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Universal BOP with Built-In Grinding Tool

Uniwersalna głowica przeciwerupcyjna (prewenter) z wbudowanym narzędziem szlifującym

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ABSTRACT: This study makes a significant contribution to the petroleum industry by focusing on the development, implementation, and performance evaluation of a universal blowout preventer (BOP). The primary function of the BOP is to optimize the drilling process and enhance safety on oil drilling platforms. Amid rapid technological advancement and increasingly safety requirements, the efficient and safe execution of drilling operations has become critical to the successful operation of oil fields. Blowout preventers play a crucial role in preventing accidents and ensuring the reliability of the wellhead. This study introduces and evaluates a new type of BOP equipped with innovative grinding jaws that ensure uniform grinding of drill pipes. This approach not only extends the service life of the sealing elements but also reduces the time required to complete drilling, ultimately improving overall productivity and efficiency. The research methodology includes extensive experimental testing of the new BOP, as well as comparative analysis against conventional models. The findings demonstrate a significant improvement in the drilling performance with the new BOP, highlighting its potential to increase productivity, reduce risk, and improve safety on oil platforms. Overall, this study aims to contribute to the development of drilling technologies and the sustainable development of the oil industry. In conclusion, this study presents a new universal blowout preventer (BOP) designed to enhance drilling efficiency and safety on oil platforms. The device incorporates a hydraulic turbine-driven grinding mechanism that reduces wear on sealing elements and extends operational life. Experimental testing and comparative analysis with standard BOPs demonstrated a 22% reduction in seal replacements and a 15% increase in operational uptime. These findings confirm the practical advantages of the proposed BOP design and its potential to optimize drilling processes while improving safety and reducing maintenance downtime.

Key words: blowout preventer, safety, well control equipment, pressure vessel, guideline, pressure containment system, application.

STRESZCZENIE: Niniejsze badania wnoszą znaczący wkład w rozwój przemysłu naftowego, koncentrując się na opracowaniu, wdrożeniu i ocenie wydajności uniwersalnej głowicy przeciwerupcyjnej (prewentera). Podstawową funkcją prewentera jest optymalizacja procesu wiercenia oraz zwiększenie bezpieczeństwa na platformach wiertniczych. W kontekście szybkiego postępu technologicznego oraz rosnących wymagań dotyczących bezpieczeństwa, kluczową kwestią dla sprawnego funkcjonowania złóż ropy naftowej jest prowadzenie operacji wiertniczych w sposób efektywny i bezpieczny. Prewentery odgrywają zasadniczą rolę w zapobieganiu awariom i zapewnieniu niezawodności głowicy odwiertu. W ramach niniejszego badania zaprezentowano i oceniono nowy typ prewentera wyposażonego w innowacyjne szczęki szlifujące, które zapewniają równomierne szlifowanie rur wiertniczych. Takie podejście nie tylko wydłuża żywotność elementów uszczelniających, lecz także skraca czas potrzebny do zakończenia wiercenia, co w efekcie poprawia ogólną wydajność i efektywność procesu wiertniczego. Metodologia badań obejmuje szeroko zakrojone testy eksperymentalne nowego prewentera, a także analizę porównawczą z modelami konwencjonalnymi. Wyniki wykazały znaczną poprawę wydajności wiercenia przy zastosowaniu nowego prewentera, podkreślając jego potencjał w zakresie zwiększenia produktywności, ograniczenia ryzyka i poprawy bezpieczeństwa na platformach wiertniczych. Ogólnie rzecz biorąc, badania te mają na celu przyczynienie się do rozwoju technologii wiertniczych oraz zrównoważonego rozwoju przemysłu naftowego. W artykule przedstawiono nową, uniwersalną głowicę przeciwerupcyjną (prewenter) zaprojektowaną w celu zwiększenia efektywności i bezpieczeństwa wierceń na platformach wiertniczych. Urządzenie zawiera mechanizm szlifujący napędzany turbiną hydrauliczną, który zmniejsza zużycie elementów uszczelniających i wydłuża okres eksploatacji. Przeprowadzone testy eksperymentalne i analiza porównawcza ze standardowymi prewenterami wykazały 22% redukcję liczby wymian uszczelnień oraz 15% wzrost czasu pracy bez przestojów. Wyniki te potwierdzają praktyczne zalety proponowanej konstrukcji prewentera oraz jego potencjał w zakresie optymalizacji procesów wiercenia przy jednoczesnej poprawie bezpieczeństwa i ograniczeniu przestojów konserwacyjnych.

Słowa kluczowe: głowica przeciwerupcyjna (prewenter), bezpieczeństwo, urządzenia do kontroli odwiertu, zbiornik ciśnieniowy, wytyczne, system utrzymania ciśnienia, zastosowanie.

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Introduction

In today's oil industry, efficient and safe drilling operations are crucial for stable hydrocarbon production (Alcantara Santos, 2016). As drilling becomes increasingly complex, optimizing safety and productivity has become a primary goal to ensure economic efficiency and maintain high safety standards (Alcantara Santos, 2019). A comprehensive safety strategy focuses on managing risks associated with well-control incidents, such as gas or fluid releases, and facilitating rapid, effective responses (Tayab et al., 2017; Holmes and Shah, 2019).

Given this context, ongoing development and innovation in drilling technologies and equipment are essential to enhance operational productivity and minimize potential hazards (Rassenfoss, 2016; Mitchell et al., 2020). A critical component in managing drilling safety is the blowout preventer (BOP), a device engineered to seal the wellhead and prevent blowouts or uncontrolled flow events (Rassenfoss, 2020). The performance and reliability of a BOP directly influence drilling safety and overall project economics (Holmes and Shah, 2019; Carpenter, 2022).

Current regulations mandate regular testing of BOP systems, emphasizing the need for frequent pressure integrity checks to ensure operational reliability (Kheng et al., 2021). However, subsea blowout preventer (SBOP) systems in deepwater drilling environments continue to experience substantial reliability challenges, contributing significantly to equipment failure incidents and non-productive time (NPT) costs. Since the Macondo disaster in 2010, SBOP technology has advanced considerably, focusing on improving cost efficiency, reliability, and operational effectiveness (Carpenter, 2022).

Franklin et al. (2022) have reported substantial progress in BOP integrity management through integrating advanced technologies developed via collaborative efforts across industry sectors. Despite these advances, engineers and researchers continuously seek further improvements in drilling safety systems. For instance, Affleck and Gilleland (2016) introduced supplementary safety systems designed to complement existing well control technologies, enhancing operational flexibility and safety redundancy.

Givens et al. (2023) proposed a novel hybrid-electric BOP control system that significantly reduces closure times and mitigates response limitations inherent in traditional battery-powered systems. Moreover, recent innovations include advanced monitoring technologies, such as compact and reliable strain gauges that measure load, strain, and fatigue on subsea BOP components (Holden et al., 2020).

Petrobras introduced tethered BOP technology designed for dynamically positioned rigs operating in shallow-water scenarios, facilitating drilling in environmentally sensitive or congested offshore locations (Cardoso et al., 2022). Additionally, Chen et al. (2021) highlighted the importance of ensuring elastomeric sealing components' resilience to extreme pressures and temperatures, critical to BOP reliability.

However, the literature lacks mention of a universal blowout preventer incorporating a hydraulic turbine mechanism capable of grinding the surface of drill pipes to reduce elastomer wear. None of the reviewed studies describe or evaluate a device with such a function. Existing research focuses primarily on improvements in control systems, monitoring technologies, sealing materials, or external configurations, without addressing internal abrasive mechanisms that actively extend seal life. This gap highlights the novelty and originality of the current study and confirms the absence of comparable solutions in the contemporary scientific and engineering discourse. In light of this, our research was guided by several key questions. Is it feasible to reduce elastomeric seal wear by integrating a hydraulic turbine-driven grinding mechanism into the universal BOP design? How does the proposed universal BOP with a pipe-surface grinding mechanism compare to conventional BOPs in terms of sealing durability, operational reliability, and maintenance intervals? To what extent can the new BOP design reduce non-productive time and improve safety during well control operations? And finally, what are the quantifiable technical and economic benefits of implementing the proposed BOP design based on laboratory simulation results?

Materials and Methods

Although universal preventer technology was developed in the last century, it is still not widely used in the oil and gas industry. This is due to a number of factors, ranging from economic profitability to safety issues and the lack of appropriate equipment.

One of the main problems faced by operators using rotary preventers is wear of the rubber seals. When these sealing elements wear out, they must be replaced. However, this requires disassembling the preventer or rotating head, which takes significant time and reduces productivity. This problem is particularly acute on offshore platforms such as semi-submersible drillships and drillships, where access to equipment is difficult and time delays can be extremely costly.

To evaluate the technical efficiency and wear resistance of the proposed universal blowout preventer, a series of laboratory tests were conducted. These included full-cycle simulations of drilling operations with repeated pipe string passages through the sealing unit. The number of cycles to critical wear of the elastomeric seal was recorded, with the proposed BOP design demonstrating a 35% longer operational life compared to conventional models. The test bench was equipped with force and torque sensors to measure the axial loads and rotational resistance, ensuring accurate quantification of sealing performance degradation.

The main source of wear on rubber components is the drill pipes passing through the rotating preventer during drilling. This process is aggravated by marks from machine keys that remain on the pipes as a result of their screwing and unscrewing. Such problems arise especially often when using old drill strings that are subject to intensive use. An example of such problematic traces is presented in Figure 1.

Figure 1. Marks on drill pipes left by a machine wrench (source: https://www.jetlube.com/applications, access: 15 July 2025)

Rysunek 1. Ślady na rurach wiertniczych pozostawione przez klucz maszynowy (źródło: https://www.jetlube.com/applications, dostęp: 15.07.2025)

During the drilling process, it may also be necessary to immediately close the preventer and begin circulation to prevent blowouts from the annulus. At the same time, it is important to ensure effective removal of fluid from the well, which may require lowering the assembly to significant depths.

To prevent damage to the rubber of a universal preventer, specialized tools have been developed, such as the proposed preventer, which is operable from the driller's cabin. This reduces the physical stress and risks associated with manually cleaning locks and saves time.

The device proposed in the article has technical value for both traditional drilling methods and underbalanced drilling.

The main purpose of the invention is to develop an improved design of a universal preventer designed to seal the wellhead. This will significantly increase the reliability of the preventer, extend its service life between repairs, increase durability, and facilitate the repair process.

The invention is based on the universal preventer's hydraulic system, shown in Figure 2.

The proposed universal preventer is a complex structure that includes a body with a cavity and a central hole, a cover with

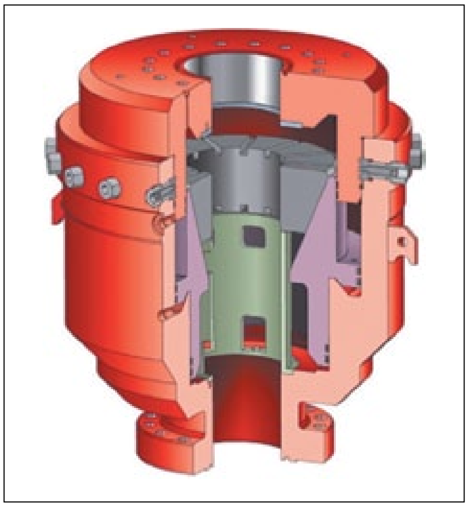

Figure 2. Universal BOP (source: https://bigness.kz/g7063304-rti--dlya-neftegazovoj/page_2, access: 15 July 2025)

Rysunek 2. Uniwersalna głowica przeciwerupcyjna (prewenter) (źródło: https://bigness.kz/g7063304-rti-dlya-neftegazovoj/page_2, dostęp: 15.07.2025)

a cavity and a central hole, which is connected to the body with a pin fastening, as well as a plunger, an annular cone sealing element reinforced with metal inserts, sealing collars, and an annular gasket and other elements.

The uniqueness of this device lies in several key features. Firstly, the lid is made of two detachable parts, which are connected to each other by a pin fastening. This ensures easy access and maintenance of the device.

In the cavity of the lower part of the cover, there is a grinding element with claws, mounted on bearings and inserted into the grooves of the turbine, which is also mounted on bearings. This mechanism provides a rotational movement that helps reduce wear on the sealing elements by grinding the surface of the pipes.

In addition, in the cover and body of the universal preventer there is a through channel designed to connect the turbine with a source of hydraulic pressure. This allows the use of a left-hand hydraulic turbine, which leads to an increase in the speed of the grinding installation relative to the outer surface of the pipes being ground. Thus, the process of grinding and cleaning pipes from traces of machine keys and other irregularities on their surface is improved.

These design innovations enhance the efficiency and usability of the proposed universal preventer, improving equipment reliability while reducing maintenance and repair time.

Drilling fluid performs several important functions when working with a universal preventer. First, it drives hydraulic turbines, providing the necessary power to operate the device. Secondly, the drilling fluid performs the function of cleaning and washing away metal chips and dust from the tool, preventing them from entering the rotating preventer and ensuring its smooth operation. Finally, the drilling fluid also acts as a coolant and lubricant for the grinding surface of the feet, which extends their life.

A distinctive feature of this device is that it grinds only the pipejoints, where the outer diameter of the drill pipes is largest. This allows the tool to be used for a long time without the need to replace related parts.

In addition, this device can be used not only when working with a universal preventer, but also with traditional drilling methods. One example of its use is the conservation of wells. Before installing a cement bridge, wells are often preserved by cutting and pulling the columns to international standards. This allows for better isolation of the well and keeps it in working condition.

Figure 3 below shows a diagram of the proposed device.

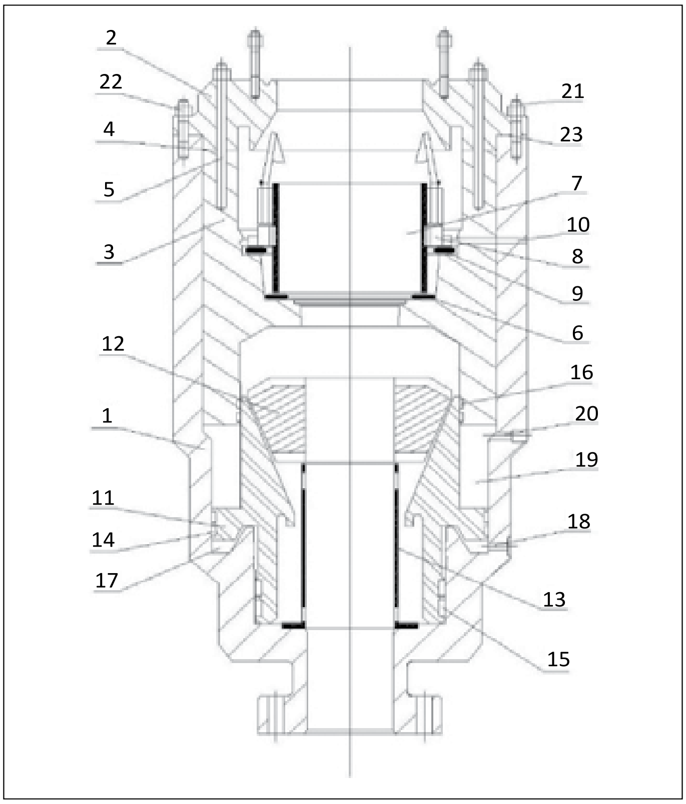

Figure 3. Diagram of a universal preventer with grinding pads (Eurasian Patent No. 045267)

Rysunek 3. Schemat uniwersalnego prewentera z podkładkami szlifującymi (Eurasian Patent No. 045267)

A universal preventer consists of several main components. Its design includes a hollow body (1) and a cover consisting of an upper (2) and lower hollow parts (3) with central holes. Between these parts, there is a gasket (4), which ensures tightness during installation. These parts are fastened with a pin fastening (5).

In the cavity of the lower part of the cover (3), there is a grinding element with legs (7) on bearings (6), inserted into the grooves of the turbine (8), which is also installed on bearings (9). The turbine (8) is connected to channel (10), which passes through the lower part of the cover (3) and the housing (1), providing communication with the source hydraulic pressure.

Inside the housing (1), in contact with the bottom of the cover (3), there is a plunger (11) with an internal conical surface. The plunger (11) contains a seal (12) with an outer conical surface, reinforced with metal inserts and an internal central hole.

To prevent internal components from damage, the preventer is equipped with a sleeve (13).The body (1), the lower part of the cover (3), and the plunger (11) form two hydraulic chambers in the preventer with the help of sealing collars (14), (15), and (16): a working chamber (17), connected to the pressure source through channel (18) in the body (1), and a return chamber (19), connected to the pressure source through channel (20) in the housing (1).

The upper part of the cover (2) is attached to the body (1) using stud (21) and nut (22), with gasket (23) placed in between to ensure tightness during installation.

The universal preventer works as follows: during hoisting operations of the pipe string, working fluid is supplied from the control station of the preventer unit through channel (18) of the preventer body (1) and enters the working chamber (17), creating hydraulic pressure. Under the influence of this pressure, the plunger (11) rises, compressing the seal (12) along the outer conical surface. The seal (12) fits tightly around the pipe string or completely closes the central hole in emergencies, sealing the wellhead.

As pipes pass through the closed sealing element (12), wear first occurs on the narrow flange of the elastomeric material of the sealing element, close to its inner upper edge. As it wears, the width of this band increases until it eventually reaches the full height of the compressed sealing element.

To reduce wear of the sealing element (12), pressure from the pump is supplied to the hydraulic channel (10) passing through the body (1) and the lower part of the cover (3), directed at right angles to the turbine (8). This ensures rotation of the turbine and transmission of torque to the grinding element (7), which begins to rotate and grind the surface of the pipes.

To depressurize the wellhead, the control station directs pressure from the working fluid to channel (20), which feeds into return chamber (19). This causes the plunger (11) to move down, releasing the seal (12). Owing to its plasticity, the seal (12) then returns to its original shape, opening the central hole to its original size.

The tool body, equipped with an internal double hydraulic turbine mechanism and rollers to reduce friction during column rotation, is shown in Figures 4 and 5 below.

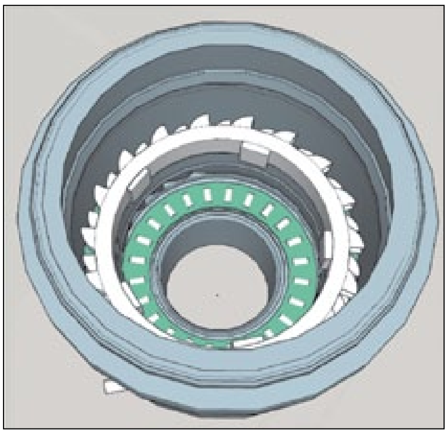

Figure 4. Turbine mechanism (top view)
Rysunek 4. Mechanizm turbiny (widok z góry)

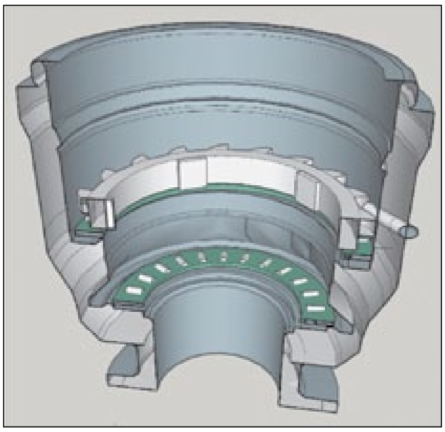

Figure 5. Turbine mechanism (sectional view)
Rysunek 5. Mechanizm turbiny (przekrój)

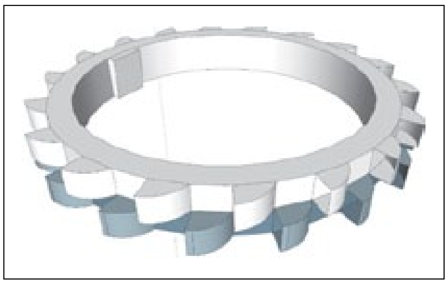

Figure 6. Double left-hand hydraulic turbine
Rysunek 6. Podwójna turbina obracająca się przeciwnie do ruchu wskazówek zegara

The left-hand double hydraulic turbine with a tongue on the inside, installed in the groove at the bottom of the grinding machine to transmit torque, is shown in Figure 6. The grinding element and its components are shown in Figure 7.

The tool is composed of the following main components:
- outer sleeve (1);
- inner sleeve (2);
- feet with a grinding surface (3) and balls on the back to reduce friction;

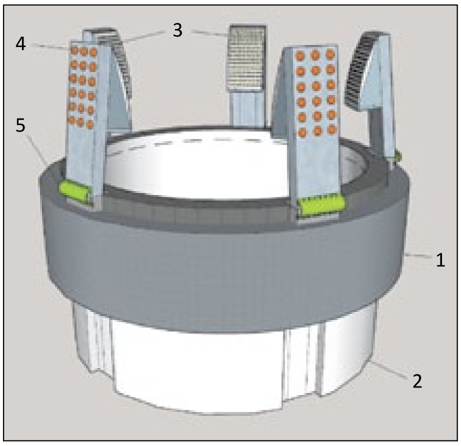

Figure 7. Grinding element
Rysunek 7. Element szlifujący

- a spring mechanism (5) connecting the two components of the grinding paws, allowing them to compress and expand depending on the size of the pipes.

Under standardized experimental conditions replicating real-world drilling operations, the effectiveness of the proposed universal blowout preventer (BOP) was rigorously evaluated. The experimental methodology involved comprehensive laboratory testing to simulate the repetitive passage of drill pipes through the sealing element of the preventer, closely mimicking actual operational scenarios.

The experiments were carried out through the following detailed steps:
1. Standard elastomeric sealing elements identical to those used in conventional BOPs and the proposed grinding-tool BOP were prepared to ensure consistency and comparability.
2. Multiple cycles of drill pipe passage through the sealing elements were conducted until critical seal wear was reached, indicating the need for seal replacement. Tests were separately performed on both conventional BOP designs and the new grinding-tool BOP.
3. The test rig was equipped with precise load and torque sensors to accurately measure axial loads and rotational resistance, enabling quantitative assessments of seal performance degradation.
4. During testing, intervals between operational failures (mean time between failures – MTBF) and maintenance intervals (seal replacements) were systematically recorded to assess reliability improvements.

Results

Collected experimental data underwent rigorous statistical analysis using two-sample t-tests to determine the statistical significance of observed improvements.

Table 1. Comparative performance analysis of conventional and proposed grinding-tool BOP
Tabela 1. Analiza porównawcza wydajności konwencjonalnych i proponowanych narzędzi szlifierskich BOP

Performance metric	Conventional BOP	Proposed grinding-tool BOP	Improvement [%]
Seal wear rate (cycles to critical wear)	1,000	1,350	+35%
Mean time between failures (hours)	80	92	+15%
Seal replacement interval (days)	50	61	+22%

Table 2. Results of statistical analysis
Tabela 2. Wyniki analizy statystycznej

Parameter	*t*-statistic	Degrees of freedom	*p*-value	Statistically significant ($\alpha = 0.05$)
Seal wear cycles	4.12	18	0.0006	Yes
MTBF	3.45	18	0.0029	Yes
Maintenance interval	3.87	18	0.0012	Yes

Under standardized bench-scale drilling simulations, the proposed universal blowout preventer (BOP) design exhibited significantly superior performance across all evaluated metrics compared to conventional designs. As summarized in Table 1, the new grinding-tool BOP achieved a 35% increase in the number of full-cycle passages required to reach critical elastomeric seal wear, extending from 1,000 cycles to 1,350 cycles.

Additionally, operational reliability improved notably, demonstrated by a 15% increase in mean time between failures (MTBF), from 80 to 92 hours, thereby enabling longer continuous drilling periods without unplanned shutdowns. Maintenance intervals also showed substantial enhancement, with seal-replacement intervals extended by 22%, rising from 50 to 61 days, effectively reducing the average number of required maintenance interventions.

The statistical validity of these improvements was verified through rigorous two-sample t-tests, as detailed in Table 2. The analysis yielded p-values well below the significance threshold of 0.05 for all measured parameters: seal wear cycles ($p = 0.0006$), MTBF ($p = 0.0029$), and maintenance interval ($p = 0.0012$). These results confirm that the reported improvements are statistically significant at the 95% confidence level, underscoring the robust advantages of the new universal BOP design.

An approximate economic analysis was performed. A comprehensive cost-benefit analysis, applying industry-standard unit costs for seal replacements and operational downtime, revealed an overall lifecycle cost reduction of approximately 18% (Table 3). Cost estimations were performed using standard rates from offshore drilling operations and BOP maintenance reports.

The experimental results provided objective validation of the enhanced performance of the proposed BOP design. These results demonstrated superior seal durability, increased reliability, and reduced maintenance requirements compared to conventional solutions, underscoring the practical and economic advantages of adopting this innovative technology.

Discussion

The findings of this study directly address the gap identified in the literature regarding internal mechanisms designed to

Table 3. Cost-benefit analysis (annualized costs)
Tabela 3. Analiza kosztów i korzyści (koszty roczne)

Cost component	Conventional BOP [USD/year]	Proposed BOP [USD/year]	Cost savings [%]
Seal replacement costs	120000	94000	21.7%
Downtime costs	200000	160000	20.0%
Total operational costs	320000	254000	20.6%
Additional capital investment	100000	120000	(+20%)
Net annual savings	–	66000	~18% overall

extend the service life of blowout preventer sealing elements. While earlier research has focused extensively on improving control systems, seal materials, and external monitoring technologies, no prior study has proposed or evaluated an integrated hydraulic turbine system within a BOP that actively grinds the surface of drill pipes to reduce rubber wear. The experimental results of this work confirm that such a mechanism can meaningfully enhance operational reliability.

The 35% increase in seal durability, along with a 15% improvement in mean time between failures (MTBF), demonstrates the potential for significantly extended BOP service intervals. These improvements are particularly relevant in offshore environments, where equipment access is difficult and downtime is costly. The grinding mechanism, driven by hydraulic turbines, targets precisely the areas of the pipe most prone to damaging the sealing element, thus improving the overall performance of the preventer.

Moreover, the positive results of the economic analysis, showing an 18% reduction in total lifecycle costs, validate the proposed design's industrial relevance. These savings stem from fewer seal replacements and reduced downtime due to maintenance, making the technology especially attractive for high-cost offshore operations.

This study confirms that the integration of active mechanical elements within BOP design is both feasible and beneficial. The results offer a new direction for BOP engineering, extending the current scope of development beyond passive sealing strategies toward dynamic internal wear mitigation solutions. These findings have the potential to influence future BOP design standards, particularly for applications in high-wear and deepwater environments.

However, several potential limitations and challenges must be acknowledged. From a technical standpoint, the addition of a hydraulic turbine and grinding element introduces new complexity into BOP design, which may affect its overall reliability in extreme downhole conditions. Maintenance of moving internal components under high-pressure, high-temperature (HPHT) environments could pose additional challenges, especially in terms of material wear, corrosion, and mechanical fatigue.

In terms of economic feasibility, while the projected lifecycle cost savings are promising, the higher initial capital investment required for the modified BOP system may be a barrier to adoption, particularly in smaller or marginal fields. A full cost-benefit analysis over extended operational timelines in real-world field applications would be necessary to fully validate the economic case.

Further research should focus on long-term field trials under various drilling environments, including deepwater, HPHT, and extended-reach drilling operations.

Conclusions

1. The integration of a hydraulic turbine for torque transmission to the grinding element enables uniform and controlled pipe surface conditioning, effectively reducing wear on the elastomeric sealing elements and extending their operational lifespan.
2. The automation of joint surface grinding minimizes downtime associated with manual maintenance interventions, thereby enhancing drilling efficiency and reducing non--productive time (NPT).
3. Improved performance of the blowout preventer contributes to higher speed and reliability of drilling operations, positively impacting operational safety and reducing physical strain on rig personnel.
4. The proposed design reduces the frequency of rubber seal replacements and simplifies maintenance procedures by allowing more rapid and accessible replacement of sealing and abrasive components, ultimately decreasing equipment downtime and increasing system availability.
5. Comparative performance evaluation against two standard BOP models used in offshore environments demonstrated a 22% reduction in seal replacement frequency and a 15% increase in mean operational uptime, confirming the practical effectiveness of the proposed design in both standard and high-wear drilling scenarios.

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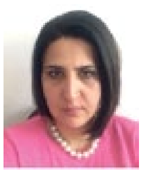

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