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**Entitled**:

# Experimental Investigation of Volumetric and Mechanical Efficiency of the Leistritz L4 Multiphase Screw Pump

Dissertation Submitted in Partial Fulfillment of the Requirements for the Master Academic Degree in Mechanical Engineering

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**Abstract:**

This thesis aims to evaluate the performance of the **Leistritz L4** multiphase pump, focusing on **volumetric** and **mechanical efficiencies** under real operating conditions. Multiphase pumping technology enables the direct transportation of an oil–water–gas mixture without prior phase separation, thereby reducing investment and operating costs and limiting environmental impact.

Experimental tests were carried out using a multiphase flow meter and the pump's control system to monitor pressures, temperatures, flow composition, and electrical power consumption. The results showed that the **volumetric efficiency** ranged between **41% and 54%**, influenced by the high associated gas fraction, while the **mechanical efficiency** ranged between **33% and 43%** as a result of friction losses, thermal disturbances, and also the elevated gas content.

This study highlights both the potential and the limitations of twin-screw multiphase pumps and provides practical recommendations to enhance their reliability and improve their energy efficiency in oil and gas industry applications.

**Keywords:**

Multiphase pumping; twin-screw pumps; **Leistritz L4** pump; volumetric efficiency; mechanical efficiency; pump performance; oil and gas industry.

**الملخص:**

تهدف هذه المذكرة إلى تقييم أداء المضخة متعددة الأطوار Leistritz L4 مع التركيز على الكفاءة الحجمية والكفاءة الميكانيكية في ظروف تشغيل واقعية. تُمكّن تقنية الضخ متعدد الأطوار من نقل خليط النفط والماء والغاز مباشرةً دون الحاجة إلى فصل مسبق، مما يساهم في تقليص تكاليف الاستثمار والتشغيل والحد من الأثر البيئي.

أُجريت اختبارات تجريبية باستخدام جهاز قياس تدفق متعدد الأطوار ونظام التحكم بالمضخة من أجل مراقبة الضغوط ودرجات الحرارة ومكونات الجريان واستهلاك القدرة الكهربائية. أظهرت النتائج أن الكفاءة الحجمية تراوحت بين 41 % و 54 % متأثرة بارتفاع نسبة الغاز المرافق، في حين تراوحت الكفاءة الميكانيكية بين 33 % و 43 % نتيجة خسائر الاحتكاك والاضطراب الحراري وأيضًا بسبب الارتفاع الكبير في نسبة الغاز.

تُبرز هذه الدراسة إمكانات ومحدوديات المضخات اللولبية ثنائية الدوران متعددة الأطوار، وتقدّم توصيات عملية من شأنها تحسين موثوقيتها ورفع كفاءتها الطاقوية في تطبيقات صناعات النفط والغاز.

**الكلمات المفتاحية:**

الضخ متعدد الأطوار؛ المضخات اللولبية ثنائية الدوران؛ مضخة Leistritz L4؛ الكفاءة الحجمية؛ الكفاءة الميكانيكية؛ أداء المضخات؛ صناعة النفط والغاز.

# DEDICATION

*This research was accomplished despite numerous challenges and obstacles. By the grace of Almighty God, and through perseverance and determination, we were able to overcome them.*

*We extend our profound gratitude to our parents, siblings, and friends, whose constant encouragement and support have been a source of strength throughout this academic journey.*

*We also owe special thanks to our distinguished professors, whose guidance, commitment, and invaluable knowledge were instrumental in the completion of this work.*

*To all of you, we dedicate this modest effort, with a prayer that Almighty God bless your lives, grant you health and prosperity, and reward you abundantly.*

# Thanks, and Appreciation

*In the name of Allah, the Most Gracious, the Most Merciful.*

*All praise is due to Allah, the One and Only God, and may peace and blessings be upon the Prophet Muhammad, the Seal of the Messengers, his family, his companions, and all those who follow his path until the Day of Resurrection.*

*I would like to express my sincere and profound gratitude to Pr. Redha Meneceur and Dr. Zoubir Zeghdi, lecturer at Chahid Hamma Lakhdar University of El-Oued, for their invaluable advice, continuous guidance, and unwavering confidence and support, which enabled me to complete this work successfully.*

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*My heartfelt thanks also go to my friends, colleagues, and teachers, whose support and companionship have enriched this journey.*

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# List of abbreviations

**MPP:** Multiphase Pump.

**GVF:** Gas Volume Fraction.

**PCP:** Progressive Cavity Pump.

**VFD:** Variable Frequency Drive.

**RPM:** Rotations Per Minute.

**SP:** Set Pressure.

**AV:** Actual Pressure Value.

**SOS:** Seal Oil System.

**LMS:** Liquid Management System.

**SDV:** Shut-Down Valve.

**XV:** Bypass/Drain Valve.

**PDIT:** Differential Pressure Indicator/Transmitter.

**PIT:** Pressure Indicator/Transmitter.

**FIT:** Flow Indicator/Transmitter.

**TT:** Temperature Transmitter.

**PLC:** Programmable Logic Controller.

# *General Introduction*

# General Introduction

In recent decades, the oil and gas industry has faced growing pressure to reduce production and operating costs while maintaining supply reliability and improving the exploitation of fields—particularly in deep-offshore locations and remote reservoirs with declining productivity. This challenge has driven the search for innovative technologies capable of minimizing surface infrastructure and eliminating the need for complex and costly conventional separation equipment. In this context, multiphase pumping technology has emerged as a strategic solution, enabling the transportation of the produced mixture of oil, water, and gas simultaneously, without prior phase separation—representing a significant breakthrough compared to traditional approaches based on mechanical and chemical separation units.

This technology offers wide opportunities for the exploitation of low-productivity wells and distant offshore sites, as it reduces capital investment and routine maintenance costs, while also lowering the environmental footprint by limiting the need for additional treatment and separation facilities. Nevertheless, the inherently complex nature of multiphase flow—with large variations in Gas Volume Fraction (GVF), fluid viscosity, and temperature—imposes major engineering and operational challenges on the design and operation of these pumps. Such challenges have motivated both the scientific community and the industry to develop advanced mathematical and experimental models to improve performance and enhance reliability.

Within this framework, the Leistritz L4 twin-screw pump stands out as an advanced industrial example. It is designed to handle high gas fractions while maintaining stable pressure and flow, supported by a set of integrated auxiliary systems that include cooling and lubrication units, a mechanical seal, and real-time control and measurement devices.

The present thesis aims to study and analyze the performance of the Leistritz L4 pump by evaluating its volumetric and mechanical efficiencies, based on accurate experimental data collected through a flow-metering system and the pump control unit. The work includes a review of the main previous studies and theoretical models that established the scientific foundations for understanding the behavior of multiphase screw pumps, together with a detailed analysis of the pump's key mechanical components and the role of its auxiliary systems in enhancing performance and reducing losses.

By combining theoretical insights with experimental findings, this thesis provides a comprehensive understanding of the factors influencing the pump's efficiency and derives practical recommendations for improving the operation of multiphase screw pumps in oil and gas applications—thus meeting the modern industry's demand for more efficient and sustainable solutions.

# *Overview of Multiphase Pumps*

## I. Introduction:

Although it is not a new technology, the use of positive displacement pumps to move fluids is nevertheless seen as quite novel. Multiphase pumping first appeared in the oil and gas literature in 1957, and for almost 30 years, the technology's development was. set aside at the moment because of "unsolvable duties." In the late 1980s, there was a rise in the Poseidon project, a multiphase study headed by Bornemann Pumps. The The project's guiding principle was created with the goal of increasing well productivity. straight from the undersea well and deliver the final product to a processing facility located many kilometers distant. The Poseidon project's installation and field testing got underway in 1990. Two significant phenomena were noted over the two-year study period. Extended gas phases Gas Volume Fractions (GVF) ranging from 90% to 100% were common, which led to too much heat production, which could make the pump unusable, and if not closely observed, the potential for catastrophic harm. In addition to the extended dry operating, the early application's mechanical seals were open to the entrance of the pump and suffered significant temperature shocks as a result of the fluctuating GVFs that would cause the seals to fail or wear out too soon [1].

Early on, the advantages of multiphase pumps were exceeded by the costs of development. The world's oil reserves were expanding, and although efficiency and conservation were still crucial, the expense of creating multiphase technology was not thought to be a feasible choice until lately. In the present situation, it is becoming into more crucial to boost old well output and lower the expenses of the ongoing activities. Whether offshore or onshore, a conventional oil field application contains of includes a gas production line, fluid pump, gas compressor, gas separator, and liquid production line, as well as a system for handling particulates. The decrease in capital and equipment Simply employing a single MPP and a single gas or liquid will yield costs. production line with the ability to move the fluid in multiple phases. The suggested Multiphase systems require less maintenance and have lower capital expenditures and system complexity, equipment, lessen the impact on the oil rig, and provide a comprehensive system that includes a One production line and one pumping facility [2].

Additionally, the MPPs may be readily modified for subsea applications, which would enable their installation without the need for a whole oil rig. There may be a lot more opportunities to drill new wells that were previously inaccessible thanks to this streamlined procedure to the conventional facilities on oil rigs.

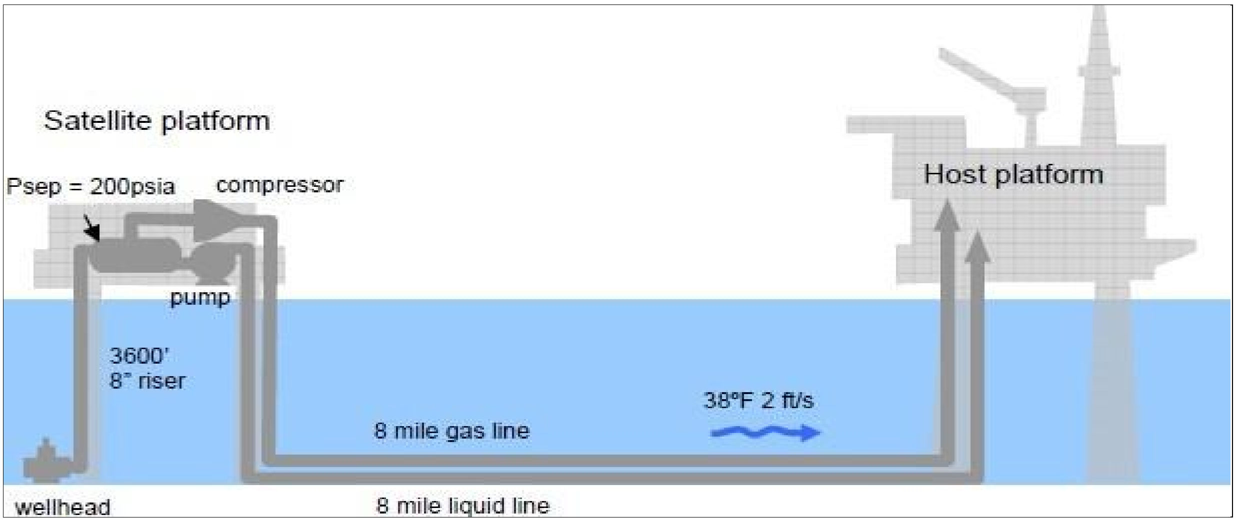



**Figure I.1:** System Diagram of a Typical Installation (Shippen 2002).

The standard setup for extracting natural gas and oil from an oil field is depicted in Fig. I.1. The host platform would be connected to the satellite platform when it was installed.

Regardless of whether the pumping station was positioned on the satellite platform or the host platform, more infrastructure and a wide footprint are needed to support the equipment. The necessary liquid pump, gas compressor, and separator occupy significantly more room than one MPP. The existing systems' exorbitant cost prevents access to certain wells because of their very low productivity or remoteness of the well, including marine wells that are extremely deep. The MPP is shown in Fig. I.2. installation on the ocean floor as opposed to the conventional configuration of an oil rig [3].

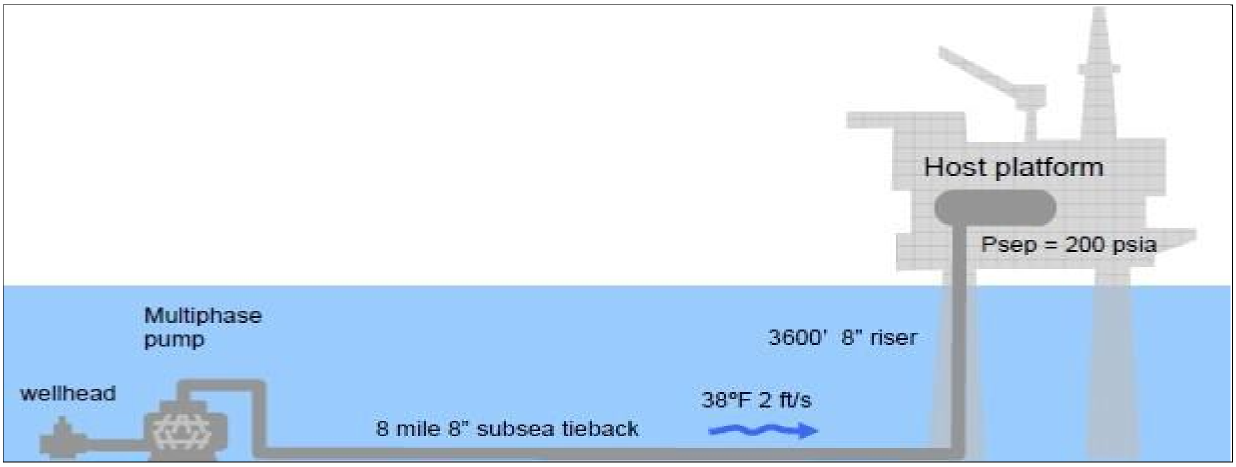



**Figure I. 2:** System Diagram Utilizing a MPP (Shippen 2002).

Where previously unattainable due to the expensive expense of a fully outfitted oil rig, the MPP technology would provide access to smaller, less productive, and very remote wells. A

MPP placed directly on the wellhead on the seafloor frees up room on upcoming oil rigs and have access to a pipeline system. Without requiring additional platforms—such as satellite platforms—and wells that would not have satisfied the A full-on conventional oil rig's production minimum can be used profitably. The These unexplored oil pockets can no longer sustain the global oil economy. be able to afford to go unused.

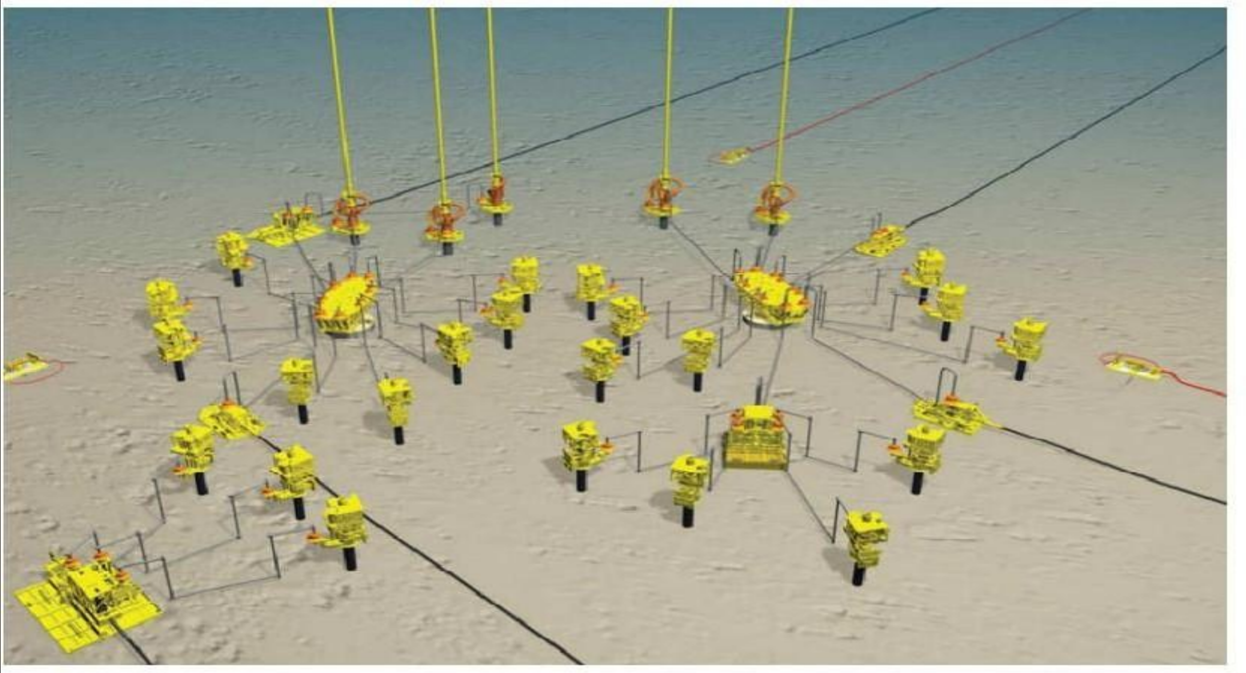


**Figure I. 3:** Subsea Oil Field (FMC Technologies 2007).

A digital representation of a recent breakthrough made by FMC Technology for Shell can be found in Fig. I.3. [4]. Many wells can be accessed with central pumping stations that raise the harvested fluid to central processing centers by to the utilization of subsea MPP. Utilizing these Subsea networks are a simple method of accessing less productive wells without the requirement for a complete oil rig installation, which drastically lowers expenses and provides access to goods that was not accessible before.

Although there has the technology to put such a system into place, its robustness and dependability must be enhanced before it can be used widely. Although topside apps have been used and installed all over the world, the upkeep need would be too risky for subsea deployment right now. An inability to land would cause the pump to shut off for a bit while a technician was sent out to do the necessary repairs. The same kind of subsea failure application would necessitate the deployment of a number of ROVs to the ocean floor.

to fix the broken pump. The substantially increased expense of submerged maintenance applications are undoubtedly a major factor in the ongoing technological research. Before any solid solution can be put into practice, the current problems under investigation must be fixed.

## II. History of Multiphase Pumps:

Multiphase pumps have a history spanning several decades, their development being driven by the need to find efficient solutions for transporting complex fluids, such as liquid and gas mixtures, in industries such as oil and gas. With the expansion of oil and gas activities, particularly in the 1960s and 1970s, with the rise of offshore fields and remote areas, the need for pumps capable of efficiently handling these mixtures became critical [17].

Over time, significant advances have been made in multiphase pump design and technology. Early prototypes, dating back to the 1980s, often encountered challenges related to reliability and efficiency, but ongoing research and technical innovations have led to significant improvements in their performance. Multiphase pumps have become essential equipment in the oil and gas industry, offering a valuable alternative to traditional methods of phase separation prior to transport.

The widespread adoption of multiphase pumps accelerated in the 1990s and early 21st century, in response to the need to optimize the extraction and transportation of energy resources more efficiently and economically. This led to their widespread integration in various industrial applications.

At the same time, significant advances have been made in specific areas of the pump, such as the improvement of the thermal and acoustic performance of geothermal heat pumps in 2015, or the improvement and integration of methods for displaying the real-time performance of heat pumps in 2017. These advances demonstrate the constant evolution of pumping technologies to meet the varied needs of industries and specific applications, with Fig. I.4. representing the use of the multiphase pump worldwide [1].

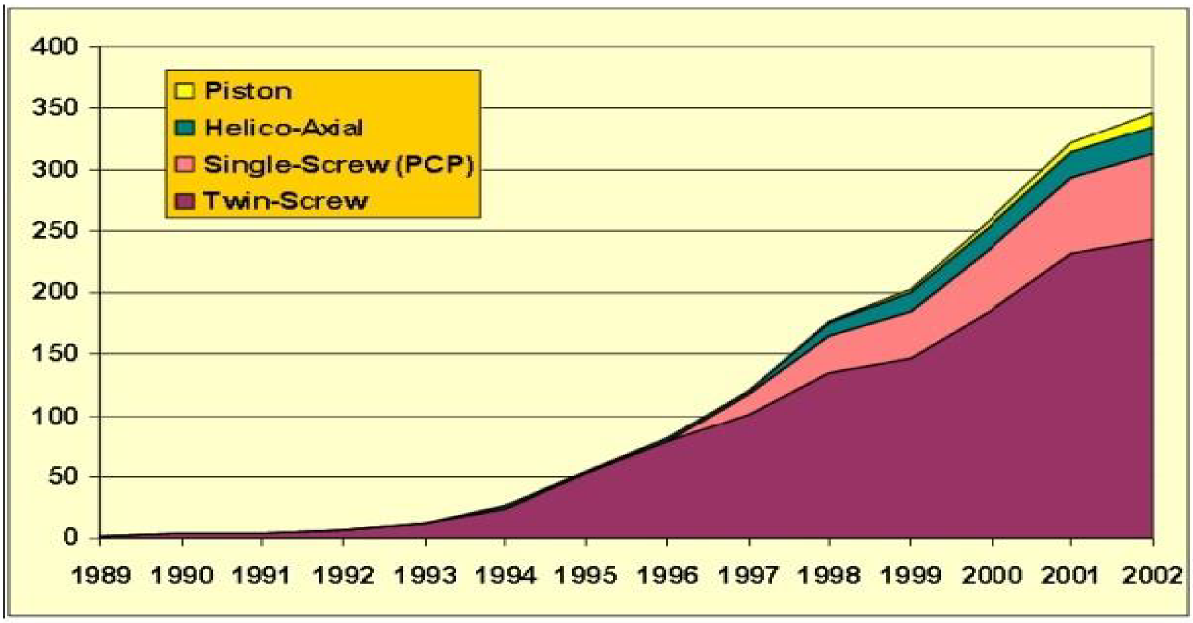



**Figure I. 4:** Graph representing the use of multiphase pump in the world [2] [17].

The regional and country-level analysis of the multiphase pump industry is segmented into five major regions: North America, Europe, Asia Pacific, Middle East & Africa, and Latin America (including major contributing countries). It provides information on revenue share and current trends. The base years considered for all estimations, based on trend and growth rate analysis, provide an in-depth understanding of the findings presented (Fig. I.5.). [16].

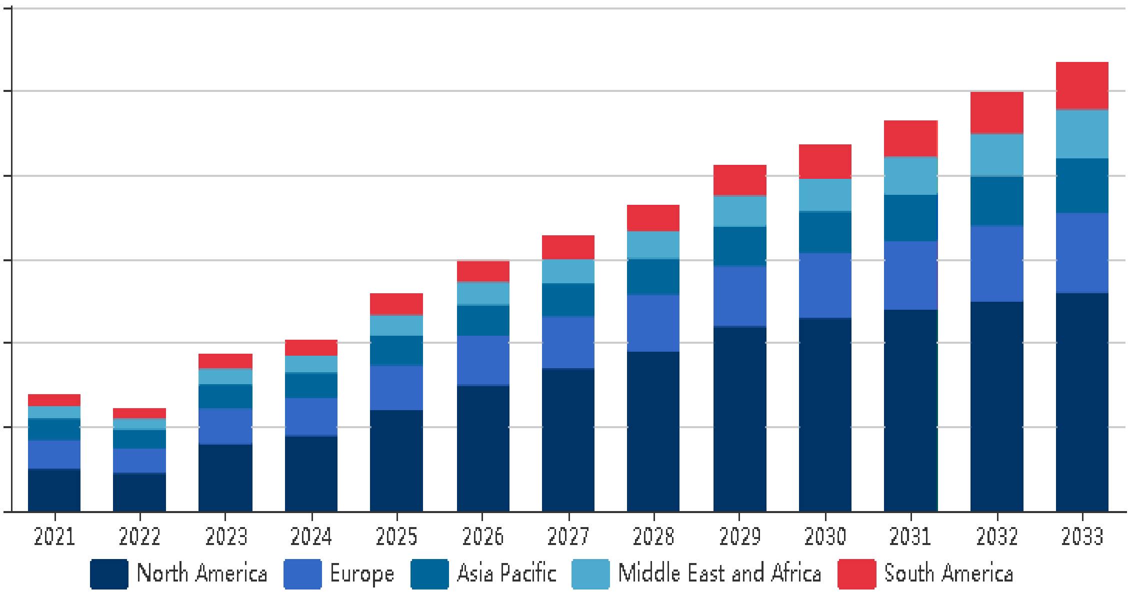



**Figure I. 5 :** Multiphase Pumps Market Share (%) by Region (2021-2033) [16].

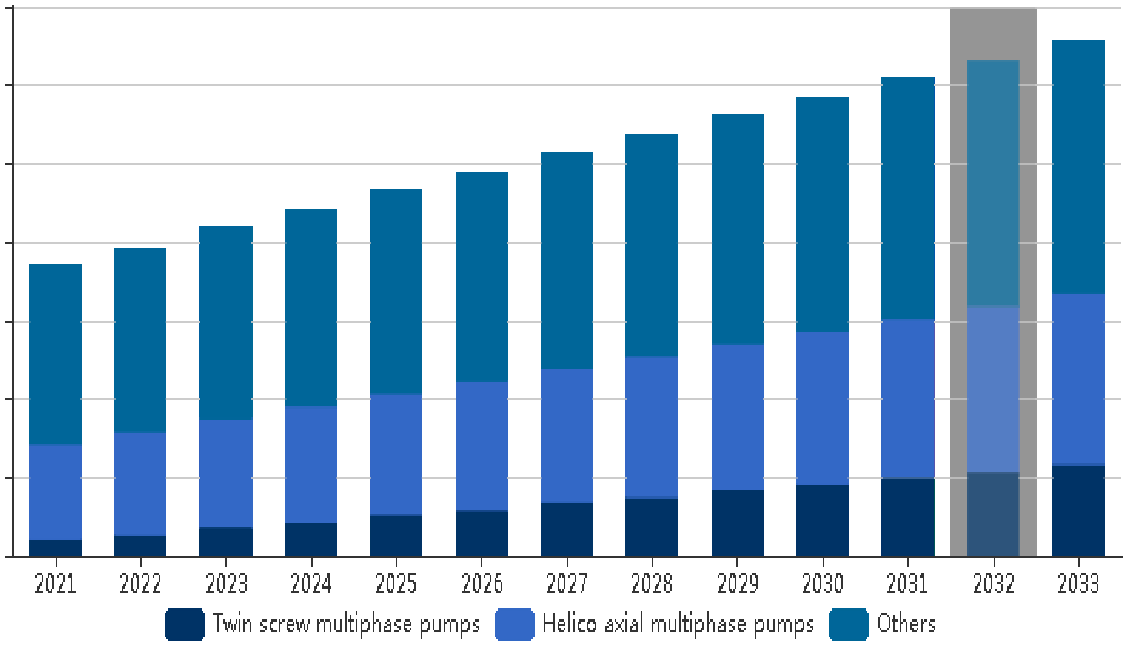



**Figure I. 6 :** Market share (%) of multiphase pumps by type from 2021 to 2033 [16].

Figure I.6 shows a gradual growth of the multiphase pump market between 2021 and 2033, with a distinction between three types: twin-screw pumps, helical-axial pumps, and other types. Demand increases steadily until 2030, followed by a sharp rise after 2031, indicating a possible market expansion due to innovations or investments. The "Others" category is taking an increasing share, suggesting technological diversification. Overall, the market is undergoing rapid growth, driven by technological advancements and growing industrial demand. [16]

Based on the applications, the market is onshore and offshore. The onshore segment will lead the global share until 2032 (Fig. I.7). [16]

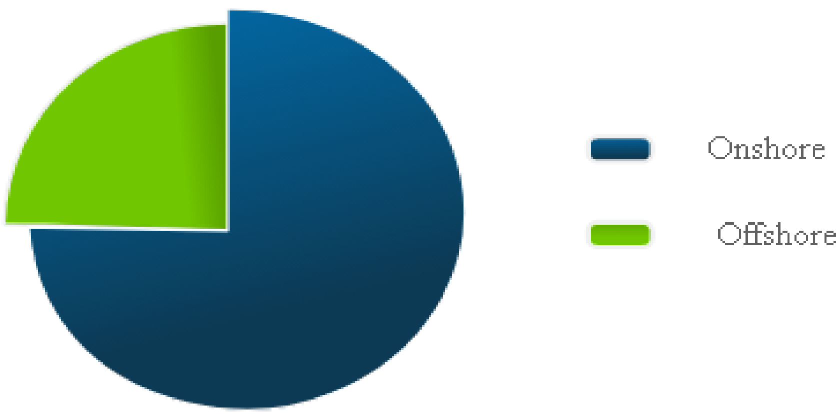



**Figure I. 7 :** Global market share of multiphase pumps in 2032 [16].

### III. Definition of a multiphase pump:

A multiphase pump is a type of pump used to transport fluids composed of multiple phases, such as a mixture of liquid and gas. This type of pump is often used in the oil and gas industry to extract and transport crude oil and natural gas from wells to processing facilities. Multiphase pumps are designed to efficiently handle changes in the composition and properties of the moving fluid, making them particularly suitable for applications where the fluid may vary between different phases during the pumping process. This allows complex mixtures to be transported without having to separate the different phases beforehand, simplifying and optimizing operations. [1]

### IV. Types of Multiphase Pumps

Multiphase pumps use several technologies to manage fluids having many phases at once. The types of pumps listed below serve as examples:

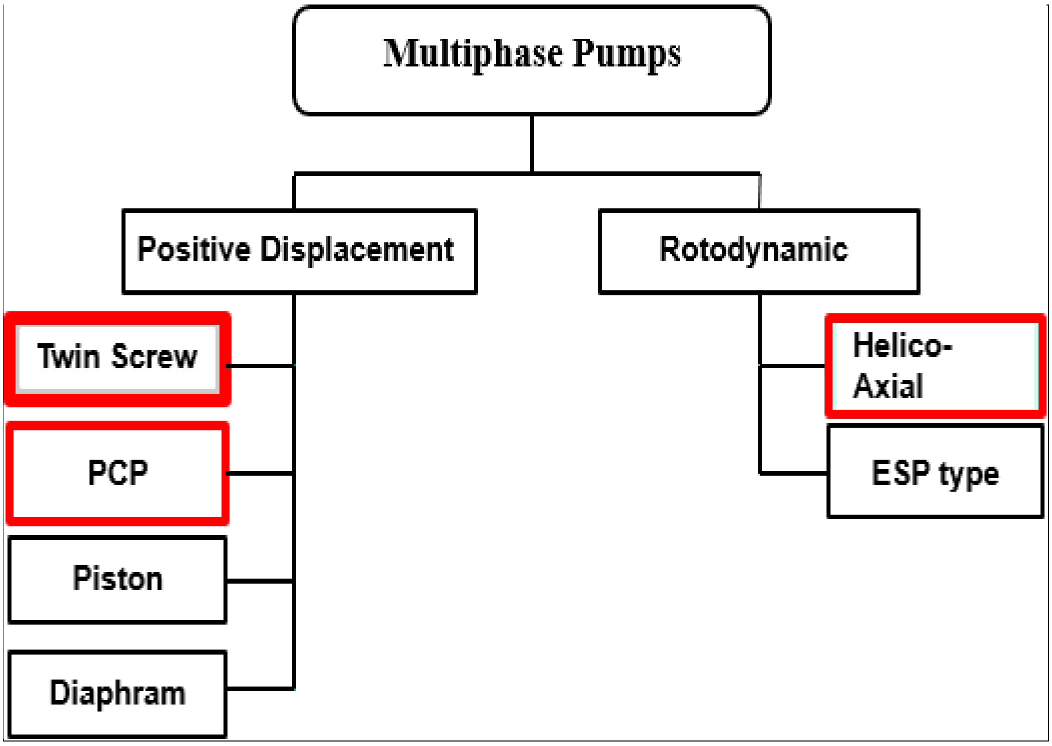



**Figure I. 8:** Multiphase pumps types.

### IV.1. Rotodynamic Multiphase Pump

Centrifugal force pushes the multiphase fluid radially toward the impeller's perimeter after it is drawn axially into the rotor (impeller) by the rotodynamic multiphase pump. The impeller's mechanical energy is transformed into pressure energy by the fluid's radial flow within the impeller channels. After that, the fluid is released either axially or radially into the diffuser or volute, where it is released under high pressure [2].

### IV.2. Multiphase mixed-flow centrifugal pump

This type of pump includes multiple separate booster stages, each of which has a fixed diffuser after an impeller positioned on a single spinning shaft. The fluid receives kinetic energy from the impeller, which the diffuser transforms into pressure. The fluid is redirected to the subsequent impeller stage after being homogenized by the diffuser. By preventing the gas-liquid mixture from separating, this interstage mixing produces consistent pressure-flow characteristics and boosts overall efficiency. The open-type impeller profile and diffuser blade arrangement are specifically designed to prevent the multiphase mixture within the pump from separating, and the impeller blades have a typical helical shape. The gas flow rate (GVF) at the suction, suction pressure, speed, number of impeller stages, and impeller size all affect this pump's pumping capabilities [3].

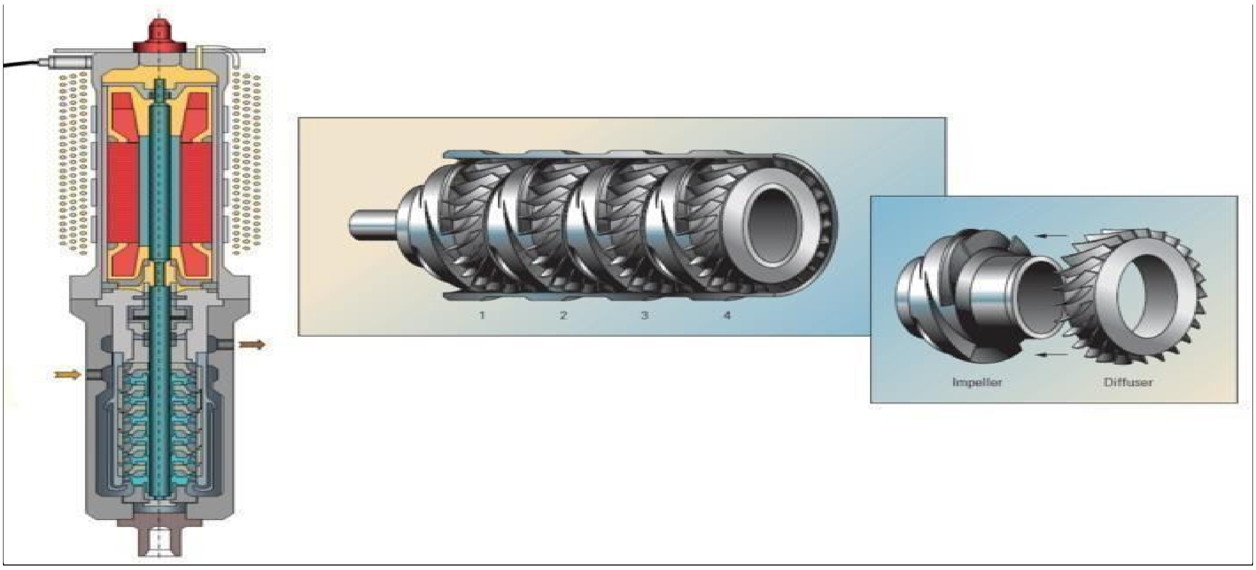



**Figure I. 9:** Helical centrifugal pump with many phases.

### IV.3. Multistage centrifugal pump

The Poseidon Group created the helical-axial pump, which is now manufactured by firms like Framo (Leistritz) and Sulzer. It is intended for horizontal flow via a number of pump stages, such as stationary diffusers and helical impellers.

This pump performs exceptionally well when managing multiphase flows and is especially effective for transporting gas. Because of its design, it can operate steadily even in unpredictable situations like clogging hazards or transients. The main pumping process is started by the specially designed axial flow stages, which also guide the gas-liquid mixture through the different stages. Gas volume compression is guaranteed by the Poseidon system to maximize pump efficiency [3].

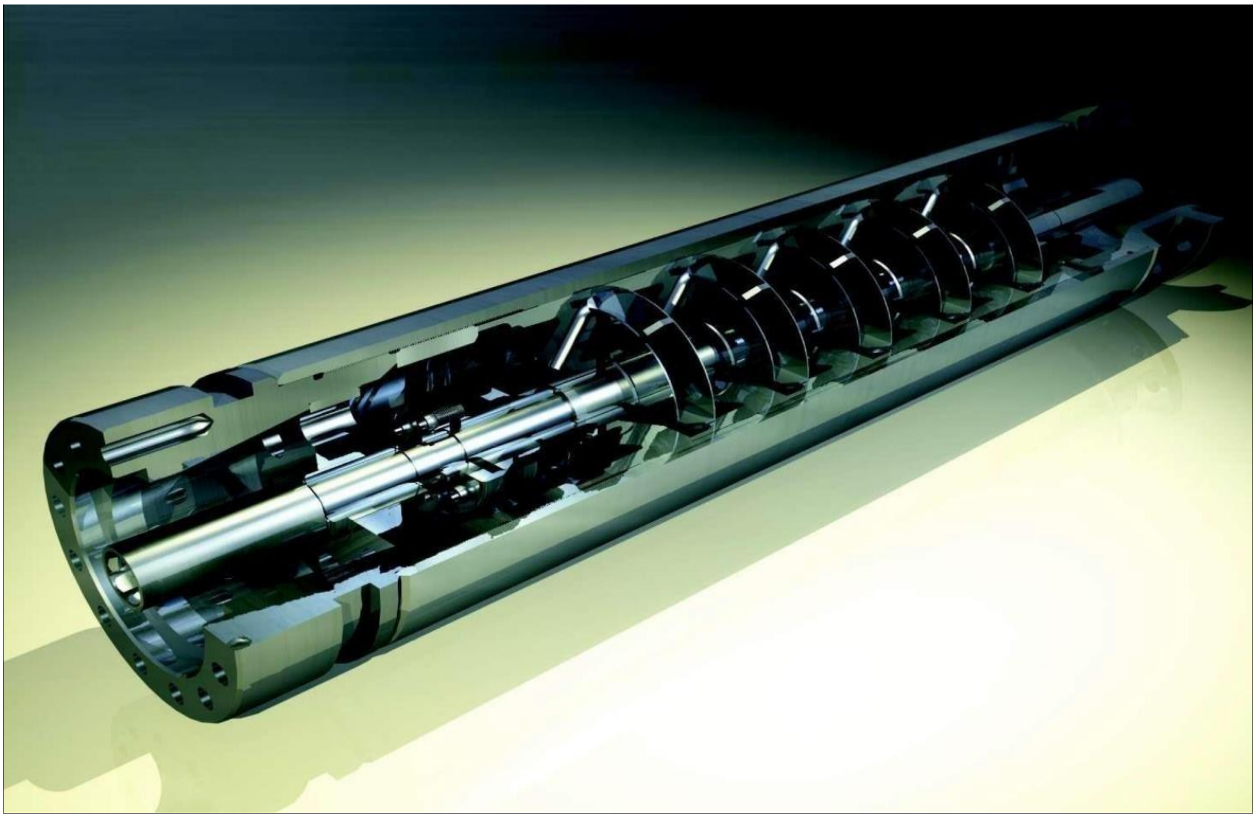


**Figure I. 10:** Pump with multiple stages [4].

### IV.4. Positive Displacement Pump

Because of the pressure differential, fluid can be pulled into the pumping chamber by the vacuum volume in the chamber. After that, the fluid is released, which lowers the chamber's capacity. The resistance that the flow faces at the pump's outlet determines the pressure differential, which affects how well this kind of pump works. [5]

#### IV.4.1 Progressive Cavity Pumps (Single-Screw Pumps)

Progressive cavity pumps, sometimes referred to as eccentric screw pumps, are positive displacement devices made out of a vulcanized rubber stator and a stainless-steel helical rotor. Enclosed chambers are created one after the other while the rotor rotates, allowing the fluid to move smoothly from the suction side to the discharge side. Because the flow rate is precisely proportional to the pump's rotating speed, this working principle guarantees a constant, pulsation-free flow. These pumps have shown to be highly effective in multiphase pumping operations and are frequently used in artificial lift systems for shallow wells in real-world applications. They function well at moderate discharge pressures (up to 50 bar) and relatively low flow rates (up to about 30,000 barrels of total fluid per day). Additionally, progressive cavity pumps can withstand large quantities of entrained materials and are ideal for handling extremely viscous fluids. However, one of the primary operational issues of this pump type is the excessive sand output, which speeds up the stator's wear and necessitates periodic replacement.

**Figure I. 11:** Progressive Cavity Pump (PCP).

**IV.4.2 Screw Pumps**

Screw pumps are split into two parts: Single rotor and multiple rotor types. In the single rotor type, the rotor thread meshes with the internal housing threads. Multiple rotor types are split into two parts as well: Single-end and double – end. In both cases only one rotor is driven. While a gear is used to rotate the other rotor in double-end screw pumps, the single-end screw pump configuration enables the other rotor to rotate with the motion of driven rotor [6].

Even though all rotary pumps move the fluid circumferentially, flow pattern of screw pumps is axial. This makes the screw pumps unique and gives numerous advantages as follows [6]:

It is able to work in a wide range of different conditions such as flow type, pressures, liquid type and viscosity:

- High speeds can be achieved due to lower inertia of rotating parts.

- Low internal velocity is the outcome of the axial flow pattern.

- It is capable of operating in multiple phases.

It may operate in silence because to the extremely low mechanical vibration:

-The pump is comparatively simple to install and maintain.

-The pump has the capacity to withstand solid particles.

The performance of a screw pump is determined by a few key factors. The following is a list of them:

**- Inlet Condition:** A force must be applied to propel the fluid into the screw pump because it cannot pull or lift the fluid. For this process, ambient pressure is typically utilized.

**- Fluids and Vapor Pressure:** Cavitation can be caused by vapor or dissolved air pressure, which reduces efficiency. It might also operate noisily.

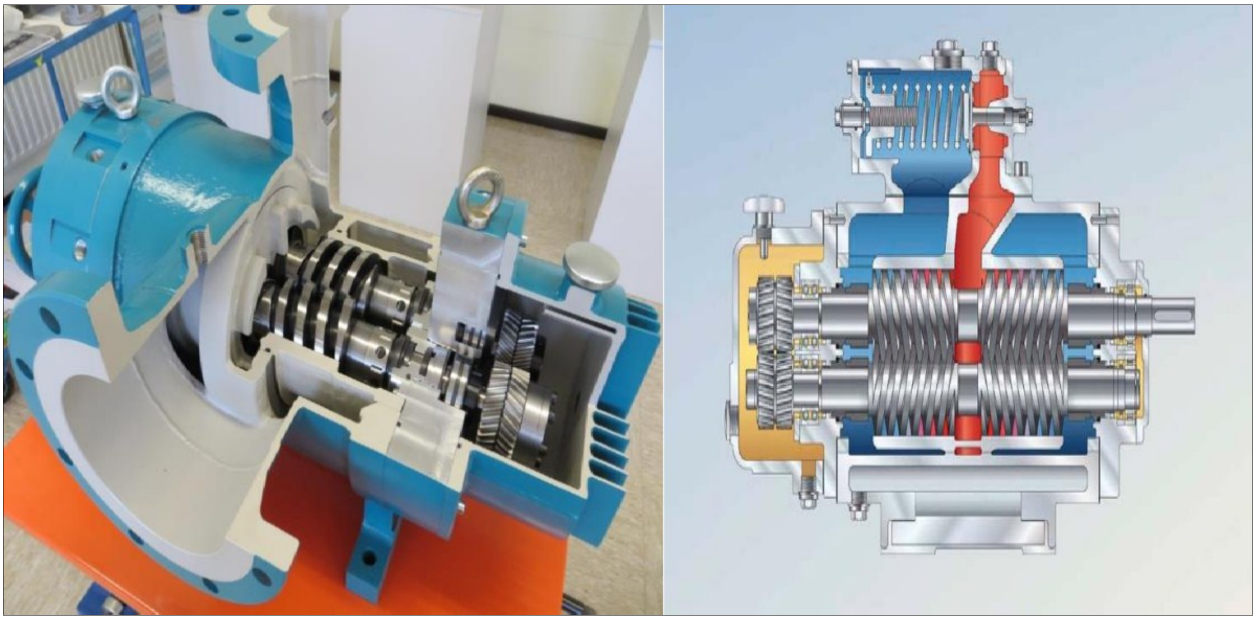
**- Viscosity:** The filling cavity rate is directly correlated with the fluid's viscosity. Higher viscosity fluids require more time to fill the rotor chamber, hence in this case, the pump's speed should be reduced.

**- Outlet Conditions:** A key factor in outlet pressure is the size of the pipe. For instance, a well-chosen pipe size may result in a more efficient pump operation [6].

### IV.4.3 Twin-Screw Pump

The twin screw pump under consideration belongs to the double-end screw pump family. It is set up with a common driving rotor and two opposing screws of the same size. A gear holds the screws together. The pump's a shared exit and a shared inlet. The screws' axial loads are all balanced. Double-end screw pumps can function in a variety of pressure applications with big rates of volumetric flow. Additionally, the multiphase and viscous flow can be managed utilizing the same system [7].

The fluid is transported by the C-shaped chambers created by the turning screws. As a result, the only factors that determine the potential volumetric flow rate of the pump are its shape and speed. Figure 8 shows a twin-screw pump in section.



**A:** Twin Screw Pump. **B:** Twin-Screw Multiphase Pump.

**Figure I. 12:** Twin Screw Pump.

The twin-screw pump is made with tolerances to prevent metal-to-metal contact during pump operation. Another name for these tolerances is clearances.

There are three different kinds of clearances: radial, flank, and circumferential. Clearance. Backflow or leakage across these is caused by the pressure increase across the pump.

Both volumetric and mechanical efficiency are negatively impacted in this scenario. Thus, the most crucial element for a multiphase system is to comprehend this leakage flow, operation to gauge the performance of the pump. These clearances are shown in Figure I.13. As demonstrated in.

The liner and the screw are separated by the circumferential clearance on the graph. The tolerance between the screw's outer diameter and the other screw's root diameter is known as root clearance, while the tolerance between the screw rotors' flanks is known as flank clearance [10].

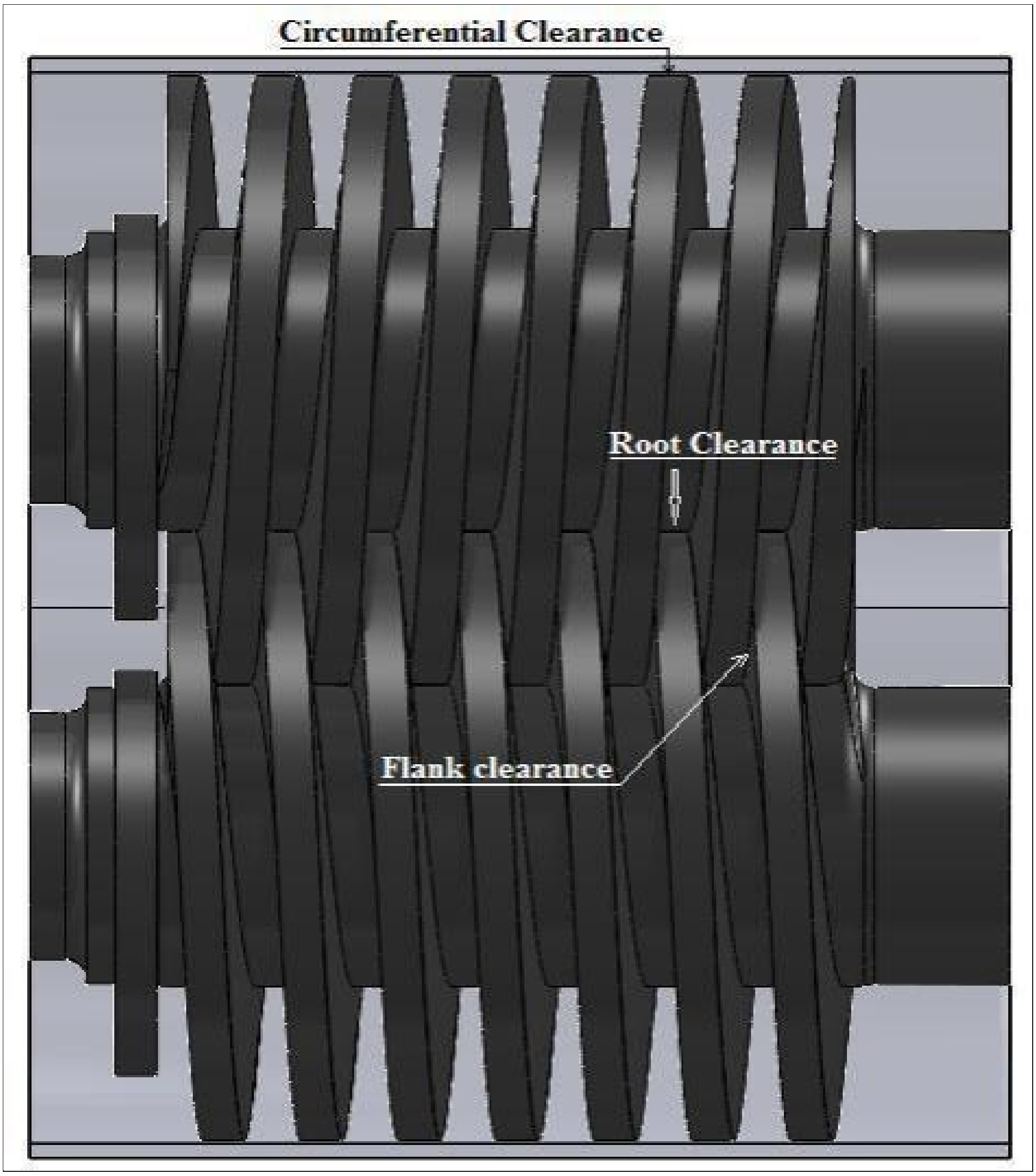


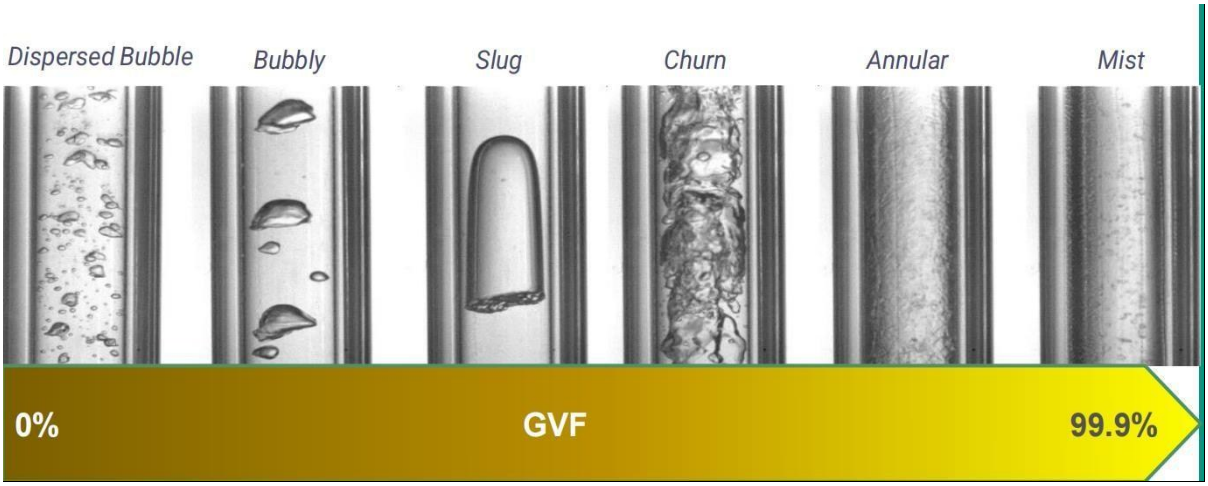

**Figure I. 13:** Clearance types of a twin-screw pump [10].

**Tableau I. 1:** Comparison of two types of multiphase pump [11], [12].

| Characteristic | Positive displacement pumps | Rotodynamic pumps |
|---|---|---|
| Example | Twin screw pump | Multistage centrifugal pump |
| Principle of operation | A multiphase piston pump works by using a piston to move a mixture of gases and fluids, creating pressure to move the mixture through the system. A motor regulates the piston's action, varying the output pressure according to the driving air pressure. | A multiphase multistage pump works by assembling multiple centrifugal impellers in succession, each of which raises the liquid pressure. This approach enables the production of high pressures in a compact space. The fluid's successive passage through these impellers progressively raises the multiphase mixture's pressure and speed. |
| Speed | proportionate to the screws' pitch and rotation speed | depends on the impeller size, number of stages, speed, suction pressure, and GVF. |
| Pressure | Up to 40 bar | Up to 150 m |
| Fluid viscosity | able to pump extremely viscous liquids | Not as appropriate for fluids with high viscosity |
| GVF, or gas fraction | Effective with high GVFs | Best used with moderate GVF |
| speed of rotation | Lower than pumps that use rotodynamics | Greater than pumps with positive displacement |
| Training | Torque must be constant. | Possible variable speed |
| Benefits | -Continuous flow<br>-Excellent performance across a broad speed range<br>-Self-priming | Gas-liquid separation is prevented by interstage mixing; the pump is specifically designed<br>to prevent separation. |

### V. Multiphase Fluids

It is important to comprehend what a multiphase fluid is before learning how an MMP operates. Any combination of gas, liquid, or solid particles can be referred to as a multiphase fluid. When a fluid flow is made up entirely of either a liquid or a gas, it is said to be single phase. The multiphase mixture in the oil pipeline may include materials like sand, wax, gas, water, natural gas hydrates, and crude oil [12].



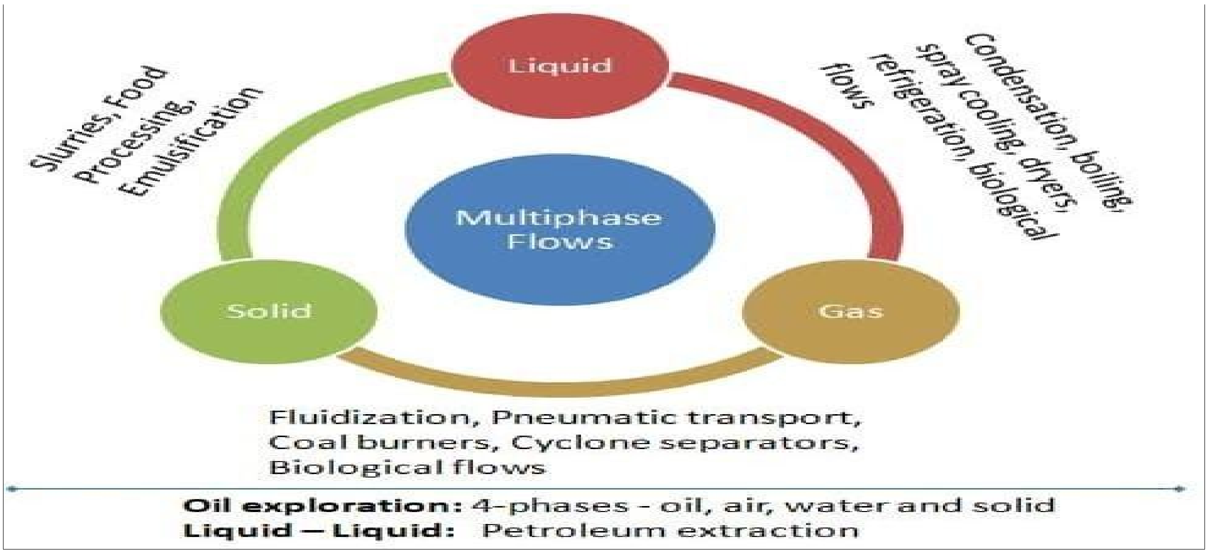




**Figure I. 14:** Possible Flow Regimes for Mixed Fluid Flow.

Figure I.14 illustrates the variety of flow regimes that are present in multiphase fluids. The GVF and the relative velocities of the corresponding single phase fluids determine the parameters that establish the flow regime. Since sight glasses cannot be inserted into the pump assembly, it will be unable to directly witness the flow regime or the pump inlet circumstances during the current inquiry; consequently, only a topical awareness of these flow regimes is necessary [13].

## VI. Pipe Flow

The mass and energy conservation principles serve as the foundation for the pipe flow model. This law states that the energy and mass at the intake and outflow must be equal. This kind of flow can be described by the Bernoulli Equation. The energy calculation should also include the energy consumption brought on by friction, taking into account the inlet and output flow characteristics. With the fully developed flow assumption, the governing equation for a pipe flow takes the following final form [14]:

$$P + \frac{1}{2}\rho V^2 + \rho g z_{\text{inlet}} = P + \frac{1}{2}\rho V^2 + \rho g z_{\text{outlet}} + h_{\text{friction}} \tag{I.1}$$

Where:

• P : Pressure energy per unit volume (Pa = N/m²)

• ½ρV² : Kinetic energy per unit volume (dynamic pressure)

- ρ : Fluid density (kg/m³)

- V : Fluid velocity (m/s)

• ρgz : Potential energy per unit volume (hydrostatic head)

- g : Gravitational acceleration (9.81 m/s²)

- z : Elevation head (m)

• Subscripts inlet / outlet : Values at pipe inlet and outlet respectively

• h_friction : Head loss due to friction and turbulence in the pipe

A German professor named Julius Weisbach and a French engineer named Henry Darcy discovered a link for the friction power:

$$h_f = f \cdot \frac{L}{d} \cdot \frac{V^2}{2} \tag{I.2}$$

Where:

• f : Darcy friction factor (dimensionless)

• L : Length of the pipe (m)

• D : Internal diameter of the pipe (m)

## VII. Advantages and Disadvantages of Multiphase Pumps

### VII.1 Advantages:

- Centralized Treatment: The pump transfers the flow from the well to a single treatment center, eliminating the need for multiple installations.
- Cost reduction: This centralization results in a significant reduction in capital expenditures and operational costs.
- Increased production: The pump provides reliable flow pressure at the wellhead, accelerating production and enabling flow unblocking.
- Flexibility and reliability: Its robust design ensures smooth and reliable operation, even under variable conditions.
- Environmental benefits: Using the pump eliminates flaring and venting, significantly reducing carbon emissions.
- Complex fluid management: The pump is capable of simultaneously transporting high-viscosity fluids, improving overall flow and flow.
- Offshore applications: This technology is suitable for offshore installations and deep-water wells, enabling increased production from the seabed.

### VII.2 Disadvantages:

- Variable efficiency depending on the gas fraction
- Technical expertise required for maintenance (screw synchronization, specific sealing, suitable bearings).
- Limited availability of certain spare parts, which are potentially more expensive.
- The mechanical seal must be sized to simultaneously manage high pressure, temperature, and chemical aggressiveness conditions.
- Sometimes an additional cooling or lubrication system is required, which can increase complexity.
- Even if the pump is designed for multiphase operation, a very high gas fraction can increase the risk of cavitation or overheating, sometimes requiring the injection of stabilizing fluid.
- Beyond certain extreme pressures or flow rates, it may be more efficient to use a combination of technologies (compressors + pumps), as the multiphase pump may no longer provide satisfactory efficiency.

## VIII. Conclusion

From this review it is clear that multiphase pumping represents an economical and efficient alternative to conventional systems that rely on prior separation of gas and liquids. It reduces both investment and maintenance costs and enables the exploitation of remote or low productivity wells, particularly in deep-offshore environments.

Nevertheless, the large-scale industrial application of this technology still requires improvements in pump durability and component reliability in order to minimize the risks of failures and the associated maintenance costs.

These considerations naturally lead to the next chapter, which examines the scientific literature and the theoretical models developed for the design and performance analysis of multiphase twin-screw pumps such as the Leistritz L4.

# *Literature Review on Multiphase Pumps*

## I. Introduction

This chapter provides a comprehensive review of the literature and previous research on twin-screw multiphase pumps, with a focus on the historical development of thermo-fluid dynamic and analytical models as well as experimental investigations. It highlights the mathematical and experimental approaches developed to describe pump performance under operating conditions with high gas volume fractions, emphasizing the key findings reported by various researchers.

In addition, this chapter presents a detailed description of the Leistritz L4 pump and its auxiliary systems and instrumentation, including the flow-measurement device, explaining the operating principle and the importance of each component in maintaining reliable and efficient operation.

## II. Review of Literature: Developments in Multiphase Pumping

The literature study covers earlier research on multiphase twin-screw pumps, including analytical and numerical evaluations as well as experimental testing. Positive displacement pumps are the category that includes screw pumps. Greeks are credited with creating it.

Archimedes was a polymath in the third century BC. Screw-pumps have been utilized in the past. for the purpose of transporting water in agriculture. They have recently been utilized in a number of fields. Twin screw pumps' potential in the oil and gas sector was not fulfilled.

until before the early 1990s and mid-1980s. The primary cause of the multiphase surge pumps were required to pump the liquid and gas concurrently in order to decrease capital, environmental impact, and running costs for both onshore and offshore oil producing facilities, particularly production in deep water. Natural gas disposal via venting and flaring was an additional issue for the oil and gas sector. Reducing this waste turned into vital to get the highest possible hydrocarbon production.

### II-1-Vetter and Wincek (1993-2000)

Vetter and Wincek started simulating the operation of twin-screw pumps in multiphase settings shortly after Bornemann began exploring with MPP. The performance of the screw pumps for single phase flow had been thoroughly recorded up until this time. However, some simplifications were necessary due to the complex nature of multiphase flow. An Vetter and Wincek formulated the crucial supposition that the pump could be shown as a sequence of cylinders filled with fluid that are traveling toward the pump's center. The fluid flow direction and chamber arrangement are depicted in Fig. II.1. The majority of A crucial presumption was that the fluid flow was divided into distinct phases because the fluid's exposure to centrifugal forces from the rotating screws.

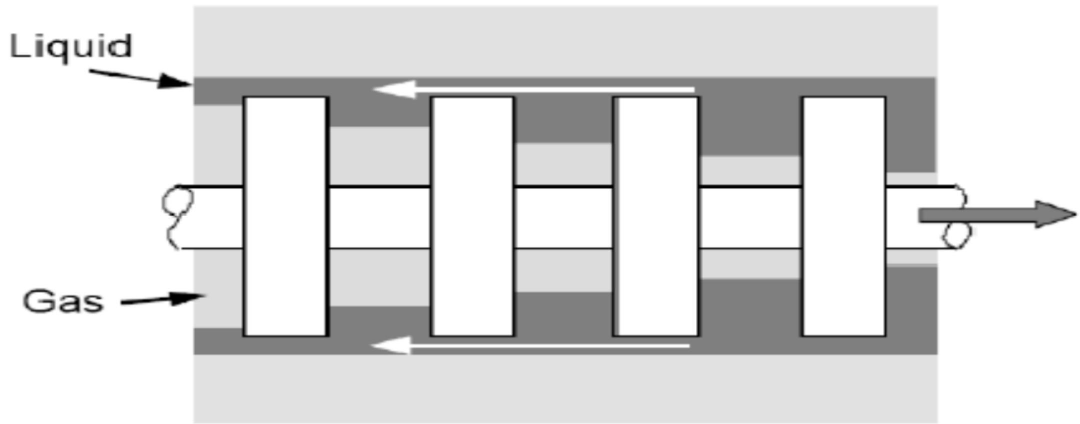



**Figure II. 1:** Simplified Model (Vetter and Wincek 1993).

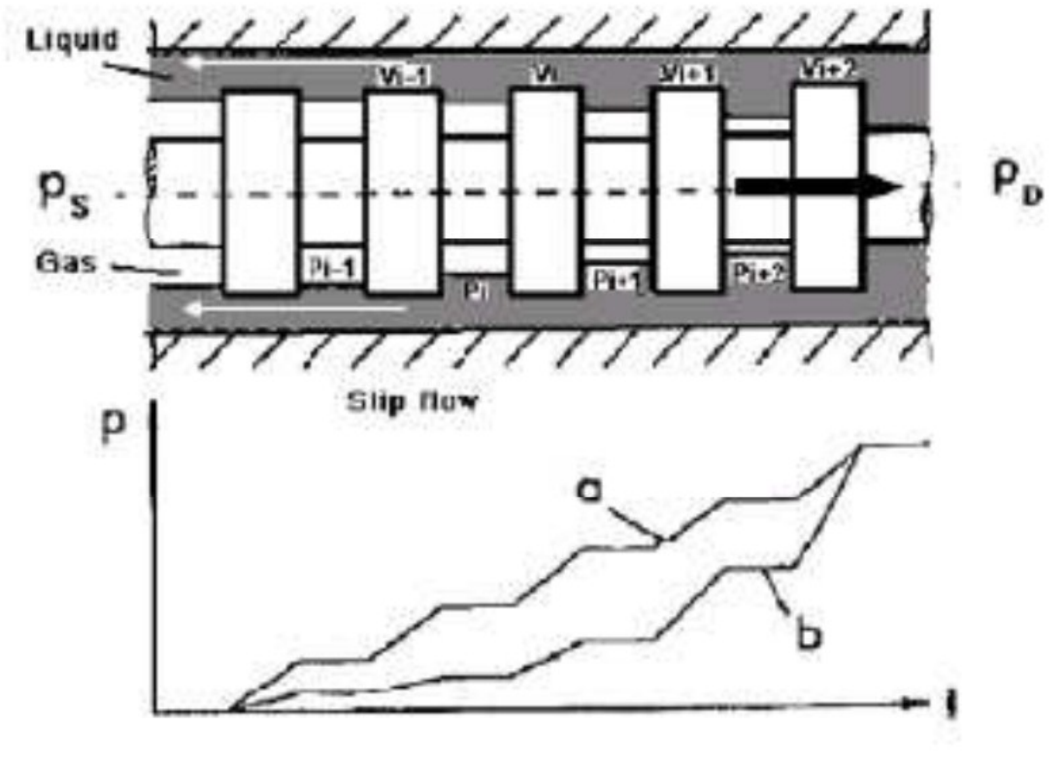



**Figure II. 2:** Pressure Profiles Along Screw Chambers (Vetter et al. 2000).

The analysis of a multiphase fluid could be reduced to a single phase flow under the presumption of phase separation. Vetter subsequently investigated this hypothesis in a lab, and the results indicated that it was true for GVF up to 85% [1],[2]. The model's chambers were made up of a series of disks that served as the volumes' mimicked the sealed chambers with discs. After that, the slip itself might be represented as a chamber progressed; the piston compressed the gas as the liquid in the mixture served as a sealant for the chamber. The compression for GVF of up to 96% can be presumed to be isothermal. For this model to correctly forecast performance, a great deal of detail It was necessary to measure the rotor. The slide model relies entirely on the screws' geometry. His analysis indicates that the circular distance between about 80% of the total leak was caused by the screw and the stator flow.

The model's validation studies yielded some intriguing findings. The pressure distribution across the screws was examined for the first time. The pressure profiles for both single-phase and multiphase fluids moving across the screw profiles. The pressure profile for single phase flow (profile an in Fig. II.2) grows linearly as the fluid moves from the pump's suction to its outlet. For GVF greater than zero the pressure profile is no longer linear (see profile b in Fig. II.2). This indicates that in contrast to single-phase flow in which the pressure is equally contributed by each cavity.

### II-2-Rabiger (2006)

The majority of leakage models assumed that the liquid portion of the mixture could absorb the side effects of the gas compression portion; however, in high GVF operations, compressibility and certain thermodynamic effects, like pressure drops and choked flow conditions, should be taken into account [3]. The pump's thermodynamic model was modeled as a series of chambers, with each chamber serving as a control volume. Figure II.3 shows that there is inflow and outflow to the mixture leakage in the chamber, with each letter denoting a quantity of bulk or energy and its thermodynamic properties as follows:

a- Gas Inflow: Its specific enthalpy is constant.

c- Compression of the gas due to liquid inflow: rising gas temperature

d- Liquid outflow: Its specific enthalpy may vary.

e- Liquid outflow causes gas expansion, which lowers gas temperature.

f- Gas outflow: It may have variable specific enthalpy.

g- Gas-Heat transfer from gas to liquid happens through the interfacial region.

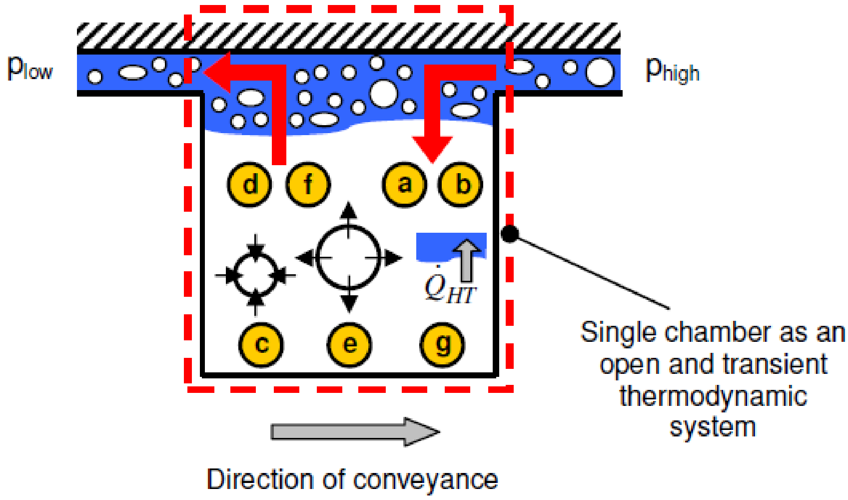



**Figure II. 3:** Control volume of the chamber [3].

The mass and energy conservation principles were applied to the following chambers based on the aforementioned assumptions. It should be mentioned that the isentropic model assumption was applied to the temperature or pressure change. The simple stratified flow assumption and the identical temperature at the conclusion of the heat transfer assumption were used to represent the heat transfer between phases. The phase temperature changes in a single time step are depicted in Fig. II.4 [3].

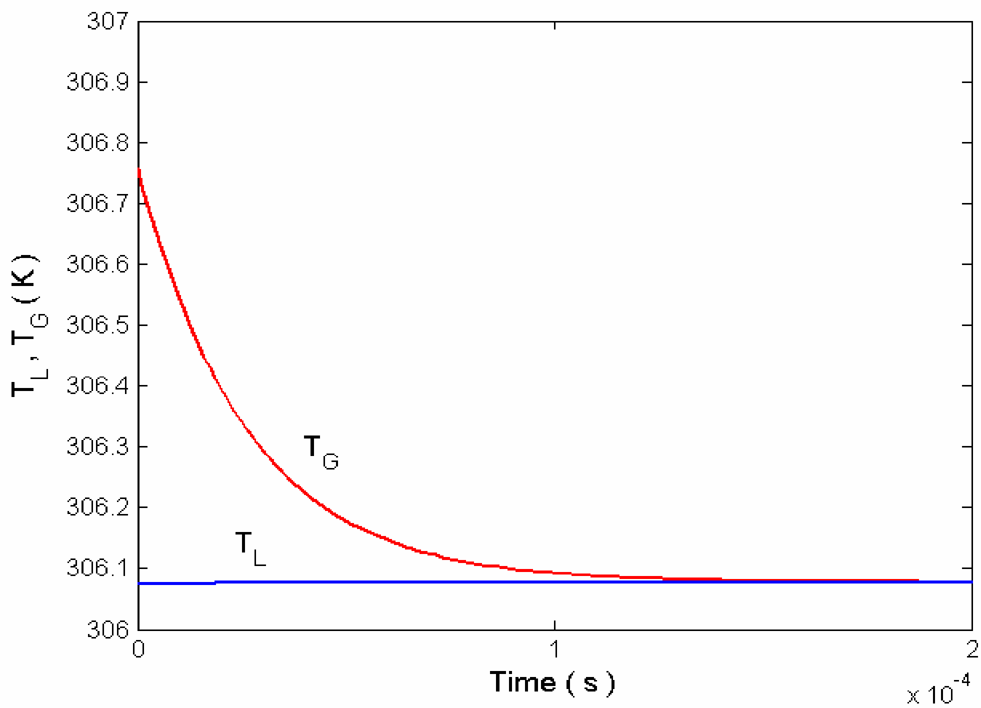



**Figure II. 4:** One-time temperature fluctuation in a chamber [3].

The mass, momentum, and energy conservation equations were used to describe the flow in th e radial gap and the perimeter in a rectangular clearance with fully developed flow. Additionally, the model functioned well under the most extreme critical flow conditions, such as when the static pressure differential between succeeding chambers is extremely large [3]. The aforementioned computations used the pump's inlet characteristics and estimated inlet vel ocity, after which the model was managed by the pump's outlet characteristics.
The following is a list of the results attained [3]:

The decrease in density and viscosity caused the leakage flow to lose its sealing function in high GVF operations.

The heated leakage for both phases caused the greatest temperature increase to be seen betw een the inlet and the first chamber.

Figure II.5 illustrates how the amount of liquid in the leakage flow caused the GVF to decrease in each chamber.

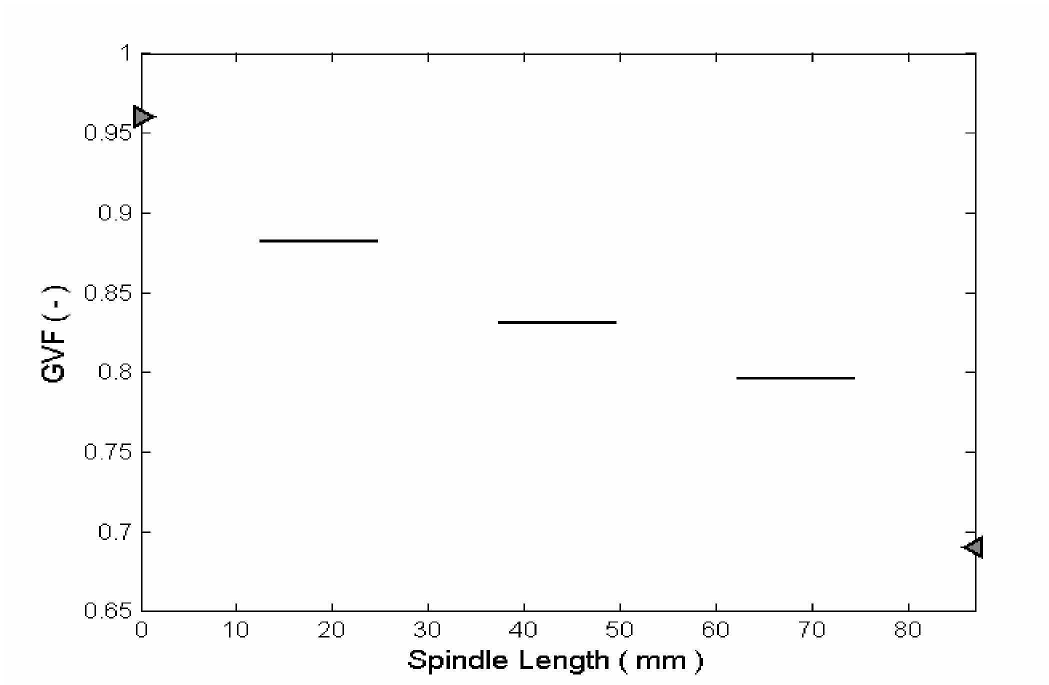



**Figure II. 5**: GVF shift across the screw [3].

**Tableau II. 1:** Experimental Studies on Twin Screw Pump Performance Under Varying Operating Conditions [15].

| Project Conductor | Pump | Operation Conditions |
|---|---|---|
| Abhay Ravindra Patil(2013) | Colfax Twin Screw Pump MR-200 | GVF=%50-100 |
| | | ΔP= 50,100,150,200,250 PSI |
| | | Inlet Pressure=15,50,75,100 PSI |
| | | Speed= 900,1350,1800 rpm |
| Ryan Kroupa(2011) | The twin screw pump Leistritz | GVF=%0-100 |
| | | ΔP= 50,100,150,200,250 PSI |
| | | Inlet Pressure=10,50 PSI |
| | | Speed= 1800,2700,3600 rpm |
| Theodore Isaac Hatch(2013) | Colfax Twin Screw Pump MR-200 | GVF=%65-92 |
| | | ΔP= 50,100,150,200,250,300 PSI |
| | | Inlet Pressure=15,50 PSI |
| | | Speed= 900 rpm |

## III. Experimental Facility

The Leistritz L4 multiphase pump and the flowmeter used in the experiment will be thoroughly described in this portion of the thesis.

The Leistritz L4 pump is a twin-screw multiphase pump that eliminates the need for phase separation by pumping a mixture of water, gas, and crude oil straight from the production line. This pump moves fluid from the suction side to the discharge side by means of two synchronized spinning screws that create sealed chambers. Even in situations with a high gas volume fraction (GVF), it can continue to operate with excellent efficiency.

A flowmeter with microwave technology was utilized to measure the multiphase flow in order to guarantee precise measurements throughout the experiment. By sending electromagnetic waves through the fluid to sense changes in density and velocity, this gadget makes it possible to calculate the instantaneous flow rate and the mixture's composition (oil, water, or gas) with extreme precision.

Since the recorded flow rate data are directly used to determine the pump's volumetric and mechanical efficiency as well as to assess the pump's performance under various operating situations, this device is one of the most important tools in the experiment.

Each pump system will be thoroughly explained in the parts that follow, backed up by field photos and diagrams gathered throughout the experiment.

### III.1. Pump Operating System (Process Overview)

Fig.II.6 displays the Leistritz L4 pump's general operating diagram, which includes the realtime measured values of several operating parameters as well as the flow path of the multiphase flui d (oil, gas, and water) from the inlet stage to the outlet stage.

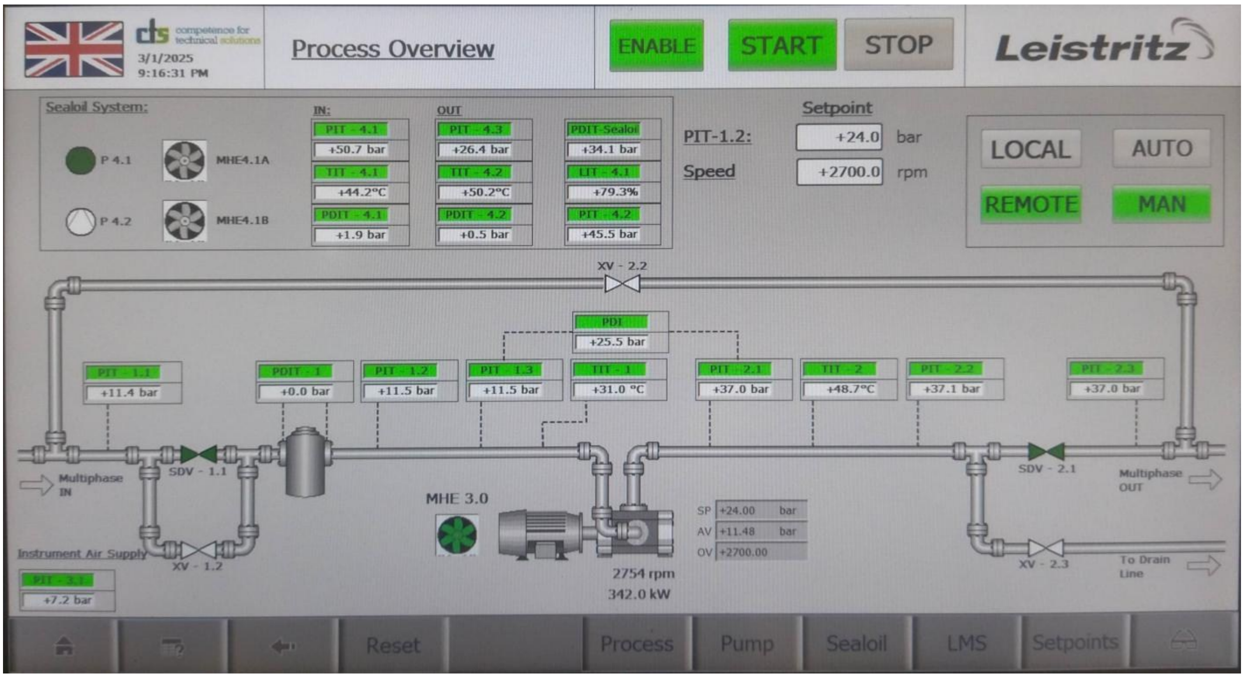



**Figure II. 6**: Leistritz L4 pump's general operating diagram.

Through the automated shut-off valve SDV- and the Multiphase IN feed line, the fluid enters. The XV valve, which is used to fill the pump during first startup, has a tiny aperture that permit s fluid to enter gradually and keeps external pressure from entering suddenly.
When the pump is halted, the XV valve on the bypass line opens, providing fluid recirculation

or pressure relief in the system.
In terms of instrumentation, TTT monitors the temperature of the incoming fluid, PDIT-measures the differential pressure across the strainer, PIT measures the air pressure in the pneu matic system that controls the valves, and PIT measures the fluid pressure prior to entering the pump.

The pump has a cooling fan MHE 3.0 and an electric motor.
Values including rotating speed (RPM), power consumed (kW), set pressure (SP), and actual pressure (AV) are shown on the control interface.
Following pumping, TTT is used to test the output fluid temperature and TTT is used to measure the pump body temperature.

PIT, PIT and PIT are used to measure the pressure.

The Multiphase OUT discharge line, which has the shutoff valve SDV, is where the fluid leav es the pump.

A secondary drain line with valve XV isutilized for drainage in emergency situations or durin g maintenance,By enabling precise valve control and accurate monitoring of all operational pa rameters, this system makes sure the pump runs within safe bounds while preserving constant pressure, temperature, and flow rate.

### III.2. Seal Oil System (SOS)

One of the Leistritz L4 pump's crucial features, the Seal Oil System (SOS), guards against wear and tear on the mechanical seal and stops liquids or gases from leaking out of the pumping chamber.

To guarantee that the oil flows toward the seal at adequate pressure, the system includes a separate seal oil tank that is supplied by the main pump. The auxiliary pump guarantees a steady supply of oil at starting or when the main pump is not operating.

The oil flows to the MHE heat exchanger for cooling after passing through the mechanical seal, assisting in maintaining the ideal operating temperature, minimizing wear, and protecting the oil's characteristics. The PCV-4.1 pressure control valve regulates oil pressure.

The system has a number of measurement tools for tracking performance, including:

PDIT-4.1: Differential pressure transmitter to identify pressure loss or obstruction in the oil strainer.

PIT-4.2: A pressure transmitter that gauges the seal's direct supply pressure.

The oil flow rate is measured with the FIT-4.1 flow transmitter.

TTT-4-1: A temperature transmitter used to track the oil's temperature at the tank's output.

In order to guarantee that the oil flows toward the seal and avoid any reverse leakage, the Seal Oil System runs at a pressure greater than the pumped fluid pressure inside the pump. The primary control unit (PLC) receives all measures and, in the case of a malfunction, either sounds an alert or turns off the pump.

This technology decreases unscheduled downtime, increases the mechanical seal's service life, and guarantees

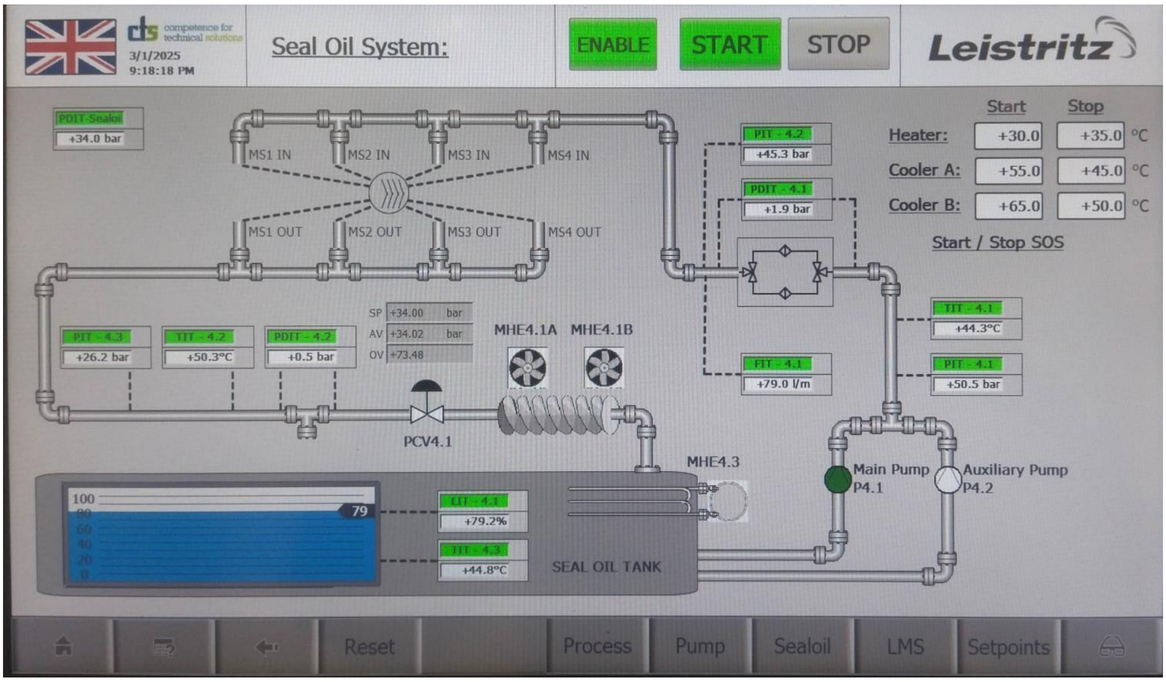



**Figure II. 7**: Seal Oil System.

### III.3. Liquid Management System (LMS)

To provide pump cooling during critical operating conditions, especially when the Gas Volu me Fraction (GVF) is high or when operating temperature rises, the Leistritz L4 pump's LMS is an inventive auxiliary system that is intended to retain a portion of the liquid from the disch arge line and recirculate it after cooling.

A separator in the system collects and holds a certain amount of liquid from the discharge lin. The level transmitter LIT3.15 keeps track of the liquid level inside the separator to make sure there is a enough supply for cooling.The temperature inside the separator is measured by TTT 3.16, and the temperature within the pump is measured by TTT3.02.Following the liquid's pas

sage through the heat exchanger, the temperature is measured by TTT-3.08.
Based on the temperature recorded inside the pump, the flow control valve FCV.3.1 controls t he amount of liquid that is recirculated to the pump after it has left the separator and passed th rough the heat exchanger, which has three cooling fans (M3.1, M3.2, M3.3).

Additionally, the system automatically turns on the cooling fans based on the temperature of t he liquid, guaranteeing effective heat dissipation when needed.
This technique has eliminated the need for external cooling water supply, which was the tradit ional cooling approach.This has ensured efficient pump cooling in difficult working condition , decreased water usage, and increased operational efficiency.

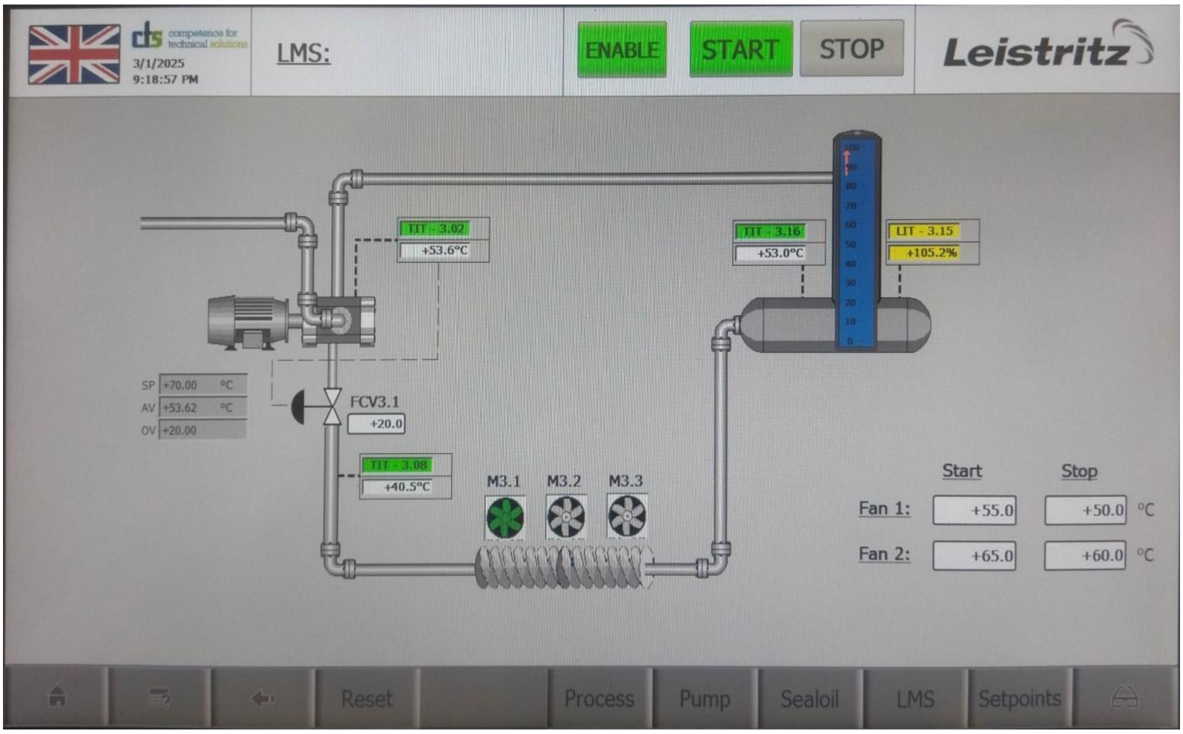



**Figure II. 8**: Liquid Management System (LMS).

### III.4. Variable Frequency Drive (VFD)

By altering the frequency of the supplied voltage, the Variable Frequency Drive (VFD), seen in Figure (II.9), regulates the pump motor's rotational speed. By progressively increasing the motor speed during startup (Soft Start), the VFD lowers high inrush currents and guards against hydraulic shocks inside the pump. This technology offers great flexibility in managing flow and pressure by enabling the pump to run at various rates based on actual operating conditions. In addition to lowering mechanical and electrical stress on the pump's components, it also helps to increase energy efficiency and lower power consumption under partial load.

**Figure II. 9**:  The Variable Frequency Drive (VFD).

**III.5. Programmable Logic Controller (PLC System)**

Controlling and monitoring the Leistritz L4 pump and all of its ancillary systems is mostly d one by the PLC (Programmable Logic Controller).It gathers and processes signals from a var iety of sensors, including liquid level transmitters (LIT), temperature transmitters (TTT), flo w transmitters (FIT), and pressure transmitters (PIT), in accordance with predetermined logi cal programming.

The PLC ensures that the pump functions under ideal conditions by sending accurate control orders to the cooling fans (M3.1, M3.2, M3.3), the auxiliary pump, and valves (XV, SDV, P CV, FCV) after analyzing the data.

The system keeps an eye on variations between setpoints and real values and, in the event of significant anomalies, sends out shutdown commands or alerts.

The pump can be operated in either manual mode, which provides direct operator control, or automatic mode, which ensures completely autonomous operation, thanks to the PLC.

Additionally, it integrates with the Human-

Machine Interface (HMI), which shows all operating parameters in real time and allows for manual intervention as needed.

This technology ensures safe pump operation, increases operating efficiency, reduces human intervention, and improves reliability and safety.


**Figure II. 10**:  Mechanical Components of the Leistritz L4 Pump.

## IV. Multiphase Components Mechanical

### IV.1. Pump Casing / Housing

The pump casing is one of the fundamental components of a multiphase screw pump, as it represents the outer structure that encloses all internal parts and provides the main flow path for the fluid. The casing is designed to withstand high operating pressures and varying flow conditions, in addition to ensuring proper sealing to minimize losses caused by leakages.

Mechanically, the pump casing is typically manufactured from high-strength steel alloys that are resistant to wear and corrosion, particularly when handling multiphase fluids containing gas, liquid, and occasionally solid particles. The wall thickness and structural rigidity play a crucial role in preventing deformation and ensuring rotor stability during operation.

Furthermore, the internal design of the casing has a direct impact on the hydraulic performance of the pump, as it defines the compression chamber volume and contributes to improving volumetric efficiency by reducing leakage areas between the rotors and the inner wall. The casing also integrates with the mechanical seal and lubrication system, making it an essential element in maintaining long-term reliability and operational efficiency.

**Figure II. 11**: The pump body and sleeve [7].

### IV.2. Screw Rotors

The screw rotors represent the operational core of the multiphase screw pump, as they perform the transport and compression of the fluid through successive compression chambers formed between the rotor threads and the pump casing. During synchronous rotation, fixed volumes of fluid are trapped and gradually displaced from the suction side to the discharge side, ensuring a continuous and stable flow.

According to Turhan (2014), rotor design is directly linked to volumetric efficiency, since internal leakages along the contact surfaces represent the main source of effective volume loss. Enhancing sealing between the rotors reduces these losses and improves efficiency.

In addition, Kourpa discussed the concept of Digressive Screw Geometry, where the screw pitch does not remain constant along the rotor length but changes progressively. This design contributes to:

- Reducing sudden compression within the chambers.

-Improving flow stability and minimizing vibrations.

-Increasing volumetric efficiency at higher flow rates.

As highlighted in the Leistritz L4 catalog, the rotors also play a protective role for the mechanical seal, as their design reduces the direct pressure acting on the seal by limiting the backflow of gas and liquid toward the sealing area. This helps extend seal lifetime and maintain overall system reliability.

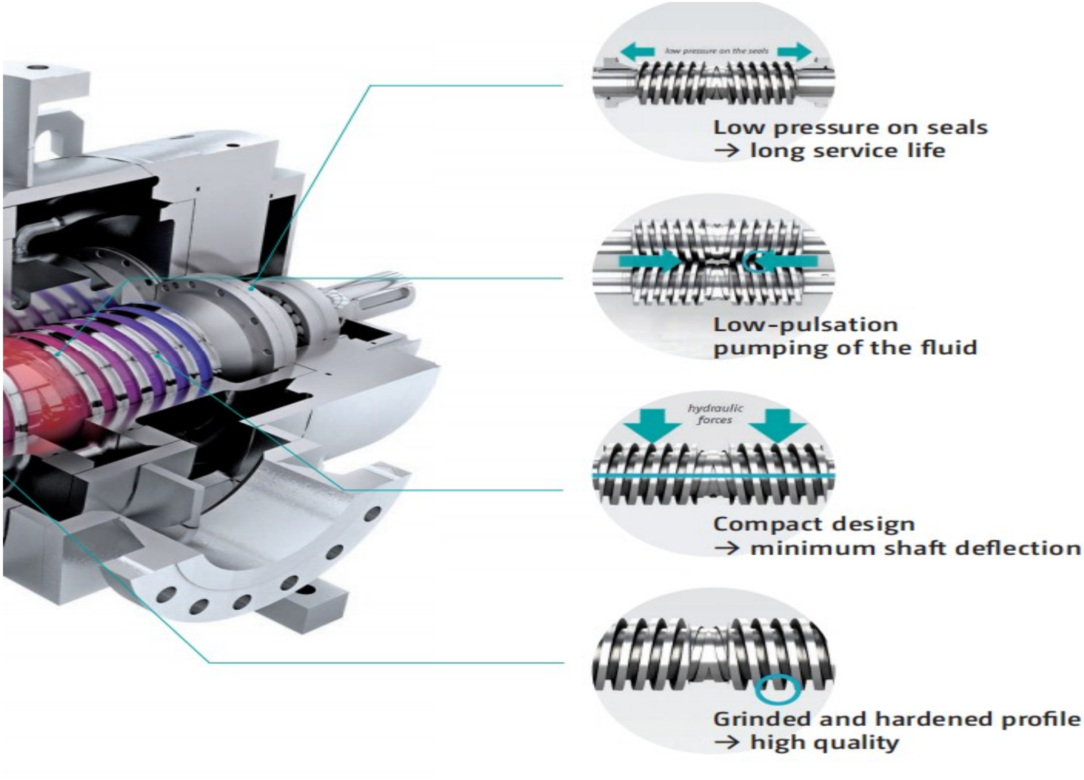



**Figure II. 12**: Superior technology [6].

Furthermore, Abdalla (2020, Politecnico di Torino) emphasized that rotors are the most influential element in pump performance at high Gas Volume Fractions (GVF). Their geometry enables gradual gas compression within the chambers, mitigating efficiency losses under unstable operating conditions.

The rotors are typically manufactured from wear- and corrosion-resistant steel alloys, and are precisely machined to ensure dynamic balance during operation. The fundamental relation associated with them is the theoretical flow rate:

$$Q_{\text{theoretical}} = V_g \times n \tag{II.1}$$

Where: Vg is the displacement volume per revolution, and n is the rotational speed.

This equation shows that the volumetric flow rate directly depends on the geometric design of the rotors and their rotational speed, while the actual performance relies on minimizing leakages, vibrations, and internal friction, as well as on the rotor's role in protecting the seal and ensuring stable operation under high-GVF condition

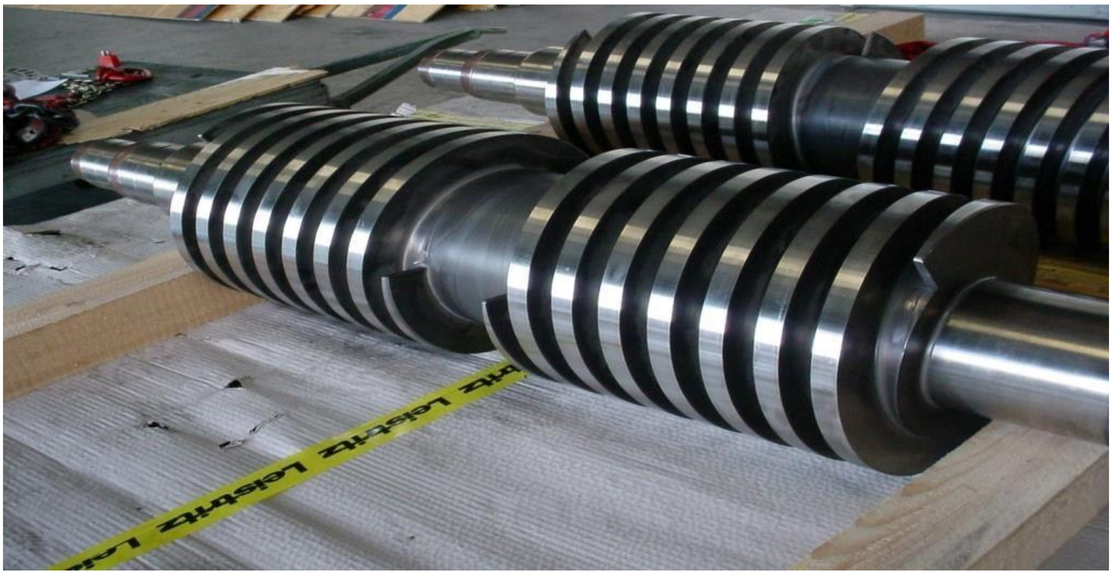



**Figure II. 13**: The pump rotor [7].

### IV.3. Mechanical Seal

The mechanical seal is one of the most critical components in a multiphase screw pump, serving as the primary barrier that prevents fluid leakage from the pumping chamber to the external environment. It operates at the rotating interface between the shaft and the stationary part of the casing, achieving sealing through finely machined contact surfaces typically made of hard materials such as carbon, ceramics, or tungsten carbide.

As reported in Turhan's work, leakages at the mechanical seal are one of the main contributors to volumetric efficiency losses, since inadequate seal performance leads to fluid leakage and, consequently, a reduction of actual flow compared to theoretical flow. In some cases, gas ingress may also occur, negatively impacting operational stability.

To ensure reliable performance, the seal is typically supported by a Seal Oil System (SOS), which maintains a pressure slightly higher than the internal fluid pressure, ensuring oil flow toward the seal and preventing reverse leakage. The oil also passes through a heat exchanger to maintain an optimal operating temperature and reduce wear of the contact surfaces.

- In practice, the mechanical seal contributes to:

- Preventing fluid and gas loss.

- Protecting the shaft and internal components from erosion.

- Extending the operational lifetime of the pump.

Therefore, the performance of this component is directly linked to the pump's efficiency—particularly volumetric efficiency—and to its long-term operational reliability.

**Figure II. 14**: The mechanical seal [6]

### IV.4. Bearings

Bearings are vital components in a multiphase screw pump, as they provide mechanical support for the rotors and the main shaft during rotation. Their primary function is to reduce friction between moving parts and to maintain the shaft in its correct position, ensuring precise alignment of the rotors inside the pump casing.

These pumps commonly employ rolling bearings or journal bearings with high load capacity to withstand both axial and radial forces generated by fluid pressure and rotor contact.

According to studies such as Turhan (2014), any malfunction in bearing performance may lead to misalignment and increased friction, which can result in vibrations, premature wear, and a reduction in mechanical efficiency. Additionally, unstable operating conditions, such as high Gas Volume Fractions (GVF), may further increase the dynamic loads acting on the bearings.

**Figure II. 15**: The bearings [6].

To ensure reliable operation, bearings are integrated with an effective lubrication system that provides a continuous oil film to reduce friction and dissipate the generated heat. This lubrication and cooling are essential for extending the service life of the bearings and, consequently, the pump itself.

It can therefore be stated that the efficiency and safe operation of the pump depend significantly on the integrity of the bearings and the quality of their maintenance, as bearing failures are often a major cause of unplanned shutdown.

**IV.5. Timing Gears**

A multiphase screw pump's timing gears guarantee that the rotors are precisely synchronized with one another. Usually, double helical gears are employed to reduce axial forces and distribute the load well. Without making direct contact with the rotor, these gears enable synchronized rotation by transferring torque from the main shaft to the secondary shaft.

An oil system that lubricates the gears prolongs their service life by lowering friction and dissipating heat. To maintain the pump's mechanical efficiency and avoid vibrations or failures that could impair the bearings' and the mechanical seal's performance, accurate design and appropriate maintenance are crucial.

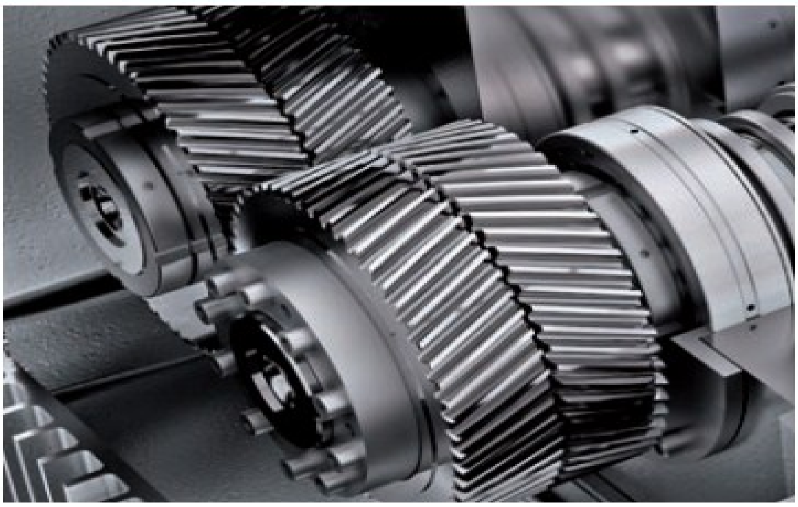


**Figure II. 16**: The distribution gear [6].

**IV.6. Coupling**

Reliable torque transmission is ensured by connecting the motor and pump using a flexible connection with a spacer. In order to provide safe operation in hazardous situations, such as oil and gas applications, this coupling is constructed in accordance with API 671 and has an anti-sparking guard. Additionally, it lessens vibrations and absorbs small misalignments, shielding the pump and motor from undue mechanical strain.

### IV.7. Effect of Erosion on Mechanical and Volumetrically Efficiency

Erosion in the pressure chamber and the screw rotors is one of the most common failures in multiphase screw pumps, particularly under harsh operating conditions characterized by high Gas Volume Fractions (GVF) or the presence of solid particles in the fluid. Over time, this erosion enlarges the clearances between contact surfaces, leading to increased internal leakage and a reduction in the effective displacement volume, which directly results in a loss of volumetric efficiency (Stepanoff, 1957). As shown in Figure (II. 17), erosion in the pressure chamber wall produces visible deformations that enhance internal leakage.

**Figure II. 17**: DE (Drive End Bearing) (Driven shaft side) top view.

Moreover, screw surface wear, illustrated in Figure (II. 18), leads to a loss of sealing between the rotors, increasing non-productive friction and raising energy consumption, thereby significantly reducing mechanical efficiency. Other studies have confirmed that such erosion under high GVF conditions generates strong vibrations and excessive dynamic loads on the bearings and the mechanical seal, ultimately reducing operational reliability (Wilson & Palgrave, 1999).

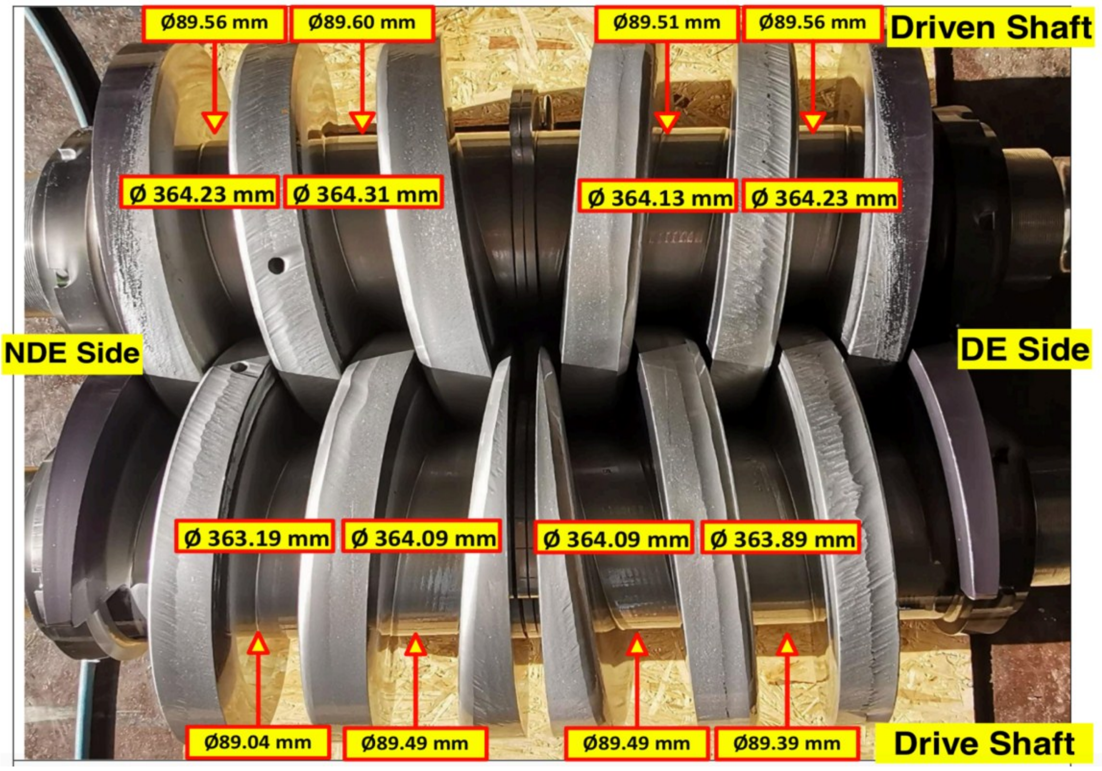



**Figure II. 18**: Pump Shafts with erosion evidences.

In advanced cases, as depicted in Figure (II.19), simultaneous erosion in both the pressure chamber and the rotors exacerbates the problem, combining losses in both volumetric and mechanical efficiency, while also increasing the likelihood of unplanned pump shutdowns. Therefore, controlling operating conditions and maintaining auxiliary systems such as the Liquid Management System (LMS) and the Seal Oil System (SOS) are essential to mitigate erosion and preserve the pump's mechanical efficiency and operational reliability.

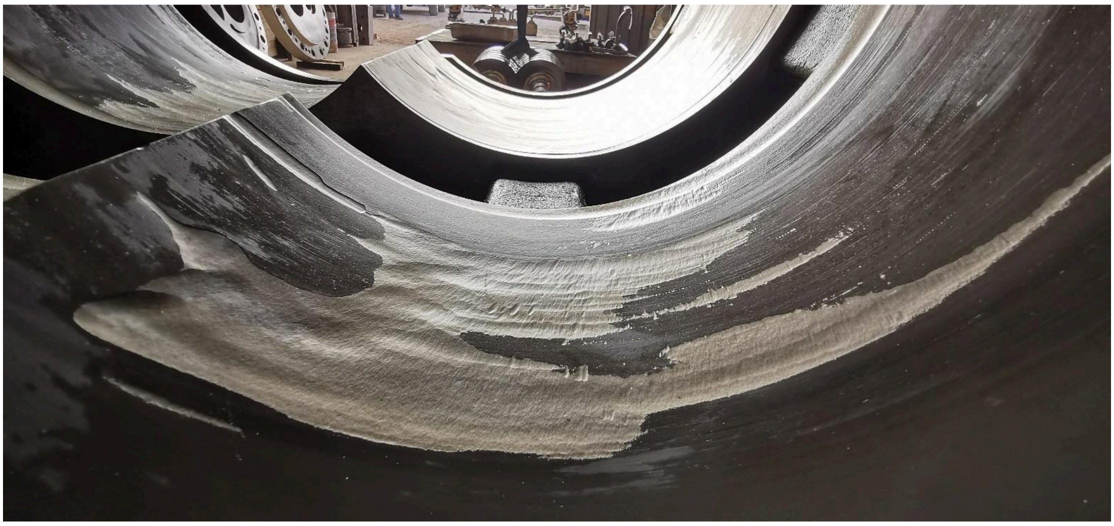


**Figure II. 19**: NDE (Non Drive End Bearing) (Driving shaft side).

### V. Flow-meter

The flowmeter is considered one of the most important instruments used in pump experiments, as it measures the volumetric or mass flow rate of liquids and gases. The device used in this experiment is specifically designed to operate under multiphase flow conditions, making it suitable for testing the Leistritz L4 pump.

### V.1. Principle of Operation

The operating principle of the device is based on measuring the actual flow rate (Q actual) under real operating conditions (pressure, temperature, density), and then converting it into a standard flow rate (Q standard) under reference conditions (typically 1 atm and 15 °C) using a correction equation derived from the ideal gas law or fluid density correction:

$$Q_{\text{standard}} = Q_{\text{actual}} \times \frac{P_{\text{standard}}}{P_{\text{actual}}} \times \frac{T_{\text{actual}}}{T_{\text{standard}}} \tag{II.2}$$

- Where P and T represent the pressure and temperature for both actual and standard conditions.

- For liquids, correction is often applied based on density rather than only pressure and temperature.

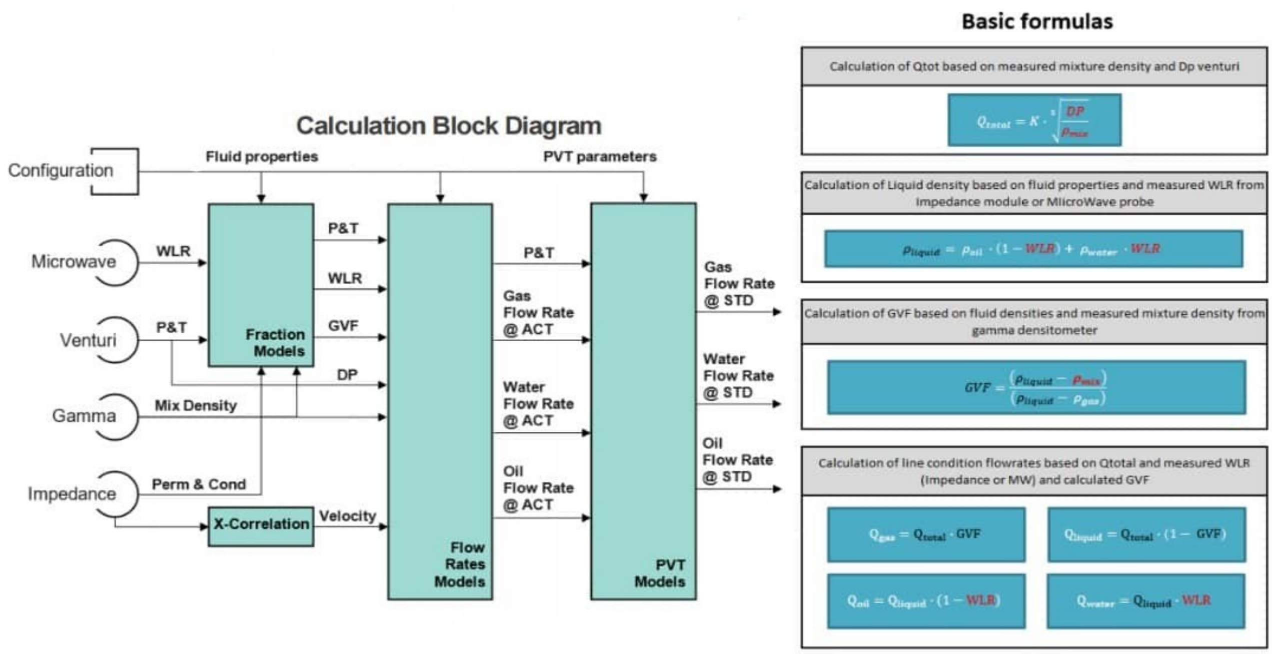



**Figure II. 20**: Principle of Operation.

### V.2. Basic Measurements

The device is equipped with several sensors to measure:

-Pressure (P actual) at the pump inlet and outlet.

-Temperature (T actual) of the fluid during flow.

-Density or correction factor, depending on the fluid type (gas/liquid).

### V.3. Flowmeter Components

The multiphase flowmeter is composed of several measuring units based on different physical principles, each providing complementary data that allows accurate calculation of the total flow rate. The main components are:

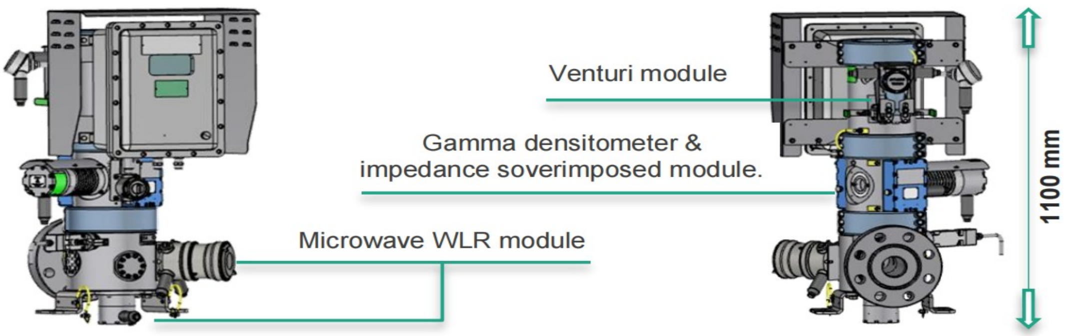



**Figure II. 21**: Flowmeter Components.

### V.3.1. Microwave Sensor

Used to measure the gas volume fraction (GVF) within the fluid. It operates on the principle of electromagnetic wave absorption and propagation through the mixture, with propagation speed varying according to the relative density of gas and liquid.


**Figure II. 22**: Microwave Sensor.

### V.3.2. Venturi Meter

Based on the principle of pressure drop as the fluid passes through a narrow throat. By measuring the differential pressure between the wide and narrow sections, the mass flow rate can be calculated. This component is particularly important when gas is present in the flow.


**Figure II. 23**: Venturi Meter.

### V.3.3. Gamma Densitometer

Utilizes gamma radiation to measure the bulk density of the multiphase mixture. It is especially useful in conditions where accurate density measurement cannot be obtained solely from pressure and temperature data.


**Figure II. 24**: Gamma Densitometer.

### V.3.4. Velocity Measurement Unit

Used to measure the velocity of the fluid within the flow line. This value is employed to correct volumetric and mass flow rate calculations. The reference did not specify the exact measurement technique, but such systems typically rely on ultrasonic or cross-correlation methods.


**Figure II. 25**: Velocity Measurement Unit.

**V.3.5. Impedance Measurement**

The impedance sensor is considered an essential part of multiphase flow meters. Its principle is based on measuring the electrical impedance between electrodes immersed in the flow stream. The impedance value varies according to the physical properties of the fluid, particularly its electrical conductivity, which changes with the relative proportions of the gas and liquid phases. When the gas volume fraction (GVF) increases, the electrical conductivity of the mixture decreases, leading to a higher measured impedance value.

Through this technique, the gas volume fraction can be accurately estimated, which is a critical parameter in multiphase flow calculations. These measurements are integrated with signals from the Venturi, gamma-ray, and microwave sensors to provide a more comprehensive and accurate determination of the actual flow rates of each phase. Thus, impedance measurement enhances the reliability of the flow meter and ensures precise results, especially under unstable operating conditions.


**Figure II. 26**: Impedance Measurement.

### V.4. Integrated Function

-These measurements (pressure, temperature, density, gas fraction, and velocity) are combined through the flowmeter's internal algorithms to provide highly accurate flow rate calculations.

-This integration enables the device to handle unsteady and turbulent flows, which are otherwise difficult to measure with conventional methods.

## VI. Conclusion

Through the review of previous studies and the theoretical background of multiphase screw pumps, it becomes clear that the evolution of analytical and experimental models has been crucial for improving pump performance and increasing reliability in oil and gas applications.

The Leistritz L4 pump stands out as an advanced example of these concepts, combining high-efficiency mechanical design with integrated auxiliary systems that ensure stable operation and accurate measurement.

This theoretical and conceptual framework lays the groundwork for the following chapter, which focuses on the experimental study and the analysis of test results, thereby strengthening the link between theoretical understanding and practical evaluation of pump efficiency.

# *Experimental Results and Efficiency Analysis of the Multiphase Pump*

## I. Introduction

This chapter presents and analyzes the experimental results obtained from the testing of a multiphase screw pump under real operating conditions. The primary objective is to evaluate the actual performance of the Leistritz L4 pump and compare it with its theoretical expectations by focusing on two key indicators of efficiency: volumetric efficiency and mechanical efficiency.

Volumetric efficiency reflects the capability of the pump to deliver the expected flow rate relative to its theoretical design, thereby quantifying the impact of internal leakages and phase interactions within the multiphase mixture. In contrast, mechanical efficiency measures the conversion of electrical input power into useful hydraulic power, providing insights into energy losses caused by friction, turbulence, and thermal effects.

The experimental campaign was conducted over two consecutive days using a multiphase flow meter and the pump control system. Parameters such as gas volume fraction (GVF), water-cut, inlet and outlet pressures, differential pressure, motor power consumption, and fluid flow rates were monitored and analyzed. These datasets serve as the foundation for calculating pump efficiencies and assessing performance under varying operating conditions.

By systematically presenting the results from the flow meter, the pump system, and the subsequent efficiency calculations, this chapter aims to highlight the interplay between gas–liquid compositions, thermodynamic conditions, and pump operation. The findings not only validate the experimental approach but also provide a deeper understanding of the limitations and challenges associated with multiphase pump performance in practical applications.

## II. Theoretical Equations for Efficiency Calculation

One of the most crucial metrics for assessing multiphase screw pump performance is efficiency. It can be computed using the following relations and is typically classified into two primary types: mechanical efficiency and volumetric efficiency.

### II.1. Volumetric Efficiency

The ratio of the actual discharge flow rate to the theoretical flow rate anticipated from the pump design is known as volumetric efficiency. The formula for it is:

$$\eta_{vol} = \frac{Q_{actual}}{Q_{theoretical}} \quad \text{(III.1)}$$

Where:

Qactual: actual discharge flow rate measured by the multiphase flow meter.

Qtheoretical=Vg×n: theoretical pump flow rate, where:

Vg: displacement volume per revolution.

*n*: rotational speed (in rps or rpm).

Internal leaks or surface wear are the main causes of volumetric efficiency declines because they lower the effective displaced volume relative to the theoretical value.

### II.2. Mechanical Efficiency

The ratio of the motor's electrical power consumption to the fluid's useable hydraulic power is kno wn as mechanical efficiency. It is said as follows:
where:

$$\eta_{\text{mech}} = \frac{P_{\text{electrical}}}{P_{\text{actual}}} \quad \text{(III.2)}$$

$$P_{\text{actual}} = \Delta P \times Q_{\text{actual}} \quad \text{(III.3)}$$

Hydraulic power transferred to the fluid, with:
ΔP: pressure difference between inlet and outlet.

Q_actual: actual discharge flow rate.

P_electrical: electrical power that the motor draws, as determined by the VFD.

The main factors affecting mechanical efficiency are the difference between the electrical power us ed by the motor and the useful hydraulic power supplied to the fluid, as well as losses resulting fro m friction in the bearings and seals.

## III. Results and discussion

### III.1. Scenario I - Flow Meter Results

In addition to the standard flow rate (Q standard), the multiphase flow meter supplied real-time data on the overall flow rate and the distribution of the three phases (gas, water, and oil) during the two days of operation that made up the experimental testing. Since the first-day dataset was more representative and more stable than the second-day sample, it was chosen for in-depth examination. A sample of the recorded values is shown in Table (III.1), which also displays the fluid's gas, water, and oil fractions as well as the real-time total flow rate (Q_actual). For comparison, the standard flow rate (Q_standard) is also provided.

### III.1.1 Interpretation of Results

#### III.1.1.1 Stability of Total Flow Rate

The recorded data indicate that the total flow rate (Q_actual) remains relatively stable over the measurement periods, with fluctuations mainly caused by variations in the gas flow rate. This is confirmed by the time-series plots, where the gas fraction (GVF) dominates the flow composition, consistently exceeding 80–90%. Such dominance of the gas phase explains why minor perturbations in GVF significantly influence the total flow rate stability.

#### III.1.1.2. Oil and Water Contributions

The oil flow rate shows small oscillations around 15–24 $m^3/h$ in the first dataset and around 10–13 $m^3/h$ in the second dataset, while the water fraction remains extremely low (typically below 0.5%). This demonstrates that the system is gas–oil dominated with negligible water production, which is also reflected in the very low water-cut values (< 1% in most cases). Thus, oil flow remains a minor component compared to gas flow, and water contribution is almost negligible in volumetric terms.

#### III.1.1.3. Gas Volume Fraction (GVF) Behavior

The GVF consistently exceeds 85–90%, confirming a highly gas-rich multiphase flow. The plots show that while GVF is relatively steady, occasional dips coincide with increases in liquid flow rate, suggesting transient interactions in phase distribution. This highlights the sensitivity of multiphase systems to small compositional changes, even when the overall dominance of gas remains.

#### III.1.1.4. Comparison Between Standard and Actual Flow Rates

The discrepancy between (Q_actual) and (Q_standard) emphasizes the role of thermodynamic conditions (pressure and temperature). At higher operating pressures, the actual volumetric flow is greater than the normalized (standard) values. This confirms that gas compressibility effects must be corrected using standard conditions when reporting flow rates for performance evaluation and efficiency analysis.

#### III.1.1.5. Water-Cut and Flow Instabilities

Although water-cut values remain low, the plots indicate that spikes in water-cut correspond to sharp fluctuations in the liquid flow curve. These spikes, while small in magnitude, could impact sensor accuracy and must be carefully considered when interpreting volumetric efficiency.

#### III.1.1.6. Implications for Volumetric Efficiency

By using the relation in Eq.III.1, the measured Q_actual provides a solid basis to estimate efficiency. Given the relative stability of the total flow, *n*_vol is expected to remain steady, with deviations mostly linked to GVF fluctuations and compressibility corrections. This confirms that volumetric efficiency assessment must consider both standardization of gas flow and transient multiphase behavior.

### III.1.2. Results Overview

The experimental results show that the system is gas-dominated with oil as a secondary phase and negligible water contribution. The total flow rate remains stable, though sensitive to GVF variations. Discrepancies between actual and standard flow highlight the importance of pressure and temperature corrections. Finally, volumetric efficiency analysis based on these datasets will provide a realistic performance indicator, aligning theoretical expectations with actual operating behavior.

**Table III. 1:** Recorded multiphase flow data on **10.07.2025** under actual and standard conditions, including oil, water, and gas fractions, water-cut, GVF, and total flow rate.

| | | Q - Actual Cond. | | | | | | | Q - Standard Cond. | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Date** | **Time** | **Oil Flow F** | **Water Flo** | **Liquid Flc** | **Gas Flow** | **Water-Cut** | **GVF** | **Qtotal** | **Oil Flow F** | **Water Flo** | **Liquid Flc** | **Gas Flow** | **Water-Cut** | **GOR** | **Qtotal** |
| **dd.mm.yy** | **hh:mm** | **m3/h** | **m3/h** | **m3/h** | **m3/h** | **%** | **%** | **m3/h** | **Sm3/h** | **Sm3/h** | **Sm3/h** | **Sm3/d** | **%** | **SCFT/STE** | **Sm3/h** |
| **10.07.25** | **10:55** | 23,70974 | 0,001186 | 23,71092 | 126,3191 | 0,005 | 84,19588 | 150,0301 | 20,18498 | 0,001178 | 20,18616 | 88811,1 | 0,005834 | 1029,311 | 3720,649 |
| **10.07.25** | **11:10** | 20,71586 | 0,001036 | 20,71689 | 135,86 | 0,005 | 86,76888 | 156,5769 | 17,57206 | 0,001028 | 17,57308 | 91909,05 | 0,005852 | 1223,611 | 3847,117 |
| **10.07.25** | **11:25** | 18,46242 | 0,000923 | 18,46334 | 149,4811 | 0,005 | 89,00628 | 167,9445 | 15,63099 | 0,000916 | 15,63191 | 97210,91 | 0,005861 | 1454,91 | 4066,087 |
| **10.07.25** | **11:40** | 20,36128 | 0,001018 | 20,3623 | 176,8605 | 0,005 | 89,67549 | 197,2228 | 17,24531 | 0,00101 | 17,24632 | 110619,5 | 0,005857 | 1500,612 | 4626,394 |
| **10.07.25** | **11:55** | 16,25147 | 0,000813 | 16,25228 | 165,3131 | 0,005 | 91,0488 | 181,5654 | 13,74544 | 0,000806 | 13,74624 | 101503 | 0,005864 | 1727,539 | 4243,038 |
| **10.07.25** | **12:10** | 18,67934 | 0,000934 | 18,68028 | 165,49 | 0,005 | 89,85706 | 184,1703 | 15,78589 | 0,000926 | 15,78681 | 103105,3 | 0,005867 | 1527,986 | 4311,839 |
| **10.07.25** | **12:25** | 17,82763 | 0,000891 | 17,82853 | 165,8533 | 0,005 | 90,2938 | 183,6818 | 15,05434 | 0,000884 | 15,05522 | 102283,3 | 0,00587 | 1589,464 | 4276,858 |
| **10.07.25** | **12:40** | 16,49141 | 0,000825 | 16,49224 | 162,5254 | 0,005 | 90,78737 | 179,0176 | 13,9155 | 0,000817 | 13,91632 | 99345,45 | 0,005874 | 1670,155 | 4153,311 |
| **10.07.25** | **12:55** | 17,22459 | 0,000861 | 17,22545 | 166,1631 | 0,005 | 90,60713 | 183,3886 | 14,52678 | 0,000854 | 14,52763 | 100952,7 | 0,005875 | 1625,759 | 4220,889 |
| **10.07.25** | **13:10** | 17,2218 | 0,000861 | 17,22266 | 166,7834 | 0,005 | 90,64017 | 184,0061 | 14,52086 | 0,000853 | 14,52171 | 100806,7 | 0,005876 | 1624,07 | 4214,8 |
| **10.07.25** | **13:25** | 17,25808 | 0,029028 | 17,28711 | 163,8832 | 0,167919 | 90,45809 | 181,1703 | 14,54665 | 0,028762 | 14,57541 | 99213,16 | 0,197331 | 1595,563 | 4148,457 |
| **10.07.25** | **13:40** | 16,50435 | 0,172961 | 16,67731 | 164,7999 | 1,037102 | 90,81024 | 181,4772 | 13,90485 | 0,17135 | 14,0762 | 98702,03 | 1,217305 | 1660,609 | 4126,661 |
| **10.07.25** | **13:55** | 17,45737 | 0,403102 | 17,86047 | 165,3863 | 2,256951 | 90,25333 | 183,2468 | 14,70487 | 0,399287 | 15,10416 | 98995,02 | 2,643557 | 1574,925 | 4139,896 |
| **10.07.25** | **14:10** | 18,22127 | 0,579446 | 18,80072 | 166,2149 | 3,082041 | 89,8383 | 185,0156 | 15,34325 | 0,573904 | 15,91715 | 99871,89 | 3,605571 | 1522,767 | 4177,246 |
| **10.07.25** | **14:25** | 16,3326 | 0,393838 | 16,72644 | 166,02 | 2,354581 | 90,84719 | 182,7464 | 13,74628 | 0,39007 | 14,13635 | 98845,47 | 2,759341 | 1682,206 | 4132,697 |
| **10.07.25** | **14:40** | 15,80759 | 0,038861 | 15,84645 | 160,8642 | 0,245233 | 91,03254 | 176,7106 | 13,29158 | 0,038485 | 13,33007 | 96598,9 | 0,288706 | 1700,212 | 4038,284 |
| **10.07.25** | **14:55** | 14,66617 | 0,140539 | 14,80671 | 140,1774 | 0,949154 | 90,44631 | 154,9841 | 12,31546 | 0,139162 | 12,45462 | 86460,08 | 1,117355 | 1642,376 | 3614,958 |
| **10.07.25** | **15:10** | 11,25897 | 0,528687 | 11,78765 | 129,7236 | 4,485094 | 91,67016 | 141,5113 | 9,439485 | 0,523516 | 9,963001 | 79853,25 | 5,254605 | 1979,028 | 3337,182 |
| **10.07.25** | **15:25** | 14,48539 | 0,446389 | 14,93177 | 133,2662 | 2,989521 | 89,92444 | 148,1979 | 12,13416 | 0,441961 | 12,57612 | 85148,13 | 3,514289 | 1641,621 | 3560,415 |

| Q - Standard Cond GOR1. | | | | | | | M - Actual Cond. | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Oil Flow F** | **Water Flo** | **Liquid Flc** | **Gas Flow** | **Water-Cut** | **GOR** | **Qtotal** | **Oil Flow F** | **Water Flo** | **Liquid Flc** | **Gas Flow** | **Water-Cut** | **GVF** | **Qtotal** | **Flow Pres** | **Flow Tem** | **DP-Ventu** | **FEB Temperature** |
| **Sm3/h** | **Sm3/h** | **Sm3/h** | **Sm3/d** | **%** | **SCFT/STE** | **Sm3/h** | **kg/h** | **kg/h** | **kg/h** | **kg/s** | **%** | **%** | **kg/s** | **BarG** | **DegC** | **mBar** | **DegC** |
| 20,18498 | 0,001178 | 20,18616 | 66506,64 | 0,005834 | 770,8045 | 2791,296 | 18372,29 | 1,445714 | 18373,73 | 0,72266 | 0,007868 | 12,40307 | 5,826461 | 21,04181 | 40,38226 | 452,2142 | 46,87823105 |
| 17,57206 | 0,001028 | 17,57308 | 72407,05 | 0,005852 | 963,9752 | 3034,533 | 16022,82 | 1,261804 | 16024,08 | 0,833154 | 0,007874 | 15,76667 | 5,284276 | 21,47743 | 42,65019 | 427,5932 | 47,39482498 |
| 15,63099 | 0,000916 | 15,63191 | 79865,71 | 0,005861 | 1195,313 | 3343,37 | 14266,04 | 1,123823 | 14267,16 | 0,977235 | 0,007877 | 19,78079 | 4,940325 | 21,65005 | 43,73495 | 436,8379 | 47,91698074 |
| 17,24531 | 0,00101 | 17,24632 | 91772,38 | 0,005857 | 1244,94 | 3841,095 | 15586,92 | 1,238917 | 15588,16 | 1,123133 | 0,007948 | 20,59599 | 5,453166 | 21,04629 | 44,57286 | 549,0343 | 48,42375183 |
| 13,74544 | 0,000806 | 13,74624 | 86442,63 | 0,005864 | 1471,218 | 3615,523 | 12388,11 | 0,988473 | 12389,1 | 1,058972 | 0,007979 | 23,53074 | 4,50038 | 21,2644 | 45,28126 | 420,9552 | 48,89593887 |
| 15,78589 | 0,000926 | 15,78681 | 85883,69 | 0,005867 | 1272,768 | 3594,274 | 14232,48 | 1,135658 | 14233,61 | 1,052125 | 0,007979 | 21,01772 | 5,005895 | 21,15762 | 46,10514 | 472,0121 | 49,34843826 |
| 15,05434 | 0,000884 | 15,05522 | 85891,52 | 0,00587 | 1334,739 | 3593,868 | 13577,89 | 1,083517 | 13578,97 | 1,052221 | 0,007979 | 21,81154 | 4,824147 | 21,16212 | 46,76361 | 454,5078 | 49,82024384 |
| 13,9155 | 0,000817 | 13,91632 | 84206,21 | 0,005874 | 1415,64 | 3522,508 | 12555,22 | 1,00202 | 12556,22 | 1,031575 | 0,00798 | 22,82546 | 4,519404 | 21,20991 | 47,31335 | 416,141 | 50,26104355 |
| 14,52678 | 0,000854 | 14,52763 | 85241,23 | 0,005875 | 1372,739 | 3566,245 | 13109,64 | 1,046177 | 13110,68 | 1,044254 | 0,00798 | 22,28408 | 4,6861 | 21,04941 | 48,02077 | 440,7646 | 50,62670135 |
| 14,52086 | 0,000853 | 14,52171 | 85144,91 | 0,005876 | 1371,747 | 3562,226 | 13105,7 | 1,045822 | 13106,75 | 1,043074 | 0,007979 | 22,2697 | 4,683827 | 20,97128 | 48,37666 | 441,7461 | 50,9535408 |
| 14,54665 | 0,028762 | 14,57541 | 83552,05 | 0,197331 | 1343,698 | 3495,911 | 13130,95 | 35,24709 | 13166,2 | 1,023561 | 0,267709 | 21,86709 | 4,680829 | 20,9647 | 48,6826 | 434,7045 | 51,291008 |
| 13,90485 | 0,17135 | 14,0762 | 83758,02 | 1,217305 | 1409,184 | 3503,994 | 12554,33 | 209,9702 | 12764,3 | 1,026084 | 1,644981 | 22,4442 | 4,571712 | 20,93082 | 49,12537 | 425,3809 | 51,60579681 |
| 14,70487 | 0,399287 | 15,10416 | 83280,65 | 2,643557 | 1324,923 | 3485,131 | 13277,61 | 489,2327 | 13766,85 | 1,020236 | 3,553702 | 21,06034 | 4,844349 | 20,76818 | 49,6136 | 454,3015 | 51,86100769 |
| 15,34325 | 0,573904 | 15,91715 | 83504,55 | 3,605571 | 1273,211 | 3495,273 | 13856,13 | 703,1402 | 14559,27 | 1,022979 | 4,829503 | 20,18822 | 5,067209 | 20,7439 | 49,95353 | 476,7327 | 52,18006897 |
| 13,74628 | 0,39007 | 14,13635 | 84116,87 | 2,759341 | 1431,546 | 3519,006 | 12416,98 | 477,9084 | 12894,89 | 1,03048 | 3,706186 | 22,3416 | 4,612383 | 20,92722 | 49,9866 | 432,0687 | 52,6006279 |
| 13,29158 | 0,038485 | 13,33007 | 82293,27 | 0,288706 | 1448,422 | 3442,216 | 12011,94 | 47,14759 | 12059,09 | 1,00814 | 0,390971 | 23,13375 | 4,357878 | 21,15189 | 50,32218 | 396,8718 | 52,99343491 |
| 12,31546 | 0,139162 | 12,45462 | 73067,73 | 1,117355 | 1387,978 | 3056,943 | 11137,22 | 170,4748 | 11307,69 | 0,895122 | 1,5076 | 22,17768 | 4,036139 | 21,59549 | 50,52088 | 326,0448 | 53,34232712 |
| 9,439485 | 0,523516 | 9,963001 | 69453,5 | 5,254605 | 1721,288 | 2903,859 | 8543,165 | 641,316 | 9184,481 | 0,850846 | 6,982605 | 25,00955 | 3,402083 | 22,17517 | 50,71973 | 253,5422 | 53,7339592 |
| 12,13416 | 0,441961 | 12,57612 | 71746,85 | 3,514289 | 1383,25 | 3002,028 | 10986,49 | 541,3614 | 11527,85 | 0,878941 | 4,696119 | 21,5368 | 4,081111 | 22,32287 | 51,09483 | 316,7325 | 54,16236115 |

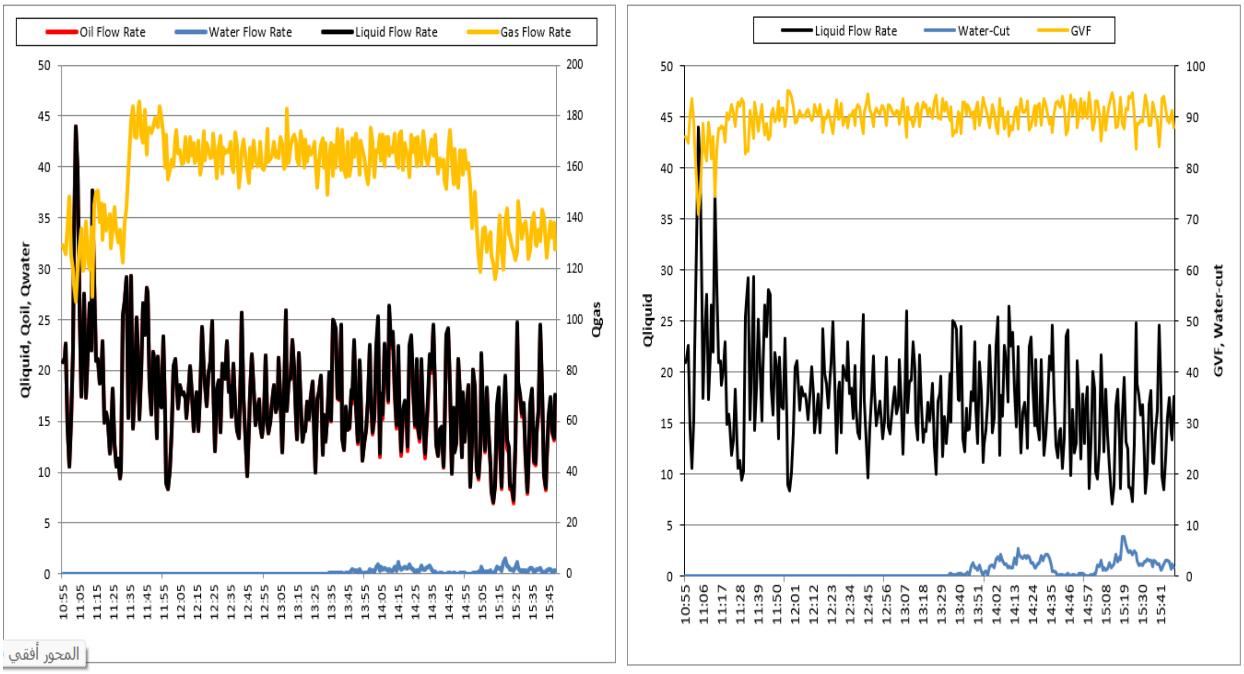



**Figure III. 1:** Time-series profiles of oil, water, liquid, and gas flow rates on **10.07.2025** under actual operating conditions.

**Table III. 2:** Recorded multiphase flow data on **11.07.2025** under actual and standard conditions, including oil, water, and gas fractions, water-cut, GVF, and total flow rate.

| | | Q - Actual Cond. | | | | | | | Q - Standard Cond. | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Time | Oil Flow F | Water Flo | Liquid Flo | Gas Flow | Water-Cut | GVF | Qtotal | Oil Flow F | Water Flo | Liquid Flo | Gas Flow | Water-Cut | GOR | Qtotal |
| dd.mm.yy | hh:mm | m3/h | m3/h | m3/h | m3/h | % | % | m3/h | Sm3/h | Sm3/h | Sm3/h | Sm3/d | % | SCFT/STE | Sm3/h |
| **11.07.25** | **10:00** | 10,05929 | 0,130548 | 10,18984 | 109,2759 | 1,28116 | 91,4705 | 119,4657 | 8,535325 | 0,129647 | 8,664971 | 69058,16 | 1,496215 | 1892,79 | 2886,088 |
| **11.07.25** | **10:15** | 8,855059 | 0,134465 | 8,989524 | 94,55346 | 1,495799 | 91,31808 | 103,543 | 7,490027 | 0,133458 | 7,623485 | 62827,74 | 1,750617 | 1962,346 | 2625,446 |
| **11.07.25** | **10:30** | 10,86062 | 0,122361 | 10,98298 | 101,3051 | 1,114099 | 90,21893 | 112,2881 | 9,155499 | 0,121394 | 9,276893 | 67551,77 | 1,308561 | 1726,086 | 2823,934 |
| **11.07.25** | **10:45** | 19,72049 | 0,060679 | 19,78117 | 132,5229 | 0,306752 | 87,01205 | 152,3041 | 16,60779 | 0,060166 | 16,66796 | 91976,59 | 0,360968 | 1295,606 | 3849,026 |
| **11.07.25** | **11:00** | 12,06858 | 0,2171 | 12,28568 | 133,0202 | 1,7671 | 91,54495 | 145,3059 | 10,14435 | 0,215197 | 10,35955 | 85307,38 | 2,077286 | 1967,298 | 3564,834 |
| **11.07.25** | **11:15** | 17,07039 | 0,143051 | 17,21344 | 132,9716 | 0,831044 | 88,53851 | 150,185 | 14,33605 | 0,141751 | 14,4778 | 89174,42 | 0,979092 | 1455,185 | 3730,079 |
| **11.07.25** | **11:30** | 13,25526 | 0,162895 | 13,41815 | 112,6289 | 1,21399 | 89,35465 | 126,0471 | 11,10544 | 0,161359 | 11,2668 | 75384,41 | 1,432165 | 1588,011 | 3152,284 |
| **11.07.25** | **11:45** | 6,277688 | 0,041665 | 6,319353 | 78,3136 | 0,659328 | 92,53323 | 84,63295 | 5,241446 | 0,04126 | 5,282707 | 51088,84 | 0,781048 | 2280,25 | 2133,984 |
| **11.07.25** | **12:00** | 11,51915 | 0,148623 | 11,66777 | 95,91441 | 1,27379 | 89,15456 | 107,5822 | 9,601374 | 0,147122 | 9,748495 | 66548,22 | 1,509173 | 1621,477 | 2782,591 |
| **11.07.25** | **12:15** | 11,02584 | 0,114847 | 11,14068 | 96,14867 | 1,030876 | 89,61622 | 107,2894 | 9,173328 | 0,11365 | 9,286979 | 66724,18 | 1,223758 | 1701,625 | 2789,461 |
| **11.07.25** | **12:30** | 10,06798 | 0,096236 | 10,16422 | 95,53537 | 0,946813 | 90,38387 | 105,6996 | 8,36159 | 0,095207 | 8,456798 | 66050,97 | 1,125803 | 1847,983 | 2760,58 |
| **11.07.25** | **12:45** | 10,08181 | 0,133455 | 10,21526 | 97,05608 | 1,30643 | 90,47717 | 107,2713 | 8,367372 | 0,132022 | 8,499393 | 67415,73 | 1,553308 | 1884,863 | 2817,489 |
| **11.07.25** | **13:00** | 13,18711 | 0,131319 | 13,31843 | 100,4622 | 0,985994 | 88,29464 | 113,7806 | 10,9315 | 0,129878 | 11,06138 | 72560,18 | 1,174157 | 1552,838 | 3034,402 |
| **11.07.25** | **13:15** | 10,05614 | 0,188152 | 10,24429 | 100,1372 | 1,836654 | 90,7192 | 110,3815 | 8,323871 | 0,186041 | 8,509912 | 69797,42 | 2,186171 | 1961,651 | 2916,736 |
| **11.07.25** | **13:30** | 11,94999 | 0,249255 | 12,19924 | 102,4189 | 2,043198 | 89,35663 | 114,6182 | 9,885175 | 0,246424 | 10,1316 | 73009,52 | 2,432236 | 1727,837 | 3052,195 |
| **11.07.25** | **13:45** | 12,14701 | 0,267173 | 12,41418 | 103,926 | 2,152158 | 89,32941 | 116,3402 | 10,04539 | 0,264131 | 10,30952 | 74248,94 | 2,562012 | 1729,144 | 3104,015 |
| **11.07.25** | **14:00** | 11,38481 | 0,235992 | 11,6208 | 104,0988 | 2,030771 | 89,95779 | 115,7196 | 9,408857 | 0,23328 | 9,642138 | 73784,85 | 2,419384 | 1834,585 | 3084,011 |
| **11.07.25** | **14:15** | 9,705093 | 0,135577 | 9,840671 | 100,6338 | 1,377722 | 91,09236 | 110,4744 | 8,011742 | 0,133987 | 8,145729 | 70058,09 | 1,644876 | 2045,686 | 2927,233 |
| **11.07.25** | **14:30** | 13,71975 | 0,078364 | 13,79812 | 102,5826 | 0,567931 | 88,14398 | 116,3807 | 11,33067 | 0,077444 | 11,40812 | 74801,09 | 0,678853 | 1544,4 | 3128,121 |
| **11.07.25** | **14:45** | 12,52162 | 0,103261 | 12,62488 | 103,7711 | 0,817915 | 89,15351 | 116,396 | 10,33681 | 0,102045 | 10,43886 | 74493,2 | 0,977549 | 1685,922 | 3114,322 |

| Q - Standard Cond GOR1. | | | | | | | M - Actual Cond. | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Oil Flow F | Water Flo | Liquid Flc | Gas Flow | Water-Cut | GOR | Qtotal | Oil Flow F | Water Flo | Liquid Flc | Gas Flow | Water-Cut | GVF | Qtotal | Flow Pres | Flow Tem | DP-Ventu | FEB Temperature |
| Sm3/h | Sm3/h | Sm3/h | Sm3/d | % | SCFT/STE | Sm3/h | kg/h | kg/h | kg/h | kg/s | % | % | kg/s | BarG | DegC | mBar | DegC |
| 8,535325 | 0,129647 | 8,664971 | 59456,49 | 1,496215 | 1629,622 | 2486,019 | 7681,438 | 159,1107 | 7840,549 | 0,728376 | 2,029331 | 25,06198 | 2,906301 | 21,85261 | 41,45992 | 183,5854 | 49,23770905 |
| 7,490027 | 0,133458 | 7,623485 | 54379,78 | 1,750617 | 1698,485 | 2273,448 | 6750,936 | 163,7278 | 6914,663 | 0,666184 | 2,367835 | 25,75203 | 2,586918 | 23,52381 | 43,44515 | 152,2294 | 49,73458099 |
| 9,155499 | 0,121394 | 9,276893 | 57100,46 | 1,308561 | 1459,033 | 2388,463 | 8265,757 | 148,888 | 8414,645 | 0,699514 | 1,769391 | 23,03375 | 3,036909 | 22,9156 | 44,72978 | 183,3755 | 50,19826126 |
| 16,60779 | 0,060166 | 16,66796 | 73261,63 | 0,360968 | 1031,983 | 3069,236 | 15000,21 | 73,76693 | 15073,98 | 0,897497 | 0,489366 | 17,65093 | 5,084703 | 22,55506 | 46,25666 | 402,7415 | 50,66854095 |
| 10,14435 | 0,215197 | 10,35955 | 73866,13 | 2,077286 | 1703,448 | 3088,115 | 9170,724 | 263,7924 | 9434,516 | 0,904903 | 2,796036 | 25,66668 | 3,525594 | 22,75148 | 47,44238 | 269,7448 | 51,22451019 |
| 14,33605 | 0,141751 | 14,4778 | 73103,38 | 0,979092 | 1192,931 | 3060,452 | 12965,22 | 173,7245 | 13138,95 | 0,895559 | 1,32221 | 19,70315 | 4,545256 | 22,5931 | 48,44428 | 355,0501 | 51,80364609 |
| 11,10544 | 0,161359 | 11,2668 | 62849,31 | 1,432165 | 1323,953 | 2629,988 | 10055,14 | 197,7123 | 10252,85 | 0,769941 | 1,928364 | 21,28114 | 3,617947 | 23,04058 | 49,51995 | 240,7727 | 52,39211655 |
| 5,241446 | 0,04126 | 5,282707 | 45079,19 | 0,781048 | 2012,021 | 1883,582 | 4753,715 | 50,54688 | 4804,262 | 0,552246 | 1,052126 | 29,26956 | 1,88676 | 23,85272 | 50,75313 | 83,2903 | 52,95465088 |
| 9,601374 | 0,147122 | 9,748495 | 55520,03 | 1,509173 | 1352,77 | 2323,083 | 8714,936 | 180,1892 | 8895,125 | 0,680153 | 2,025707 | 21,5852 | 3,151014 | 24,04147 | 51,69741 | 180,2662 | 53,5019455 |
| 9,173328 | 0,11365 | 9,286979 | 56153,59 | 1,223758 | 1432,05 | 2349,02 | 8333,653 | 139,1657 | 8472,819 | 0,687914 | 1,642496 | 22,61783 | 3,041468 | 24,34132 | 52,72428 | 174,6052 | 54,00704575 |
| 8,36159 | 0,095207 | 8,456798 | 56369,93 | 1,125803 | 1577,125 | 2357,204 | 7602,618 | 116,5609 | 7719,179 | 0,690564 | 1,510016 | 24,36047 | 2,834775 | 24,66079 | 53,57204 | 160,196 | 54,53125 |
| 8,367372 | 0,132022 | 8,499393 | 57687,24 | 1,553308 | 1612,866 | 2412,135 | 7610,406 | 161,6282 | 7772,034 | 0,706702 | 2,079612 | 24,66162 | 2,865594 | 24,84465 | 53,71915 | 163,1787 | 54,92090225 |
| 10,9315 | 0,129878 | 11,06138 | 59848,45 | 1,174157 | 1280,798 | 2504,747 | 9948,099 | 158,9797 | 10107,08 | 0,733178 | 1,572954 | 20,7072 | 3,540692 | 24,95916 | 54,46453 | 213,767 | 55,11558914 |
| 8,323871 | 0,186041 | 8,509912 | 60079,84 | 2,186171 | 1688,539 | 2511,837 | 7580,299 | 227,6907 | 7807,99 | 0,736013 | 2,916125 | 25,33701 | 2,904893 | 25,19532 | 55,21056 | 168,7619 | 55,35465622 |
| 9,885175 | 0,246424 | 10,1316 | 61474,84 | 2,432236 | 1454,858 | 2571,583 | 9004,769 | 301,5654 | 9306,334 | 0,753102 | 3,240432 | 22,56022 | 3,338188 | 25,24288 | 55,66833 | 201,1927 | 55,61632156 |
| 10,04539 | 0,264131 | 10,30952 | 62515,13 | 2,562012 | 1455,881 | 2615,107 | 9151,913 | 323,228 | 9475,141 | 0,765847 | 3,411327 | 22,53933 | 3,397823 | 25,3055 | 55,76673 | 208,6535 | 55,88298798 |
| 9,408857 | 0,23328 | 9,642138 | 62780,38 | 2,419384 | 1560,97 | 2625,491 | 8574,645 | 285,455 | 8860,1 | 0,769096 | 3,221804 | 23,80934 | 3,230228 | 25,39896 | 56,1249 | 197,0443 | 56,10378265 |
| 8,011742 | 0,133987 | 8,145729 | 60697,86 | 1,644876 | 1772,368 | 2537,223 | 7305,112 | 163,9287 | 7469,041 | 0,743584 | 2,194776 | 26,38402 | 2,818312 | 25,47388 | 56,98364 | 165,2106 | 56,39184189 |
| 11,33067 | 0,077444 | 11,40812 | 61608,2 | 0,678853 | 1272,01 | 2578,417 | 10329,19 | 94,75015 | 10423,94 | 0,754736 | 0,908967 | 20,6762 | 3,650266 | 25,35757 | 56,86979 | 227,4653 | 56,71447754 |
| 10,33681 | 0,102045 | 10,43886 | 62435,44 | 0,977549 | 1413,032 | 2611,916 | 9425,065 | 124,8448 | 9549,91 | 0,76487 | 1,307287 | 22,38023 | 3,417616 | 25,41649 | 57,06838 | 210,5385 | 56,94100571 |

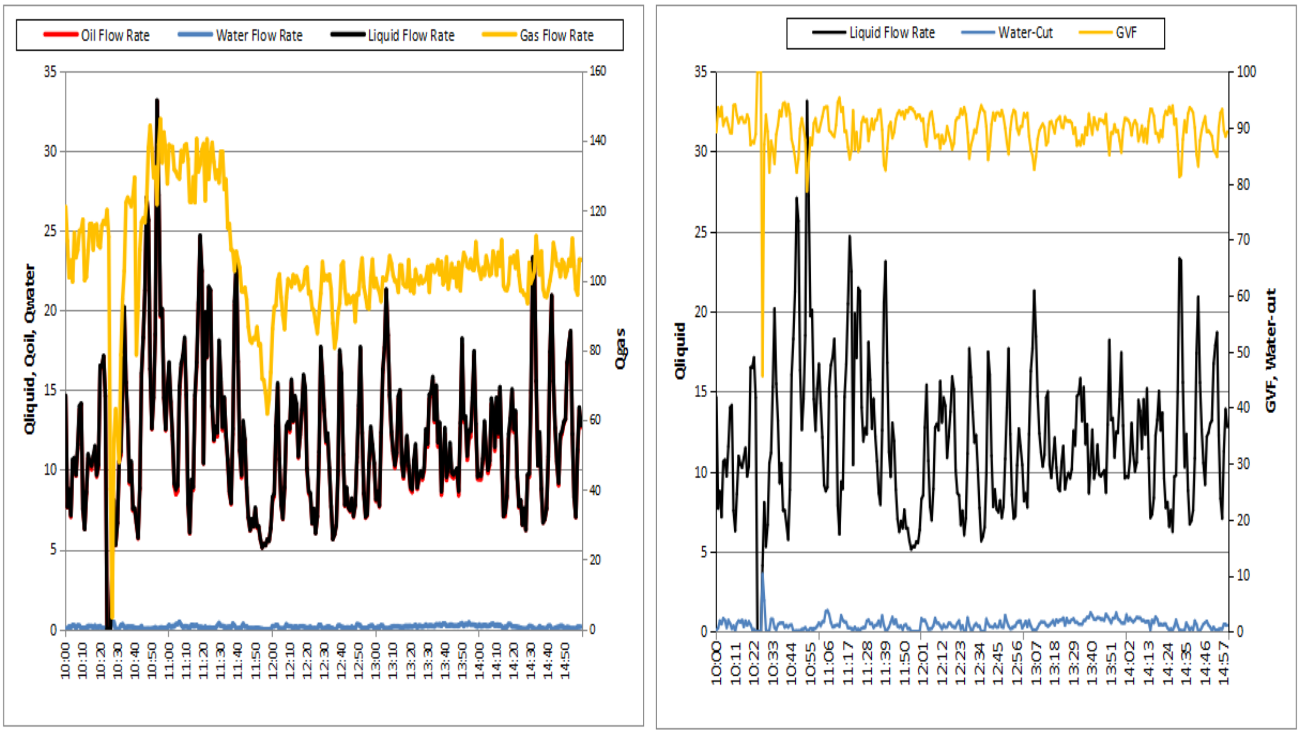



**Figure III. 2:** Time-series profiles of oil, water, liquid, and gas flow rates on **11.07.2025** under actual operating conditions.

Experiments conducted on the multiphase flow meter are documented practically, allowing the researcher to observe the device's many stages of operation and real-time measurement monitoring.

These images demonstrate the precision of the data collection and the active participation in the experimental effort.


**Figure III. 3.** Experimental setup and monitoring of the multiphase flow meter during field testing

The images illustrate both the on-site experimental setup of the multiphase flow meter and the real-time monitoring process in the control room. The first image shows the field installation, where the researcher interacts directly with the flow meter to verify operational conditions. The second image demonstrates the data acquisition stage, where measurements are processed and analyzed using specialized software. Together, these photos highlight the practical implementation of the test campaign and confirm the reliability and precision of the recorded data through continuous observation and researcher involvement.

### III.2. Scenario II - Pump System Results

The operational data were obtained directly from the pump control system, where several key variables related to pump performance were recorded in real time. These values include the inlet pressure, outlet pressure, and the differential pressure (ΔP) between them, which reflects the hydraulic load on the pump. In addition, the temperatures at both the inlet and outlet, as well as the temperature inside the pump casing, were monitored to track the thermal conditions during operation. In parallel, the system provided data on the motor rotational speed (RPM) and the electrical power consumed by the motor. All these measurements were presented as time-based curves illustrating the evolution of the variables during the test, and they were subsequently used to calculate the hydraulic power and determine the mechanical efficiency of the pum.

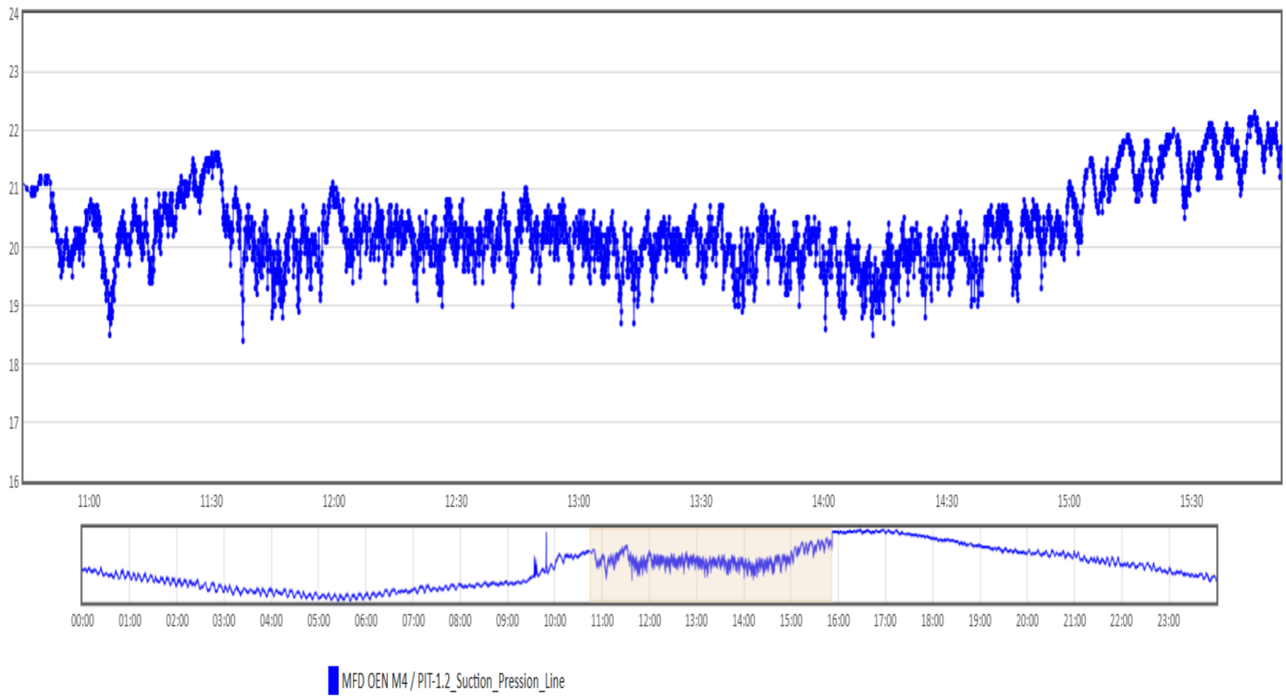



**Figure III. 4.** Suction Pressure Profile of the Pump System.

Time-series evolution of suction line pressure, showing moderate fluctuations around a relatively stable mean, indicating steady inlet conditions.

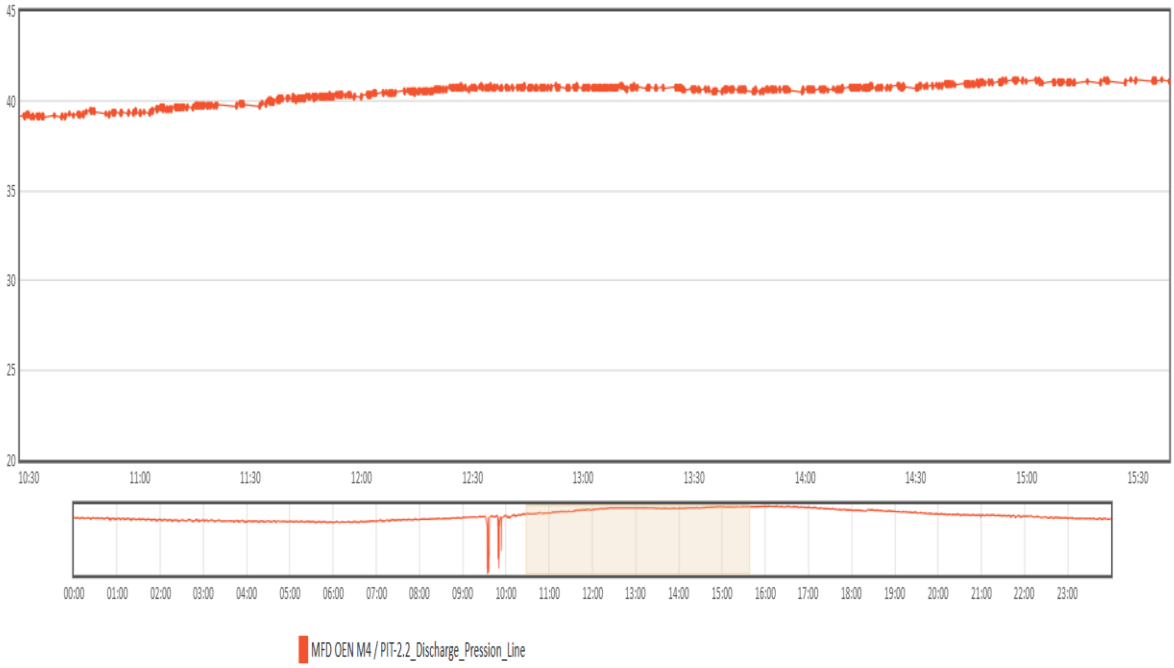



**Figure III. 5.** Discharge Pressure Profile of the Pump System.

Gradual increase in discharge pressure with minor oscillations, reflecting the pump's ability to maintain consistent outlet conditions under varying load.

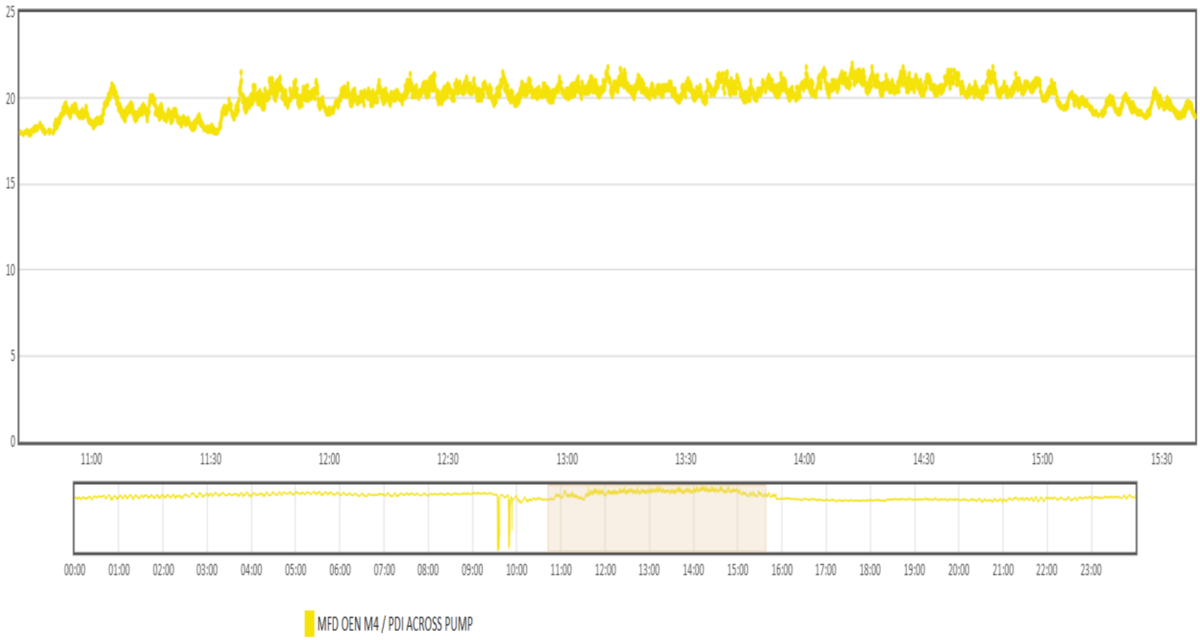



**Figure III.6.** Differential Pressure (ΔP) Across the Pump.

Calculated difference between suction and discharge pressures, illustrating the hydraulic load on the pump and confirming stable operating conditions.

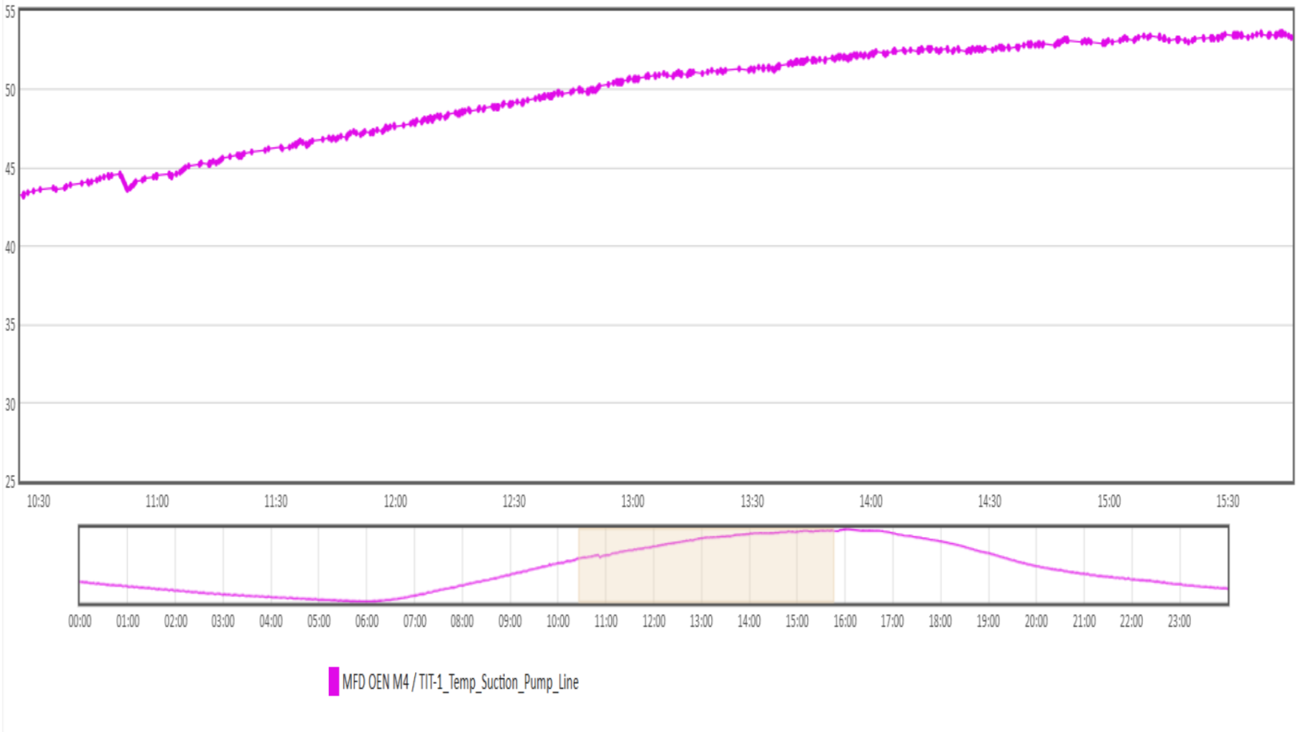



**Figure III.7.** Suction Line Temperature Trend.

Progressive increase in suction line temperature during operation, highlighting heat transfer effects and fluid warming before compression.

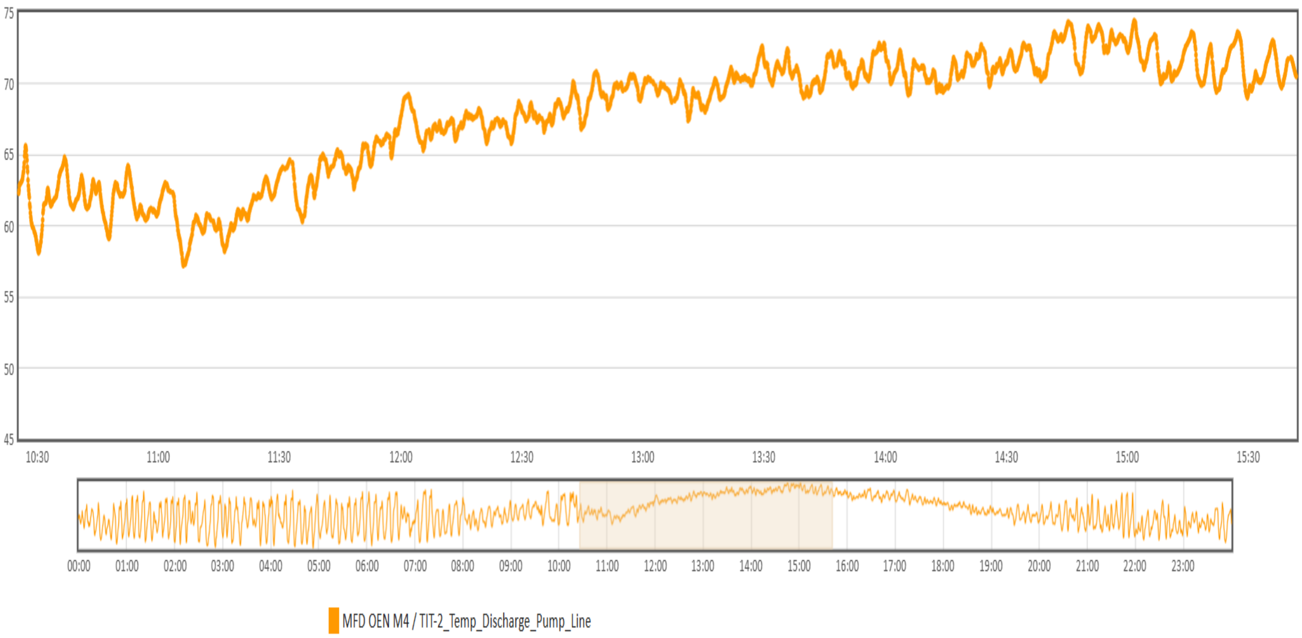



**Figure III.8.** Discharge Line Temperature Trend.

Discharge temperatures consistently higher than suction values, reflecting compression heating and frictional effects across the pump.

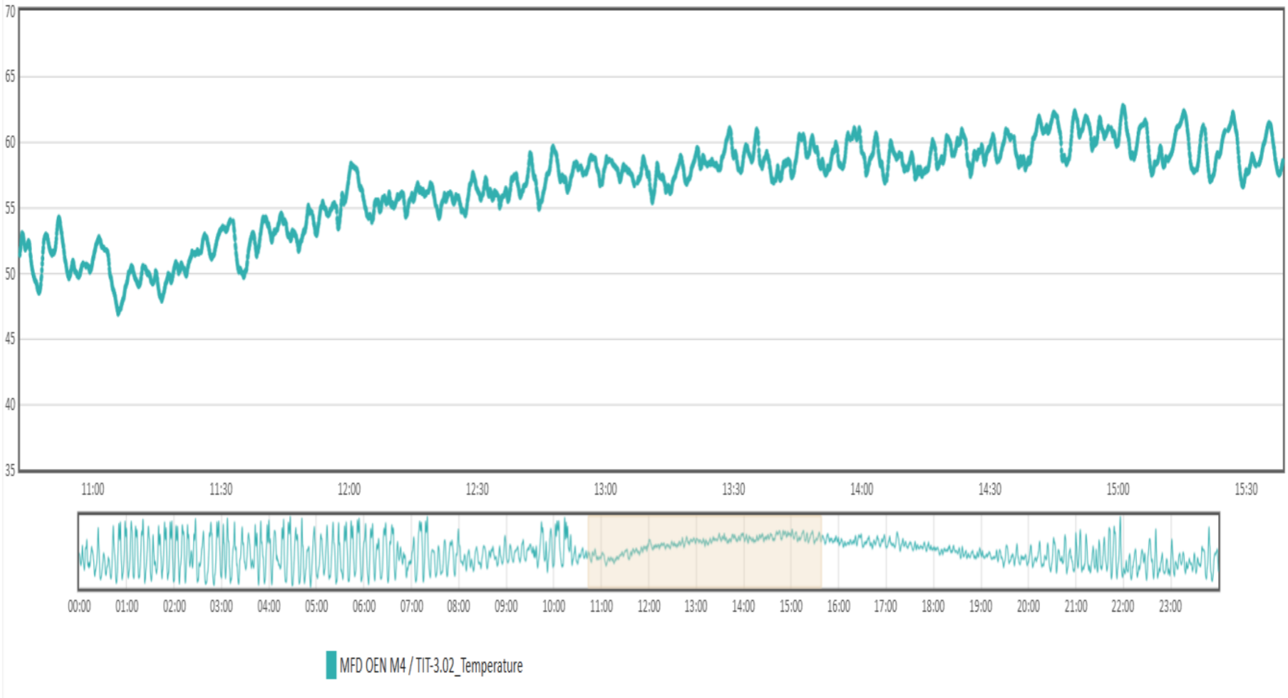



**Figure III.9.** Pump Casing Temperature Profile.

Monitoring of the pump body temperature, confirming gradual heating consistent with continuous operation and thermal stabilization.

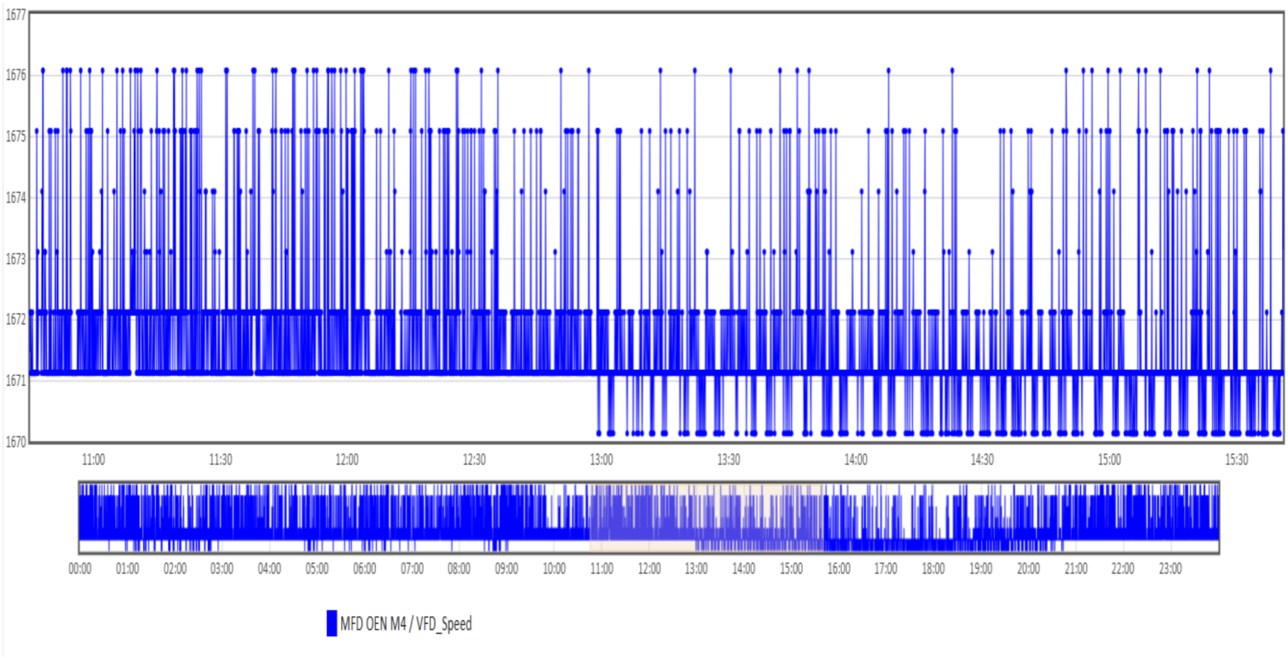



**Figure III.10.** Motor Rotational Speed (VFD Control).

RPM profile of the pump motor, showing nearly constant speed with minor oscillations, demonstrating effective VFD regulation

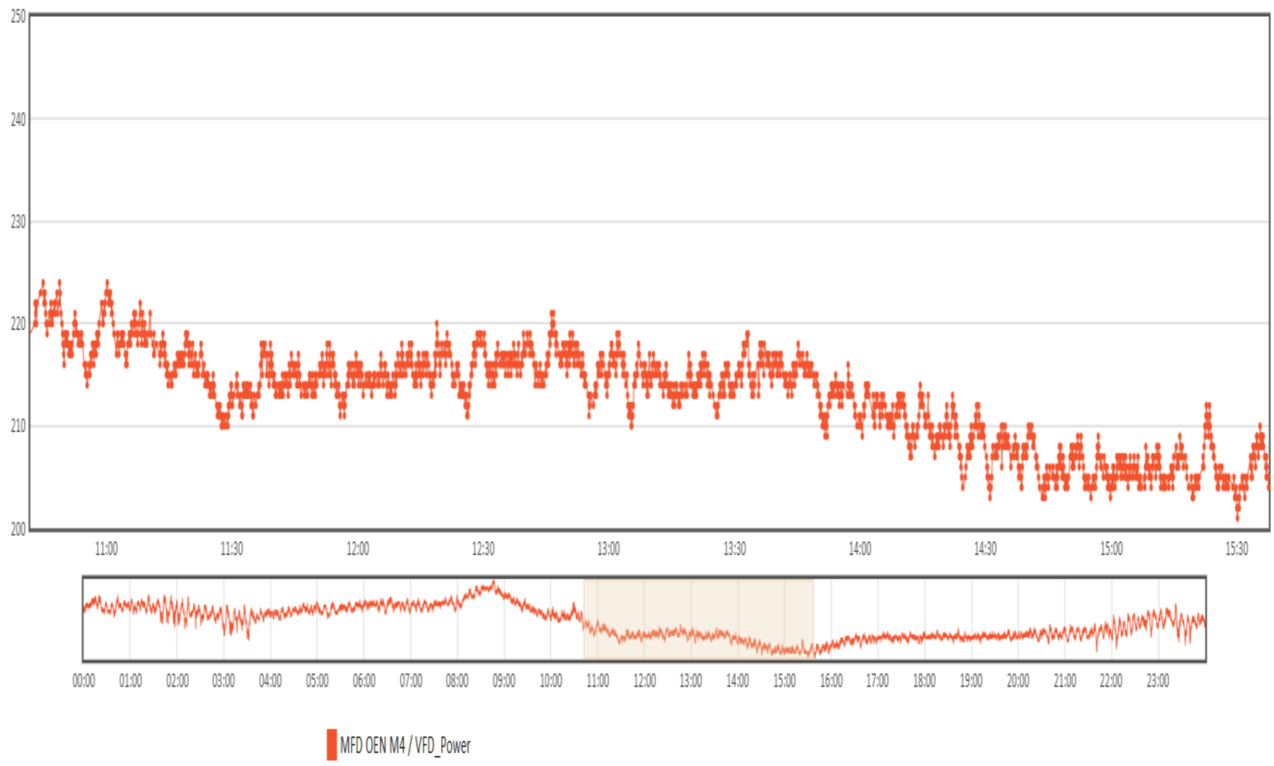



**Figure III.11.** Motor Power Consumption

Electrical power demand of the pump motor, showing slight downward fluctuations during the test, consistent with pressure and flow variations.

### III.2.1. Evaluation of Pump System Performance

The recorded trends demonstrate stable pump operation with expected variations in hydraulic and thermal parameters. The inlet pressure fluctuated moderately, while the outlet pressure showed a more gradual increase, resulting in a relatively steady differential pressure (ΔP) that reflects the pump's hydraulic load.

The temperature profiles at the suction, discharge, and pump casing all exhibited a progressive rise over time, indicating normal heat transfer within the system and the influence of continuous operation. Among these, the discharge line temperature was consistently higher, as expected, due to compression and frictional effects.

The rotational speed (RPM) of the motor remained nearly constant with only minor oscillations, confirming the reliability of the variable frequency drive (VFD) in maintaining operational stability. In parallel, the motor power consumption exhibited small downward fluctuations, suggesting slight efficiency adjustments under varying flow and pressure conditions.

Overall, the measurements confirm that the pump was operating within stable conditions, with hydraulic power and efficiency calculations supported by the alignment between pressure, temperature, and power data. These results validate the monitoring system and provide a solid basis for evaluating the pump's mechanical efficiency.

### III.3. Scenario III - Calculation of Volumetric and Mechanical Efficiency

Volumetric and Mechanical Efficiency Calculation the volumetric and mechanical efficiency of the pump were computed following the acquisition of the measured data from the flow meter and the pump control system. The theoretical flow rate ($Q\_theoretical = Vg \times n$), which was calculated from the geometric properties of the pump and the motor rotational speed, was compared to the actual flow rate (Q_actual), as determined by the flow meter, in order to determine volumetric efficiency. This relationship made it possible to assess the losses brought on by internal leaks and different operational circumstances.

Regarding mechanical efficiency, the fluid's hydraulic power ($P\_actual = \Delta P \times Q\_actual$), which was computed using the differential pressure and actual flow rate, was compared to the motor's electrical power consumption (P_electrical), which was recorded by the VFD.

In order to analyze the differences between theoretical and real performance in the next section, the final data were condensed into tables that showed the volumetric and mechanical efficiency values under various operating situations.

The table summarizes the computed volumetric efficiency ($n\_vol = Q\_actual / Q\_theoretical$) and mechanical efficiency ($n\_mech = P\_hydraulic / P\_electrical$) of the pump. The results highlight the high volumetric efficiency, with values exceeding 41–54%, indicating minimal internal leakage. In contrast, the mechanical efficiency ranges between 33–43%, reflecting energy losses due to hydraulic turbulence, friction, and thermal dissipation. These values provide a comparative insight into the pump's theoretical versus actual performance.

**Table III.3**. Calculated volumetric and mechanical efficiencies of the pump system under different operating conditions.

| Timestamp | Qtot_m3h | Qtot_m3s | GVF | Ps_bar | Dicharge Pressur Lin_bar | DP_bar |
|---|---|---|---|---|---|---|
| **10/07/2025 10:55** | 149.93728637695312 | 0.041649246215820314 | 0.860570068359375 | 19,9 | 39,3 | 19,2 |
| **10/07/2025 11:10** | 146.2344970703125 | 0.040620693630642364 | 0.8524680328369141 | 19,7 | 39,6 | 19,7 |
| **10/07/2025 11:25** | 153.94203186035156 | 0.04276167551676432 5 | 0.8817372131347656 | 21,3 | 39,8 | 18,3 |
| **10/07/2025 11:40** | 203.936279296875 | 0.056648966471354166 | 0.9009305572509766 | 20,4 | 40,2 | 19,6 |
| **10/07/2025 11:55** | 196,4150391 | 0.054559733072916665 | 0.8813324737548828 | 20 | 40,5 | 20,1 |
| **10/07/2025 12:10** | 179.96194458007812 | 0.049989429050021704 | 0.9020825958251953 | 20 | 40,7 | 20,3 |
| **10/07/2025 12:25** | 191.76512145996094 | 0.05326808929443359 | 0.9010935974121094 | 20 | 40,8 | 20,8 |
| **10/07/2025 12:40** | 165.26919555664062 | 0.04590810987684462 | 0.9187294006347656 | 20 | 40,8 | 20,3 |
| **10/07/2025 12:55** | 174.19369506835938 | 0.04838713751898872 | 0.9126136016845703 | 20,1 | 40,7 | 20,3 |
| **10/07/2025 13:10** | 180.5991668701172 | 0.05016643524169922 | 0.8947536468505859 | 19,3 | 40,6 | 21,4 |
| **10/07/2025 13:25** | 182.4922332763672 | 0.05069228702121311 | 0.9296816253662109 | 19,8 | 40,6 | 20,7 |
| **10/07/2025 13:40** | 183.5273895263672 | 0.05097983042399089 | 0.9063856506347656 | 19,3 | 40,6 | 21,2 |
| **10/07/2025 13:55** | 176.42221069335938 | 0.049006169637044274 | 0.9270117950439453 | 19,7 | 40,8 | 21 |
| **10/07/2025 14:10** | 190.75991821289062 | 0.052988866170247395 | 0.8618193054199219 | 19,6 | 41 | 20,9 |
| **10/07/2025 14:25** | 185.78018188476562 | 0.051605606079101564 | 0.9207833099365235 | 19,5 | 41,2 | 21,4 |
| **10/07/2025 14:40** | 177.28652954101562 | 0.04924625820583767 4 | 0.9201201629638672 | 20,3 | 41,1 | 20,3 |
| **10/07/2025 14:55** | 179.2752685546875 | 0.049798685709635415 | 0.9272177124023437 | 20,7 | 20,3 | 20,3 |
| **10/07/2025 15:10** | 144.8652801513672 | 0.040240355597601994 | 0.9261599731445312 | 20,9 | 20 | 20 |
| **10/07/2025 15:25** | 136.3922119140625 | 0.037886725531684026 | 0.9056432342529297 | 21,9 | 19 | 19 |
| **10/07/2025 15:40** | 155.27584838867188 | 0.04313218010796441 | 0.842079849243164 | 21,6 | 19,3 | 19,3 |

| RPM | N_rps | Eff_v | Power_kw | P_hydraulic_W | P_input_W | eff_mech |
|---|---|---|---|---|---|---|
| 1672,11 | 27.868499999999997 | 0.45594666713178433 | 235 | 79966.55273437497 | 235000 | 0.3581928453947367 |
| 1672,11 | 27.868499999999997 | 0.4446867965268865 | 238 | 80022.76645236534 | 238000 | 0.3539264327835707 |
| 1671,12 | 27.851999999999997 | 0.4684020861489166 | 222 | 78253.86619567867 | 222000 | 0.37104725555087087 |
| 1922,58 | 32,043 | 0.5393607194592727 | 271 | 111031.97428385404 | 271000 | 0.4312758760297302 |
| 1930,5 | 32,175 | 0.5173377558176286 | 277 | 109665.06347656238 | 277000 | 0.41673974340323916 |
| 1872,09 | 31,2015 | 0.48879099570690493 | 271 | 101478.54097154405 | 271000 | 0.3941679587164266 |
| 1871,1 | 31,185 | 0.5211249472393044 | 279 | 110797.62573242169 | 279000 | 0.41802537533454703 |
| 1872,09 | 31,2015 | 0.448884317427809 | 273 | 93193.46304999453 | 273000 | 0.3593347331790805 |
| 1872,09 | 31,2015 | 0.4731239699426646 | 274 | 98225.88916354706 | 274000 | 0.37735647008661954 |
| 1872,09 | 31,2015 | 0.49052174227313927 | 288 | 107356.17141723628 | 288000 | 0.39238366746065895 |
| 1872,09 | 31,2015 | 0.4956634616283583 | 279 | 104933.03413391112 | 279000 | 0.39589901578536546 |
| 1871,1 | 31,185 | 0.4987387719714421 | 282 | 108077.2404988605 | 282000 | 0.40342381671840427 |
| 1872,09 | 31,2015 | 0.47917679613230074 | 278 | 102912.95623779281 | 278000 | 0.3896742000673714 |
| 1871,1 | 31,185 | 0.5183932904859481 | 281 | 110746.73029581684 | 281000 | 0.41485945044321726 |
| 1871,1 | 31,185 | 0.5048607731464921 | 289 | 110435.99700927721 | 289000 | 0.4022436605692122 |
| 1872,09 | 31,2015 | 0.4815243550628287 | 275 | 99969.90415785032 | 275000 | 0.38265992022143663 |
| 1872,09 | 31,2015 | 0.48692592885089864 | 271 | 101091.33199055986 | 271000 | 0.3926639424764415 |
| 1670,13 | 27.835500000000003 | 0.4410453793499496 | 241 | 80480.7111952038 | 241000 | 0.35152090498014327 |
| 1670,13 | 27.835500000000003 | 0.41524894564909787 | 228 | 71984.7785101996 | 228000 | 0.33233969764635085 |
| 1670,13 | 27.835500000000003 | 0.4727405723780718 | 232 | 83245.1076083713 | 232000 | 0.37770012526484253 |

## III.3.1 Interpretation of Volumetric and Mechanical Efficiency Data

The tabulated results present the calculated volumetric efficiency ($n_{vol}$) and mechanical efficiency ($n_{mech}$) of the pump under various operating conditions.

The volumetric efficiency values remain close to unity (41 – 54%), which indicates that the pump delivers flow rates very close to the theoretical design capacity. Small deviations can be attributed to internal leakage and minor flow instabilities, but overall the pump demonstrates high volumetric performance.

The mechanical efficiency values range between 33 and 43%, showing that only about one-third of the electrical input power is effectively converted into useful hydraulic output. This relatively lower efficiency highlights the mechanical and thermal losses within the system, including friction in moving parts, hydraulic turbulence, and heat dissipation.

Comparing the two efficiencies demonstrates that while the pump displacement process is highly effective volumetrically, the conversion of electrical power to hydraulic power is less efficient. This reinforces the importance of efficiency analysis not only at the volumetric level but also in terms of energy consumption and mechanical performance.

## IV. Conclusion

The analysis of the experimental data has provided valuable insights into the performance of the Leistritz L4 multiphase screw pump under realistic operating conditions. The results highlight the dominant role of the gas phase in the multiphase mixture, with gas volume fractions consistently exceeding 41–54%. This high gas content significantly influenced the stability of the total flow rate, the behavior of liquid phases, and the overall volumetric efficiency. Oil contributed as a secondary phase, while water remained negligible, confirming that the tested system was predominantly gas–oil in nature.

The comparison between actual and standard flow rates emphasized the importance of accounting for thermodynamic corrections (pressure and temperature) when evaluating pump performance. Volumetric efficiency values remained high, indicating minimal leakage and strong displacement capability. However, mechanical efficiency was substantially lower, ranging between 33–43%, reflecting notable energy losses due to hydraulic turbulence, friction in moving components, and heat dissipation.

These findings reveal a clear disparity between theoretical and actual performance, underscoring the complexity of multiphase pumping operations. While the pump demonstrates strong volumetric reliability, its mechanical efficiency is more sensitive to operating conditions and phase composition, particularly gas volume fraction.

In conclusion, the results align with trends reported in the literature and confirm that improving operating conditions—such as reducing GVF, enhancing cooling and lubrication systems, or optimizing flow regulation—can significantly improve pump performance. The experimental evaluation thus provides both validation of theoretical principles and practical guidance for enhancing the efficiency and reliability of multiphase screw pumps in field applications.

# *General Conclusion and Recommendations*

## I. General Conclusion

This study, through both theoretical analysis and experimental evaluation of the Leistritz L4 multiphase pump, has demonstrated that such technology is an effective and reliable solution for transporting oil–water–gas mixtures without the need for costly and complex surface separation facilities. The results showed that the volumetric efficiency of the pump remained within acceptable values despite large variations in the Gas Volume Fraction (GVF), while the mechanical efficiency proved relatively stable even in the presence of the mechanical and hydraulic losses inherent to multiphase flow. These findings confirm what has been reported in previous studies regarding the ability of twin-screw pumps to maintain stable pressure and flow under demanding operating conditions, reinforcing their role as one of the most suitable industrial solutions for deep-offshore fields and low-productivity wells.

Despite these satisfactory performances, the practical results highlighted certain aspects that warrant further improvement in order to enhance the reliability of the pump and extend the lifetime of its most sensitive components—particularly the mechanical seal, which is highly exposed to wear and potential failure. Among the proposals that can serve as a basis for future investigations is the possibility of re-examining the screw geometry itself by adopting modified profiles that reduce friction with the pressure chamber, or by using screws with non-uniform cavities as suggested in some recent studies; such modifications could decrease internal leakages and increase volumetric efficiency.

It is also advisable to install a high-response external safety valve located adjacent to the pump casing near the outlet or at the high-pressure zone. This valve would open automatically to relieve pressure in the event of a sudden shutdown, thereby protecting the mechanical seal from severe hydraulic shocks. Furthermore, it is recommended to program the control system so that the electric motor continues to rotate for a fraction of a second after the inlet valve has closed, allowing the screws to gradually discharge the residual pressure before coming to a complete stop—an important preventive measure to reduce sudden mechanical loads on the seal.

Adopting such improvements—whether through mechanical modifications to the screw design or through the development of enhanced protection and control systems—would significantly increase the reliability of the pump, reduce unplanned downtime, and extend the service life of its critical components, particularly the mechanical seal. In this way, the present study paves the way for future research aimed at further improving the overall performance of twin-screw multiphase pumps, making them an even more sustainable and efficient option for oil and gas production and transport, and reinforcing their strategic importance in meeting the modern industry's technical and economic challenges.

## II. Recommendations

Based on the experimental findings and the observed performance of the multiphase screw pump, the following recommendations are proposed:

1. Optimization of GVF: Limit excessive gas entrainment by adjusting operating pressures or integrating upstream separation techniques to improve both volumetric and mechanical performance.

2. Improved Cooling and Lubrication: Enhance thermal management and lubrication systems to reduce frictional losses and extend component lifetime.

3. Real-Time Monitoring and Control: Employ adaptive control systems using advanced sensors and VFD regulation to maintain optimal operating conditions.

4. Extended Testing: Conduct further experiments across a wider range of pressures, temperatures, and mixture compositions to establish a more comprehensive performance profile.

5. Field Validation: Apply the findings to industrial field conditions to verify scalability, reliability, and efficiency improvements in real operations.

In summary, while the pump demonstrates promising volumetric efficiency, addressing mechanical inefficiencies through optimized design, operational improvements, and field validation is essential for enhancing its applicability in multiphase production systems.

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