INVESTIGATION ON THE COMPARISON OF PERFORMANCES OF VARIOUS TYPE OF POSITIVE DISPLACEMENT PUMP

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ABSTRACT

Positive displacement pumps have extreme significance across multiple industries as they provide a dependable and economical means of transferring fluids. Engineers compared the efficiency and performance of various positive displacement pumps to determine which was the most effective for fluid transfer. In light of the critical impact that volumetric and mechanical efficiency have on overall pump design, the research centred on these parameters. To accomplish this, the study provided a comprehensive examination of gear, piston, vane, and swash plate pumps, demonstrating their efficiency across diverse operational scenarios to draw a conclusion, which pump that is the best to be used inside the steering gear system. The relevant research framework offered valuable perspectives on the current body of knowledge. Utilizing Tecquipment's MFP103 Positive Displacement Pump Test Set, experiments were conducted per the research methodology, with operating parameters systematically altered. The results of this study enhance knowledge regarding the efficiency of positive displacement pumps, which assists engineers in the process of choosing the most appropriate pump for a wide range of fluid transfer applications onboard ship.

Keywords: efficiency, pumps, gear, piston, vane, swash-plate.

1.   INTRODUCTION

Fluid transmission in steering gear systems depends on centrifugal and positive displacement pumps, underscoring the need for careful equipment selection. Positive displacement pumps are used for managing viscous and shear-sensitive fluids because of their durability in frequent dry conditions. On the other hand, materials that are sensitive to shear and have a high viscosity present problem for centrifugal pumps. The choice of these pumps has a substantial impact on the overall performance, dependability, and efficiency of the system in industrial operations, depending on several variables including flow rate, pressure needs, fluid properties, temperature, corrosiveness, and solids present. That is why positive displacement pumps find wide-ranging applications due to their talented ability to transport fluids. These pumps ensure a consistent flow rate, regardless of changes in pressure, unlike centrifugal pumps where the flow rate varies with pressure. To evaluate positive displacement pumps' (piston, gear, vane, and swash plate) effectiveness under various operating circumstances, this study attempts to create a performance curve for these types of pumps. The study's significance lies in its ability to maximize pump use while enhancing efficiency and reducing maintenance. One of the limitations is that the equipment used is limited to the MFP103 Positive Displacement Pump at UNIKL MIMET Marine Lab and is centred on positive displacement pumps. The study supports advances in positive displacement pump technology and aids in the informed selection of pumps.

2. LITERATURE REVIEW

In general, reciprocating and rotational pumps are subclasses of positive displacement pumps, distinguished by how their pressure-generating components rotate. Using mechanized components, such as plungers or pistons, these pumps propel liquid through cylindrical chambers. Ensuring a constant fluid volume per stroke is of greatest significance, as the flow rate is determined by both the piston velocity and the internal structure. At the pump's output port, positive displacement pumps generate pressure through resistance, capturing a set amount of fluid and transferring it from suction to discharge via control valves. Because of this unidirectional flow, they are capable of manipulating extremely viscous fluids.

Onboard ships positive displacement and centrifugal pumps are critical components of ships' propulsion systems, essential pumps that are strategically positioned for optimal operation. Centrifugal pumps, which are commonly found in engine rooms, effectively regulate fluid volumes at low pressures while facilitating cooling water circulation, bilge draining, and ballasting. They assist in the administration of ballast water, thereby contributing to the vessel's stability. Positive displacement pumps, on the other hand, are strategically positioned to regulate fluid flow precisely in hydraulics, fuel oil transfer, and lubrication systems. Controlling fluid flow in the face of pressure variations is an essential capability that directly impacts steering gear and cargo management. Furthermore, positive displacement pumps guarantee a dependable fuel supply through the transportation of fuel oil from storage to engines, thereby guaranteeing continuous operation. When utilized in conjunction, these compressors ensure the efficient and uninterrupted operation of vital shipboard systems.

The steering gear system, which is an essential element aboard vessel, serves to enable course and direction changes and is therefore critical to the secure navigation of the vessel. The pumps are critical components that are vulnerable to failures within the steering gear system. They are critical in supplying the right amount of hydraulic pressure to propel the vessel's rudder. Pump failures may be caused by cavitation-induced damage, gradual deterioration, or hydraulic fluid contamination. Hydraulic pressure loss, which frequently occurs due to pump malfunctions, leakage, or valve issues, has the potential to completely obstruct the steering gear. Electrical malfunctions, including power supply issues and dysfunctional control interfaces, can also cause disruptions in electro-hydraulic systems.

Table 1: Steering Gear Defects: Data from One Country Covering 11994 Ship Operating Years (Cowley & Cow Ley Phd, 2010)

TYPE OF DEFECTS	NUMBER
Scoring of sliding surfaces due to contaminated oil	52
Mounting defects, loosening of fastenings	176
Failure of a bearing	96
Fluid leakage, wear of packings	82
Failure of a pump	123
Failure of non-essential components	7
Wear of valve parts	34
Total per 1526 steering gears	570

Table 2: Summary Of Study Of 71 Steering Gear Failures On 40 Ships (Cowley & Cow Ley Phd, 2010)

TYPE OF DEFECTS	NUMBER	PERCENTAGE OF TOTAL
Purely mechanical failures (rudder, rudder stock, blade, pintles yoke, linkage between ram and yoke, etc.)	3	4
Electrical failures (pump motors, circuits)	5	7
Remote control system failures	14	20
Hydraulic system failures (rams, pumps, piping, fittings)	49	69

The distribution data that J. Cowley surveyed and gathered are shown in Tables 1 and 2, respectively. These tables describe several examples that include flaws in the steering gear system that are found aboard ships. In Table 1, out of 570 incidences of steering gear system defects, the failure of a pump has emerged as the second-highest contributing element, greatly impacting the occurrence of defects in the steering gear system. This is the case because the failure of a pump is the second-highest contributing factor. The failure of the pump in the steering gear system is recognized as a contributing factor on 40 ships, which suggests that this pattern is aligned with what is seen in Table 2.

Table 3: Causes of the 49 Hydraulic System Failures (Cowley & Cow Ley Phd, 2010)

HYRAULIC SYSTEM FAILURES	NUMBER
Loss of oil 9	9
Oil leak at the pump shaft outlet	12
Seizing up or scoring of polished pump faces	7
Pump bearing	5
Pump casing or motor/pump linkage	5
Non-return slide valve	4
Controls of pump power unit	2
Incorrect pump assembly	2
Feed valves or outlet valves	2
Dirt in oil filters	1
TOTAL	**40**

Table 4: Steering Gear Failure: Data from One Country on Ships Of 500 GT And Upwards (Cowley & Cow Ley Phd, 2010)

HYRAULIC SYSTEM FAILURES	NUMBER
Steering gear failed 24	24
Functioned properly when tested (cause not identified)	18
Air in hydraulics	8
Power failure (includes local or total)	24
Ram or cylinder failure (includes seals)	6
Piping failure (pipe, hose, flange)	9
Valve or pump failure	19
Motor or engine failure (includes couplings)	18
Control system component failure	44
Rudder angle indicator failure	2
Cold oil	1
TOTAL	**173**

According to the data presented in Table 3, a significant 70% of steering gear hydraulic system failures can be ascribed to suboptimal pump performances. This alarming trend is evident in seven out of ten cases. In the same vein, vessel failures attributable to valve or pump malfunctions rank second in severity among vessels with a Gross Tonnage (GT) of 500 or more, as shown in Table 4. This critical information emphasizes the indispensable function that pumps perform in maintaining the steering gear system's dependability. The importance of this data emphasizes the necessity for thorough examination and proactive strategies to resolve and avert potential complications, specifically those associated with pump malfunctions.

Despite developments in pump technologies, the positive displacement pump continues to be crucial on account of its consistent flow rate, dependable operation, and adaptability to a wide range of applications. Nevertheless, it is crucial to decide on pump material that corresponds with the properties of the fluid, underscoring the significance of making well-informed decisions. The dependability and durability of positive displacement pumps are impacted by repetitive loading patterns, particularly within a pre-established range of speeds.

Recent research indicates that the positive displacement pump continues to be a crucial component in a multitude of industries, thereby emphasizing its enduring importance. A comprehension of the fundamental principles governing these pumps are essential for all parties engaged in their specification, engineering, and utilization. The present literature review provides an overview of the historical and technological context related to positive displacement pumps, underscoring their persistent significance and the necessity for additional research in this domain. By comparing the performance of various positive displacement pumps under a variety of operational conditions, the current study addresses a lack of understanding by bringing light to the effectiveness of these pumps.

3.   RESEARCH METHODOLOGY

An essential element of the Modular Fluid Power (MFP) collection by TecQuipment, the Positive Displacement Pump functions by capturing and compelling a predetermined volume of fluid into the discharge channel. The MFP103 apparatus is comprised of a variety of incorporated water pumps, such as gear, vane, piston, and swash plate pumps. In contrast to rotodynamic pumps, which produce a constant output, positive displacement pumps frequently manifest pulsations. In order to ensure the stability of the flow, pulsation dampers are commonly integrated. TecQuipment intentionally abstains from incorporating pulsation dampers, thereby enabling users to employ a mechanical pressure gauge for the purpose of analyzing and differentiating output pulsations.

Each of the four pumps will be tested in three experiments to evaluate its effectiveness under varying conditions. In the first experiment, each pump will operate at an identical rate of 1600 revolutions per minute. The pumps will be subjected to pressure variations ranging from 1 bar to 15 bars for testing purposes. Experiment 2 will involve the operation of all pumps at a constant pressure of 15 bar. The pumps will be subjected to differential pump speed testing ranging from 800 to 1600 rev/min. Experiment 3 will involve maintaining a consistent delivery pressure (15 bar) and speed (1600 rev/min) for all pumps. All pumps will be subjected to a reduction in inlet pressure from -0.1 bar to -0.7 bar at this time.
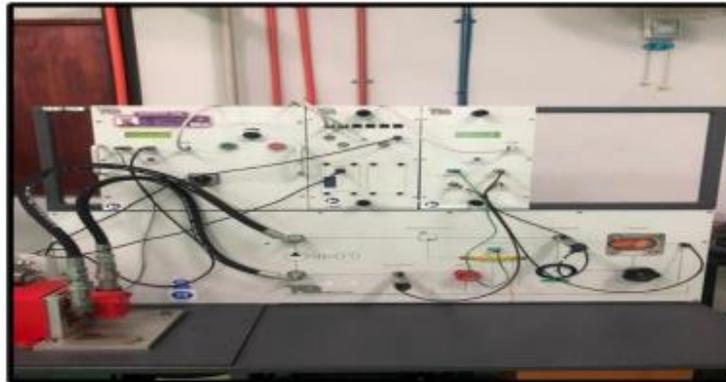

Figure 1: General Layout of MFP103 Positive Displacement Pump Set

For the purpose of data analysis, the VDAS system, which consists of both hardware and software components, is utilized. Test data is automatically recorded and computed by this system, which generates graphical representations in the form of charts and tables. Time is saved substantially, errors are minimized, and data export for subsequent processing in other software is facilitated by the VDAS. The procedure entails the utilization of a mechanical pressure gauge to analyze the output pulsations of different pumps, while TecQuipment deliberately excludes pulsation dampers as shown in Figure 1. This methodology permits an in-depth examination of the pulsation properties that occur throughout the operation of the pump. In detail, Figure 2 (a) and (b) shows the VDAS system with its software layout. Data can be collected and analyzed by just looking at the monitor.
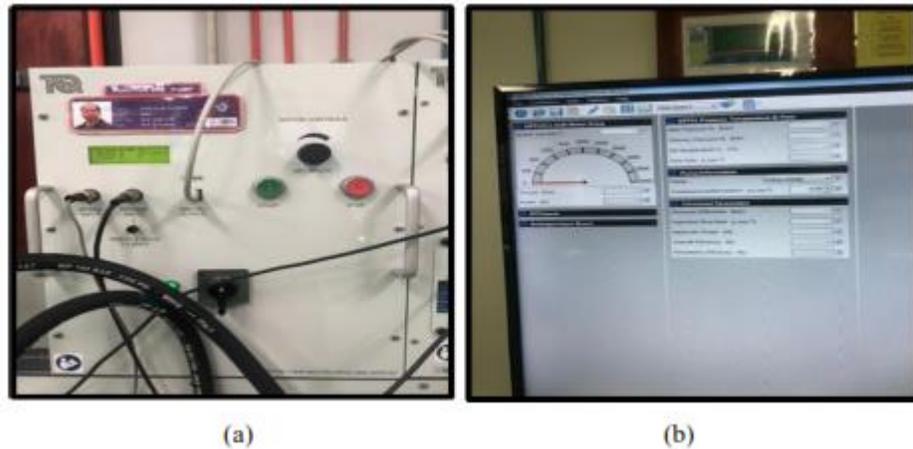
Figure 2: VDAS System

4.   RESULTS AND DISCUSSION

4.1   Experiment 1- The Effect of Delivery Pressure at Constant Pressure

After all the pumps are successfully run, every data and results on each pump have been collected to be analyzed. All of the four pumps generated difference type of results based on the volumetric efficiency, overall efficiency, shaft power, and flowrate. For an easy comparison method, all the data are taken out from the table and simplify it into graphs so that the curves of performances will be easily observed and compared.
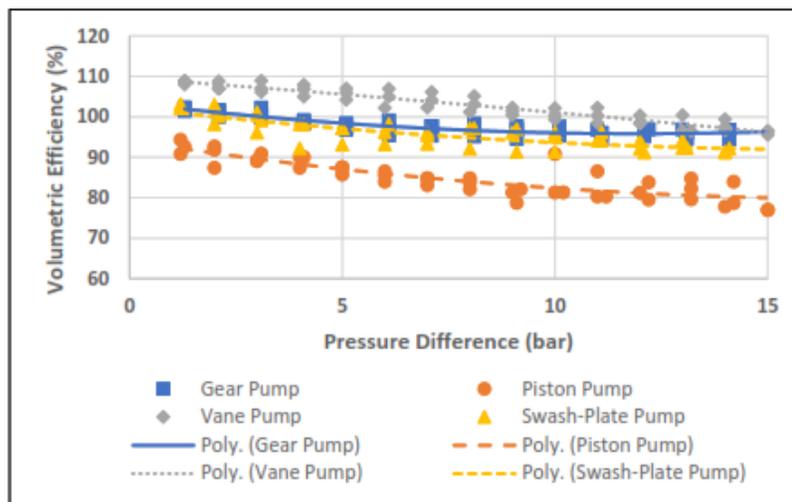
Figure 3: Pump Curves of Volumetric Efficiency with respect to Pressure Difference at speed of pump (1600 rev/min)

Results from a test based on experiment 1, in which each pump is run at its maximum speed of 1600 rev/min, are shown in Figure 3. A graph showing the volumetric efficiency with respect to pressure difference curve is presented. The plots show that the volumetric efficiency of the pumps steadily drops as the delivery pressure increases in 1-bar increments until the pressure reaches 15 bar. This is because, under increased load, components may undergo stresses or strains that reduce their efficiency. The graph shows that the vane pump has the greatest volumetric efficiency, at average of 102.7% with the gear pump coming in at a close second at average of 97.6%. The piston pump, meanwhile, is at the very bottom, approximately at average of 84.8%. The vane pump may be the most efficient of the bunch, but once the pressure reaches 10 bar, the volumetric efficiency of the gear pump remains constant.

Therefore, it is reasonable to assume that mechanisms involving pressure differential at constant speed are best served by gear pumps, which provide the most efficient pumping action.
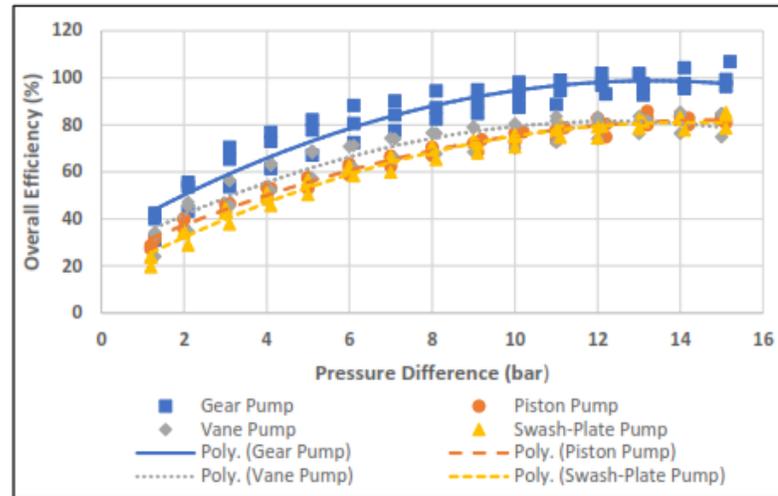

Figure 4: Pump Curves of Overall Efficiency with respect to Pressure Difference at speed of pump (1600 rev/min)

Figure 4 displays the overall curves for a speed of 1600 rev/min under different pressure difference. The overall efficiency of all of the four pumps rises progressively creating smooth upward trends in the graph. In terms of overall efficiency, gear pumps rank first at average of 81.5%, followed by vane, piston, and swash-plate pumps. Since vane pumps are more likely to be affected by variations in load, their efficiency may decrease as the delivery pressure rises, as seen in the figure, the overall efficiency of gear pumps is much higher than that of vane pumps. Gear pumps are known to have more consistent performance even when subjected to different loads.
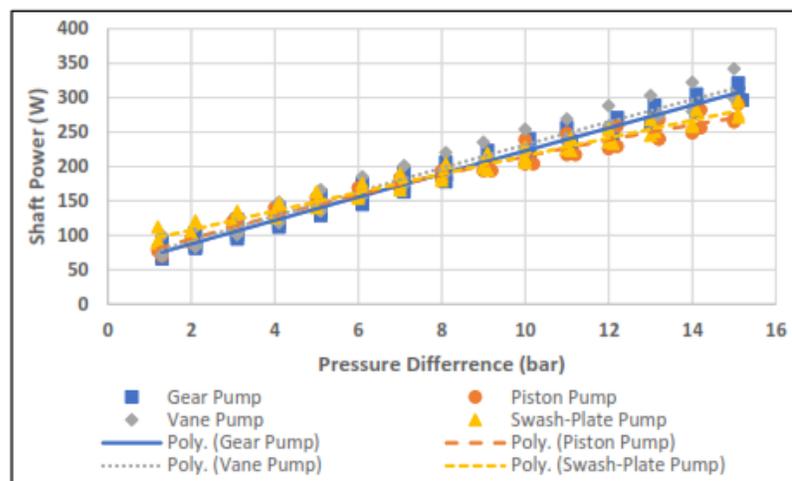

Figure 5: Shaft Power with respect to Pressure Difference at speed of pumps (1600 rev/min)

Figure 5 displays the shaft power with respect to pressure difference. From the low to high pressure difference, the graph shows that the trend of shaft power is increasing. According to the data shown in the graph, the vane pump generates the most shaft power at maximum of 342 Watts, while the piston pump generates the least, at maximum of 290 Watts. The gear pump generates less shaft power at low-pressure differences, but once the pressure reaches 8 bar, the shaft power increases to the point where it ranks second in terms of power produced. It is noteworthy that an increase in shaft power results in a corresponding decrease in pump efficiency, as the increased power required for fluid transmission necessitates a greater consumption of electric supply.
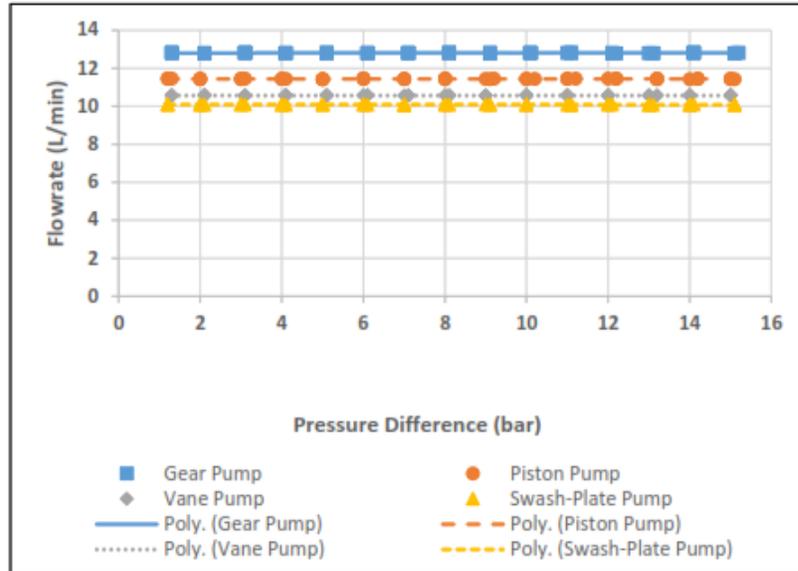
Figure 6: Pump Curves of Flowrate with respect to Pressure Difference at speed of pump (1600 rev/min)

Figure 6 displays the trend curves of flowrate with respect to the pressure difference. From the beginning until 15 bar is achieved, the flowrate of these pumps remains constant, as seen in the figure. Gear pumps, on the other hand, is at the highest because it provides the finest flowrate value. However, in comparison to the other pumps, the swash-plate pump has the lowest flowrate. The reason for this is because the gear pump has a bigger volume, which is 8.00 cc/rev, however the size of the swash-plate is only 6.3 cc/rev. Therefore, the comparison is dependent on the volume of the pump. The higher the volume, the higher the flow rate produced.

4.2   Experiment 2- The Effect of Speed at Constant Delivery Pressure
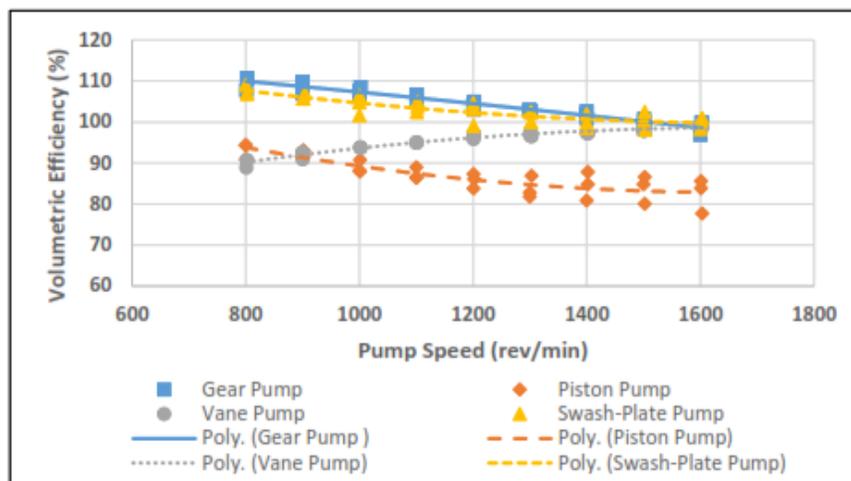

Figure 7: Pump Curves of Volumetric Efficiency with respect to Pump Speed at Constant Pressure (15 bar)

Test results derived from experiment 2, whereby each pump is operated at a constant pressure of 15 bar with a speed ranging from 800 to 1600 rev/min. Here appears a graph as shown in Figure 7, depicting the relationship between volumetric efficiency with respect to constant pressure. As the pump's speed increases in 100 rev/min increments up to 1600 rev/min, the volumetric efficiency of the gear, swash-plate, and piston pumps decreases, as seen in the figure. When compared to other types of pumps, gear pumps have the highest number of volumetric efficiencies which is at average of 104.4%. The volumetric efficiency of the vane pump is the only one that exhibits a moderate increase. Therefore, it's reasonable to assume that the other positive displacement pump is more susceptible to variations in load or speed, leading to a decline in volumetric efficiency with increasing pump speed. When compared to other types of pumps, vane pumps may be more reliable at speed below than 1600 rev/min, but the efficiency stays constant after it reaches 1600 rev/min.
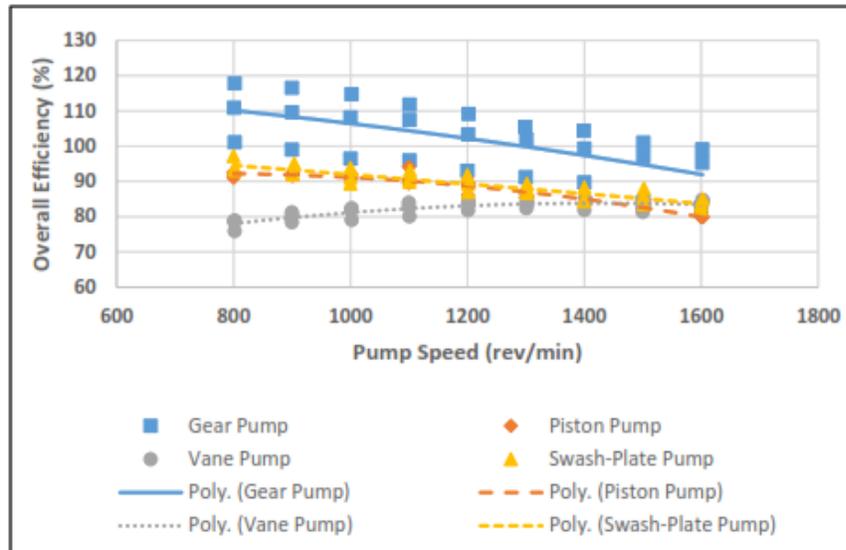

Figure 8: Pump Curves of Overall Efficiency with respect to Pump Speed at Constant Pressure (15 bar)

The experimental curves of overall efficiency with respect to pump speed is shown by Figure 8. The graph shows that reaching a pump speed of 1600 rev/min causes a slight drop in overall efficiency across the gear, piston, and swash plate pump. The vane pump's overall efficiency grows steadily from the start, average at 88.8%, even if the gear pump's overall efficiency is better. Since a mechanism makes use of differential of speed, it follows that the gear pump is still the best choice for the job.
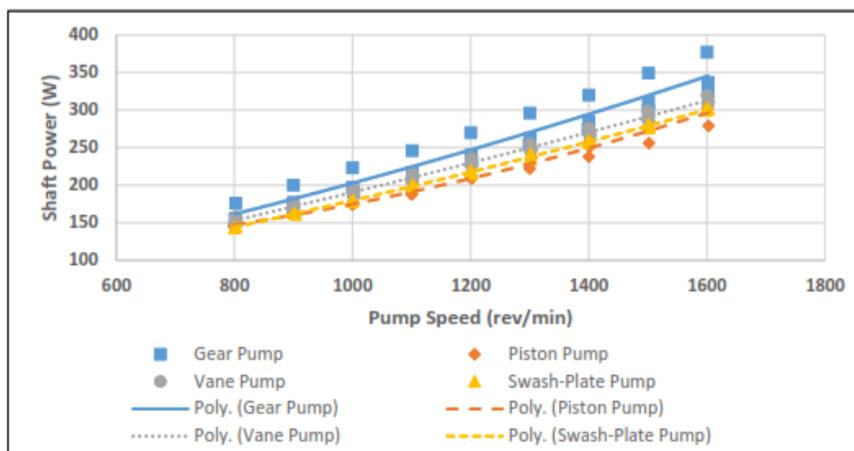

Figure 9: Pump Curves of Shaft Power with respect to Pump Speed at Constant Pressure (15 bar)

The graph clearly shows that the gear pump produces the most shaft power compared to the other pumps, at maximum of 377 Watt, as can be seen in Figure 9. Gear pumps are designed with an internal geometry that allows them to effectively manage fluids, ensuring a steady and smooth flow. The efficiency of the process of translating mechanical energy into fluid power may be improved in this way. On the whole, the piston pump has been the least efficient in terms of shaft power which at average of 214 Watt. The shaft power of any pump is linearly proportional to the square of the pump speed.
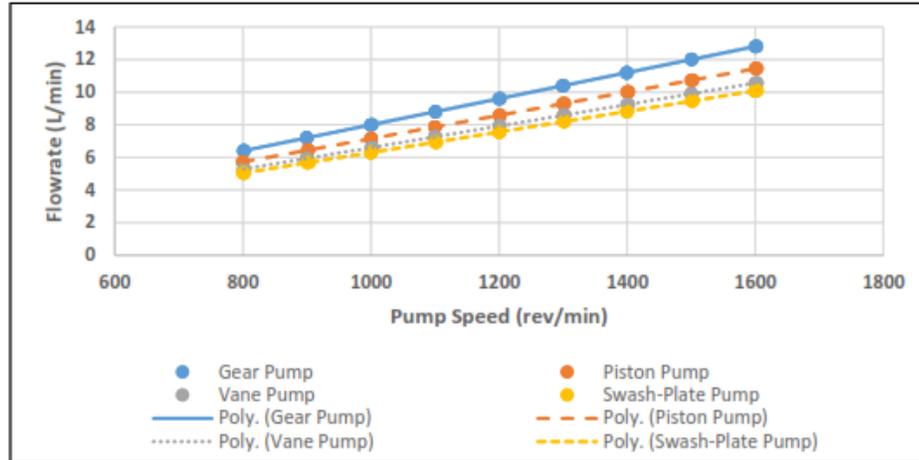

Figure 10: Pump Curves of Flowrate with respect to Pump Speed at Constant Pressure (15 bar)

Figure 10 shows the curve that was drawn based on the experiment that measured the relationship between flowrate and pump speed. The graph illustrates how the flowrate of each pump used varies with the pump speed. The graph clearly shows that the flowrate of these pumps increases progressively from the beginning until 1600 rev/min is attained. Conversely, gear pumps are preferred because they provide the best value in terms of flowrate. The swash-plate pump, however, has the slowest flowrate of the bunch. The size of the swash-plate is only 6.3 cc/rev, but the gear pump has a size similar to 8.00 cc/rev, hence this is the reason why gear pump has the highest flowrate. The reason for this is the disparity in the dimensions of the pump's individual volumes.

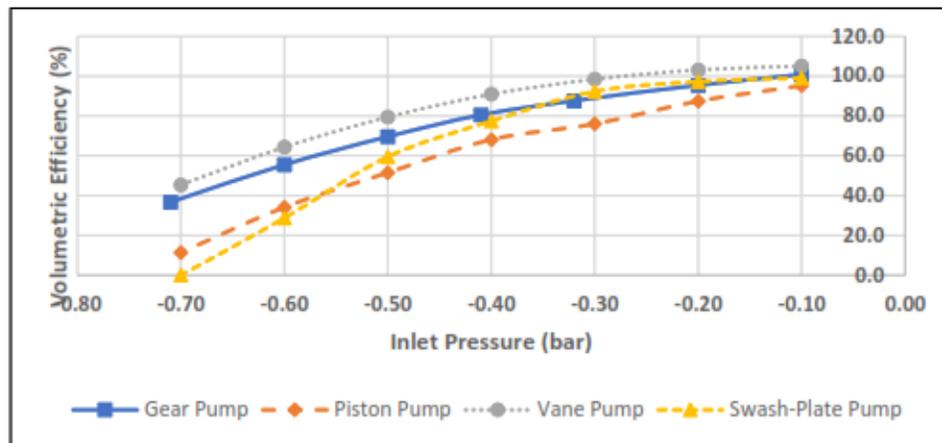### 4.3   Experiment 3- The Effect of Cavitation on Pump Performance

Figure 11: Pump Curves of Volumetric Efficiency with respect to Inlet Pressure at speed of pump (1600 rev/min)

Pump curves showing volumetric efficiency with respect to inlet pressure at a speed of 1600 rev/min are shown in Figure 11. The graph shows that as the inlet pressure drops in the pump, the volumetric efficiency drops as well. In terms of volumetric efficiency, the vane pump is once again at the top of the list with efficiency at average of 83.8%, followed by the gear, piston, and swash-plate pumps. While the swash-plate pump initially outperforms its competitors, its efficiency begins to decline at inlet pressures of around -0.40 bar and eventually drops to zero at -0.70 bar. Visual observation reveals that during the operation of a swash-plate pump, bubble formation at the oval gear flowmeter occurs as soon as the inlet pressure decreases. Additionally, it produces an extremely deafening noise and vibrates heavily. On the other hand, minimal commotion and vibration are generated, and the operation of a vane pump results in the formation of fewer bubbles, therefore, vane pumps have the highest volumetric efficiency.
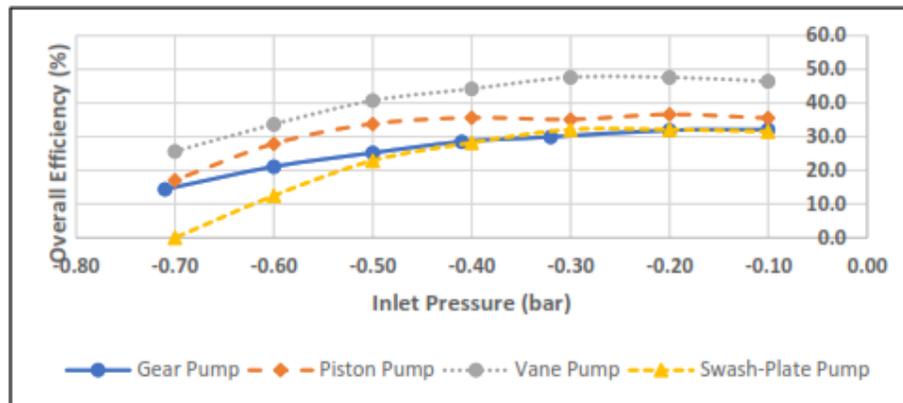

Figure 12: Pump Curves of Overall Efficiency with respect to Inlet Pressure at pump speed (1600 rev/min)

Figure 12 shows the pump curves at a speed of around 1600 rev/min, illustrating the overall efficiency with respect to inlet pressure. All of the pumps' efficiency decreases as the inlet pressure decreases, as shown in the graph. With an initial efficiency of 48% and a subsequent decline to 28%, the vane pump exhibits the best total efficiency. Similar to the piston pump, the efficiency of the other pumps decreased with time, going from 35% to 19%. The swash-plate pump has the worst overall efficiency of any pump type, ranging from around 30% to 0% after a run.
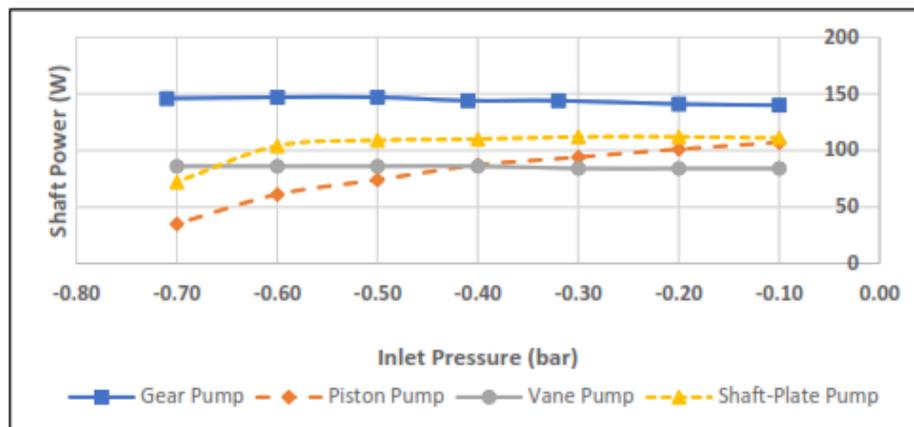

Figure 13: Pump Curves of Shaft Power with respect to Inlet Pressure at speed of pump (1600 rev/min)

Pump curves of shaft power against inlet pressure are shown in Figure 13, with a constant speed of 1600 rev/min. Among the four pumps, the gear pump consistently delivers the most shaft power, at average of 140 Watts, as shown in the graph. The internal geometry of gear pumps makes them excellent fluid managers, guaranteeing a constant and smooth flow. Shaft power efficiency has been worse for piston pumps, with a reduction of 40 watts at an inlet pressure of -0.70 bar. The vane pump maintains a continuous, smooth line by setting the shaft power at 80 watts until it stops running. Any pump's shaft output grows in a square root relationship with the speed of the pump.
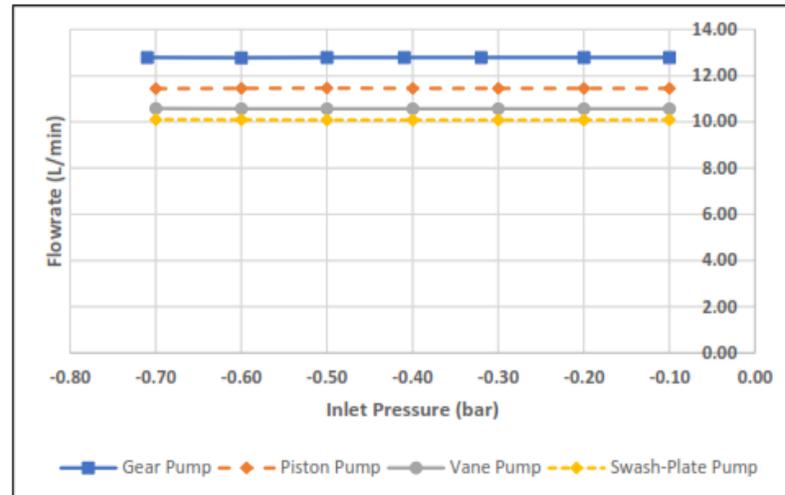
Figure 14: Pump Curves of Flowrate with respect to Inlet Pressure at speed of pump (1600 rev/min)

In Figure 14, the experimentally-derived curve representing the relationship between flowrate with respect to inlet pressure. As can be seen in the figure, the flowrate of each pump in the system changes as the inlet pressure drops. The flowrate of these pumps is constant from the beginning until -0.07 bar is reached, as seen on the graph. Conversely, gear pumps excel due to their superior flowrate value, which is around 13 L/min. Having said that, the swash-plate pump's flowrate of around 10L/min is the lowest of the bunch. This is because, although the swash-plate's capacity is 6.3 cc/rev, the gear pump's capacity is 8.00 cc/rev, which is the maximum value of size. This is due to the fact that the pump components are of different volumes.

5.   CONCLUSION AND RECOMMENDATION

Piston pumps generate intense pulses, whereas gear and swash-plate pumps generate weaker pulses. The power consumption of each pump is determined by the delivery pressure and velocity. Gear and piston pumps operate at maximum efficiency when the pace and pressure are optimal. Altering the rotational velocity promptly influences the flow rate, whereas the delivery pressure exerts a negligible influence, which is customary for these pumps.

A certain degree of reduction in volumetric efficiency was observed with decreasing inlet pressures for every pump. The stability of the vane pump was consistently maintained despite fluctuations in the inlet pressures. All pumps produced noise during cavitation with the exception of the gear pump, which maintained its accuracy despite extremely low inlet pressures. During cavitation, the vane pump maintained consistent readings and remained silent.

Conforming to our research objectives, these results provide us with insight into the performance of various pumps. We now comprehend the characteristics of each pump type under varying conditions, including pulse intensity, power consumption, and efficiency. The significance of selecting pumps with pure fluids is evident, demonstrating the practical implications of our research.

When daily operation and maintenance requirements are moderate, piston pumps are the best option. With minimal maintenance and pulsation requirements, gear pumps operate efficiently with pure fluids. Vane pumps are ideal for circumstances requiring consistent flow and high efficiency, even when dealing with a variety of fluids. Applications requiring pure fluids, high efficiency, and a constant flow despite fluctuations in demand are ideal candidates for swash-plate pumps. These results inform practical pump selections, thereby accomplishing the particular objectives we established.

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