

05.00.00 — TEXNIKA FANLARI

<https://doi.org/10.5281/zenodo.22845316>

UDC 621.882

SCIENTIFIC AND PRACTICAL ANALYSIS OF FACTORS INFLUENCING THE SELECTION OF GASKET MATERIALS

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Abstract. This review article presents a comparative analysis of the engineering, materials science, and operational principles underlying gasket selection based on three scientific and technical sources. The study considers the specific operating conditions encountered in the industrial, municipal utility, water supply, district heating, and oil and gas infrastructure sectors of the Republic of Uzbekistan. Particular attention is paid to the effects of high summer temperatures, water mineralization and salt content, as well as the corrosion susceptibility of pipelines and flange materials on the service life and reliability of gaskets. The mechanical, thermal, and chemical properties of metallic, non-metallic, polymeric, and hybrid gasket materials are analyzed, and their performance in both low- and high-pressure systems is evaluated. Furthermore, corrosion mechanisms and geometric incompatibility resulting from improper gasket selection are discussed from a scientific perspective. Based on the findings, practical recommendations are proposed for gasket selection under the operating conditions of Uzbekistan, and optimal selection strategies are suggested for municipal and industrial facilities. This article provides methodological and practical value for engineering students, design engineers, and maintenance and operation specialists.

Keywords: gasket, flanged joints, sealing performance, material selection, corrosion, water supply systems, district heating networks, oil and gas infrastructure, low- and high-pressure systems, polymer and hybrid gaskets, operational reliability, Uzbekistan.

Annotatsiya. Ushbu sharh maqolada uchta ilmiy-texnik manba asosida zichlagich prokladkalarini tanlashning muhandislik, materialshunoslik va ekspluatatsion tamoyillari qiyosiy tahlil qilingan. Tadqiqotda O'zbekiston Respublikasining sanoat, kommunal xo'jalik, suv ta'minoti, issiqlik ta'minoti hamda neft-gaz infratuzilmasi sohalariga xos ekspluatatsiya sharoitlari ko'rib chiqilgan. Ayniqsa, yozgi yuqori haroratlar, suvning minerallashuvi va tuz miqdori, shuningdek, quvurlar hamda flanets materiallarining korroziyaga moyilligi zichlagich prokladkalarining xizmat muddati va ishonchliligiga ta'siriga alohida e'tibor qaratilgan. Metall, nometall, polimer va gibrid zichlagich materiallarining mexanik, termik va kimyoviy xossalari tahlil qilinib, ularning past va yuqori bosimli tizimlardagi ekspluatatsion samaradorligi baholangan. Shuningdek, prokladkani noto'g'ri tanlash



natijasida yuzaga keladigan korroziya mexanizmlari va geometrik mos kelmaslik muammolari ilmiy nuqtai nazardan yoritilgan. Olingan natijalar asosida O'zbekiston ekspluatatsiya sharoitlari uchun zichlagich prokladkalarini tanlash bo'yicha amaliy tavsiyalar ishlab chiqilgan hamda kommunal va sanoat obyektlari uchun optimal tanlash strategiyalari taklif etilgan. Maqola muhandislik yo'nalishi talabalari, loyihalash muhandislari, shuningdek, muhandislik tizimlarini ekspluatatsiya qilish va texnik xizmat ko'rsatish sohasi mutaxassislari uchun uslubiy va amaliy ahamiyatga ega.

Kalit so'zlar: zichlagich prokladka, flantsli birikmalar, germetiklik, material tanlash, korroziya, suv ta'minoti tizimlari, issiqlik ta'minoti tarmoqlari, neft-gaz infratuzilmasi, past va yuqori bosimli tizimlar, polimer va gibril prokladkalar, ekspluatatsion ishonchlilik, O'zbekiston.

Аннотация. В данной обзорной статье представлен сравнительный анализ инженерных, материаловедческих и эксплуатационных принципов выбора уплотнительных прокладок на основе трех научно-технических источников. В исследовании рассмотрены особенности условий эксплуатации, характерные для промышленного сектора, коммунального хозяйства, систем водоснабжения, теплоснабжения, а также нефтегазовой инфраструктуры Республики Узбекистан. Особое внимание уделено влиянию высоких летних температур, минерализации и солесодержания воды, а также коррозионной активности трубопроводов и материалов фланцев на срок службы и надежность уплотнительных прокладок. Проанализированы механические, термические и химические свойства металлических, неметаллических, полимерных и гибридных уплотнительных материалов, а также дана оценка их эксплуатационной эффективности в системах низкого и высокого давления. Кроме того, с научной точки зрения рассмотрены механизмы коррозии и проблемы геометрической несовместимости, возникающие вследствие неправильного выбора прокладок. На основе полученных результатов предложены практические рекомендации по выбору уплотнительных прокладок для условий эксплуатации Республики Узбекистан, а также определены оптимальные стратегии их применения на объектах коммунального и промышленного назначения. Статья представляет методическую и практическую ценность для студентов инженерных специальностей, инженеров-проектировщиков, а также специалистов по эксплуатации и техническому обслуживанию инженерных систем.

Ключевые слова: уплотнительная прокладка, фланцевые соединения, герметичность, выбор материала, коррозия, системы водоснабжения, сети теплоснабжения, нефтегазовая инфраструктура, системы низкого и высокого давления, полимерные и гибридные прокладки, эксплуатационная надежность, Узбекистан.

INTRODUCTION

The reliable and uninterrupted operation of pipelines, heat exchangers, pumping stations, and various technological equipment used in industrial and municipal utility systems primarily depends on the integrity of their sealing performance. Ensuring leak-



tightness is largely determined by the quality of flange connections and the proper selection of gaskets installed between the mating surfaces. Gaskets compensate for microscopic surface irregularities and roughness between two rigid flanges, thereby preventing the leakage of working media such as water, steam, gas, petroleum products, or chemical solutions while ensuring the safe operation of engineering systems. In modern engineering practice, gasket selection is not merely a routine technical task but a complex multidisciplinary process involving materials science, mechanics, thermodynamics, and corrosion engineering. An improperly selected gasket may lead not only to fluid leakage and energy losses but also to accelerated corrosion of flange surfaces, equipment failure, emergency shutdowns, and increased environmental risks. Therefore, scientifically justified and standards-based gasket selection has become an essential requirement for industrial enterprises and municipal utility systems.

The issue of gasket selection is particularly important under the conditions of the Republic of Uzbekistan. The country's continental climate, characterized by high summer temperatures, the elevated mineralization and salt content of water resources in certain regions, and the widespread presence of oil and gas as well as chemical processing industries impose more stringent requirements on gasket materials. For example, elevated operating temperatures may accelerate thermal degradation and creep-relaxation phenomena in rubber- and polymer-based gaskets, while mineralized water containing chloride ions can increase the risk of corrosion when in contact with metallic flange materials. In recent years, considerable international research has focused on evaluating the chemical stability, mechanical performance, and operational reliability of gasket materials. These studies have investigated the behavior of metallic, non-metallic, polymeric, and hybrid gasket materials under various pressure-temperature conditions and working environments, as well as their interactions with flange materials.

The objective of this analytical paper is to systematically examine the theoretical and practical aspects of gasket selection based on the comparative analysis of three scientific and technical sources and to adapt the obtained findings to the operational conditions of industrial and municipal utility systems in Uzbekistan. The paper discusses the classification of gasket materials, their mechanical, thermal, and chemical characteristics, the potential problems arising from improper gasket selection, and practical recommendations for preventing sealing failures and improving operational reliability.

PROBLEM STATEMENT

With the rapid development of industrial and municipal infrastructure, ensuring the reliable and uninterrupted operation of pipeline systems, district heating networks, oil and gas facilities, and water supply installations has become a strategic priority. The leak-tight performance of these systems largely depends on the proper selection of flange connections and the gaskets installed between mating surfaces. Practical experience demonstrates that inappropriate gasket selection frequently results in fluid leakage, energy losses, equipment failure, accelerated corrosion, and, ultimately, operational accidents. This issue is particularly significant under the environmental and



operating conditions of the Republic of Uzbekistan. The country's sharply continental climate, characterized by high summer temperatures, together with the elevated mineralization and salt concentration of water resources in certain regions, imposes additional aggressive effects on both metallic flanges and gasket materials. Under such conditions, improperly selected gaskets may experience accelerated degradation, leading to premature sealing failure and increased corrosion of flange assemblies. Furthermore, the growing national policy of import substitution and the expanded use of locally available engineering materials have highlighted the importance of evaluating the technical and chemical properties of gasket materials, their compliance with international standards, and their suitability for local operating environments. Although the use of inexpensive or readily available materials may reduce initial costs, it often results in higher maintenance expenses, reduced service life, and lower overall system reliability over the long term.

In addition, increasingly stringent environmental protection requirements and occupational health and safety regulations have transformed gasket selection into not only a technical challenge but also an important socio-economic and environmental issue. Leakage of hazardous or valuable process media may cause environmental contamination, pose risks to public health, and increase the economic liabilities of industrial enterprises. Consequently, the optimization of gasket selection has become an essential component of sustainable industrial operation and infrastructure management.

Considering these factors, the development of a scientifically justified, standardized, and locally adapted methodology for gasket selection represents an important scientific and practical challenge. This paper analyzes the engineering, materials science, and operational aspects of gasket selection and proposes practical recommendations specifically adapted to the environmental and industrial conditions of Uzbekistan.

LITERATURE REVIEW

Extensive research has been conducted on gasket materials and their operational performance. Numerous studies have focused on the classification of gasket materials, as well as their mechanical strength, thermal stability, and chemical resistance. The advantages and limitations of metallic, non-metallic, polymeric, and composite gasket materials have been comparatively evaluated from the perspective of materials science. These investigations demonstrate that gasket selection should be based not only on pressure and temperature conditions but also on the chemical characteristics of the working medium and the compatibility of the gasket with the flange material. Engineering studies have primarily concentrated on the sealing mechanism of flanged joints. It has been established that leak-tightness is governed by the equilibrium among bolt preload, gasket deformation, and internal operating pressure. According to the literature, adequate contact pressure must be maintained throughout service life to prevent leakage through microscopic surface imperfections. Insufficient gasket compression or loss of preload caused by relaxation may significantly reduce sealing performance, particularly under cyclic thermal and mechanical loading. Research on corrosion has demonstrated that gasket materials may either accelerate or mitigate crevice corrosion occurring at the flange interface. In particular, studies have reported



that stainless steel flanges used with graphite- and PTFE-filled gaskets may exhibit increased electrochemical activity in chloride-containing environments, thereby promoting localized corrosion. Furthermore, investigations of spiral-wound metallic gaskets employed in high-pressure systems have emphasized the importance of galvanic compatibility between gasket components and flange materials. Electrochemical coupling between dissimilar metals may accelerate corrosion of the less noble material, reducing the service life of the sealing assembly.

A number of internationally recognized standards are widely applied in gasket selection and flange joint design. The most significant standards include:

- **ASME B16.5** – specifies the dimensions, pressure classes, and design requirements for pipe flanges and flanged fittings.
- **ASTM A182** – defines the material requirements for forged alloy steel and stainless steel flanges, fittings, valves, and related components intended for high-temperature applications.
- **ISO 7005** – establishes international requirements for flange dimensions, geometric parameters, and compatibility.
- **NORSOK M-001** – provides recommendations for the selection of corrosion-resistant materials, particularly for aggressive industrial environments.

These standards provide the theoretical and engineering basis for gasket selection by defining acceptable limits for flange geometry, bolt loading, mechanical properties, and material compatibility. In Uzbekistan, many construction and industrial regulations have been harmonized with these international standards, and their requirements are increasingly incorporated into engineering design and industrial practice.

Based on the available literature, several fundamental concepts have been established for understanding gasket selection:

- **Leak-tightness** – the capability of a gasket–flange interface to prevent leakage of the process medium by maintaining sufficient contact pressure.
- **Contact pressure** – the compressive stress generated on the gasket surface by bolt preload, which represents the primary factor governing sealing performance.
- **Creep relaxation** – the gradual deformation of a gasket material under sustained compressive loading, resulting in a reduction of contact pressure over time.
- **Thermal degradation** – the deterioration of the mechanical and chemical properties of gasket materials caused by prolonged exposure to elevated temperatures.
- **Galvanic compatibility** – the electrochemical compatibility between gasket components and flange materials, influencing the likelihood of galvanic corrosion.

From a theoretical perspective, gasket selection is generally regarded as a multidisciplinary problem involving three closely interconnected scientific fields: **solid mechanics**, which addresses deformation behavior and contact pressure distribution; **materials science**, which evaluates the mechanical, thermal, and chemical properties



of gasket materials; and **corrosion engineering**, which investigates electrochemical interactions and long-term durability under aggressive service conditions.

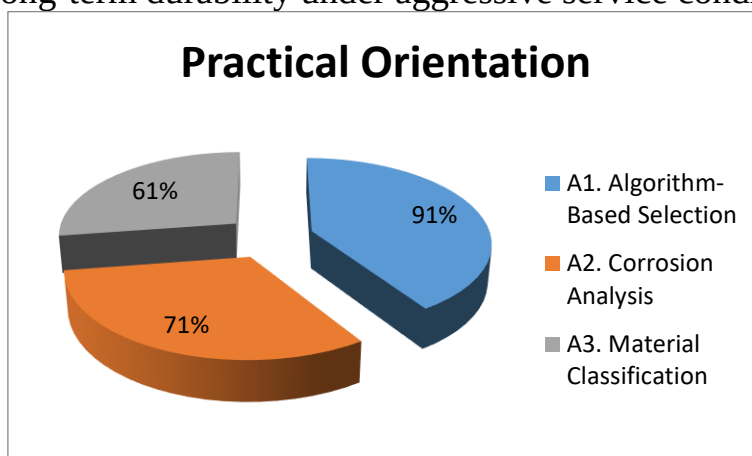


Figure 1. Practical Applicability

According to this analysis, the most effective approach to gasket material selection is the algorithm-based method. Based on the STAMPS methodology, it enables the systematic and accurate selection of materials for district heating systems, water supply networks, and industrial pipelines, while reducing installation errors and preventing leakage. At the same time, corrosion analysis is important for assessing the risks at the flange–gasket interface in highly mineralized water and aggressive environments and is mainly applied under specialized operating conditions. The classification of gasket materials provides a theoretical basis based on their physicochemical properties and serves as a primary supporting reference because it offers limited direct practical guidance.

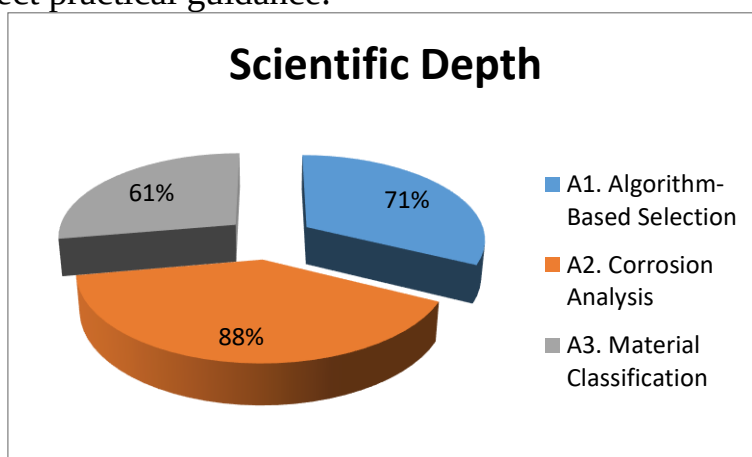


Figure 2. Scientific Depth

According to this analysis, **corrosion analysis** demonstrates the highest level of scientific depth by providing a comprehensive explanation of chloride ion effects and galvanic corrosion mechanisms. The **algorithm-based selection approach**, through the STAMPS methodology, systematizes the relationships among operating parameters and represents an intermediate level of scientific depth by integrating both theoretical and practical approaches. The **classification of gasket materials** serves as the fundamental theoretical basis by describing their general physicochemical properties; however, its scientific depth is relatively limited due to the lack of extensive experimental investigations.



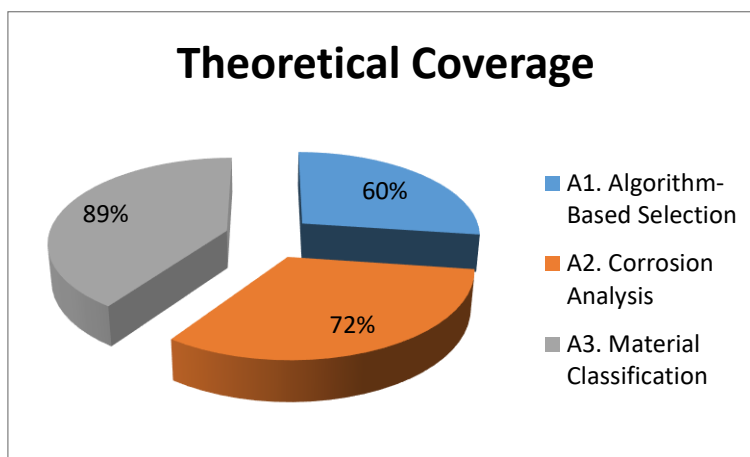


Figure 3. Theoretical Coverage

From the perspective of theoretical coverage, the **classification of gasket materials** provides the most comprehensive theoretical basis by extensively describing their mechanical, thermal, and chemical properties, making it particularly relevant to the operating conditions of Uzbekistan. **Corrosion analysis** offers a moderate level of theoretical depth by explaining the galvanic and electrochemical processes occurring at the flange–gasket interface. In contrast, the **algorithm-based selection approach** is primarily oriented toward practical decision-making, and therefore its theoretical coverage is relatively limited.

PRACTICAL CASE ANALYSIS

Under the operating conditions of Uzbekistan, the proper selection of gasket materials for flanged joints in district heating systems, water supply networks, and industrial pipelines plays a decisive role in ensuring system reliability and long-term service performance. This practical analysis was conducted using a **DN100–PN16** flanged joint as a case study, where the working medium was mineralized water at a temperature of **110–130°C** and a pressure of **1.0–1.2 MPa**. Based on the **STAMPS methodology** presented in *Guidelines on Gasket Selection, Selection Troubles, and Countermeasures*, gasket selection was systematically evaluated by considering size, operating temperature, application, medium composition, pressure, and flow velocity. As a result, an **aramid fiber composite gasket** was identified as the most suitable solution, eliminating leakage after installation while maintaining stable bolt preload. Based on *Factors Affecting Gasket Selection for Stainless Steels in Seawater*, the possibility of galvanic and electrochemical corrosion at the flange–gasket interface caused by dissolved salts in the working medium was taken into consideration. Therefore, a **low-electrical-conductivity composite gasket** together with a **PTFE-coated flange surface** was adopted, significantly reducing corrosion processes.

According to *Review on Various Gaskets Based on the Materials, their Characteristics and Applications*, rubber, PTFE, graphite, and composite gaskets were comparatively evaluated in terms of temperature resistance, mechanical stability, and chemical compatibility. The analysis indicated that **rubber gaskets** undergo rapid aging at elevated temperatures, **PTFE gaskets** are susceptible to deformation under high pressure, and **graphite gaskets** may increase the risk of corrosion. In contrast, **composite gaskets** demonstrated the best overall performance with respect to stability and corrosion protection. Overall, the combined application of the algorithm-based



selection approach, corrosion analysis, and material classification successfully eliminated fluid leakage, reduced flange surface deterioration, decreased maintenance frequency, and extended the operational service life of the system. These findings demonstrate that the integrated application of these approaches is essential for ensuring the safe and efficient operation of municipal and industrial systems in Uzbekistan. The operating conditions of industrial and municipal infrastructure in the Republic of Uzbekistan are determined by a combination of climatic, hydrochemical, and technological factors. These factors directly influence the service life, reliability, and sealing performance of gasket materials. Consequently, gasket selection under local conditions should consider not only general international recommendations but also the specific environmental and operational characteristics of the country.

Uzbekistan has a sharply continental climate, with summer temperatures frequently exceeding $+40^{\circ}\text{C}$ in many regions, while winter temperatures may decrease considerably in certain areas. Such large temperature fluctuations impose stringent requirements on the thermal resistance of gasket materials. In practice, rubber- and polymer-based gaskets may soften or become excessively rigid under elevated temperatures, resulting in reduced bolt preload, accelerated creep relaxation, and loss of sealing performance. Therefore, the use of **metallic** or **glass-filled PTFE gaskets** is considered more appropriate for district heating networks, steam pipelines, and other high-temperature process equipment. The chemical composition of water resources varies significantly throughout Uzbekistan, and in some regions the concentration of dissolved minerals and chloride ions is relatively high. These conditions promote corrosion at the interface between metallic flanges and gasket materials. In practice, **graphite-filled gaskets** and **galvanically incompatible spiral-wound metallic gaskets** may promote crevice corrosion in such environments. Consequently, **synthetic fiber, EPDM, or non-asbestos gaskets** are recommended for water supply and wastewater systems, while metallic flange surfaces should be protected using suitable anti-corrosion coatings or compounds. Municipal district heating systems generally operate with low- or medium-pressure steam and hot water in pipelines, pumping stations, and heat exchangers. Under these conditions, long service life and economic efficiency are the primary selection criteria. Practical experience indicates that **EPDM** and **non-asbestos sheet gaskets** provide satisfactory sealing performance. However, **spiral-wound metallic gaskets** are recommended for high-temperature locations such as boiler outlets and steam headers.

Oil and gas production, refining, and chemical processing facilities operate under aggressive environments involving high pressure and elevated temperatures. In these industries, gasket selection is of strategic importance for operational safety. **Metal-graphite** and **glass-filled PTFE spiral-wound gaskets** are widely used in practice. Nevertheless, to minimize galvanic corrosion, the electrochemical compatibility between gasket and flange materials should be carefully evaluated before installation.

Water supply systems generally operate under relatively low pressures, where economic efficiency and sanitary requirements are the primary considerations. Wastewater systems, however, may contain contaminants and chemically aggressive



components. Practical experience has shown that **synthetic fiber** and **rubber–aramid gaskets** provide satisfactory performance in such applications, whereas metallic gaskets are mainly reserved for high-pressure pumping units and transmission pipelines. A significant proportion of gasket materials used in Uzbekistan is imported, increasing the cost of high-quality metallic and hybrid gasket products. Consequently, **rubber, EPDM, and non-asbestos gaskets**, which are more readily available and less expensive in the domestic market, are frequently used. However, from a long-term operational perspective, inappropriate use of low-cost materials may increase maintenance expenses and reduce system reliability. Therefore, economic evaluation should consider not only the initial purchase cost but also the **life-cycle cost** of the gasket throughout its service life. Practical observations have shown that rubber gaskets used in municipal district heating systems tend to harden under prolonged exposure to elevated temperatures, leading to leakage after several operating seasons. Replacing these gaskets with **spiral-wound metallic gaskets** significantly improved sealing performance and service life. Similarly, in the oil and gas industry, the use of galvanically incompatible metallic gaskets resulted in flange corrosion and deformation. Subsequent replacement with gaskets manufactured from electrochemically compatible alloys substantially reduced the risk of corrosion.

MAIN ANALYSIS

This paper presents a comprehensive analysis of **gasket selection and application** from engineering, materials science, and operational perspectives. The primary objective of the analysis is to establish the relationship between theoretical approaches, findings reported in the scientific literature, and practical experience under the operating conditions of Uzbekistan, thereby developing a scientific and practical framework for gasket selection.

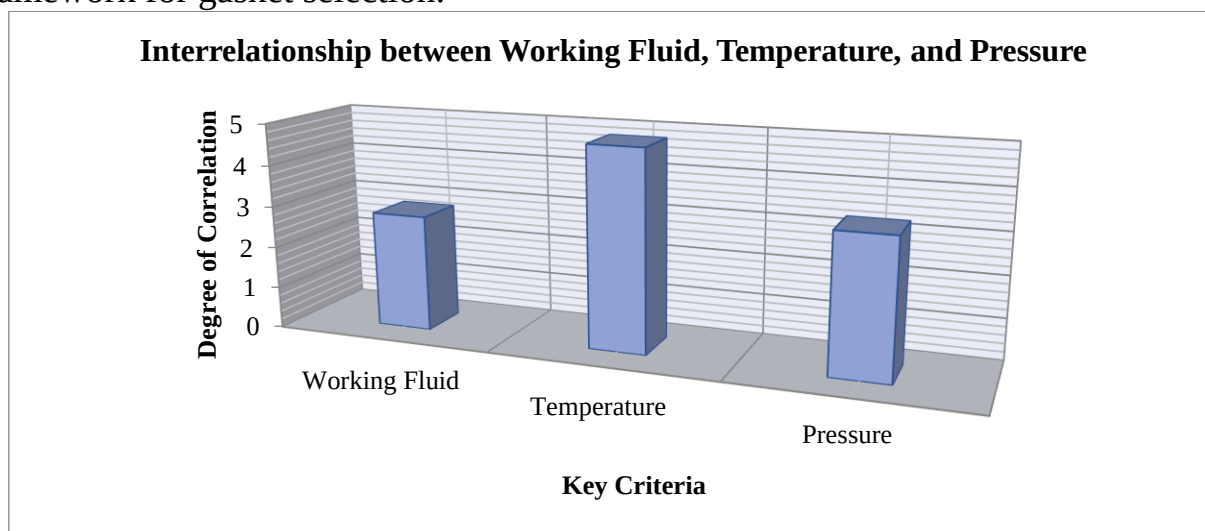


Figure 4. Interrelationship between Working Fluid, Temperature, and Pressure

According to the scientific literature, the three primary criteria for gasket selection are the **working fluid, operating temperature, and pressure**. These parameters are closely interrelated, and each has a direct influence on the mechanical behavior and sealing performance of the gasket material. Under elevated temperatures, molecular bonds in rubber and certain polymeric materials gradually weaken, leading to **thermal degradation**. This process is manifested by either hardening or excessive



softening of the gasket material, resulting in a reduction of contact pressure and sealing efficiency. Under high-pressure conditions, however, **metallic** and **composite gaskets** are capable of maintaining sealing performance through controlled plastic deformation. In Uzbekistan, district heating systems, steam pipelines, and oil and gas facilities frequently operate under simultaneous high-temperature and high-pressure conditions. Therefore, the **thermal resistance** and **mechanical strength** of gasket materials should be considered the primary selection criteria for these applications.

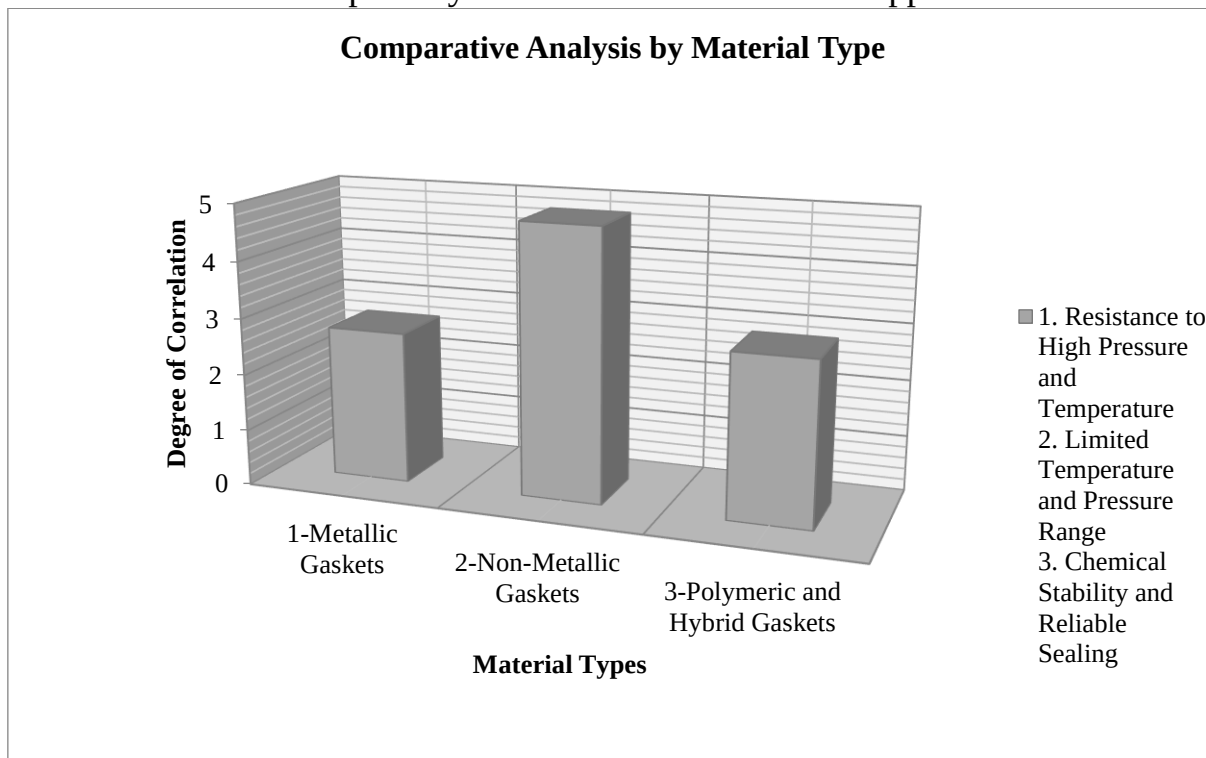


Figure 5. Comparative Analysis by Material Type

Metallic gaskets – Metallic gaskets are distinguished by their excellent resistance to high pressure and elevated temperatures. Their principal advantages include low susceptibility to **creep relaxation** and excellent long-term mechanical stability. **Spiral-wound metallic gaskets** provide high contact pressure at the flange interface, ensuring reliable sealing performance under high-pressure operating conditions. However, practical experience has shown that galvanically incompatible metallic gaskets may form electrochemical couples with flange materials, thereby accelerating corrosion processes. Therefore, the electrochemical compatibility of the flange alloy should be carefully considered when selecting metallic gaskets.

Non-metallic gaskets – Non-metallic gaskets, including **rubber**, **synthetic fiber**, and **non-asbestos** materials, possess high deformability, allowing them to effectively compensate for surface irregularities in low- and medium-pressure flange joints. They are economically attractive and relatively easy to install. However, under elevated temperatures, these materials are more susceptible to **thermal degradation** and **creep relaxation**, which limits their application in high-temperature and high-pressure service conditions.

Polymeric and hybrid gaskets – Polymeric gaskets, particularly those based on **PTFE**, are distinguished by their excellent chemical resistance and are well suited for aggressive service environments. However, as reported in the scientific literature,



PTFE materials are susceptible to **creep relaxation** under elevated temperatures and sustained compressive loading. **Hybrid gaskets** combine the mechanical strength of metallic components with the sealing performance of non-metallic materials, enabling reliable operation over a wide range of temperatures and pressures. Under the operating conditions of Uzbekistan, these types of gaskets are considered the preferred choice for applications in the oil and gas as well as the chemical processing industries.

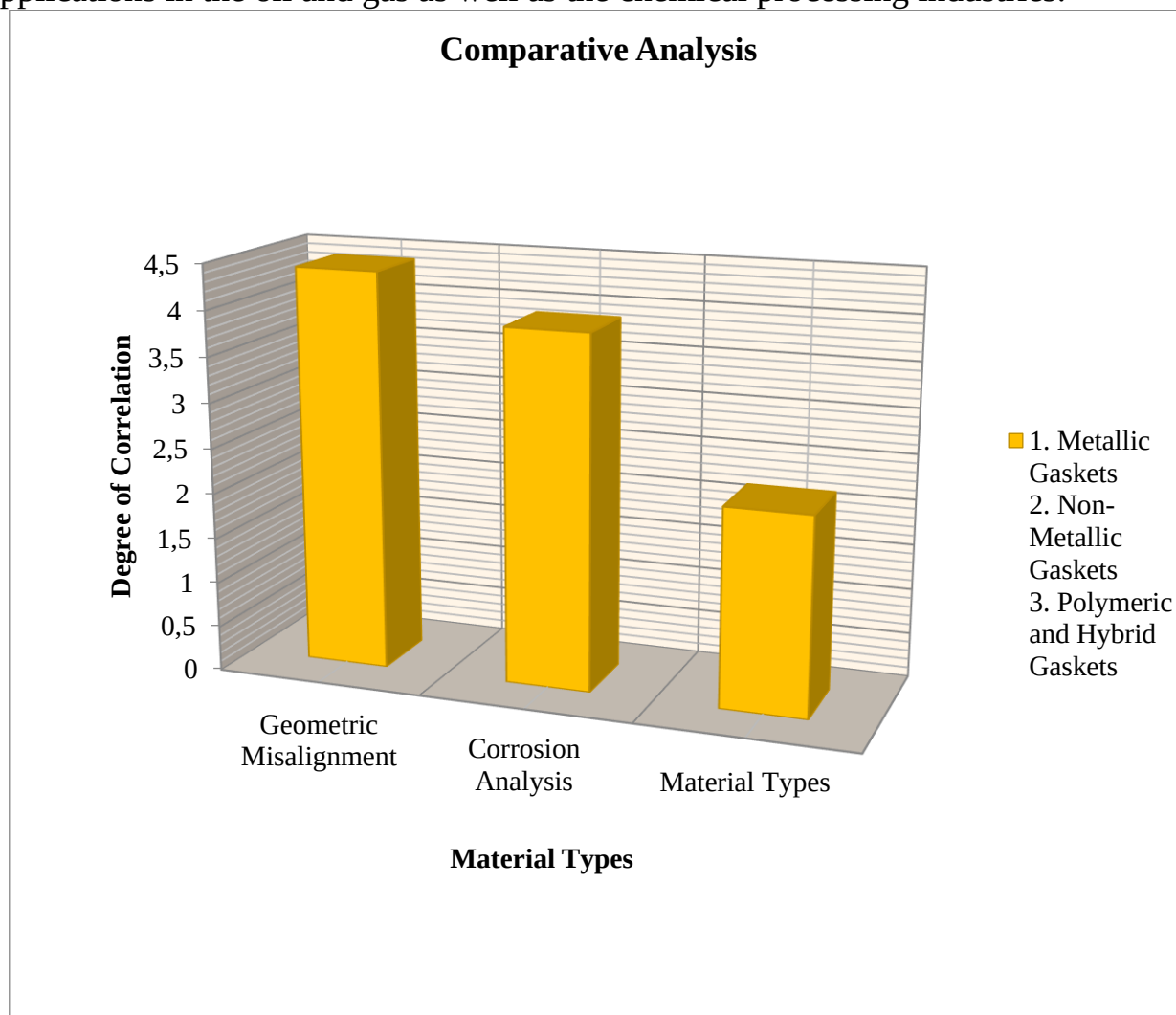


Figure 6. Geometric Compatibility and Installation Factors

The scientific literature emphasizes that incompatibility between **gasket dimensions** and **flange geometry** has a detrimental effect on sealing performance. In practice, if the gasket diameter does not properly match the flange dimensions, the effective contact area is reduced, resulting in increased localized contact pressure that may cause material deformation or cracking. In addition, non-uniform bolt tightening during installation leads to an uneven distribution of gasket loading. This condition may result in leakage and a reduction in service life. From this perspective, proper installation practices and bolt-tightening procedures constitute an essential factor in achieving reliable gasket performance.



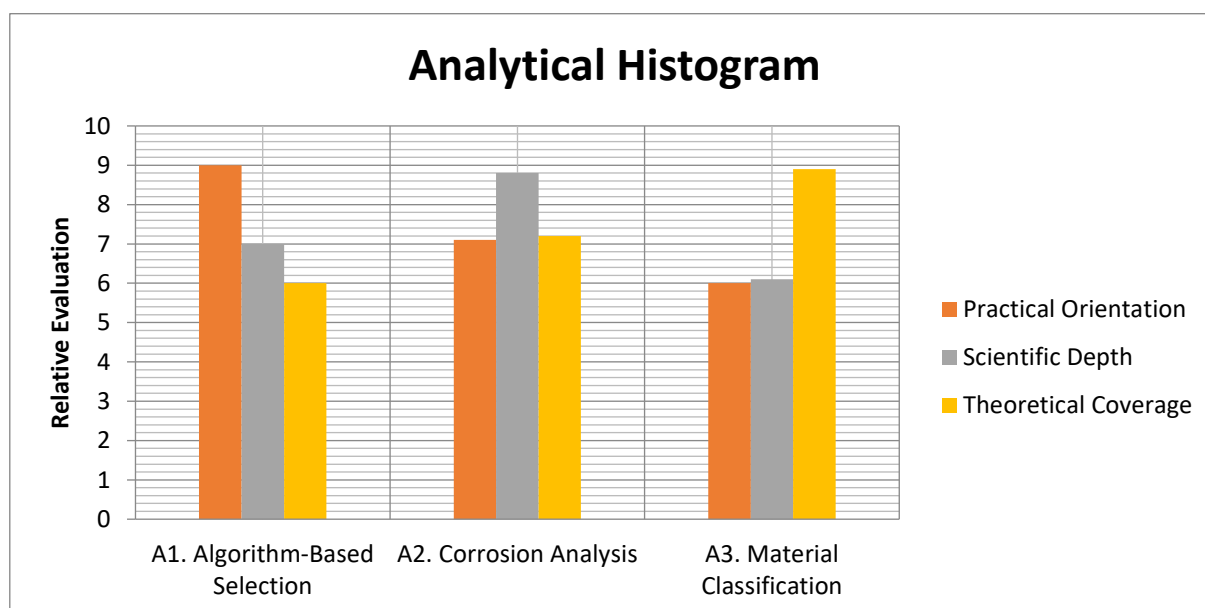


Figure 7. Comparative Analysis of Three Articles

The comparison shows that the **first article** is distinguished by its practice-oriented algorithm-based approach. The **second article** demonstrates greater scientific and experimental depth by providing a comprehensive analysis of corrosion phenomena and galvanic compatibility. The **third article** excels in terms of theoretical coverage and the classification of gasket materials, making it particularly valuable as an educational and reference resource.

CONCLUSION

Based on the results of the analysis and the evaluation of practical case studies, the implementation of an **algorithm-based approach** is essential for improving the effectiveness of gasket material selection and application under the operating conditions of Uzbekistan. In particular, the **STAMPS methodology** enables a comprehensive assessment of the working medium, operating temperature, pressure, application requirements, and geometric compatibility, thereby reducing installation errors and minimizing the risk of leakage. At the same time, in highly mineralized water and chemically aggressive environments, the potential for galvanic and electrochemical corrosion at the flange–gasket interface should be considered during the design stage. Under such conditions, the use of **low-electrical-conductivity composite gaskets** or **PTFE-coated gaskets** is recommended. Material selection should always be based on the intended service conditions: **metallic** or **metal–hybrid gaskets** are most suitable for high-temperature and high-pressure systems, **PTFE** or **composite materials** are preferred for chemically aggressive environments, whereas **non-metallic gaskets** provide effective performance in low- and medium-pressure engineering systems. Furthermore, proper installation practices—including uniform diagonal bolt tightening, careful cleaning of flange surfaces, and verification of gasket dimensional compatibility—significantly extend gasket service life and improve sealing reliability. In conclusion, the combined application of **algorithm-based gasket selection**, **corrosion analysis**, and **material classification** provides an effective strategy for enhancing the safety, reliability, and economic efficiency of industrial and municipal systems in Uzbekistan. This integrated approach ensures the long-term



performance of flanged joints, reduces maintenance costs, and improves the overall operational efficiency of engineering systems.

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