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Performance Analysis of Parallel Pipe Arrangement Hydraulic Ram Pump Supporting 1 Waste Valve and 2 Delivery Valves

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ABSTRACT

A pump is a device used to move fluids from a lower elevation to a higher elevation. The hydraulic ram pump (hydram pump) performs the same function but operates without external energy sources such as electricity or fuel. The term “hydram” originates from the words hydro (water) and ram (impact or pressure). This pump utilizes the kinetic energy of flowing water, which is converted into pressure through the water hammer effect. As a result, part of the water is delivered to a higher elevation while the remainder is discharged through the waste valve. This study aims to evaluate the performance of a hydram pump by analyzing its discharge capacity, pump head, hydraulic power, and efficiency at different suction valve openings. The results show that the maximum discharge capacity was obtained at a 90° valve opening, reaching 0.00012346 m^3/s, while the minimum capacity occurred at 70°, with a value of 0.000063539 m^3/s. The highest pump head was recorded at a 60° valve opening, measuring 2.334 m, whereas the lowest head occurred at 90°, with a value of 1.664 m. Maximum hydraulic power reached 2.092 W at 80° and 90°, while the lowest value was 1.612 W at 60°. The highest efficiency achieved was 24.32% at 90°, and the lowest was 12.64% at 60°. These results indicate that the hydram pump operated with relatively low efficiency and suboptimal performance.

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1. INTRODUCTION

Water is a vital resource essential for the survival of living things, including humans, animals, and plants. Communities require large amounts of water [1], both from surface and groundwater sources [2], utilizing various technologies capable of lifting and channeling water from its source to agricultural lands and residential areas [3]. Therefore, it is necessary to explore and develop an adequate irrigation technology model, utilizing appropriate, efficient, and economical technology [4] so that its management does not rely on electricity or other fuels. This technology requires low operational costs and does not burden the community in conducting their business activities [5].

Water pumps [6] are currently widely available on the market, and come in many types. However, these pumps generally require electrical energy [7] for their drive. This often presents a challenge for residents living in areas without access to electricity from the state electricity company (PLN) [8]. Therefore, a pump installation that can operate without using electricity is necessary.

The design of the piping system [9] is crucial and has a significant impact on pump performance. Arranging pipes in parallel or connecting several pump units on the same pipe line will produce a larger water capacity with a water capacity that is a multiple of each pump installed [10], provided that the pumps installed in parallel have the same pump capacity.

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2. METHOD

2.1 Research Flow Chart

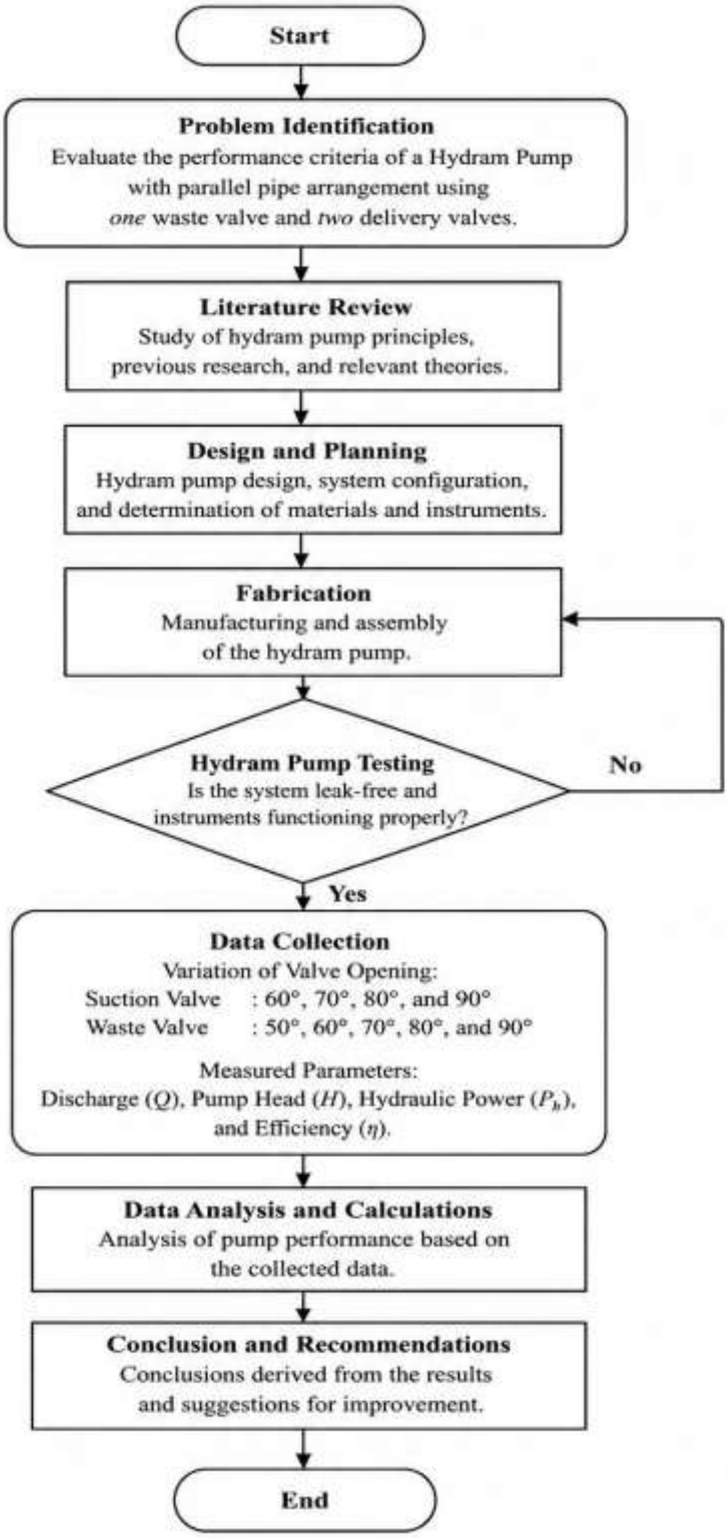

Figure 1. Research Flow Chart Diagram

2.2 Research Procedures

2.2.1 Initial Inspection

Before conducting the test, the following inspections were performed:

1. Check all connections of the parallel hydraulic ram pumps to ensure the system is properly installed and functioning normally.
2. Check the condition and function of measuring instruments, such as the pressure gauge and V-Notch Weir on the discharge side.
3. Check the suction and waste valve openings and ensure there are no leaks.
4. Check the entire hydraulic ram pump installation to ensure the system is leak-free.
5. Prepare equipment and carry out the test according to the research procedures.

2.2.2 Data Collection Procedure

Data collection was carried out through the following steps:

1. Measure the ambient and water temperatures using a thermometer.
2. Adjust and record variations in the suction and waste valve openings according to the test conditions.
3. Measure the water level at the V-Notch Weir on the discharge and waste sides.
4. Record all measurement data for each valve opening variation.
5. Repeat measurements to obtain accurate and consistent data.

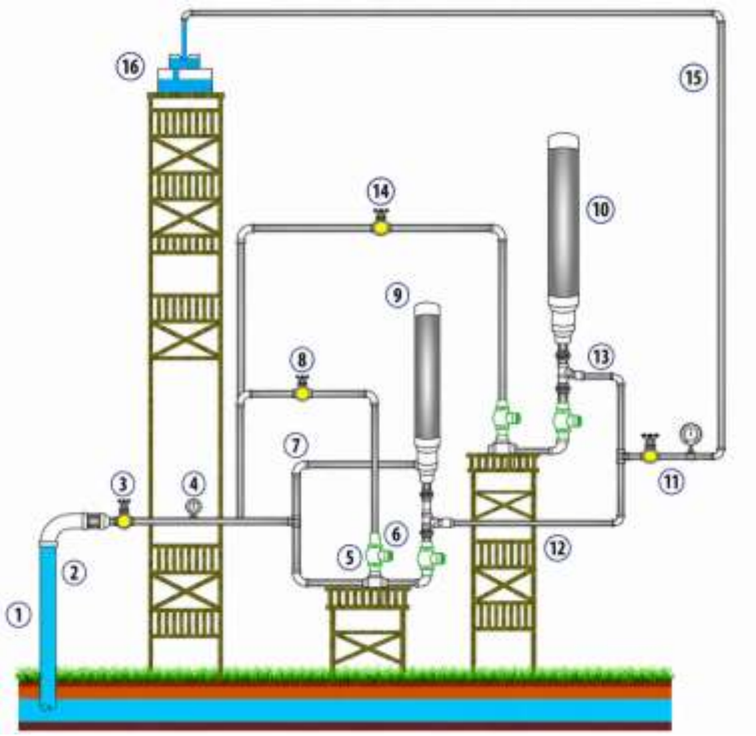

Figure 2. Pump Testing Scheme

Component Description:

1. Water Source Reservoir
2. Drive Pipe
3. Suction Valve
4. Pressure Gauge
5. Hydram Pump Body
6. Waste Valve
7. Primary Delivery Valve
8. Secondary Delivery Valve
9. Primary Air Chamber

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10. Secondary Air Chamber
11. Parallel Delivery Pipe
12. Control Valve A
13. Control Valve B
14. Discharge Valve
15. Delivery Pipe
16. Elevated Storage Tank

3. RESULTS AND DISCUSSION

Table 1. Test Result Data

KS	KL	V-Notch Discharge (cm)	V – Notch Waste (cm)	Water Pressure (Psi) Suction Pipe	Pipe Go out	Water Temperature (^oC)	HS	HD
60˚	50˚	2.5	4.7	1.8	29	26	0.5	201.3
	60˚	2.5	4.7	1.8	29	26	0.5	201.3
	70˚	2.4	4.7	1.8	29	26	0.5	201.2
	80˚	2.4	4.4	1.8	29	26	0.5	201.2
	90˚	2.4	4.4	1.8	29	26	0.5	201.2
70˚	50˚	2.7	4.7	2	29	26	0.5	201.5
	60˚	2.5	4.7	2	29	26	0.5	201.3
	70˚	2.5	4.7	2	29	26	0.5	201.3
	80˚	2.4	4.4	2.1	29	26	0.5	201.2
	90˚	2.3	4.4	2.1	29	26	0.5	201.1
80˚	50˚	3	4.7	2.5	29	26	0.5	201.8
	60˚	2.9	4.4	2.5	29	26	0.5	201.7
	70˚	2.9	4.4	2.5	29	26	0.5	201.7
	80˚	2.8	4.4	2.6	29	26	0.5	201.6
	90˚	2.8	4.5	2.6	29	26	0.5	201.6
90˚	50˚	3	4.5	2.5	29	26	0.5	201.8
	60˚	3	4.5	2.5	29	26	0.5	201.8
	70˚	3	4.3	2.5	29	26	0.5	201.8
	80˚	3	4.2	2.6	29	26	0.5	201.8
	90˚	3	4.2	2.8	29	26	0.5	201.8

Table 1 presents the experimental results of a hydraulic ram pump (hydram) operated under varying waste valve angles (KS) of 60°, 70°, 80°, and 90°, combined with delivery valve angles (KL) of 50°, 60°, 70°, 80°, and 90°. The measured parameters include V-notch discharge height, V-notch waste height, suction pipe pressure, delivery pipe pressure, water temperature, supply head (HS), and delivery head (HD). These measurements were conducted to evaluate the influence of valve angle configurations on the flow characteristics and overall hydraulic ram pump performance.

Based on the data, the V-notch discharge values generally increase as the waste valve angle (KS) increases. At KS = 60°, the discharge height ranges between 2.4 and 2.5 cm, while at KS = 80° and 90°, the discharge height reaches approximately 3.0 cm. This trend indicates that a larger waste valve angle allows a greater volume of water to be delivered through the delivery pipe. The increase in discharge is associated with a stronger water hammer effect, which serves as the primary energy source driving the hydraulic ram pump.

The V-notch waste measurements remain relatively stable, ranging from 4.2 to 4.7 cm throughout the experiments. This observation suggests that a portion of the incoming water continues to be discharged through the waste valve to sustain the cyclic operation of the pump. In hydraulic ram systems, waste flow is essential because it generates the sudden valve closure required to create the water hammer pressure surge. Therefore, maintaining a balance between pumped flow and waste flow is critical for achieving efficient pump operation.

The suction pipe pressure exhibits a gradual increase from 1.8 psi at KS = 60° to 2.8 psi at KS = 90°. This increase indicates that larger valve angles produce stronger pressure impulses during the waste valve closure process. In contrast, the delivery pipe pressure remains constant at 29 psi for all test conditions. The stable delivery pressure suggests that the downstream flow resistance and delivery system configuration remained unchanged throughout the experiment, resulting in a nearly constant outlet pressure.

The water temperature was maintained at 26°C during all tests. This constant temperature is significant because the physical properties of water, such as density and viscosity, are temperature-dependent [11]. By keeping the temperature constant, the influence of thermal variations on pump performance was minimized, ensuring that the observed changes were primarily caused by valve angle adjustments.

The supply head (HS) remained constant at 0.5 m for all experimental conditions, while the delivery head (HD) varied only slightly between 201.1 and 201.8 cm. The relatively stable HD values indicate that the hydraulic ram pump maintained a consistent pumping height despite variations in valve settings. The highest delivery head of approximately 201.8 cm was achieved at KS = 80° and 90°, suggesting that these configurations provided a more effective conversion of hydraulic energy into useful pumping work. From a scientific perspective, the performance of the hydraulic ram pump can be explained through the principles of conservation of energy and the water hammer phenomenon. When the waste valve closes suddenly, the momentum of the moving water within the drive pipe is abruptly interrupted, generating a high-pressure wave. This transient pressure surge forces the delivery valve to open and pushes a portion of the water into the delivery pipe and air chamber. The process is an application of the unsteady-flow momentum equation in fluid mechanics [12].

Furthermore, the measured pressure and head values can be interpreted using the Bernoulli Equation, which states that the total energy of a fluid consists of pressure energy, kinetic energy, and potential energy. In a hydraulic ram pump, a portion of the potential energy associated with the supply head is transformed into pressure energy through the water hammer effect and subsequently converted back into potential energy at a higher elevation, represented by the delivery head.

From the standpoint of fluid dynamics, the valve angle directly influences the valve closing time, flow rate, pressure pulse intensity, and energy transfer efficiency. Variations in KS and KL alter the dynamics of valve movement and the resulting pressure fluctuations within the system. Consequently, different valve configurations produce measurable changes in discharge rate and suction pressure. The experimental results demonstrate that valve geometry is a crucial design parameter for optimizing hydraulic ram pump performance, particularly in enhancing water delivery capacity and improving energy utilization without requiring any external power source.

Table 2. Calculation Result Data

KS	KL	Q Waste (m^3/s)	Q Discharge (m^3/s)	Head Pump (m)	Head Sistem (m)	Hydraulic Power (W)	η Vol
60°	40°	0	0	0	0	0	0
	50°	0.0003793	7.8266E-05	2.321329	3.0853813	1.7747683	13.76
	60°	0.0003793	7.8266E-05	2.3222439	3.0853813	1.7754677	13.766
	70°	0.0003793	7.0672E-05	2.3344555	2.8455652	1.6116423	12.641
	80°	0.0003216	7.0672E-05	2.3344555	2.8455652	1.6116423	14.498
	90	0.0003216	7.0672E-05	2.3344555	2.8455652	1.6116423	14.498
70°	40°	0	0	0	0	0	0
	50°	0.0003793	9.487E-05	2.1526649	3.6891084	1.9949902	16.127
	60°	0.0003793	7.8266E-05	2.1819976	3.0899142	1.6682427	13.773
	70°	0.0003793	7.8266E-05	2.1819976	3.0899142	1.6682427	13.773
	80°	0.0003216	7.0672E-05	2.1227139	2.8455652	1.4654618	14.498
	90°	0.0003216	6.3539E-05	2.1321074	2.6334993	1.3233771	13.27
80°	40°	0	0	0	0	0	0
	50°	0.0003793	0.00012346	1.7344664	4.9206569	2.0918184	19.822
	60°	0.0003216	0.00011343	1.7595059	4.4604028	1.9495782	21.035
	70°	0.0003216	0.00011343	1.7595059	4.4604028	1.9495782	21.035
	80°	0.0003216	0.0001039	1.7105758	4.051282	1.7361704	19.69
	90°	0.0003402	0.0001039	1.7105758	4.051282	1.7361704	18.866
90	40°	0	0	0	0	0	0
	50°	0.0003402	0.00012346	1.7344664	4.9206569	2.0918184	21.493
	60°	0.0003402	0.00012346	1.7344664	4.9206569	2.0918184	21.493
	70°	0.0003037	0.00012346	1.7344664	4.9206569	2.0918184	23.332
	80°	0.0002863	0.00012346	1.6638859	4.9206569	2.0066962	24.32
	90°	0.0002863	0.00012346	1.6638859	4.9206569	2.0066962	24.32

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Table 2 presents the calculated performance parameters of the hydraulic ram pump under different combinations of waste valve angle (KS) and delivery valve angle (KL). The calculated variables include waste discharge rate (Q Waste), delivery discharge rate (Q Discharge), pump head, system head, hydraulic power, and volumetric efficiency (ηVol). These parameters are used to evaluate the effectiveness of the hydraulic ram pump in converting the available water energy into useful pumping work.

The results indicate that the waste discharge (Q Waste) generally ranges from approximately 0.0002863 to 0.0003793 m^3/s, while the delivery discharge (Q Discharge) varies between 6.3539×10^{-5} and 1.2346×10^{-4} m^3/s. The delivery discharge tends to increase as the waste valve angle increases from 60° to 90°. The highest delivery discharge value of 1.2346×10^{-4} m^3/s is obtained at KS = 90° with several delivery valve angle configurations. This trend suggests that larger waste valve angles enhance the water hammer effect, thereby increasing the volume of water delivered to the outlet.

The pump head values range from approximately 1.66 to 2.33 m. Interestingly, the highest pump head occurs at KS = 60°, reaching about 2.33 m, whereas larger waste valve angles tend to reduce the pump head slightly. This behavior indicates that although higher valve angles improve discharge capacity, part of the available energy is distributed toward increasing flow rate rather than generating additional pressure head [13]. Therefore, a trade-off exists between pumping capacity and pressure generation.

The system head varies from approximately 2.63 to 4.92 m. The highest system head values are observed at KS = 80° and KS = 90°, particularly for KL values between 50° and 80°. These results demonstrate that the hydraulic ram pump is capable of delivering water to significantly higher elevations than the available supply head, which is the fundamental advantage of hydraulic ram technology. The increased system head reflects the successful conversion of kinetic energy into pressure energy through the water hammer mechanism.

A similar trend is observed for hydraulic power, which ranges from approximately 1.32 W to 2.09 W. The maximum hydraulic power of about 2.09 W is achieved at KS = 80° and KS = 90° with KL = 50°. Hydraulic power is directly related to both discharge and head; therefore, configurations that provide high discharge while maintaining a large delivery head naturally produce greater hydraulic power output.

The most notable result is found in the volumetric efficiency (ηVol) values. Efficiency increases significantly with larger waste valve angles. At KS = 60°, volumetric efficiency ranges from approximately 12.64% to 14.50%, whereas at KS = 90°, it reaches a maximum value of 24.32%. This improvement indicates that a greater proportion of the incoming water is successfully delivered to the outlet rather than being discharged through the waste valve. Consequently, KS = 90° appears to provide the most efficient operating condition among the tested configurations.

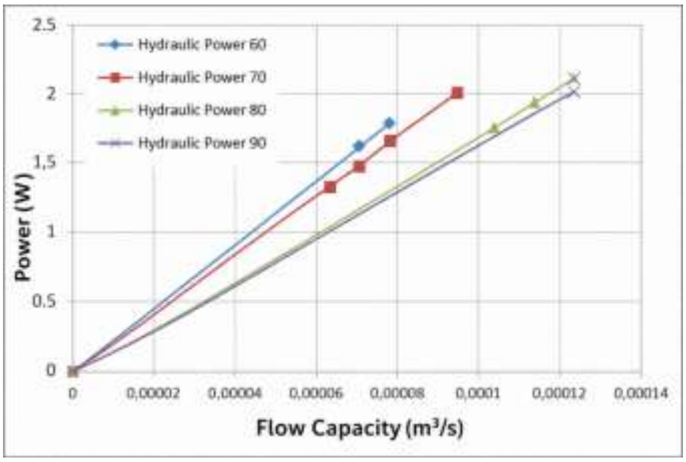

Figure 3. Effect of Flow Capacity on Hydraulic Power

The figure 3 that hydraulic power increases with increasing flow capacity across all conditions of 60, 70, 80, and 90. The resulting relationship tends to be linear, indicating that the greater the water flow rate, the greater the hydraulic energy available for conversion into power. At conditions 60 and 70, the power increases gradually, reaching approximately 1.8 W and 2.0 W, respectively. At conditions 80 and 90, the maximum power is higher, reaching approximately 2.1 W at a flow rate approaching 0.00012 m^3/s. Scientifically, this phenomenon corresponds to the hydraulic power equation $P_h = \rho g Q H_P$, where power is directly proportional to flow rate (Q) and head (H). Therefore, increasing flow capacity increases the potential and kinetic energy of the fluid that can be utilized by the system, resulting in greater hydraulic power [14]. This graph indicates that the system performance is still in a stable and efficient operating condition within the tested flow capacity range.

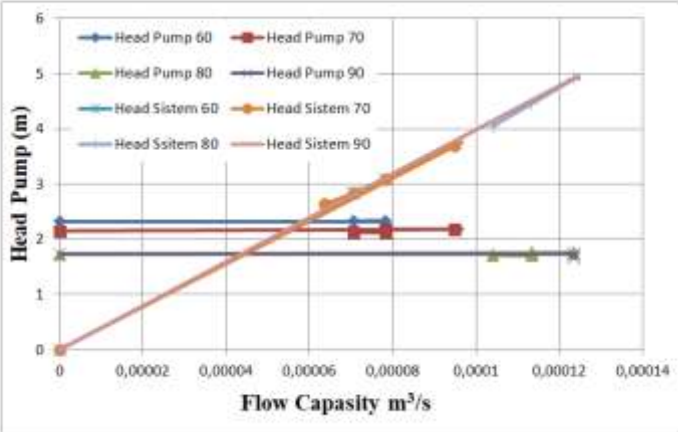

Figure 4. Effect of Flow Capacity on Pump Head and System Head

Figure 4 shows the relationship between pump head and system head and flow capacity at various operating conditions (60, 70, 80, and 90). The pump head curve tends to be constant at each condition, with values of approximately 2.35 m for the 60 condition, 2.15 m for the 70 condition, and approximately 1.70 m for the 80 and 90 conditions. Conversely, the system head curve increases linearly with increasing flow capacity, indicating that energy losses due to friction and flow resistance in the system increase at higher flow rates. The point of intersection between the pump head and system head curves is the system's operating point, the point at which the energy produced by the pump equals the energy required by the system to move the fluid [15]. Scientifically, this phenomenon aligns with the characteristics of a piping system, which follows the relationship $H_s = H_{statis} + kQ^2$, where system head increases with increasing flow rate, while pump head is determined by the pump's ability to generate pressure. This graph shows that changes in operating conditions affect the balance between pump capability and system head requirements, thus determining the actual flowrate and overall performance of the hydraulic system.

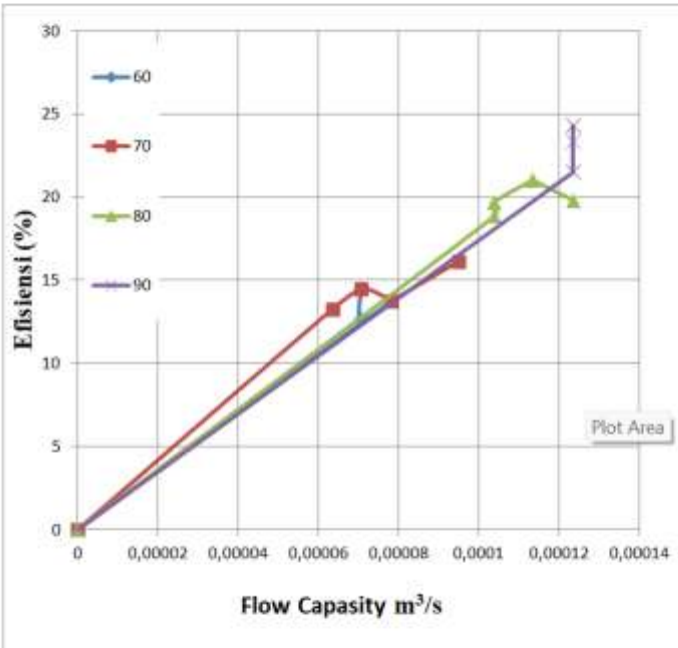

Figure 5. Efficiency Performance of the Hydraulic Ram Pump at Different Flow Capacities

4. CONCLUSION

Based on the experimental and calculation results, the performance of the hydraulic ram pump is significantly influenced by the configuration of the waste valve angle (KS) and delivery valve angle (KL). Increasing the waste valve angle from 60° to 90° generally enhances the water hammer effect, resulting in higher discharge rates, increased suction pressure, and improved water delivery capacity. The highest delivery discharge of 1.2346×10^{-4} m^3/s was achieved at KS = 90°, indicating that larger waste valve openings promote more effective transfer of hydraulic energy into useful pumping flow.

The calculated results further show that hydraulic power increases with increasing flow capacity. The maximum hydraulic power obtained was approximately 2.09 W, achieved at KS = 80° and 90° with KL = 50°, demonstrating that higher flow rates combined with sufficient delivery head produce greater power output. Although the highest pump head of approximately 2.33 m occurred at KS = 60°, larger waste valve angles provided better overall performance by increasing discharge and system head, highlighting the trade-off between pressure generation and flow delivery in hydraulic ram pump operation.

The volumetric efficiency exhibited the most significant improvement with increasing waste valve angle. Efficiency increased from approximately 12.64–14.50% at KS = 60° to a maximum of 24.32% at KS = 90° with KL = 80° and 90°. This indicates that a larger proportion of the supplied water was successfully pumped to the delivery line rather than discharged through the waste valve. Therefore, the configuration of KS = 90° can be considered the optimum operating condition among the tested variations.

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