valve

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A B S T R A C T

This research examines equivalent stress and strain distribution in hermetic elements of an enhanced gate valve, focusing on wear effects and material properties. A novel computational framework for trapezoidal cross-sectioned sealing components was developed in MATLAB, integrating fuzzy logic and the "bee colony" optimization method to refine pressure distribution analysis. Finite element analysis and simulations enhance the reliability of valve hermetic elements under varying conditions. Key findings include equations governing stress and deformation in sealing components, considering structural and technological parameters. The study identifies 62 degrees as the optimal angular displacement for the trapezoidal hermetic element, minimizing wear and ensuring efficient sealing. Material interactions, such as ST20X-ST20X and ST40X-ST20X, were analyzed to assess wear behavior. Harder materials exhibited greater resistance but increased persistent wear. Advanced parametric analysis and 3D visualization establish a structured methodology for optimizing valve design. The results contribute to improving high-pressure valve applications through refined material selection, structural geometry, and sealing configurations. This research enhances valve technology and serves as a foundation for future innovations in industrial valve performance optimization.

1. INTRODUCTION

The rapid evolution of modern industrial technology necessitates the continuous improvement of equipment used in the oil and gas industry. Ensuring the reliability and longevity of critical machinery is essential for maintaining operational efficiency. Among the fundamental components in these systems, valves play a vital role in controlling fluid flow, regulating pressure, and preventing leakages. However, due to their constant exposure to extreme pressures and aggressive environments, valve components—particularly hermetic sealing elements—are highly susceptible to wear, corrosion, and fatigue. The durability of these sealing elements significantly impacts the overall performance of valve systems, making it crucial to optimize their design.

In this study, the materials used for the sealing assembly include ST20X and ST40X structural steels, selected for their strength and wear resistance under high-pressure conditions. These materials are widely used in valve manufacturing and meet standardized specifications for mechanical integrity and corrosion resistance. The sealing interface also includes a compliant component made of nitrile butadiene rubber (NBR), known for its elasticity, oil resistance, and effective sealing capability. This combination of metallic and elastomeric materials allows for reliable sealing performance while accommodating mechanical stress and pressure fluctuations.

Gate valves (Fig. 1), widely used in high-pressure applications, are particularly prone to erosion caused by continuous fluid flow and abrasive particles. The frictional interaction between sealing elements contributes to wear, reducing the valve's effectiveness over time. Addressing these challenges requires a systematic approach that integrates advanced computational modelling and experimental validation. This study focuses on determining the optimum angle for the sealing element of an improved gate valve, aiming to enhance its resistance to wear and extend operational lifespan. By applying finite element analysis (FEA) and numerical simulations, this research establishes a robust framework for optimizing sealing element configurations.

Sr No	Gate Valve
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

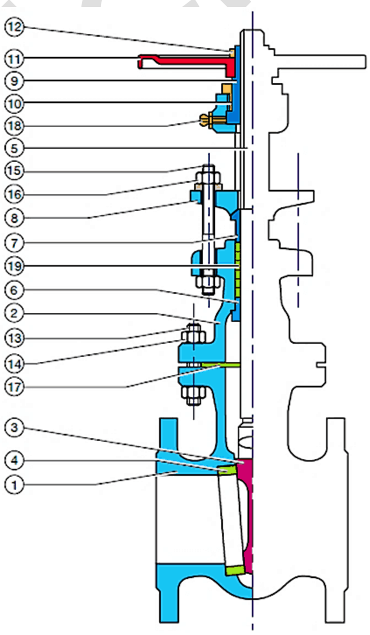

Fig. 1. Gate valve elements.

Several studies have explored methodologies to improve valve performance through material selection, lubrication techniques, and numerical modelling. Ri et al. investigated valve coatings using numerical analysis, concluding that applying specialized lubrication coatings can significantly reduce erosion. Their atmospheric pressure experiments demonstrated the effectiveness of lubrication in minimizing wear-related failures [1].

P. Kansara et al. conducted CAD-based finite element analysis (FEA) to simulate stress distribution in valve hermetic elements. Their study modelled pressure increments from zero, providing valuable insights into thermal and harmonic effects on valve components. The research utilized ANSYS Fluent software, confirming that thermal stresses contribute significantly to valve wear [2].

In another significant study authors developed a numerical model to examine elastic deformations, transitions of wear characteristics for rubber/steel seal pairs during the abrasive wear process, surface pressure distribution, and elastic-hydrodynamic lubrication within valve plates. The research highlighted how mechanical forces impact sealing efficiency, emphasizing the importance of optimizing structural parameters to improve valve longevity [3].

Investigations into the thermal shock resistance of valve materials have also been conducted. Authors performed numerical analyses to assess material strength under high-pressure conditions, optimizing valve components to achieve near-zero leakage performance. The research underscores the need for advanced material selection in designing wear-resistant sealing elements [4].

Further experimental validation was carried out and a flow coefficient analysis for valve constructions was conducted. Using a test bench and ANSI/ISA-75.02-1996 regulations, Euler's equations applied to simulate fluid dynamics, demonstrating the correlation between flow behavior and sealing efficiency Tribological characteristics of gas pipeline fittings with composite materials applied to verify the results in different conditions [5].

A commonly used industrial valve, the globe valve, also operates under extreme pressure conditions, requiring robust design optimizations. Authors applied Computational Fluid Dynamics (CFD) to analyze flow simulation and wear characteristics in globe valves. By considering nonlinear hydraulic effects, the study identified opportunities for improving efficiency and minimizing noise in valve designs [6]. The comparative effectiveness of CFD and ANSYS simulations has been widely debated in valve engineering. While these modelling techniques offer valuable predictive insights, discrepancies remain between simulation outputs and real-world applications. To bridge this gap, the present study leverages SOLIDWORKS software to analyze wear patterns, stress distributions, and optimal angular configurations in improved gate valve constructions [7]. By determining the optimal sealing angle for trapezoidal hermetic elements, this research aims to enhance valve durability, minimize erosion, and improve sealing efficiency under high-pressure conditions. The findings will contribute to the development of next-generation industrial valves, aligning with the oil and gas sector's demand for enhanced reliability and performance.

In line with industrial best practices, standard guidelines such as ASME B16.20:2012, ASME PCC-1:2010, and ASME PCC-1:2019 are instrumental in defining the mechanical integrity of pressure boundary components, including sealing elements. These standards outline the specifications for metallic gaskets and bolted flange joint assemblies, which are critical in valve design to ensure leak-tight performance under high-pressure conditions. The insights from these standards were used as a reference framework in developing the computational methodology and interpreting the sealing behavior of the proposed valve configuration [8,9].

Additional recent studies further support the relevance of wear analysis in valve components. The behavior of valve flanges using octagonal ring gaskets under varying temperature conditions modeled, offering insights into thermal effects on sealing interfaces [10]. The erosion characteristics of parallel gate valves under different flow regimes were modeled in FME Transactions [1], confirming the significant role of flow-induced wear. An experimental study examined axial and radial stress distributions in soft materials used for valve stem sealing, emphasizing the importance of mechanical properties in predicting sealing reliability [11]. Furthermore, another research evaluated the wear and corrosion resistance of coated sealing surfaces, proposing advanced surface treatments to extend service life [12]. These findings underscore the critical need for robust modeling and material evaluation in the design of modern sealing systems.

2. COMPUTATIONAL AND NUMERICAL ANALYSIS OF SEALING ELEMENTS

This study employs a combination of finite element analysis (FEA), numerical simulations, and optimization algorithms to determine the optimum sealing angle for the hermetic elements of an improved gate valve. A computational framework was developed using SOLIDWORKS for 3D modelling, ANSYS for structural validation, and MATLAB for numerical optimization, integrating the bee colony algorithm to refine angle variations. The methodology focuses on analysing stress distribution, deformation behaviour, and wear resistance under varying operational conditions.

The finite element model was structured to evaluate the impact of pressure fluctuations, material selection, and sealing element geometry. The hermetic element, designed with a trapezoidal cross-section, was subjected to multiple loading conditions to identify the most effective displacement angle. The study incorporated different material combinations, including ST20X-ST20X and ST40X-ST20X, to assess their influence on wear patterns. The materials used in the simulations include ST20X and ST40X, which are classified under structural carbon steels. ST20X corresponds to a low-carbon steel grade with good ductility and machinability, commonly aligned with the GOST 1050-88 or equivalent DIN EN ISO 683-1 standards. It typically has a tensile strength of 370–470 MPa and yield strength of approximately 235 MPa. ST40X is a medium-carbon steel used for components requiring higher wear resistance and strength, with mechanical properties conforming to GOST 4543-71 or equivalent standards such as AISI

1045. Its tensile strength ranges between 580–740 MPa, and it offers improved resistance to surface degradation under repeated loading. These material specifications were used in assigning input values for the stress-strain simulations and comparative wear analysis. By simulating real-world conditions, the model effectively captured the stress-strain responses, helping to optimize the sealing element's geometry and material selection. The efficiency and reliability of valve systems are directly influenced by the design and dimensions of their critical components. The selection of structural elements and their connections plays a crucial role in overall performance, particularly in linear valve configurations, where key parameters define functionality and durability. The geometric shape and dimensions of working components are fundamental in ensuring optimal operation, long-term reliability, and the ability to withstand industrial demands. When analysing linear valve structures, several critical parameters must be considered:

Dimensional characteristics of the valve in both assembled and disassembled states.

Stress distribution across structural components and connection nodes, considering exposure to various operational environments, including corrosive, acid-alkaline, and aggressive conditions.

Thermal treatment processes applied to valve components, such as surface hardening techniques and the arrangement of elements within the valve assembly.

The overall size and shape of key valve components are determined by operational requirements and environmental conditions. Structural elements must not only fulfil their primary functional roles but also exhibit resilience to applied forces, efficient load distribution, and sustained performance throughout their operational lifespan. Sealing integrity is maintained through metal-metal or metal-rubber couplings, ensuring leak-proof closure. Among the various components, hermetic sealing elements are particularly vulnerable to wear and degradation due to continuous exposure to mechanical and environmental stresses.

This study specifically focuses on the sealing seat interface between the hermetic element and the valve body, where mechanical compression and fluid-induced erosion occur due to direct exposure to internal flow. The erosive effects modelled in this research are primarily associated with solid particle impact and turbulent shear forces that act on the exposed edges of the hermetic element during valve operation. Other sealing components such as bonnet gaskets or stem packings are outside the scope of this study.

While rubber components are known to absorb fluid and may promote corrosion, the rubber interface used in this study is mechanically confined and supported by metallic elements. In future studies, alternative materials such as PTFE or fluoropolymer composites will be considered to improve chemical resistance and erosion protection in high-corrosivity environments.

The secure integration of sealing elements within a valve system is influenced by physical-mechanical and technological factors. Physical-mechanical factors pertain to the intrinsic material properties, such as strength, elasticity, and resistance to wear, while technological factors involve the stress-deformation state of the sealing elements, affected by pressure variations, displacement speeds, and operational conditions. The combined impact of these factors plays a decisive role in determining the durability and efficiency of sealing elements in enhanced valve designs.

In modelling the hermetic element's interaction within the sealing interface, the elastomeric contact surface was assumed to be made of nitrile butadiene rubber (NBR), a material widely used in industrial valves due to its chemical resistance and sealing capability. For simplification under quasi-static and small-deformation conditions, a linear elastic (Hookean) material behaviour was assumed, using a Young's modulus of 0.1 MPa and a Poisson's ratio of 0.49, consistent with published properties of NBR under moderate temperatures. Frictional interaction between the sealing element and mating surfaces was considered, with a coefficient of friction of 0.65 for dry contact. Specifically, in the equilibrium calculations illustrated in Figure 2, the frictional force was accounted for as part of the stress distribution model, influencing the shear component in the derived expressions.

However, we acknowledge that rubber is fundamentally a non-Hookean material whose stress-strain behaviour is nonlinear and sensitive to temperature, strain rate, and pressure. A more accurate representation involves hyperplastic constitutive modelling. For example, rubber's stress behaviour may be defined using strain energy functions such as the Mooney-Rivlin or Neo-Hookean models. A generalized stress formulation is given by:

$$\sigma_i = 2C_1 J^{-5/3}\left[\lambda_i^2 - \frac{I_1}{3}\right] + 2D_1\,(J-1) \quad (1)$$

where, C_1 and D_1 are material-specific constants, λ_i is the principal stretch ratio, I_1 is the first strain invariant, and J is the deformation volume change. Although not used in the present study, this approach provides a more rigorous basis for analysing elastomeric sealing elements, especially under large deformations or thermal loading.

The mechanical properties of materials used in hermetic elements are critical in ensuring reliability. The chosen material must meet the stringent operational demands imposed by industrial applications. Additionally, technological considerations introduce further complexity by incorporating dynamic pressure fluctuations and movement speeds into the stress-deformation analysis of sealing elements. Understanding these interactions is essential for enhancing overall sealing performance and structural integrity.

A key aspect of this dynamic relationship is the force distribution on the hermetic element, which is vital for both its efficiency and the overall functionality of the valve system. Achieving optimal fastening and sustained valve performance requires a comprehensive understanding of the interplay between material properties and operational forces. The correlation between stress and deformation in rubber ring fasteners, which are critical for securing hermetic elements through moulding effects, is primarily influenced by the configuration and dimensions of the sealing component.
Therefore, an in-depth analysis of initial stress conditions and subsequent deformation behaviour is necessary. The design and geometric structure of the fastening mechanism significantly impact performance and reliability, reinforcing the need for precise engineering and material optimization in advanced valve designs.

The precise geometry of the hermetic element plays a critical role in its overall functionality and sealing efficiency. A detailed analysis of the initial stress conditions and deformation behaviour provides key insights into the complex mechanics governing the secure placement of the hermetic element within rubber ring fasteners. One of the most significant design considerations is the cross-sectional shape of the hermetic element, which, in this study, is assumed to have a trapezoidal cross-section (Fig. 2).

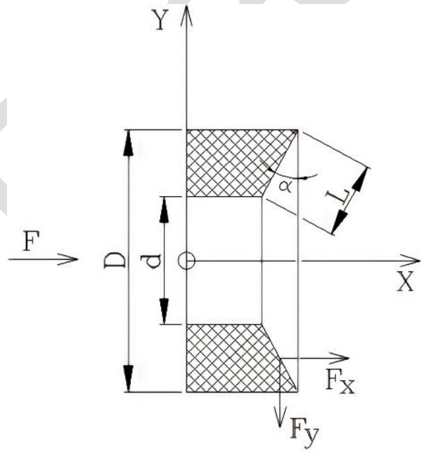

Fig. 2. Calculation scheme for the trapezoidal cross-sectioned hermetic element

To determine the equivalent stress, the force components acting on the sealing element are analysed. Based on the proposed calculation scheme, the equivalent stress can be determined using the following formulation:

$$\sigma = \sqrt{\sigma_X^2 - \sigma_X \cdot \sigma_Y + \sigma_Y^2 + 3\tau_{XY}^2} \qquad (2)$$

where, σ_X, σ_Y- main stresses over X & Y axis, τ_{XY} is shear stress. In the chosen scheme $\tau_{XY} = 0$ Mpa.

As it is known, according to the generalized Hooke's law, the relationship between the principal stresses $\sigma_x; \sigma_y; \sigma_z$ acting in three directions, and the relative strain is as follows:

$$E_x = \frac{1}{E}\left[\sigma_x - \mu(\sigma_y + \sigma_z)\right] \qquad (3)$$

$$E_y = \frac{1}{E}\left[\sigma_y - \mu(\sigma_x + \sigma_z)\right] \qquad (4)$$

$$E_z = \frac{1}{E}\left[\sigma_z - \mu(\sigma_x + \sigma_y)\right] \qquad (5)$$

In plane problems, as is known, the previously mentioned equations are simplified. Since $\sigma_z = 0$, the determination of deformations will be as follows:

$$E_x = \frac{1}{E}(\sigma_x - \mu\sigma_y) \tag{6}$$

$$E_y = \frac{1}{E}(\sigma_y - \mu\sigma_x) \tag{7}$$

$$\gamma_{xy} = \frac{\tau_{xy}}{G} = \frac{2\cdot(1+\mu)}{E}\cdot\tau_{xy} \tag{8}$$

if, $\sigma_z \neq 0;\ E_z = 0$, then,

$$\sigma_z = \mu(\sigma_x + \sigma_y) \tag{9}$$

If we solve the variations for constructing the equilibrium equations in terms of the dependence of displacement on stress, we obtain the following equations:

$$E_x = \frac{1+\mu}{E}\left[(1-\mu)\sigma_x - \mu\sigma_y\right] \tag{10}$$

$$E_y = \frac{1+\mu}{E}\left[(1-\mu)\sigma_x - \mu\sigma_x\right] \tag{11}$$

$$\gamma_{xy} = \frac{\tau_{xy}}{G} = \frac{2\cdot(1+\mu)}{E}\cdot\tau_{xy} \tag{12}$$

Considering that the displacement moves along the X-axis at a certain angle, we perform the calculations based on equation (9) for the expression Ex=0. The given data are accepted as follows: P = 70 MPa; D= 9 mm; d= 6 mm; $\mu = 0.34$; E= 0.1 MPa; $\alpha = 0 \div 90$;

2.1 Optimization and validation of the sealing angle

The opening and closing of the improved valve design are achieved by rotating its gate by 90 degrees (figure 3). The flow of the product passing through the inlet port is blocked by the rotation of the gate, which is then exposed to the pressure of the passing fluid. The semi-ellipsoidal shape of the gate element ensures an optimal distribution of pressure over its surface. As a result, sealing elements of the valve's sealing assembly experience reduced loading, enhancing their durability. Due to the load distribution along the sealing surfaces, the gate is pressed against the seal-gate pair, creating a complete sealing at the outlet port of the valve, thereby fully stopping the fluid flow. The hermetic elements positioned behind the seal ensure a hermetic sealing between seal and valve body. A disc-shaped spring provides initial sealing between the gate and the seal during assembly and counteracts the fluid pressure in operational conditions.

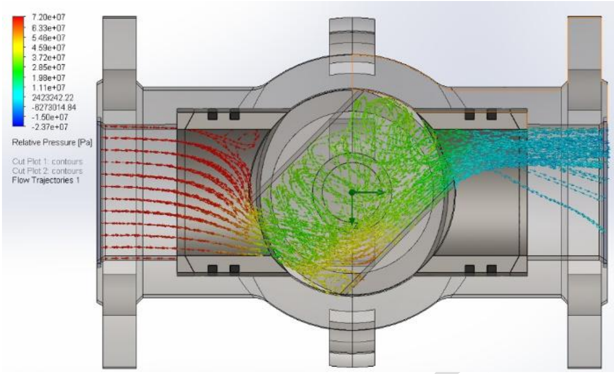

Fig. 3. Simulation model from SOLIDWORKS for improved valve design.

To optimize the sealing angle of the hermetic element in an improved gate valve, a comprehensive numerical approach was employed. The study integrates finite element analysis (FEA), computational modelling, and optimization techniques to determine the most effective angle for minimizing wear while ensuring optimal sealing performance.

The optimization process involves evaluating the stress distribution and deformation characteristics of the trapezoidal cross-sectioned sealing element under varying operating conditions. The sealing angle plays a crucial role in distributing forces evenly, reducing stress concentrations, and enhancing the overall reliability of the valve. By applying MATLAB's bee colony algorithm, the study refines angle variations and identifies 62 degrees as the optimal displacement angle that minimizes wear and ensures effective sealing. The numerical validation of the proposed optimization was conducted using SOLIDWORKS for 3D modelling (Fig. 3) , for stress-strain analysis, and MATLAB for optimization algorithms. The equivalent stress equations derived for the hermetic element were applied to the numerical model to evaluate deformation behaviour under varying force projections along the X and Y axes.

To further validate the results, findings from this study were compared with previous research on valve optimization techniques. Some authors demonstrated that lubrication coatings significantly reduce erosion-related wear [1], while others utilized CAD-based FEA analysis to study pressure-induced stress in sealing elements [13]. Additionally, elastic deformations and hydrodynamic lubrication in valve plates examined, reinforcing the importance of stress distribution in wear reduction [14-16].

By integrating these methodologies, the study ensures accuracy in determining the optimum sealing angle, contributing to enhanced wear resistance, structural integrity, and sealing efficiency in gate valve constructions. The validated 62-degree angle presents a practical design enhancement for extending valve lifespan and improving performance in high-pressure environments. To further refine the optimal sealing angle determination, a fuzzy logic-based approach was implemented using MATLAB's Fuzzy Logic Toolbox (Fig. 4). The Rule Viewer, as shown in Figure X, illustrates the relationship between multiple input variables and their effect on the output variable, which represents optimal performance characteristics of the hermetic element. The study utilizes a multi-input, single-output (MISO) fuzzy system, where the input variables include parameters such as, Input1 (Material property factor); Input2 (Contact pressure variation); Input3 (Wear rate effect); Input4 (Thermal stress factor); Input5 (Lubrication efficiency); Input6 (Geometrical influence factor on wear). These inputs are dynamically processed through a fuzzy rule-based system, where each variable undergoes linguistic classification such as low, medium, and high impact levels.

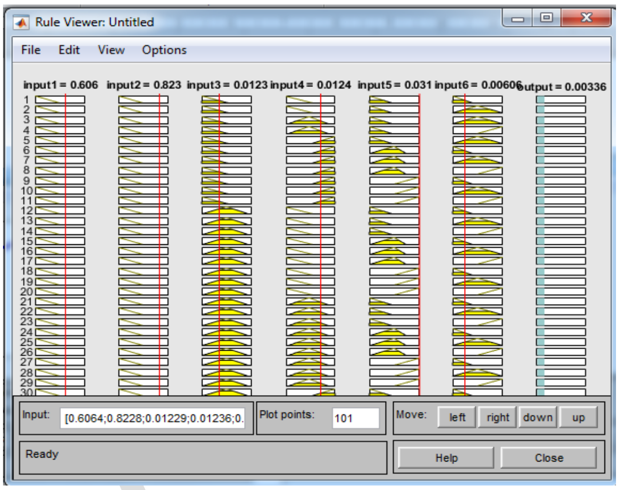

Fig. 4. Wearing intensity for the chosen valve construction hermetic element.

The fuzzy inference mechanism evaluates these inputs using predefined membership functions and logical rules to determine the optimal sealing angle. The Rule Viewer output (Figure X) presents a graphical representation of the fuzzy inference process, showing how different input variables interact and influence the output function. The yellow-shaded areas in the rule set indicate active inference pathways, highlighting the key factors that contribute to wear minimization and pressure stabilization.

The fuzzy system results confirm that a sealing angle of approximately 62 degrees yields the lowest wear rate, validating the numerical optimization findings (Fig 5).

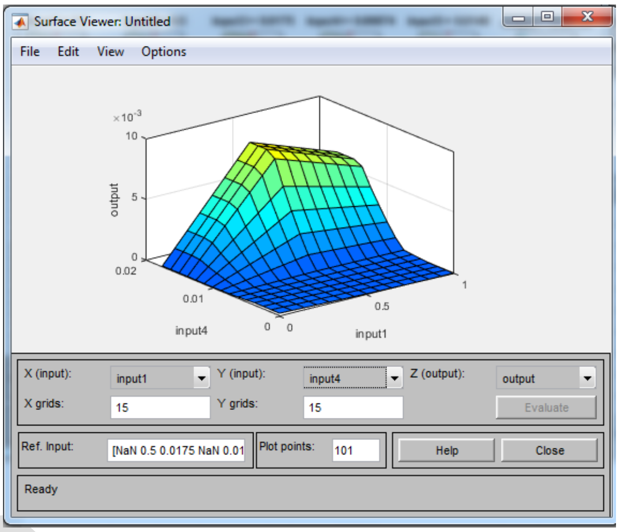

Fig. 5. Interaction between multiple input variables

By leveraging fuzzy logic alongside traditional finite element analysis, the study achieves a robust optimization framework that enhances the longevity and efficiency of the sealing element.

To enhance the accuracy of sealing angle determination, MATLAB's Fuzzy Logic Toolbox was employed to analyse the interaction between multiple input variables. The Surface Viewer (Figure X) provides a 3D visualization of how selected parameters influence the output variable, representing wear rate or sealing performance. The 3D surface plot in Figure X depicts the relationship between Input1 (e.g., material property factor) and Input4 (e.g., thermal stress impact) in determining the sealing efficiency. The output function, represented on the Z-axis, reflects how variations in these two parameters influence the sealing element's wear characteristics. The gradient change in surface elevation indicates that at higher values of Input1 and Input4, the output stabilizes, suggesting that an optimal combination of material strength and thermal resistance is crucial in minimizing wear-induced degradation. The peak of the surface plot suggests that beyond a specific range of input conditions, the improvements in sealing efficiency plateau, reinforcing the importance of selecting an optimal sealing angle. The fuzzy logic-based surface visualization supports the 62-degree sealing angle as the most effective configuration.

This approach enhances traditional finite element methods by providing a rule-based optimization framework, ensuring long-term valve durability under high-pressure conditions.

A simulation was carried out in to visualize the deformation behaviour of the sealing element under internal pressure. Figure 6 shows the equivalent strain distribution (ESTRN) for the 62° configuration, with mesh refinement applied near the contact interface. Boundary conditions are indicated in green (fixed supports), and pressure load vectors are marked in red. This model helps identify regions of stress concentration and validate the optimized angle from a structural standpoint.

As illustrated in Figure 7, the displacement curve demonstrates a gradual decrease with increasing angle, reaching a minimum displacement point at 62 degrees, marked as point A. This point represents the most stable configuration, where the hermetic element experiences minimal deformation while maintaining effective sealing properties.

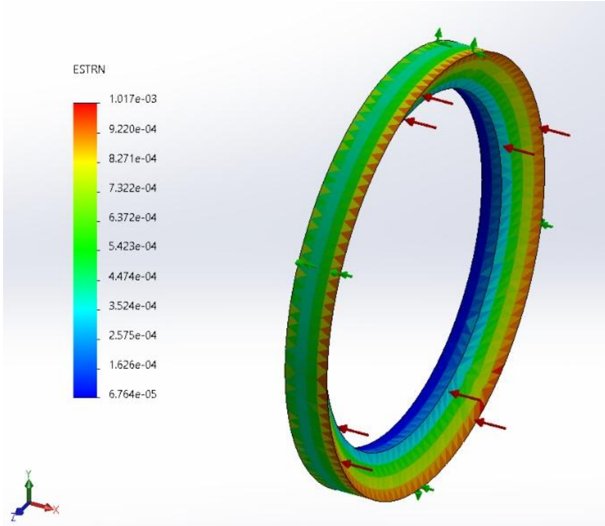

Fig. 6. The deformation/strain distribution (ESTRN) in chosen scale over trapezoidal cross sectioned element.

The corresponding stress values at this angle, σ_X= 0.0077141242 MPa and σ_Y= 0.0145081575 MPa, confirm that stress concentrations remain within an acceptable range, preventing excessive wear and mechanical failure. Additionally, the strain values, E_x = 0.0002125 and E_Y = 0.0033078, further validate the mechanical stability at this optimized configuration.

The findings align with prior finite element analysis (FEA), and fuzzy logic-based assessments, reinforcing the robustness of the 62-degree sealing angle in enhancing durability and operational efficiency.

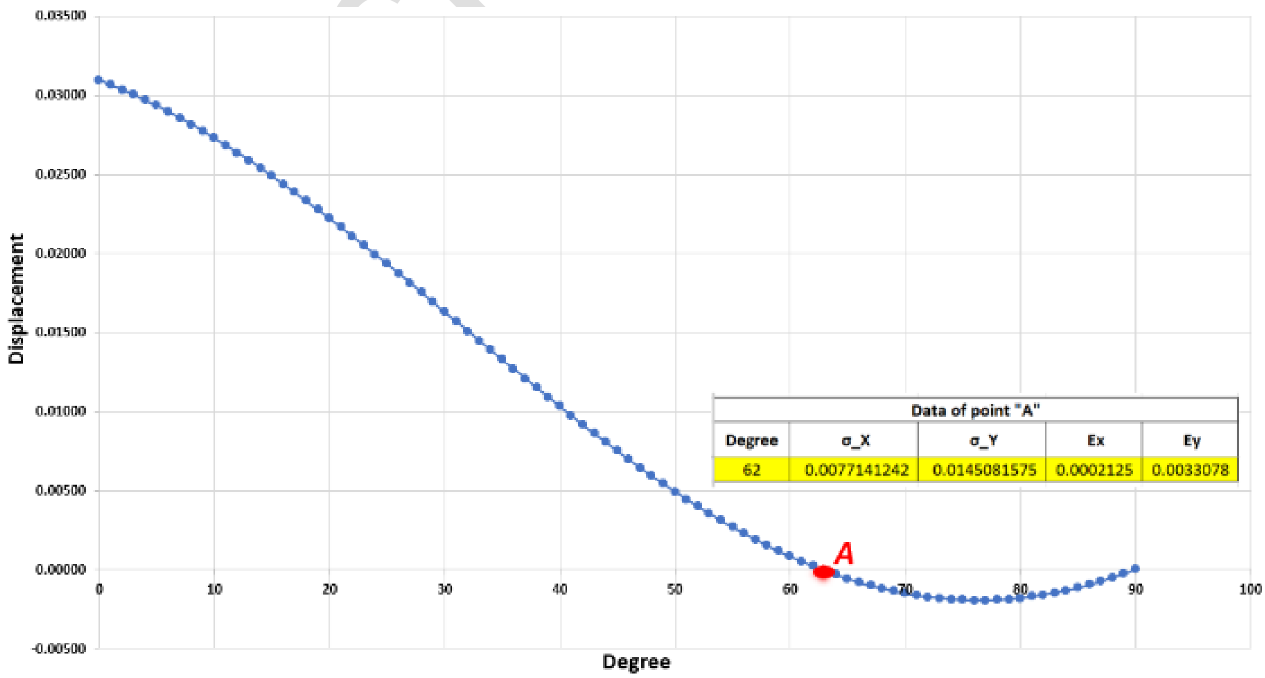

Fig. 7. Determination of the seating angle of the trapezoidal cross-section packing element.

To validate the optimality of the 62° sealing angle, additional simulations were performed for 55° and 70° configurations under identical loading and boundary conditions. Table 1 presents the comparison of equivalent stress, displacement, and estimated wear rate across these three angles.

Table 1. Comparison of sealing element performance at different angles.

Angle	Equivalent stress, MPa	Maximum displacement (mm)	Relative wear intensity
55	0.0092	0.0029	High
62	0.0077	0.0021	Low
70	0.0088	0.0027	Medium

As shown, the 62° configuration yields the lowest equivalent stress and displacement, indicating better sealing contact and reduced wear under simulated conditions. These results were further validated using the fuzzy logic inference system, reinforcing the selection of 62° as the optimal sealing angle.

3. CONCLUSION

This research provides a comprehensive analysis of the equivalent stress and strain distribution in the hermetic elements of an enhanced gate valve, emphasizing the impact of wear and material properties on performance and durability. By integrating finite element analysis, numerical simulations, and fuzzy logic-based optimization techniques, the study identifies an optimal sealing angle of 62 degrees for trapezoidal hermetic elements. This configuration effectively minimizes wear while ensuring maximum sealing efficiency under high-pressure operational conditions.

The developed computational framework, which incorporates MATLAB-based fuzzy logic and the bee colony optimization method, enables precise modelling of pressure distribution and material interactions within the sealing components.
The study demonstrates that different material pairings, particularly ST20X–ST20X and ST40X–ST20X, exhibit distinct wear behaviours under simulated loading. These results were obtained using finite element simulations incorporating verified material properties. ST40X, being a harder structural steel, showed improved wear resistance but led to higher local stress concentrations, while ST20X provided better deformation compliance. This comparison highlights the importance of strategic material selection based on the specific operational priorities of the valve system. Comparative analysis with previous research reinforces the significance of optimizing structural parameters to reduce stress concentrations and extend service life. Furthermore, the study confirms that advanced parametric evaluations and 3D visualization techniques significantly enhance the understanding of stress-strain behaviour in hermetic elements. The findings contribute to the refinement of industrial valve designs by providing a structured methodology for optimizing material properties, geometric configurations, and sealing mechanisms. By validating the 62-degree sealing angle through numerical modelling, this research establishes a practical benchmark for improving gate valve durability and operational efficiency in high-pressure environments.

Future research should explore additional material compositions and dynamic loading conditions to further refine sealing element performance. Experimental validation through real-world testing could complement the computational framework, ensuring the reliability and applicability of these findings in industrial applications. The insights gained from this study not only advance gate valve technology but also lay the foundation for broader innovations in sealing mechanisms used in oil and gas systems.

Beyond gate valves, the integrated optimization methodology presented in this study can be applied to other mechanical systems involving dynamic seals or contact elements. These include reciprocating pump seals, piston-cylinder interfaces, and other tribological components where optimizing contact geometry and material behaviour is critical to reducing wear and improving service life.

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