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Performance Characteristics of a Small Hammer Head Pump

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Abstract:
Many rural farming areas are located far from reliable electricity supply, hence, having a reliable source of water for crops and livestock can prove to be an expensive venture. A water pump operating on the water hammer effect requires no external power source and can serve as an effective means of pumping water to a higher altitude once a reliable supply is available. The small hammer-head pump was designed to operate on the hammer head effect created by the sudden stoppage of a flowing fluid. This design consisted of an inlet section followed by the pump body, a pressure section and an outlet. The experimental set-up for testing the hammer head pump was designed with a variable head input and an adjustable head output. For each test configuration, ten samples of pump supply water and pump waste water were collected. The water samples were collected for 30s in each case. The results showed delivered water flow rate varied according to a cubic variable with respect to pump outlet height. The pump was capable of delivering water to a maximum height of 8 to 10 times the height of the input head. The pump operated at average efficiencies of 26%, 16% and 6% when the delivery height was twice, four times and six times the input head, respectively. There was a 5% incremental decrease in pump efficiency as the delivery height increased in increments of the corresponding input head height.

Keywords:
Pump characteristic, hammer head, hydraulic ram.

Introduction

In many rural farming areas, having a reliable source of water for crops and livestock can prove to be an expensive venture. Especially in developing countries, farmland are located far from any reliable source of electricity, however, situated close to a water source. The water source is usually situated below the level of the farmlands and getting the water to where it is needed can be challenging. A water pump operating on the water hammer effect requires no external power source and can serve as an effective means of pumping water to a higher altitude once a reliable source is available.

The first type of pumps to use the water hammer effect is the hydraulic ram pump which was first reported in 1775 and was built by John Whitehurst [1]. His design was not automatic and was controlled by manually opening and closing a stopcock which resulted in the device only being able to raise water to a height of 4.9 meters. This involved a significant amount of work and consumed a lot of time to operate. However, in 1797 the design was improved and the first reported automatic hydraulic ram was developed by Joseph and Etienne Montgolfier to raise water to a paper mill [2]. Although this was an improved design it still contained design flaws which caused the air in the pressure chamber to dissolve or drop. In 1816 this problem was eliminated when Pierce Montgolfier designed the sniffer valve that reintroduce air into the chamber. This valve was 15 cm in radius and it was reported that the pump was able to raise water to 48 meters in height [3]. The automatic hydraulic ram has been used for centuries to lift water to heights over 100 meters and is considered the prefect machine for pumping water once certain conditions are satisfied. The pump construction was simple and consisted of a pump camber fitted with two moving parts, an impulse valve through which the driving water was wasted and a delivery valve through which the water was delivered [4]. It works solely on the power supplied from the water head in the source. This source could be a spring,

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streams, river, ponds, dam, lakes and even some wells. Basically, once any form of flow can be created, the pump can operate, however, the source must provide a steady and reliable supply of water [5]. The ram pump is ideally installed at a location lower than the water source which is used to create the flow giving the fluid (water) some velocity.

Pump Design and Construction

The small hammer-head pump was designed to operate on the hammer head effect created by the sudden stoppage of a flowing fluid. The main components of the pump operation involved two one-way valves and a pressure tank. The one-way valves were arranged such that when one closes the other opened and vice-versa. This design consists of an inlet section followed by the pump body, a pressure section and finally an outlet. A 19mm PVC ball valve was installed at the inlet section which allowed control of the water entering the body of the pump and facilitated priming of the pump. The pump was constructed using 32mm diameter PVC pipe and valves. The advantages of this material were the low coefficient of friction and the resistance to corrosion. The one-way swing valves were of brass construction. Another 13mm PVC ball valve was placed on the outlet pipe of the pump to prevent back-flow and drainage of the supplied water when the pump was not operating. Figure 1 is a schematic showing the main components of the pump design.

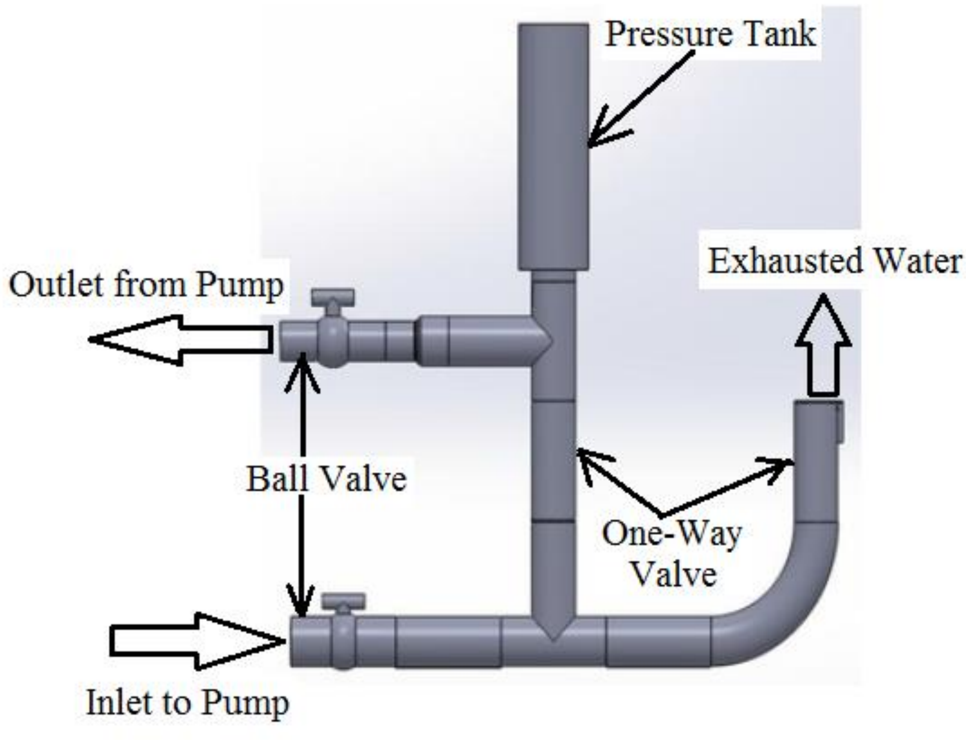

Fig. 1 Schematic of Hammer Head Pump

The pressure tank was constructed using a 127mm long 75mm diameter PVC pipe. A PVC end caps was used on one end of the pipe and reduction PVC fittings on the other end attached to the 32mm pipe. Figure 2 is a picture of the pump components in the position for assembly.

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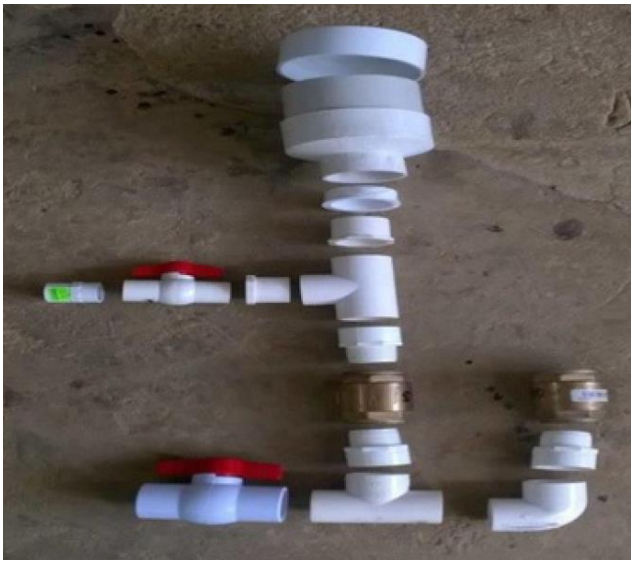

Fig. 2 Picture of pump components

Experimental Set-Up

The experimental set-up for testing the hammer head pump was designed with a variable head input and an adjustable head output. The supply of water was from a 5000L storage tank. The constant head supply tank was designed with a float that maintained the level as water was supplied to the inlet of the pump. The outlet side of the pump used variable length of 13mm diameter PVC pipe to adjust the delivery height. Figure 3 shows a schematic of the experimental apparatus.

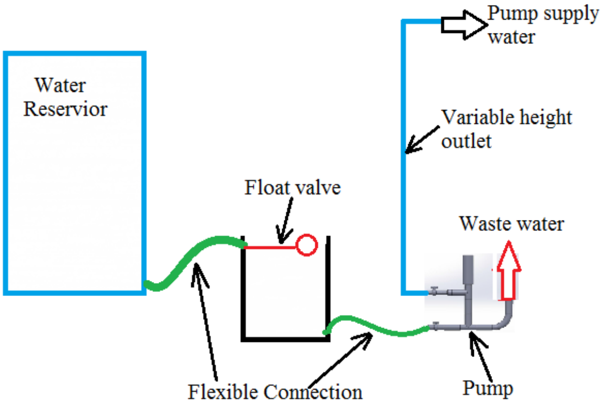

Fig. 3 Schematic of Experimental Set-up

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The water supplied by the pump was collected at fixed time intervals during operation and the volume measured with a 2000ml measuring cylinder with an accuracy of ±20ml to determine the pump supply flow rate. The waste water from the pump exhaust was also collected at fixed time intervals during operation and the volume measured with a 2000ml measuring cylinder with an accuracy of ±20ml to determine the pump waste water flow rate.

Experimental Results

Experiments were conducted by varying the input head of the water at between 30 cm to 150 cm in increments of 30cm intervals. At each corresponding input head the pump outlet height was varied between 60cm to 600cm in increments of 60cm intervals. For each test configuration, ten samples of pump supply water and pump waste water were collected. The water samples were collected for 30s in each case. The volume of water for each sample was measured and the average volume flow rate for the ten samples calculated. This procedure was repeated for each combination of supply head and pump outlet height. The calculated results were tabulated and shown on Tables 1 and 2.

Table 1: Pump output water flow rate variation with input head and outlet height

	Pump Outlet Height (cm)									
	60	120	180	240	300	360	420	480	540	600
Input Head (cm)	Water Flow Rate at Pump Outlet (Pump Supply Water) (ml/min)									
30	3600	2700	1200	700	100	0	0	0	0	0
60	5600	4800	3800	2700	1600	1000	400	200	0	0
90	7000	6800	6000	4800	4200	3100	2000	1500	700	400
120	8000	7800	6600	5200	4400	4000	3280	2400	1900	1800
150	8800	8400	8200	5600	4800	4400	4000	3000	2400	2200

Table2: Pump waste water flow rate variation with input head and outlet height

	Pump Outlet Height (cm)									
	60	120	180	240	300	360	420	480	540	600
Input Head (cm)	Water Flow Rate at Pump Exhaust (Pump Waste Water) (ml/min)									
30	11600	11200	16400	10600	10500	0	0	0	0	0
60	12800	12800	15000	12600	12600	12600	12400	12400	12400	12400
90	13800	13800	13600	13600	13600	13400	13400	13200	13200	13200
120	14800	15200	12800	15000	14800	14800	14400	14400	14400	14400
150	16000	16000	11000	16400	16000	15600	15200	15000	14800	14400

Analysis and Discussion

The simple construction water hammer pump showed that as the delivery head increased the rate of water delivered decreased for the five input head height tested. For the lowest input head of 30 cm, the pump operated up to a maximum height of 300 cm. No water was delivered beyond this height. For input head of 60 cm, the pump operated up to a maximum height of 480 cm. No water was delivered beyond this height. For input head of 90 cm, 120 cm and 150 cm, the pump delivered water up to the maximum test height of 600 cm. A plot of the data points and the regression analysis are shown on the graph in Figure 4.

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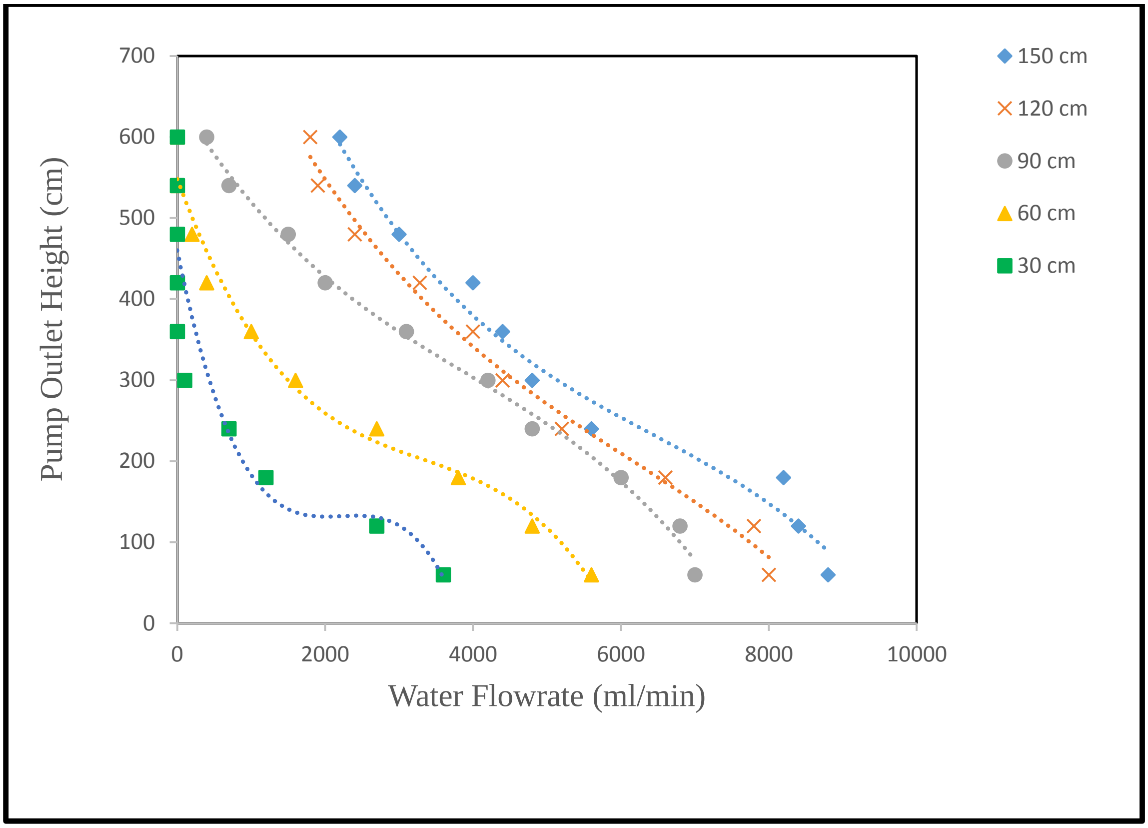

Fig. 4 Graph of supply water flow rate vs pump outlet height for various input head

The regression equations indicated the rate at which water was delivered with pump outlet height followed an x^3 variation. This corroborated the experimental data which showed that as pump outlet height decreased, there was a slow increase in delivered water flow rate. This was followed by an increase in delivered water flow rate with a close-to a linear variation. As the pump outlet height dropped lower than 120 cm, there was a decrease in the delivered water flow rate. The regression equations corresponding to the various input head heights are given in equations 1 to 5.

Input head; 150 cm: $y = (-2 \text{ x } 10^{-9})\, x^3 + (4 \text{ x } 10^{-5})\, x^2 - 0.2999x + 1082.80$ $R^2 = 0.9772$ ……………(1)

Input head; 120 cm: $y = (-1 \text{ x } 10^{-9})\, x^3 + (3 \text{ x } 10^{-5})\, x^2 - 0.2247x + 900.54$ $R^2 = 0.9882$ ……………(2)

Input head; 90 cm: $y = (-2 \text{ x } 10^{-9})\, x^3 + (2 \text{ x } 10^{-5})\, x^2 - 0.1513x + 648.43$ $R^2 = 0.9946$ …………..(3)

Input head; 60 cm: $y = (-7 \text{ x } 10^{-9})\, x^3 + (7 \text{ x } 10^{-5})\, x^2 - 0.2493x + 548.37$ $R^2 = 0.9820$ ……………(4)

Input head; 30 cm: $y = (-3 \text{ x } 10^{-8})\, x^3 + 0.0002\, x^2 - 0.4515x + 460.20$ $R^2 = 0.8242$ ……………(5)

The regression equations with the exception of the 30 cm input head equation indicated an R^2 fit of more than 0.97.

The pump efficiency was determined from the ratio of the water delivered to the total water flow. The values were calculated and tabulated on Table 3.

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Table 3: Pump efficiency variation with input head and outlet height

	Pump Outlet Height (cm)									
	60	120	180	240	300	360	420	480	540	600
Input Head (cm)	Pump efficiency (%)									
30	23.7	19.4	6.8	6.2	0.9	0	0	0	0	0
60	30.4	27.3	20.2	17.6	11.3	7.4	13.0	1.6	0	0
90	33.7	33.0	30.6	26.1	23.6	18.8	13.0	10.2	5.0	2.9
120	35.1	33.9	34.0	25.7	22.9	21.3	18.6	14.3	11.7	11.1
150	35.5	34.4	42.7	25.5	23.1	22.0	20.8	16.7	14.0	13.3

From the data for the 60 cm and 30 cm input head, the pump was capable of delivering water be between 8 to 10 times the input head with efficiencies of 1.6% and 0.9%, respectively. The difference in delivery height capacity may be due to the shorter pipe length of 300 cm compared to 480 cm associated with the 30 cm and 60 cm input head, respectively. For input head ranging between 30 cm to 150 cm, the efficiency of the pump delivering water twice the input head height ranged from 23.1% to 30.6% with an average efficiency of 26%. For input head ranging between 30 cm to 150 cm, the efficiency of the pump delivering water four times the input head height ranged from 19.4% to 13.3% with an average efficiency of 16.6%. From the three sets of data available for input head ranging between 30 cm to 90 cm, the efficiency of the pump delivering water six times the input head height ranged from 5.0% to 7.4% with an average efficiency of 6.4%. The trend indicated that as the delivery height increased in increments of twice the corresponding input head, there is a 10% decrease in efficiency.

Conclusions

- A small scale hammer head pump operated effectively without any external energy input.
- The delivered water flow rate varied according to a cubic variable with respect to pump outlet height.
- The pump was capable of delivering water to a maximum height of 8 to 10 times the height of the input head.
- The pump operated at average efficiencies of 26%, 16% and 6% when the delivery height was twice, four times and six times the input head, respectively.
- There was a 5% incremental decrease in pump efficiency as the delivery height increased in increments of the corresponding input head height.

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