ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Volume 12, Issue 04, April 2025

Review Paper: Design & Fabrication of 3X Positive Displacement Pump

[1] Sahaj Kapoor, [2] Mudit Chauhan, [3] Aryan Malik, [4] Mayan Sharma, [5] Manish Mangal
[1] [2] [3] [4] Student, ABES Engineering College, AKTU, Ghaziabad, Uttar Pradesh, India
[5] Professor, ABES Engineering College, AKTU, Ghaziabad, Uttar Pradesh, India
Corresponding Author Email: [1] sahajkapoor11@gmail.com, [5] manish.mangal@abes.ac.in

Abstract— This review paper delves into the development of a cutting-edge and compact, high-pressure Triple X plunger pump. The pump is designed to succeed in a wide range of industrial applications. Be it transferring high-pressure fluid or using it for rigorous testing. By analyzing a total of 24 research papers this review paper emphasizes the crucial need of fine-tuning pump design parameters such as the pump diameter, materials used, and the implementation of pressure needed for a small sized pump in order to achieve maximum performance. The paper also talks about the revolutionary potential of computational fluid dynamies (CFD) and multi-objective optimization techniques for improving pump design and performance as a suggestion for future development and research. Furthermore, the paper emphasizes the importance of material selection in maintaining the longevity and effectiveness of pump components. The paper presents tungsten carbide and aluminum alloys as attractive options.

Index Terms— Computational Fluid Dynamics (CFD), High-Pressure Pumping, Material Selection, Triple X Plunger Pump.

I. INTRODUCTION

Positive displacement pumps are widely used in various industrial applications due to their ability to provide a consistent flow rate regardless of system pressure. Among all one kind of positive displacement pump is the reciprocating plunger pump, which uses a plunger to move a fixed volume of fluid per cycle. If we move further, we come across the Triplex plunger positive displacement pump which is a specific type of reciprocating plunger pump that is designed to operate at high pressures.

In recent years, researchers have focused on optimizing the design and performance of positive displacement pumps, including the Triple X plunger pump. Studies have investigated the effects of pump design parameters, such as piston diameter, stroke length, and valve timing, on pump efficiency and performance. Additionally, researchers have explored the use of advanced materials, such as tungsten carbide and aluminum alloys, to improve pump durability and efficiency.

This review paper aims to provide a comprehensive overview of the current state of research on the design, optimization, and performance of Triple X plunger positive displacement pumps. The paper studies existing literature and research papers on the topic, including studies on pump design optimization, material selection, and performance analysis to provide the combination of best advice that has been used to build a Triplex Reciprocating Displacement Plunger Pump as a part of the final year project under ABES Engineering College.

II. MATERIAL SELECTION OF RECIPROCATING PUMPS FOR ENHANCED PERFORMANCE

As the demand for efficient and reliable pumping systems continues to grow, researchers and engineers are turning to advanced materials and computational tools to optimize pump design. The materials for pump components play a critical role in achieving efficient performance and minimizing energy consumption.

According to reports, properties of ceramics and tungsten carbide have huge differences in thermal conductivity, wear resistance, and corrosion resistance. For instance, tungsten carbide excels in wear resistance due to its high hardness and toughness, making it an ideal material for pump components that are subject to high wear and tear.

On the other hand, ceramics offer better corrosion resistance, making them suitable for applications where the pump is exposed to corrosive fluids. But ceramics have the greatest disadvantages of breaking down very quickly and easily whereas tungsten are considered more reliable.

In addition to ceramics and tungsten carbide, aluminum alloys have also been investigated for their potential use in pump housings. Aluminum alloys offer several benefits, including lightweight, corrosion resistance, and thermal conductivity, making them an attractive option for pump designers. Furthermore, aluminum alloys can be easily machined and fabricated, reducing production costs and lead times.

III. PERFORMANCE AND SURFACE ENGINEERING

Moving from material selection to pump performance, positive displacement pumps are ideal for applications where consistent flow rates are required, regardless of system pressure.

Research studies have reviewed the principles, selection criteria, and applications of positive displacement pumps, highlighting their advantages in handling challenging fluids and high-pressure systems. Unlike centrifugal pumps, positive displacement pumps can handle high-viscosity fluids, slurries, and gas-liquid mixtures, making them a popular choice for various industrial applications.

IV. POSITIVE DISPLACEMENT PUMPS AND COMPUTATIONAL FLUID DYNAMICS

To further optimize pump design and performance, computational fluid dynamics (CFD) has become a vital tool. CFD has been widely used to analyze and optimize centrifugal pump performance, including turbulence, cavitation, and unsteady conditions. Research studies have also applied CFD to reciprocating pumps, investigating the dynamic behaviour of valves and pump performance. By using CFD, pump designers can simulate various operating conditions, identify potential issues, and optimize pump design before physical prototyping, reducing development costs and lead times. Although this technology has not been implemented in the current project, it could be implemented in future after in-depth research.

V. REDUCED SIZE OF PUMP IN PLUNGER PUMPS

Research papers by X. Suo et al. Engineering Applications of Computational Fluid Mechanic, Binyamin Binyamin et al. Sustainability, and more, suggest that optimizing plunger pump design through adjustments in chamber dimensions, material selection, and structural configurations can enhance efficiency, reduce cavitation, and improve flow stability. It further adds that a reduced plunger pump with high efficiency is as effective and beneficial as the larger ones. The project has implemented this finding by reducing the overall size of the pump.

VI. HIGH-SPEED TUNGSTEN CARBIDE

High-speed tungsten carbide (WC) coatings are often used in reciprocating plunger pumps due to their excellent wear resistance and durability. These coatings are crucial in enhancing the performance and lifespan of pump components, especially in harsh environments. The project based plunger pump, has used tungsten carbide keeping in mind the beneficial properties. Additionally for future development and research, the paper suggests corrosion resistance and surface texturing or laser ablation and recrystallization.

VII. CORROSION RESISTANCE AND SURFACE TEXTURING

The study investigates the corrosion properties of Ni6o/WC coatings with laser-ablated micro dimples. It was found that the presence of microcracks in these dimples does not significantly alter the corrosion behavior of the coating compared to non-textured surfaces, provided the cracks do not reach the substrate. This suggests that the integrity of the coating is maintained, which is essential for applications in corrosive environments.

VIII. LASER ABLATION AND RECRYSTALLIZATION

Laser ablation is used to create micro dimples on the coating surface, which can enhance the corrosion resistance through recrystallization. This process potentially improves the durability of the coating, making it more suitable for use in acidic environments, such as those encountered by fracturing-pump plungers.

IX. GEARLESS POSITIVE DISPLACEMENT PUMP

Gearless positive displacement pumps offer several benefits, particularly in applications requiring precise fluid handling and mixing. These pumps, such as the gearless Lau-Wan fluid pump, are designed without traditional gears, which can lead to unique advantages.

Some Key Benefits of Gearless Positive Displacement Pumps Are:

A. Reduced Noise and Vibration: Traditional

Gear pumps often suffer from flow non-uniformity, leading to noise and mechanical vibrations. Gearless designs,

like the continuous-contact helical gear pumps (CCHGP), can significantly reduce or eliminate these issues, providing a quieter operation (Zhao & Vacca, 2018).

B. Enhanced Mixing Capabilities

The gearless Lau-Wan pump features a unique fluid chamber geometry that creates three-dimensional vortices, even in laminar flow regimes. This characteristic makes it particularly suitable for microfluidic mixing applications, such as biofuel processing (Wan et al., 2017).

C. Simplified Design and Maintenance

By eliminating gears, these pumps can have fewer moving parts, potentially reducing maintenance needs and increasing reliability. The design simplicity can also lead to easier prototyping and customization for specific applications (Wan et al., 2017).

D. Potential for High Efficiency in Specific Applications

Although the efficiency of gearless pumps can be low in some scenarios (e.g., less than 30% in the presence of internal leakage), their design can be optimized for specific tasks where traditional pumps may not perform as well, such as maintaining a clean tank bottom during mixing (Wan et al., 2017).

X. DISCUSSION AND CONCLUSION

This review paper provides a comprehensive analysis of the design, optimization, and performance enhancement of the Triple X plunger positive displacement pump, emphasizing its relevance in various industrial applications. The exploration of existing literature underscores the significance of advancing pump design parameters— piston diameter, materials, and design used as critical factors that influence the operational efficiency of high-pressure pumps. By synthesizing findings from 24 research papers, we establish a clear connection between refined design strategies and improved pump performance, reinforcing the necessity for continued research in this domain.

In addition, the integration of advanced materials, such as tungsten carbide, ceramics, and aluminum alloys, has emerged as a pivotal element in ensuring pump durability and performance efficiency. The distinct properties of these materials-such as wear resistance, corrosion resistance, and lightweight characteristics-are instrumental in addressing the challenges posed by high-pressure and corrosive environments. The analysis highlights that the selection of appropriate materials not only enhances the longevity of pump components but also contributes to reduced energy consumption and lower operational costs.

Furthermore, the application of computational fluid dynamics (CFD) has proven to be an essential tool in optimizing the design and performance of the Triple X plunger pump. The utilization of CFD facilitates in-depth analysis of flow dynamics, enabling engineers to identify potential performance issues such as turbulence and cavitation early in the design process. This capacity for simulation and optimization not only accelerates development timelines but also results in more reliable and efficient pumps capable of meeting the rigorous demands of contemporary industrial applications.

The findings and discussions presented in this review paper underscore the crucial role that interdisciplinary approaches play in advancing pump technology. As industries increasingly seek higher efficiency and greater reliability in pumping systems, the convergence of material science, computational techniques, and engineering principles will be pivotal. Future research efforts should continue to focus on integrating innovative materials and computational tools into the design process, emphasising real-world applications.

In conclusion, the ongoing development of the Triple X plunger positive displacement pump is essential for fulfilling the growing demands for high-performance pumping solutions. By leveraging optimization techniques, material advancements, and computational simulations, researchers can further enhance the pump's capabilities, ensuring its relevance and effectiveness in diverse industrial applications. The insights gained from this review pave the way for future studies aimed at propelling pump technology forward, ultimately leading to more efficient and sustainable industrial processes.

REFERENCES

[1] Wan, S., Lau, M., & Goh, K. (2017). Gearless Wankel-like pump/mixer: Design challenges and prospects. 2017 3rd International Conference on Power Generation Systems and Renewable Energy Technologies (PGSRET), 32-37. https://doi.org/10.1109/PGSRET.2017.8251797

[2] Zhao, X., & Vacca, A. (2018). Analysis of continuous-contact helical gear pumps through numerical modeling and experimental validation. Mechanical Systems and Signal Processing. https://doi.org/10.1016/J.YMSSP.2018.02.043

[3] Binyamin, B., & Lim, O. (2023). Numerical Analysis of the Structural and Flow Rate Characteristics of the Fuel Injection Pump in a Marine Diesel Engine. Sustainability. https://doi.org/10.3390/su15118948.

[4] Suo, X., Jiang, Y., & Wang, W. (2021). Hydraulic axial plunger pump: gaseous and vaporous cavitation characteristics and optimization method. Engineering Applications of Computational Fluid Mechanics, 15, 712 - 726. https://doi.org/10.1080/19942060.2021.1913232.

[5] Zhong, L., Wang, Z., Wang, G., He, X., Wei, G., Chen, L., Wu, X., Luo, M., Kang, G., & Li, Z. (2022). Corrosion Properties of Ni6o/WC Coating with Abrasion-Resistant Microdimples Ablated by Nanosecond Laser. Advanced Engineering Materials, 24. https://doi.org/10.1002/adem.202200328

[6] Shaun R. Aakre, Mark H. Anderson, Paul W. Brooks, Volumetric efficiency and pressure pulsations of a triplex reciprocating supercritical CO2 pump, The Journal of Supercritical Fluids, Volume 168,2021, 105072,ISSN 0896-8446, https://doi.org/10.1016/j.supflu.2020.105072

[7] Garcia-Esparza, A. T., Cha, D., Ou, Y., Kubota, J., Domen, K., & Takanabe, K. (2012). Tungsten Carbide Nanoparticles as Efficient Cocatalysts for Photocatalytic Overall Water Splitting. ChemSusChem, 6(1), 168-181. https://doi.org/10.1002/cssc.201200780

[8] Hartmetall, G. (2023, July 31). What is the difference between ceramics and tungsten carbide? | Graf Hartmetall GmbH. Graf Hartmetall GmbH. https://grafhartmetall.com/en/what-is-the-difference-between-ceramics-and-tungsten-carbide/#:-:text=Thermal%20Conductivity%3A%20Ceramics%2C%20including/20aluminum.but%20excels%20in%20wear%20resistance

[9] Alam, Md Tanwir & Ansari, Akhter. (2017). REVIEW ON ALUMINIUM AND ITS ALLOYS FOR AUTOMOTIVE APPLICATIONS. International Journal of Advanced Technology In Engineering and Science. 5. 278-294.

[10] Josifovic, A., Corney, J., & Davies, J. (2015). Valve dynamics in multi-cylinder positive displacement pump model. 2015 IEEE International Conference on Advanced Intelligent Mechatronics (AIM), 35-41. https://doi.org/10.1109/AIM.2015.7222505.

[11] Josifovic, A., Roberts, J., Corney, J., Davies, B., & Shipton, Z. (2016). Reducing the environmental impact of hydraulic fracturing through design optimisation of positive displacement pumps, Energy, 115, 1216-1233. https://doi.org/10.1016/J.ENERGY.2016.09.016

[12] Thorat, S., Kanase-Patil, A., & Bapat, A. (2015). CFD Analysis for Designing Fluid Passages of High Pressure

Reciprocating Pump.

[13] Ivantysynova, M. (2008). INNOVATIONS IN PUMP DESIGN-WHAT ARE FUTURE DIRECTIONS?., 2008, 59-64. https://doi.org/10.5739/ISFP.2008.59.

[14] Wang, Guorong & Zhong, Lin & He, Xia & Lei, Zhonggging & Li, Rong & Wang, Yunhai. (2015). Dynamic Behavior of Reciprocating Plunger Pump Discharge Valve Based on Fluid Structure Interaction and Experimental Analysis. PloS one. 10. e0140396.10.1371/journal.pone.0140396.

[15] S.R. Shah, S.V. Jain, R.N. Patel, V.J. Lakhera, CFD for Centrifugal Pumps: A Review of the State-of-the-Art, Procedia Engineering, Volume 51, 2013, Pages 715-720,ISSN 1877-7058, https://doi.org/10.1016/i.proeng.2013.01.102

[16] Singh, P. J., & Madavan, N. K. (1987). Complete Analysis And Simulation Of Reciprocating Pumps Including System Piping. https://oaktrust.library.tamu.edu/items/9803985d-6add-4ca2-aac3-a5a4a9faabd0

[17] KAMAT GmbH & Co.KG. (2024, November 22). Plunger Pump - Calculations | KAMAT. KAMAT. https://www.kamat.de/en/information-centre/plunger-pump calculations/

[18] Bolelli, G., Cannillo, V., Lusvarghi, L., & Manfredini, T. (2006). Wear behaviour of thermally sprayed ceramic oxide coatings. Wear, 261, 1298-1315. https://doi.org/10.1016/J.WEAR.2006.03.023.

[19] Liu, J., & Wang, X. (2010). Design and Experiment of a New Positive-Displacement Pump. 2010 International Conference on Computing, Control and Industrial Engineering, 1, 271-275. https://doi.org/10.1109/CCIE.2010.76.

[20] "Positive Displacement Pumps Market Trend & Outlook 2033 | FMI." Future Market Insights Inc, https://www.futuremarketinsights.com/reports/positive-displacement-pumps-market.

[21] Ovhal, Vijay. "Rapid Industrial Growth To Boost Positive Displacement Pumps Demand." Water Online, 8 Mar. 2023

[22] "Positive Displacement Pumps Market Trend & Outlook 2033 | FMI." Future Market Insights Inc, https://www.wateronline.com/doc/rapid-industrial-growth-to-boost-positive-displacement-pumps-demand-0001. https://www.futuremarketinsights.com/reports/positive-displacemenfgpumps-market.

[23] Kang, C. et al. (2024) 'Effects of particle size and reciprocating frequency of the plunger on performance and flow characteristics of a diaphragm pump', Journal of the Chinese Institute of Engineers, 47(7), pp. 853-867. doi: 10.1080/02533839.2024.2383576.

[24] UT Pumps. (n.d.). High Pressure Pumps - UTPS-15000 Model. Retrieved from (https://www.utpumps.com/high-pressure-pumps-utps-15000-model.html)