Effect of Waste Valve Tuning on Hydraulic Ram Pump Efficiency

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Abstract: A community that lives far away from an electrical power source has a problem in moving water from lowland water source location to higher location as their needs, one option to solving this problem is using hydraulic ram pump whose energy is the pressure that resulted from water hammer effect caused by the sudden stop of the water flow into the pump through its drive pipe. Some areas have a large quantity of water flow while others must deal with a limited water source, lead to the need for optimal pump efficiency. In This paper, a study on the effects of waste valve tuning on the efficiency of three inches sized hydraulic ram pump was conducted by varying the weight and stroke of the waste valve. From the experiments data and statistic correlation analysis resulting that both factors influence the efficiency as well as the interaction between them. The optimal setting for the best efficiency is at 1 kg of valve weight and 10 millimeters of valve stroke, give 70.45 % of efficiency.

1 INTRODUCTION

In many parts of the world, villages are located above springs: they do not allow water to flow to people's places by gravity. For example, in the province of East Nusa Tenggara (NTT) Indonesia, 70 percent of the population lives upstream of the nearest water source. A pump is needed to lift water from this source to their compound (Jeffery et al. 2005), but another big problem is the limited availability of electrical energy or fuel to drive the pump motor.

Using hydraulic ram pumps placed on the banks of rivers or springs, water can be pumped to agricultural land or water reservoirs automatically and without additional energy. With a good approach, the production and use of hydraulic ram pumps in developing countries will reduce farmers' expenditures such as fuel and electricity, and environmental damage can be reduced. The hydraulic ram pump can operate for years without requiring maintenance or control making it an ideal system especially in areas where motor fuel is expensive and electricity is not available to the pump system. (Hatipoğlu et al. 2018).

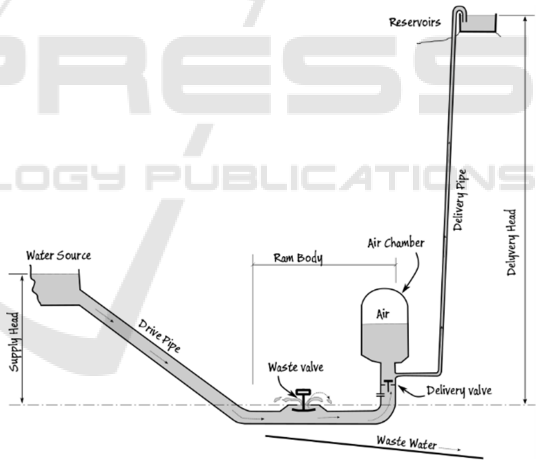

Figure 1: Typical Hydraulic Ram pump arrangement.

1.1 Hidraulic Ram Pump Instalation

As shown in figure 1, the pump works by pumping a small fraction of water that flows through it from a supply Source to a level that can be much higher than the source, it only can be operated in places where there is a steady and reliable supply of water with a sufficient fall.

The vertical distance between two water surfaces is known as the available water "head" and is a

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measure of water pressure. For instance, the Supply head represents the pressure in the ram body when it is full of water while not pumping; likewise, the pressure in the air chamber with the delivery valve closed is the delivery head. (Watt 1975)

The working cycle of the hydraulic ram pump can be described as follows; At the start of the acceleration phase, the flow in the drive pipe is stationary. The waste valve opens under its weight, and the delivery valve closes, The flow of water in the drive pipe is accelerated under the action of the supply head until the dynamic force that this flow exerts on the waste valve is sufficient to cause the waste valve to start closing at a certain critical speed. At the end of the acceleration phase, the waste valve closes quickly, and a water hammer phenomenon occurs. the pumping action takes place as a shock wave induced by the water hammer which passes through the drive pipe up and down at the velocity of the pressure wave and the delivery valve opens in response to each pressure pulse and water flow is pumped up into the reservoir. Reversal of flow in the drive pipe, occurs at the end of the pumping phase after the delivery valve closes, the resulting suction from backflow causes the waste valve to open, and the cycle is ready to start again.(Fatahi-alkouhi, Lashkar-ara, and Keramat 2019).

1.2 Waste Valve

There are only two moving parts in the Hydraulic ram pump mechanism, which are the delivery valve and the waste valve or also known as the impulse valve, these two valves work alternately and continuously during the pump operating time.

There are several developments and researches that have been carried out on the construction of waste valves; Some of them are Simple weighted Waste valve, Spring type, Rubber washer type, and Swing mechanism waste valve (Fig.2)

The Flow Pattern in the hydraulic ram pump is significantly influenced by the diameter of the orifice and disc of the waste valve(M. Suarda, Sucipta, and Dwijana 2019), The increase in waste valve beat rate per minute tends to reduce the supply flow rate, delivery flow rate, and delivery head. But it tends to increase the head ratio, flow rate ratio, and overall pump efficiency(Asvapoositkul et al. 2019), pump capacity is also affected by the weight of the waste valve(Setyawan and Siregar 2015)(Suwandi 2015), the effect of Waste Valve Height and Pressure Chamber Height is found significant on both mean and variance of the response variable (delivery flow rate) (Sarma et al. 2016), All of the waste valve design parameters for instance valve orifice and disc diameter, valve mass, and valve stroke significantly influence the performance of hydraulic ram pumps such as delivery flowrate and total efficiency of the hydraulic ram pump system. (Made Suarda et al. 2018).

Nowadays hydraulic ram pump technology is starting to be promoted again in line with efforts to utilize new renewable energy-based technology, many people design and assemble their own simple hydraulic ram pumps using pipe connections and check valves as a substitute for artificial valves, on one hand, this method is very practical and cheap but the drawbacks are it is not possible to adjust the waste valve to optimize pump performance.

This research aims to determine the effect of adjusting the weight and stroke length of the waste valve on the 3-inch hydraulic ram pump working efficiency.

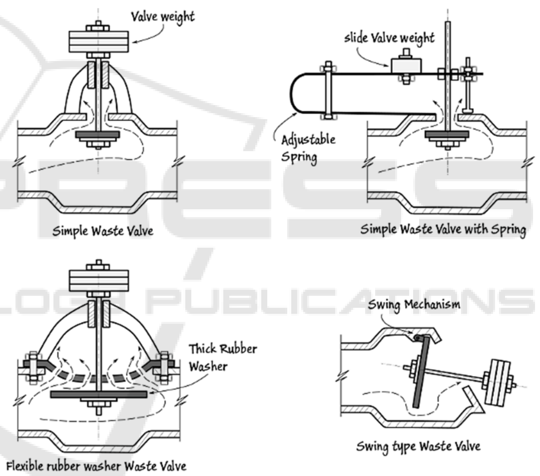

Figure 2: Types of Waste valve construction.

2 METHODS

2.1 Experimental Setup

Experiments were carried out by operating 3 inches sized hydraulic ram pump at sufficient water as shown in fig. 3, Simple model is used to varying the stroke length and weight of the waste valve (fig.4) and then measuring the wastewater flow and delivered water flow (fig.5), hydraulic ram pump installation as described in Tabel 1 and Table 2.

Figure 3: Operating 3-inch Hydraulic Ram pump.

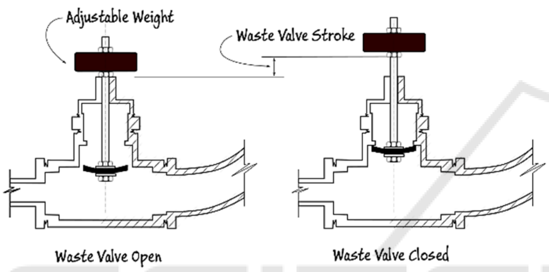

Figure 4: Waste valve weight and stroke length.

Table 1: Installation Arrangement.

	Drive Pipe	Delivery Pipe
Vertical height (head)	4.5 m	14 m
Inner Diameter	50 mm	25 mm
Length	6 m	18 m
Material	GIP	GIP

Figure 5: Delivered water flow measurement.

Table 2: Experiment Variables.

Variables	Value
Waste Valve Stroke	5mm, 10mm, 15mm, 20mm, 25mm, 30mm, 35mm, 40mm, 45mm, 50mm, 55mm, 60mm.
Waste Valve Weight	1kg, 1.5 kg, 2kg, 2.5kg, 3kg, 3.5kg, 4kg, 4.5kg, 5kg, 5.5kg, 6kg
Waste Valve pulse (beat)	Beat per minute (BPM)
Efficiency	D'Abbusion (%)

2.2 Calculation and Analysis

The calculation of the hydraulic ram pump efficiency (%) is taken from the ratio of the Supply head and Supply water flow rate to the delivery head and delivered water flow rate which is expressed in D, Aubusson equation as follows;

$$E: \frac{Q * H_d}{(Q + Q_w) * H} \quad (1)$$

A ten liters water bucket and a stopwatch were used to measure the wastewater flow rates by three repetitions for each measurement, the same method was used to measure delivered water flow rate while using an eight liters water bucket.

Head Losses calculation in the pipe system also included using the Hazen Williams formula, for the friction head losses calculations the following formula was carried out ;

$$hf = \frac{10,666 Q^{1,85}}{C^{1,85} D^{4,85}} \times L \quad (2)$$

Where *hf* is the head losses because of friction inside pipes (m), *C* is the Hazen Williams coefficient and in this research using 120 as for galvanized iron pipes, *D* is the inner diameter of pipes (m), dan *L* stands for pipes length (m). Minor head losses are also included in the considerations by using the following formula;

$$hm = \sum K \frac{V_2^2}{2g} \quad (3)$$

Where *V* is the water velocity inside the pipes (m/s) and *K* is the minor losses coefficients as shown in Table 3.

Table 3: Minor Head Losses Coefficients.

Pipe Accessories	K Value
Pipe Entrance	0.56
Gate Valve Fully opened	0.19
900 Pipe turn/ Elbows	1.5

Delivered water flow data was also used to calculate the total headloss at the delivery pipe while the sum of pumped water flow and the wastewater flow was used to calculate the drive pipe total headloss. The supply head is calculated by subtracting the static supply head by the total headloss of the drive pipe, while the delivery head was by adding the total headloss to the static head measured.

Statistical analysis was carried out on the experimental data to show how much influence the waste valve tuning has on the efficiency of the hydraulic ram pump, Statistical tests including a simple Bivariate Correlation test and a partial correlation test of Pearson Product moment as well as a multiple correlation test, Microsoft Excel was used to assist analytical calculations.

3 RESULT AND DISCUSSION

3.1 Presentation of Experimental Data

All experimental data were shorted and tabulated to construct graphs that show the influence and interaction between test variables as shown in fig. 6 and fig. 7.

From the experimental results, it turns out that the pump is only able to operate on a part of the combinations of weights and stroke lengths of the waste valve, while in adjustments with certain combinations the waste valve cannot close so that no pumping step occurs, this is illustrated in Table 4. of the pumping water flow measurement data where empty cells are indicating the pump is not working, it could happen when the waste valve stroke is set to be long enough so the bottom side of the waste valve reaches the large chamber inside the pump body as shown in fig. 4, and then large open was created reduce the lift force needed to push the valve upward at waste valve shutting cycle.

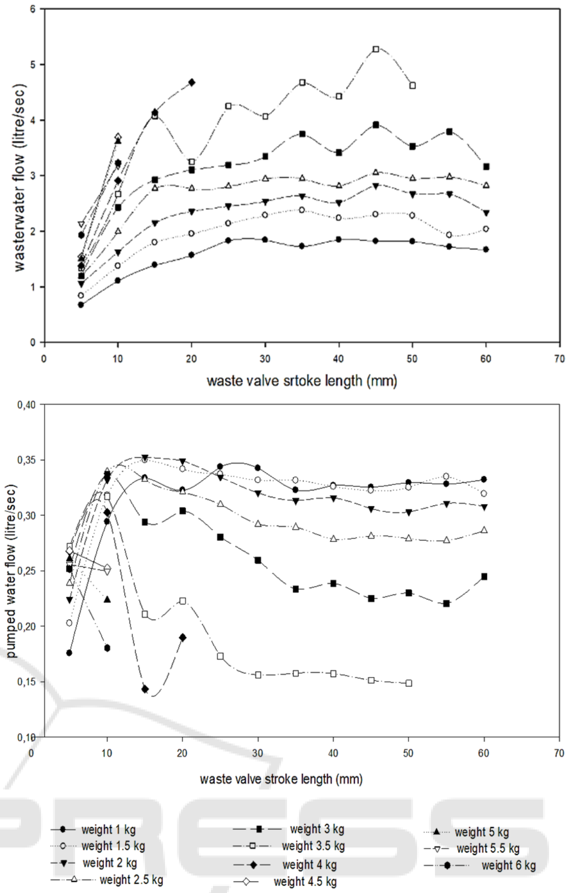

Figure 6: Wastewater and delivered water flow results.

Table 4: Pumped Water flow data in liter/second.

Waste valve stroke length	waste valve weight										
	1kg	1.5 kg	2 kg	2.5 kg	3 kg	3.5 kg	4 kg	4.5 kg	5 kg	5.5 kg	6 kg
5mm	0,18	0,20	0,22	0,24	0,25	0,27	0,27	0,27	0,26	0,26	0,25
10mm	0,29	0,32	0,33	0,34	0,34	0,32	0,30	0,25	0,22	0,25	0,18
15mm	0,33	0,35	0,35	0,33	0,29	0,21	0,14				
20mm	0,32	0,34	0,35	0,32	0,30	0,22	0,19				
25mm	0,34	0,34	0,33	0,31	0,28	0,17					
30mm	0,34	0,33	0,32	0,29	0,26	0,16					
35mm	0,32	0,33	0,31	0,29	0,23	0,16					
40mm	0,33	0,33	0,32	0,28	0,24	0,16					
45mm	0,33	0,32	0,31	0,28	0,23	0,15					
50mm	0,33	0,33	0,30	0,28	0,23	0,15					
55mm	0,33	0,33	0,31	0,28	0,22						
60mm	0,33	0,32	0,31	0,29	0,24						

As shown in fig.6 the wastewater flows tend to increase when adding weight as well as adding the length of valve stroke. For lengths longer than 25 millimeters, wastewater flows are likely to be more constant while still highly changed under influence of valve weight. In another hand, delivered water flow showed more fluctuated data for most combinations of waste valve weight and stroke length; the delivered water flows increased until the ten-millimeter length

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of waste valve stroke adjustment and for the next longer stroke adjustment the data is significantly decreasing, which means more length cause mostly reduce the pumped water flow. the most wasted water flow was 5.2 liters per second which were obtained at the combination of 4.5 mm valve stroke length by 3.5 kg valve weight, and for the highest delivered water flow was 0.35 liters per second at the combination of 15 mm valve stroke length and 2 kg valve weight.

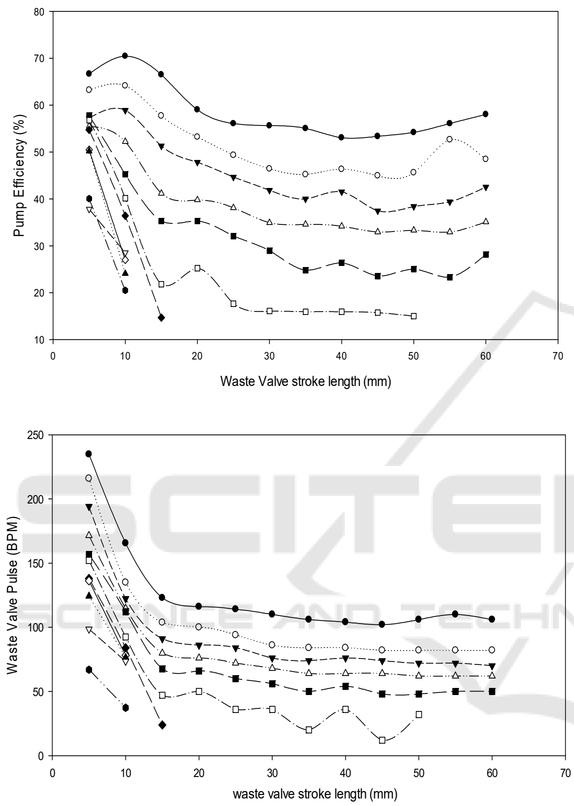

Figure 7: Pump Efficiency and Waste Valve Pulse.

Efficiency is determined by how efficiently the pump converting resource energy in the form of supply head and supply water flow rate to do works as presented by a delivery head and delivery flow rate. The first graph in fig. 7 shows that the combination of the waste valve stroke heights and weights strongly affect the pump efficiency, it can be seen that for each line of valve weight variations there is a maximum efficiency resulted from adjusting the valve stroke length, in this experiment the effective valve stroke length adjustment is between 5 mm to 10 mm, while the valve stroke length more than 15 mm shows a tendency of efficiency reduction. Maximum efficiency reached is 70.45% at 1 kg waste valve weight and 10 mm valve stroke adjustment. The second graph in Fig. 7 shows the number of waste valve pulsations which decreases with the increase of the waste valve stroke length and weight, the less number of pulses indicates the longer time the waste valve is in the open position, which increases wastewater discharge.

3.2 Statistical Analysis Results

Bivariate correlation was carried out to calculate the respective correlation coefficient (r_{x1y}) values between the variables; the weight of waste valve (x_1) and the pump efficiency (y), also the value of the correlation coefficient (r_{x2y}) between the variables stroke length (x_2) and pump efficiency.

To find out the influence of each independent variable if one variable is set (constant), a partial correlation analysis is carried out by first calculating the bivariate correlation coefficient (r_{x1x2}) between weights and stroke length then calculate the correlation coefficient (r_{p_x1y}) of the waste valve weight on efficiency if the stroke length variable is fixed and vice versa (r_{p_x2y}).

Double correlation analysis was also conducted to determine the correlation coefficient R_{yx1x2} representing the effect of valve weight and valve stroke length together on pump efficiency.

Table 5: Statistical Analysis Results.

Correlation Coefficient	Value	Test	Value	*Tables value
r_{x1x2}	-0,38			
r_{x1y}	-0,62	t1	-7,03	1,66
r_{x2y}	-0,25	t2	-2,33	
r_{p_x1y}	-0,80	t1	-11,82	1,66
r_{p_x2y}	-0,67	t2	-8,23	
R_{yx1x2}	0,81	Fh	77,32	3,12
R^2	0,66			

Number of data = 82, α =0.5 , test value>tables value

Statistical analysis shows a strong correlation between the adjustment of the weight and stroke length of the waste valve on the working efficiency of the pump. The correlation coefficient value for the valve weight variable is greater, indicating that the valve weight factor has a more significant effect on efficiency. The effect of the interaction between weight and the stroke length of the waste valve weight on efficiency is very significant at 66% while the other 34% is influenced by other factors such as pump construction factors etc, the negative value of the t-test indicates the relationship between the variables

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where the addition of weight and the stroke length of the waste valve tends to decrease the efficiency value, this is in accordance with the graphic analysis.

4 CONCLUSIONS

From the results of the research that has been carried out, it can be concluded that the adjustment of the waste valve by varying the weight and length of the waste valve stroke greatly affects the performance of the installed hydraulic ram pump, from the results of graphic and statistical analysis it can be seen the following things;

- *The addition and reduction of the waste valve weight has a more significant effect on the performance of the hydraulic ram pump, both the water flow produced and the pump work efficiency value*
- *In this study, we found the difference between valve adjustment for maximum pump discharge and waste valve adjustment for maximum efficiency. For maximum pump discharge, the waste valve is set at a weight of 2 kg with a valve stroke length of 15mm while for maximum efficiency the valve is adjusted at a weight of 1 kg and a stroke length of 10 mm. This fact provides an option for practical waste valve adjustment where for water sources with abundant source flow the adjustment can be targeted for the largest pump discharge while for sources with the limited flow the setting with maximum efficiency is a good choice.*
- *increasing both the weight and the length of the valve stroke after passing its maximum effect value does not have any beneficial effect*

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