DESIGN ANALYSIS, INSTALLATION AND PERFORMANCE EVALUATION OF A HYDRAULIC RAM PUMP SYSTEM WITH A MODIFIED WASTE VALVE

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Abstract. Hydraulic ram pump (also called hydram) is one of the oldest mechanical devices used for water lifting. It is a device that works automatically without relying on electricity or diesel fuel instead, it utilizes the principle of water hammer effect to pump a fraction of water from the source to the desired elevation. A hydraulic ram pump has two moving parts which are the waste valve and delivery valve. As a lot of studies had been carried out investigating parameters possibly affecting the performance of a hydraulic ram pump, this study aimed to design and fabricate a modified waste valve for a hydraulic ram pump with parts made from locally available off-the-shelf materials. The constructional design of the waste valve was evaluated regarding its effect on the whole hydraulic ram pump's system efficiency given the uncontrollable parameters present in the target area of installation. Results revealed that varying the height of the waste valve's stroke significantly affected the ram pump's delivery flow rate thus affecting the overall efficiency. Furthermore, results showed that for the modified design of the waste valve, having a 4 in. height for the stroke gave the optimum ram pump's system efficiency at 84.3 %.

Keywords: volume flow rate, irrigation system, water hammer, pumping system, water surges.

Classification numbers: 5.1.2, 5.5.3, 5.6.2.

1. INTRODUCTION

Flowing waters such as streams, rivers, and springs flow along the bottoms of valleys however, most of the houses and villages are located strategically higher up the hills. These scenarios are widely observed mostly in remote areas where slow-paced development usually takes place. This situation necessitates the inhabitants to carry buckets of water uphill. A technology to pump the water uphill would be very desirable in the said situations. A solar-powered electric pump could be used to address this problem however, maintenance and operation of this kind of pump are costly. Using the energy in flowing water sources, a hydraulic

ram pump (also called hydram) is a complete automatic device that pumps part of the water to a height above that of the source [1]. By using this mechanism, the residents would lessen their efforts in fetching water for daily utilization. The first American patent for a hydraulic ram pump was issued to J. Cerneau and S. S. Hallet in 1809 [2]. Harith [3] claimed that using a hydraulic pump in pumping water is far more environmentally friendly than using an electrical or fossil fuel-based energy pump. Using the water hammer effect, hydram can move water from one head to another without fuel oil or electricity [4-5]. The water hammer is a pressure surge caused by the inertia of piped moving water [6]. The water hammer concept was first explained theoretically by Zhukovsky in 1898 and was used in the work of the hydraulic ram pump [7].

The process starts when water from a certain elevation enters the drive pipe where the water momentum causes the waste valve to close. High pressure is then created causing the delivery valve to open allowing pressurized water to enter a vacuum air chamber. The air chamber will pressurize the water causing the delivery valve to close and air valve to open allowing the water to enter a delivery pipe where the pressure wave is utilized to force the water upwards [8-10]. The magnitude of the generated impulse force is primarily affected by the waste valve. The working principle of a hydraulic ram pump is guided by the concepts of acceleration, compression, delivery, and recoil [11]. The hydraulic ram pump consists two moving parts which are the impulse valve (or waste valve) and the delivery valve (or check valve) [12-13] together with several other parts such as water supply tank, drive pipe, pump body, snifter valve, air chamber, and delivery pipe [14], similarly to [15] as shown in Figure 1.
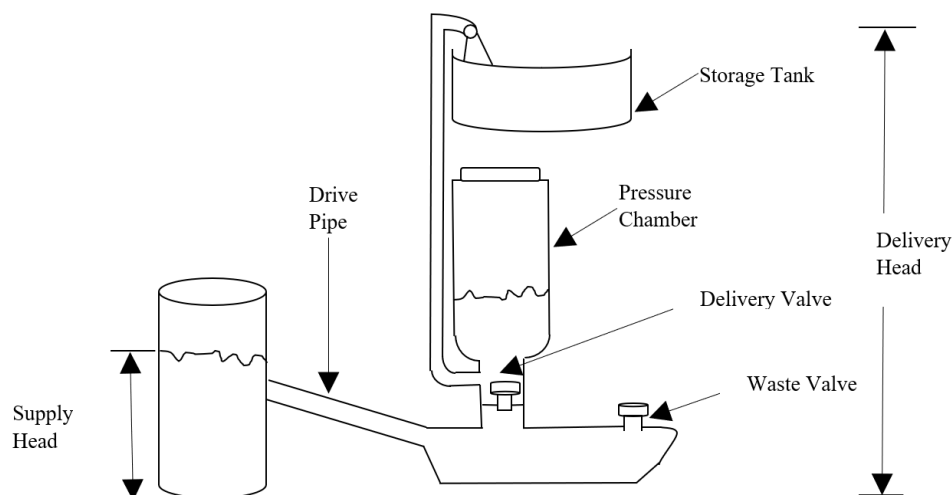

Figure 1. Schematic representation of a modern hydraulic ram pump.

The waste valve and delivery valve are the only two moving parts of a hydraulic ram pump whose design determine the ram pump's performance [16]. Since the valves are the only moving parts, the hydraulic ram pump is a very robust machine with very low maintenance cost and no skilled labor is required for its installation and operation [17]. A study regarding algebraic analysis on the forces that occur on both valves was conducted in the hopes of investigating the parameters that would affect the ram pump's performance and for design optimization [18]. On the other hand, another study presented various methods used in consideration for the planning and application of both waste valve and delivery valves [19]. Both studies end up with parallel conclusions that the design of the valves used for a ram pump has a significant effect on its

performance. This was backed up by the result of an experimental investigation conducted which showed that adding adjustable local resistance components in parallel to the delivery valve yield to a 70 % system efficiency of the developed ram pump [20]. These studies just confirmed the concept that waste valve plays a key role in improving the hydraulic ram pump's efficiency and thus requiring attention during its development for further optimization [21]. Further investigation was conducted this time however, the aimed was to investigate the effects of the height of the pressure chamber and the height of the waste valve on the output flow rate of the hydraulic ram pump [22]. Though in reality, adjustments and modifications of waste valves take a long time because of insufficient references discussing its possibility [18], however, the possibilities that by modifying the waste valve of a ram pump can improve its efficiency is an idea that cannot be disregarded.

Thus, this study aimed to design and fabricate a modified waste valve for a hydraulic ram pump with parts made from locally available off-the-shelf materials. The constructional design of the waste valve was evaluated regarding its effect on the whole hydraulic ram pump's system efficiency given the uncontrollable parameters present in the target area of installation.

2. MATERIALS AND METHODS

2.1. Ocular visit, problem inspection, and data collection

An ocular visit of the target area for the installation was conducted and necessary parameters were collected. The target locality was a small village with 19 households located at Barangay Buli, Bato Leyte, Philippines. The potential water source is a stream nearby a local falls. In order to determine the quantity delivered by a ram pump, there are three essential factors that need to be considered. These factors are the elevation between the ram pump and the water source, the vertical distance between the ram pump and the place where the water is to be delivered, and lastly the volumetric flow rate of the water source [23]. Thus, these factors were measured, and data were collected during the visit.

Figure 2. The distance between the source and the village (left) and the actual situation of the water source (right).

During the ocular visit, it was found out that the water source has a horizontal distance of approximately 885.6 ft. away from the village. The altitude from the source to the village is approximately 67.9 ft. which was considered as the delivery head of the ram pump. During the inspection, it was found out that the water source had a 2 in. diameter drive pipe already installed and reinforced with concrete (serve as a reservoir) hence causing difficulty to redesign the drive pipe size as shown in Figure 2.

2.2. Design and fabrication of the ram pump

Parts of the construction of the ram were based on several designs from previous studies conducted [1, 9, 22]. However, adjustments to suit the design of the ram pump to the already existing parameters were made. Shown in Figure 3 are the schematic design of the whole ram pump and the pressure chamber.
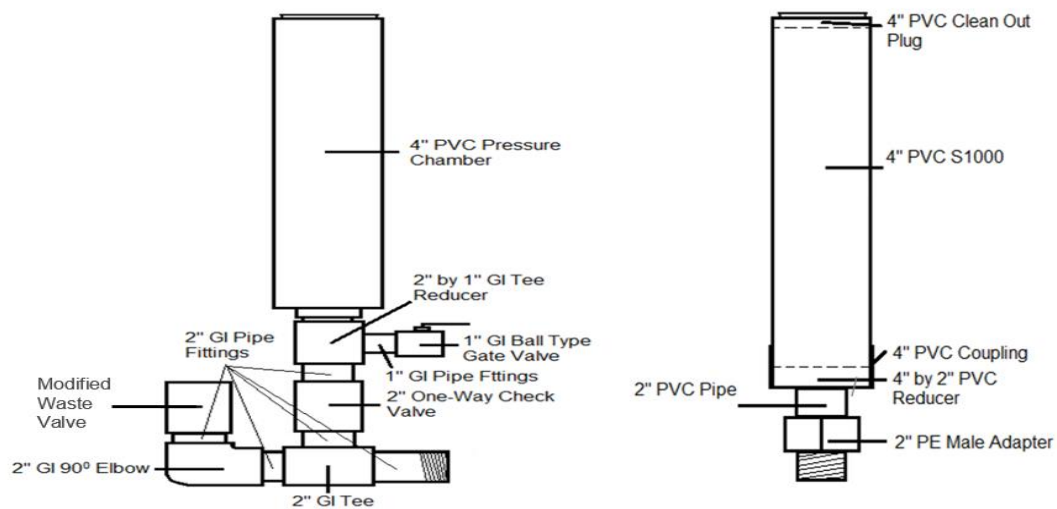

Figure 3. Schematic design of the whole ram pump (left) and design of the pressure chamber (right).

The hydraulic ram pump was constructed mostly using galvanized iron (GI) and fittings for the major parts and PVC for the pressure chamber. A 2 in. diameter GI tee was used to connect the inlet pipe, the one-way check valve, and the modified waste valve. A 2 in. × 1 in. GI tee reducer connected the check valve to the pressure chamber and to a 1 in. GI ball type gate valve by utilizing corresponding pipe fittings. Connected to the said ball type gate valve is the delivery pipe with a diameter of 1 in. To finalize the fabrication, Teflon tape was used to seal the threads, the hose was fixed with hose clamps and the PVC parts of the ram pump were grounded by PVC solvent and all-purpose epoxy.

The pressure chamber's size was based on the parameters suggested in Table 1. The length of the chamber was based on the relationship between its diameter and that of the drive pipe. A 4 in. diameter S1000 pipe was cut and used as the chamber's main body. Since the drive pipe used has a 2 in. diameter, the length of the chamber was estimated to be 62 in. thus giving it a volume of 778.72 in^3. Installed at the topmost part of the chamber is a removable cap serving as a cleanout plug for cleaning and maintenance purposes of the chamber. To connect the chamber to the ram pump's body, coupling and a reducer were installed at the bottom part of the chamber.

Connection points between the ram pump's body and the pressure chamber were sealed with all-purpose epoxy thus making a robust structure.

Table 1. Pressure chamber sizing for a hydraulic ram pump [24].

Drive Pipe Diameter (inches)	Expected Flow Per Cycle (gallons)	Pressure Chamber Volume Required (gallons)	Length of Pipe Required for Pressure Chamber (for indicated pipe diameter)							
			2 inches	2-1/2 inches	3 inches	4 inches	6 inches	8 inches	10 inches	12 inches
3/4	0.0042	0.21	15	11	7	--	--	--	--	--
1	0.0125	0.63	45	32	21	--	--	--	--	--
1-1/4	0.020	1.0	72	51	33	19	--	--	--	--
1-1/2	0.030	1.5	105	74	48	27	--	--	--	--
2	0.067	3.4	--	170	110	62	27	16	--	--
2-1/2	0.09	4.5	--	230	148	85	37	22	14	--
3	0.15	7.5	--	--	245	140	61	36	23	16
4	0.30	15	--	--	--	280	122	72	45	32
6	0.80	40	--	--	--	--	325	190	122	85
8	1.60	80	--	--	--	--	--	380	242	170

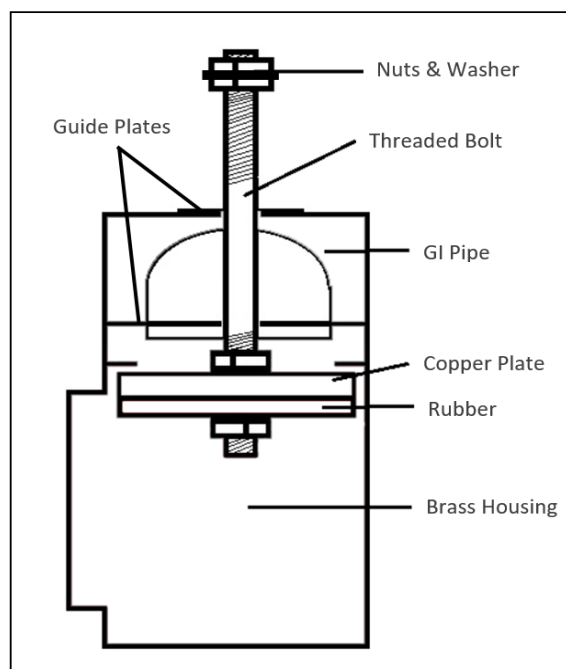## 2.3. Design and fabrication of the modified waste valve

Figure 4. Schematic design of the modified waste valve.

A locally available check valve was dismantled, and the brass housing was utilized as the housing of the modified waste valve. A 0.4 in. diameter threaded bolt was used as the movable part of the waste valve. The bolt was bolted on a copper plate reinforced with a rubber gasket at the bottom thus forming a single rigid structure. For the said structure to have a smooth vertical

movement, two guide plates were weld to a 2 in. diameter GI pipe in a perpendicular manner. Wholes which served as the outlet for the wastewater were punched to the GI pipe. By welding it to the brass housing, the GI pipe acted as the housing's extension thus giving the bolt more vertical space to move upon. Two nuts separated by a washer were installed at the upper part of the threaded bolt serving as the stopper thus the one responsible in limiting the height of the bolt's movement (stroke). The height of the bolt's stroke varied depending on the adjustment of the stopper. Shown in Figure 4 is the design of the modified waste valve.

2.4. Ramp pump installation

Since a drive pipe with 2 in. the diameter was used for the ram pump, it was expected to have a minimum length of 25 ft. and a maximum of 166 ft. However, due to the terrain of the water source's location as shown in Figure 5, it is impossible to use a longer drive pipe hence the best possible location for the ram pump to be installed was only approximately 10 ft. away from the water source. Using a drive pipe which was longer than 10 ft. resulted in an elevated location while using a shorter pipe gave the same scenario.

Figure 5. The terrain less than 10 ft. from the source (right), more than 10 ft. from the source (center), 10 ft. from the source (right).

2.5. Functionality testing and evaluation

Figure 6. Actual testing of the volume flow rate of the source (left) and height of the drop of the source (right).

Testing for the functionality of the developed ram pump was conducted before it was fixedly installed. The actual measurement of the flow rate of the water at the source was done by letting the water flow into a pale for variable minutes then the volume of the water inside the said pale was measured afterward. By actual measurement, the supply head was known to be equal to 10 ft. as shown in Figure 6.

On the other hand, actual testing of whether the modified waste valve possessed the capability necessary to deliver the water to the desired height. To do so, the whole ram pump system was temporarily installed as shown in Figure 7. The height of the stroke of the valve was varied by 0.5 in for each set-up where test runs were conducted. For each set-up, the volume flow rate of the water at the output side of the delivery pipe were measured. A more practical approach was used to measure the said volume flow rate by using an actual galloon and a stopwatch. The galloon was filled with the water for 1 minute and the volume was measured. The process was repeated ten times and the average volume flow rate for each set-up was calculated. Adjustments for the height of the valve's stroke were stopped during the instant that the ram pump was unable to deliver any water volume at the output side of the delivery pipe.

Figure 7. The volume output of the water during testing.

The testing was conducted on a hydraulic ram pump with the following specifications:
1. The diameter of the drive pipe = 2 in.
2. Length of drive pipe = 10 ft.
3. Supply head = 10 ft.
4. Supply flow = 15.38 gal/min.

5. Delivery head = 67.9 ft.
6. Delivery pipe diameter = 1 in.
7. Delivery pipe length = 885.6 ft.
8. Length of the pressure chamber = 62 in.
9. The diameter of the pressure chamber = 4 in.
10. The volume of the pressure chamber = 778.72 in.^{3}
11. Waste valve stroke variation = 1.5 in., 2.0 in., 2.5 in., 3.0 in., 3.5 in., 4.0 in., 4.5 in., 5.0 in., 5.5 in.

3. RESULTS AND DISCUSSION

3.1. Installation results

Table 2 shows both the standard minimum and maximum suggested length to be used for the drive pipe of the ram pump with respect to its size [24]. Having a drive pipe size of 2 inches would need a minimum length of 25 feet to be functional. However, using 25 feet as length of the drive pipe is impossible considering the terrain that the water source is located and the logical option was to utilize a drive pipe with a length of 10 feet, therefore, transcending the suggested standard measurements as shown in Table 2. Being able to use a length of the drive pipe that was way shorter than the minimum length required with respect to its diameter was one of the advantageous effects of the design modification done to the waste valve.

Table 2. Drive pipe length with respect to its size (recommended standard) vs. the actual length used for the ramp pump with modified waste valve.

Drive Pipe Size (inches)	Minimum Length (feet)	Maximum Length (feet)	Actual Length Used for the Ramp Pump with Modified Waste Valve (feet)
2	25	166	10

Table 3. Results of flow rate test for the water source.

Trial	Volume Flow Rate of Source (in gallons)		
	1 minute	2 minutes	3 minutes
1	15.23	29.56	46.43
2	16.12	28.43	47.92
3	15.8	31.42	44.36
4	15.79	30.89	45.89
5	15.64	30.45	46.32
Average	15.76	30.15	46.184
Average Flow rate per minute	15.67	15.07	15.39

Reflected in Table 3 are the results of the test to determine the average flow rate of the water at the source. To ensure accuracy, the water flow rate was tested for three different time

settings and five trials per setting where conducted. Results revealed that even with different time settings, the result for the average volume flow rate of the water at the source ranges from 15.07 to 15.76 gal/min and averaging these results will yield to 15.38 gal/min. With a delivery pipe diameter of 1 in. and a drive pipe diameter of 2 in., the suggested standard for the minimum and maximum pump inflow for the source are 3 gals/min. and 33 gals/min. respectively [24]. Thus, being able to produce an inflow averaging 15.38 gal/min, it is obvious that the source is capable of supplying the necessary inflow for the ram pump.

3.2. Testing and evaluation

The evaluation of the ram pump was limited only to evaluating the rate of the delivery flow and the system efficiency with respect to the height of the waste valve's stroke. As presented in Table 4, varying the height of the waste valve's stroke affected the delivery flow rate of the ram pump. Data indicated that for this specific design modification of the waste valve, setting the height of the stroke to 1.5 in. resulted in a total shut down of the ram pump which means that no water was delivered to the delivery point. This scenario also happened when a height of 5.5 in. was set. Thus, with a variation of 0.5 in., the height of the stroke's adjustments that were able to deliver water to the delivery side was limited to a range of 2 in. to 5 in. Within the said range, setting the stroke's height to 4 in. delivered the optimum result with an average delivery flow rate of 1.95 gals/min. Setting the stroke's height either higher or lower to 4 in. resulted in a lesser delivery flow rate. A study [24] suggested that for a ram pump with a delivery pipe diameter of 1 in. and a drive pipe diameter of 2 in, the minimum expected output is 0.38 gal/min. while the maximum is 4 gals/min. Having this as a reference, the delivery flow rate of the ram pump with the modified waste valve in this study is within the suggested range.

Table 4. Hydraulic ram pump's average delivery flow rate with respect to the height of the waste valve's stroke.

Height of the Waste Valve Stroke (inches)	Average Delivery Flow (gal/min)
1.5	0
2.0	0.274
2.5	1.39
3.0	1.71
3.5	1.84
4.0	1.95
4.5	1.41
5.0	0.21
5.5	0

A one-way ANOVA for the raw data was conducted to further confirm the test results. The null hypothesis was that there was no significant difference between each data set. The data set are the values of the delivery flow rate for each trial for every variation of the stroke's height. As shown in Table 5, the P-value is very much smaller than the alpha (α) level value which was set to 0.5 which denoted that the null hypothesis was rejected thus, there exists a significant

difference between each of the data sets. The result confirmed that the height of the stroke of the waste valve had a significant effect on the ram pump's delivery flow rate.

Table 5. Raw data ANOVA of the delivery flow rate test.

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	55.36344	8	6.920429	2489.474	1.6083E-93	2.054882
Within Groups	0.22517	81	0.00278			
Total	55.58861	89				

Note: SS = Sum of squares; df = Degrees of freedom; MS= Mean square.

Using the known specific parameters, the system efficiency of the ram pump was evaluated using Eq. (1).

$$\eta = \frac{q \ x \ h}{Q \ x \ H} \qquad (1)$$

where Q = supply flow; q = delivery flow; H = supply head; h = delivery head

Since the supply flow, supply head and the delivery head were known to be constant all throughout the evaluation, the only variable parameter that was substituted to Eq. (1) was the delivery flow. The delivery flow as mentioned was dependent on the height of the waste valve's stroke thus having the stroke's height of 4 in. gave the maximum system efficiency of the pump. Results in Figure 8 clearly showed that the developed ram pump can deliver a maximum system efficiency equivalent to 84.3 %. The graph also showed that setting the height of the stroke to more than 4 in. causes the ram pump's efficiency to go down more rapidly than having a height of less than 4 in.
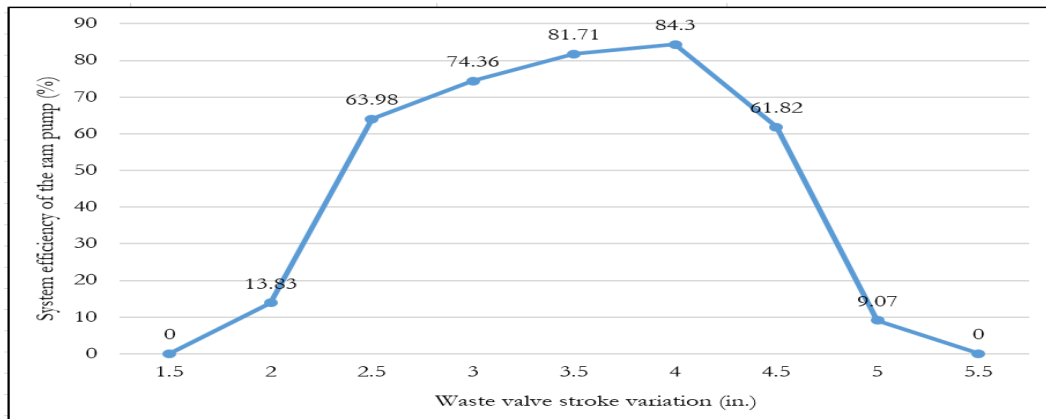

Figure 8. Hydraulic ram pump's system efficiency with respect to the height of the stroke of the modified waste valve.

4. CONCLUSIONS

Given the uncontrollable parameters already existed in the area of installation, having modified the waste valve to have an adjustable height for its stroke significantly influenced the

overall performance of a developed hydraulic ram pump. Having a limited space causes the length of the drive pipe to be limited to 10 ft. however, the design modification of the waste valve enables the ram pump system to transcend the standard parameters necessary in its drive pipe design. Thus, even though the drive pipe used was shorter than the standard length for its diameter, the hydraulic ram pump was able to deliver both a desirable delivery flow rate and a high system efficiency.

The scenario where the efficiency varies as the height of the waste valve stroke was adjusted also confirms that waste valve modifications affect the system efficiency of ram pumps. In addition, the delivery flow rate is within the expected range at an average of 1.95 gals/min. and having the highest system efficiency at 84.3 %, it cannot be denied that the modification done to the waste valve enabled the ram pump to cope up with the desired outputs even when the drive pipe was being shortened by 15 ft. with respect to the minimum standard.

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