



## Effects of Discharge Head on the Performance of a Mini-Hydraulic Ram Pump for Possible Application in Mini-Hydro Turbine Systems

C.C Kwasi-Effah<sup>1</sup>, J.C. Madu<sup>1</sup>, E.G Osayuw<sup>1</sup>, A.E Igiebor<sup>1</sup>

<sup>1</sup>Department of Mechanical Engineering, University of Benin, Benin City, Nigeria

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### Abstract

*This paper presents a study into the possible effects of the discharge head (height) on the performance of a mini-hydraulic ram pump for possible applications in mini-hydro turbine systems. After modelling and fabrication, the pump was subjected to various experiments by varying the supply heads of 2ft, 2.4ft, 2.8ft, 5.2ft, and 7ft against various delivery/discharge heads of 6 ft, 8 ft, 10 ft, 12 ft and 14 ft. It was observed that the efficiency of the system drops drastically for a delivery height to supply height ratio above 6 while producing peak power at a head ratio between 1.92 and 4. Also, the maximum volumetric flow through the pump which was 14,364 L/day was obtained at a delivery to supply height ratio of 2. It can be concluded that the performance of the hydraulic ram pump is closely associated with the delivery height/head to give optimal performance.*

## 1. Introduction

The lack of electric power supply has had serious consequences in the development of Nigeria and Sub-Saharan Africa [1]. In Nigeria, where demand supersedes the generation, the three major hydro-electric power plants; Kainji dam (760MW), Jebba dam (578 MW) and Shiroro dam (600MW) working in hand with other gas power plants cannot serve the consumers, especially in areas entirely cut-off from the national grid [2]. The Micro-hydropower system has successfully been developed in some countries; the system works based on the pumped storage-turbine scheme in which water stored at a high level reservoir runs the turbine to generate electricity at peak periods [3]. This system is receiving increasing attention from owners of housing estates and others who have properties that are not connected to the conventional electric grid [4]. [5] classified the micro-hydropower system as having a generating capacity less than 100 kW. The drawback in this system occurs at the off-peak periods, where external sources of power such as hybrid or solar/photovoltaic cells are used to pump water to a higher level for continuous power generation [3]. Therefore, there is need to develop a mechanical system for lifting water to a required elevated height just sufficient to operate a turbine while eliminating the need for the introduction of electric power to pump back water. By using the hydraulic ram pump (Hydroram), water can be lifted to the inlet source of turbine; so, water required by the turbine is recycled and fresh water requirement is reduced and this is done with no electric power requirement as long as there is continuous flow of falling water [6].

The first self-acting ram pump was invented by the Frenchman Joseph Michel Montgolfier (best known as a co-inventor of the hot air balloon) in the eighteenth century for raising water in his paper mill at Voiron [7]. A traditional hydraulic ram has only two moving parts, a spring or weight loaded "waste" valve sometimes known as the "clack" valve and a "delivery" check valve. The unit is also made up of an air chamber in which pressure is built up. In addition, there is a drive pipe supplying water from an elevated source and a delivery pipe, taking a portion of the water that comes through the drive pipe to an elevation higher than the source. The basic components include; an inlet-drive pipe, a free flow at waste valve, an outlet-delivery pipe, waste valve, delivery check valve, and a pressure vessel or air-tight chamber [8].

One of the main parameters to be considered in designing the hydraulic ram includes; diameter of air column, length of air column and delivery head [9]. The Optimum size of the hydraulic ram pump is dependent on delivery head and flows, stroke length, weight of impulse valve and volume of air chamber [10]. The hydraulic ram pump performance is strongly dependent on performance parameters such as the drive pipe discharge, drive pipe length and volumetric discharge [11]. Still on performance [12] proposed a head ratio of approximately 2 for maximum efficiency and stated that the increase in efficiency comes with a decrease in the head ratio.

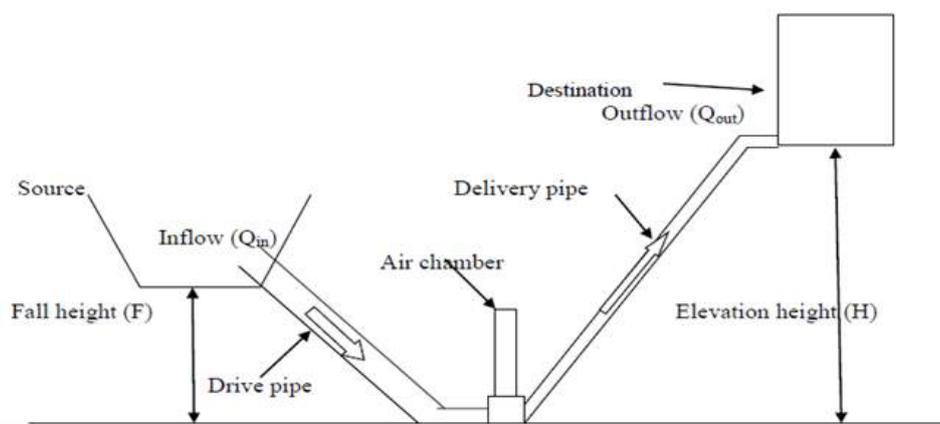


Figure 1. Schematics of the working actions of a hydraulic ram pump [13]

## 2. Methodology

The hydraulic pump ram is designed to deliver water from one hydraulic head level to a higher one. Thus, the design of this device will employ the Bernoulli's equation as its guiding equation. Bernoulli's equations states that; in an ideal incompressible fluid when the flow is steady and continuous, the sum of pressure energy, kinetic energy and potential (or datum) energy is constant along a stream line.

Mathematically:

$$\frac{P}{w} + \frac{v^2}{2g} + z = \text{Constant} \quad (1)$$

The supply volumetric flow rate,  $Q_s$  is given by

$$Q_s = \frac{V_s}{t} \quad (2)$$

Due to the fact that the flow in the pipe, the velocity is given by:

$$V_s = \frac{Q_s}{A_s} \quad (3)$$

The Reynolds number determines the nature of the flow; laminar or turbulent or in transition. The dimensionless number is given by:

$$Re = \frac{V_s d}{\nu} \quad (4)$$

Blasius provided a relationship to determine the frictionless factor for fluid flow in a pipe. The relationship is given mathematically for smooth pipe turbulent flow as:

$$f = \frac{0.316}{Re^{\frac{1}{4}}} \quad (5)$$

The head loss for flow in pipes is given by the Darcy-Weisbach equation as:

$$H_l = \frac{fL}{d} \left( \frac{V_d^2}{2} \right) \quad (6)$$

The power developed by the hydraulic ram is given by:

$$P = \rho g Q h \quad (7)$$

The Aubuisson's efficiency of the hydraulic ram is given by:

$$\eta = \frac{Q_d \times H_d}{Q_s \times H_s} \quad (8)$$

The pressure developed is given by:

$$P = \rho g h \quad (9)$$

Table 1: Design specifications data for Hydraulic Ram Pump

S/No	Design Parameters	Formula	Value
1.	Minimum supply head	$H_s$	2 ft
2.	Maximum supply head	$H_s$	7ft
3.	Minimum delivery head	$H_d$	6 ft
4.	Maximum delivery head	$H_d$	14 ft
5.	Minimum volume flow rate	$V_s / t$	732 L/d
6.	Maximum volume flow rate	$V_s / t$	14364 L/d
7.	Average inlet pressure	$\rho g h H_s$	38.062 kN/m <sup>2</sup>
8.	Average backward pressure	$\rho g H_d$	98.1 kN/m <sup>2</sup>

9.	Hydraulic diameter of supply pipe	$Q_s$	19.05 mm
10.	Hydraulic diameter of discharge pipe	$Q_d$	12.7 mm
11.	Height of air chamber	$H_a$	60 cm
12.	Maximum power of pump	$\rho g Q h$	3.977

## 2.1. Construction

After careful detailed design, the hydraulic ram pump was modelled with SOLIDWORKS 2018. It is shown in Figure 2.



Figure 2. SOLIDWORKS rendition of the proposed designed model

The Hydraulic pump ram was constructed with the following materials: A header tank, Elbow, Sockets, Ball Valve, Check Valve, Tee Joints, Multiple supply or drive pipes, A pump basement, Multiple delivery pipes, A storage tank, Reducers, Adapters, Flexible Hoses, Basement clamp, Hose clips.

## 2.2. Operating Procedures

**Step 1:** Open the inlet valve to allow the flow of water through the drive pipe under the effect of gravity.

**Step 2:** As the velocity of the water keeps building, it gets to a stage of high velocity and the water immediately shuts the waste valve.

**Step 3:** After the waste valve is closed, the water in the pump flows through the non-return valve.

**Step 4:** The air in the air chamber is compressed as a result of the effects of water hammering. This pressure continues to build up and it does so, until it is high enough to force the delivery valve open, and water flows out of the delivery pipe.

**Step 5:** Almost simultaneously, it generates recoil or back pressure that forces the waste valve to open. Hence the cycle is repeated continuously.

### 3.0. Results and Discussion

Two hydraulic ram pumps were constructed and connected in parallel. Several experiments were carried out for varying supply head of 2ft, 2.4ft, 2.8ft, 5.2ft, and 7ft against various delivery heights of 6ft, 8ft, 10ft, 12ft and 14ft. (Table 2) summarizes the results obtained for delivery heights of 6ft, 8ft, 12ft. While (**Error! Reference source not found.** 3) summarizes the results obtained for delivery heights of 12ft and 14 ft.

Table 2: Experimental result of varying supply head against discharge heads (6ft, 8ft and 10ft)

DISCHARGE HEAD, ft

Supply Head, ft	6ft			8ft			10ft		
	Flow rate(L/d)	Power (Watts)	Efficiency, $\eta$ (%)	Flow rate(L/d)	Power (Watts)	Efficiency, $\eta$ (%)	Flow rate(L/d)	Power (Watts)	Efficiency, $\eta$ (%)
2.0	9116	1.893	36.46	7388	2.045	39.40	5348	1.851	35.65
2.4	1412	0.293	4.71	1232	0.341	5.48	900	0.3115	5.00
2.8	5556	1.154	15.87	4724	1.308	18.00	4068	1.408	19.37
4.0	6972	1.448	13.94	14364	3.977	38.304	6452	2.233	21.51
5.2	8456	1.756	13.01	5892	1.631	12.09	8388	2.903	21.51
7.0	NF	0.000	0.00	NF	0.00	0.00	NF	0.00	0.00

Table 3: Experimental result of varying supply head and discharge heads (12ft and 14ft)

Supply Head, ft	12ft			14ft		
	Flow rate(L/d)	Power (Watts)	Efficiency, $\eta$ (%)	Flow rate(L/d)	Power (Watts)	Efficiency, $\eta$ (%)
2.0	4692	1.949	37.54	1800	0.872	16.80
2.4	732	0.304	4.88	NF	0.00	0.00
2.8	NF	0.00	0.00	NF	0.00	0.00
4.0	4448	1.847	17.79	6980	3.382	32.57
5.2	3068	1.274	9.44	2860	1.386	10.27
7.0	NF	0.00	0.00	NF	0.00	0.0

From Table 2 and Table 3, the pump continues to function between a supply head of 2ft and 5.2ft, however, the pump does *not function* (NF) when the supply head was increased to 7ft. The reason for this was that the head was too high a value that the pressure from such height did not allow for the intermittent opening and closing of the waste valve. As a result of this, while priming the pump, when the waste valve is poked with an object, the valve opens and shuts immediately but does not cause sufficient drop in pressure in the system to allow for its continuous opening and closing by itself. Also, as shown by the table, at certain supply and corresponding delivery heads, the pump might *not function* (NF) for reasons such as insufficient gravitation force for low supply head to meet a high delivery head; and (or) excessive pressure head for high supply heads. This can happen to the pumps when they are installed either autonomously or in parallel arrangement.

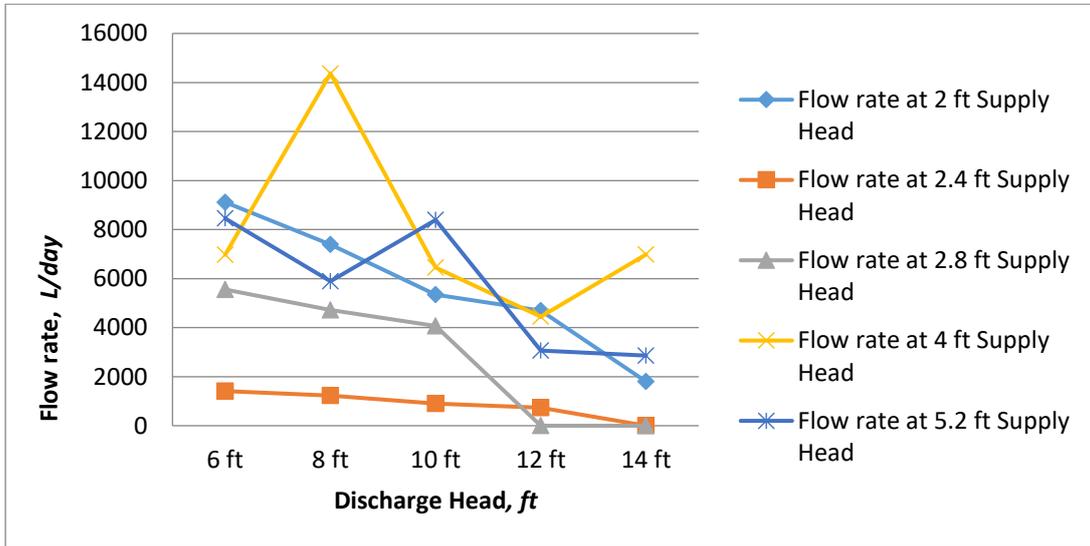


Figure 4: Plot of flow rate of varying supply head against varying discharge head

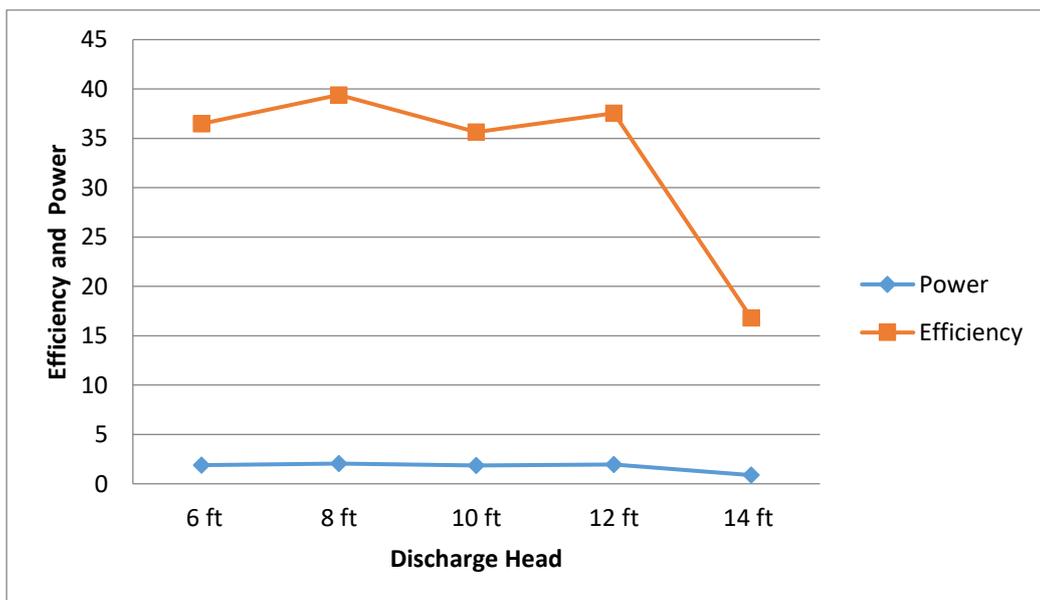


Figure 5: Plot of power and efficiency at 2 ft supply head against varying discharge head

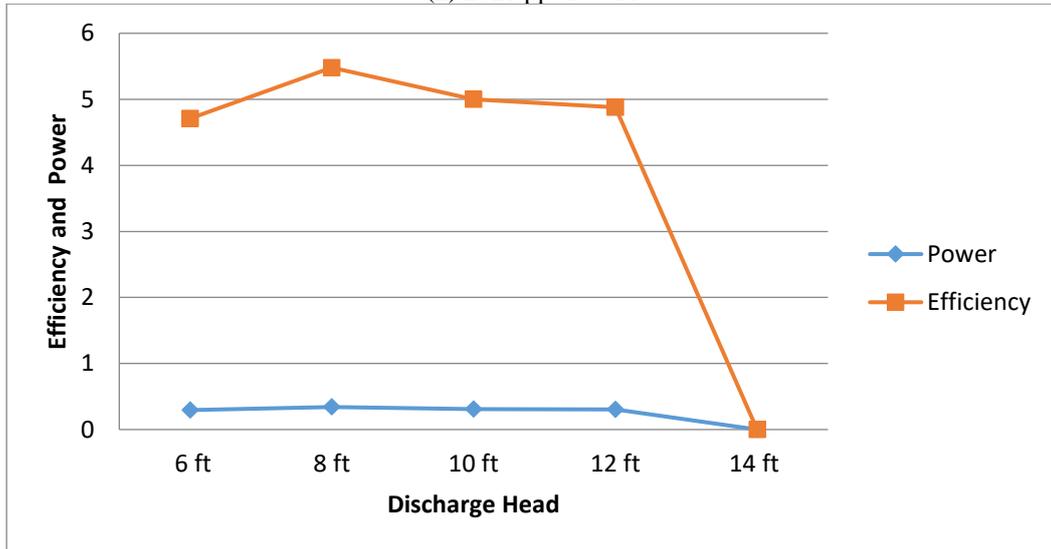


Figure 6: Plot of power and efficiency at 2.4 ft supply head against varying discharge head

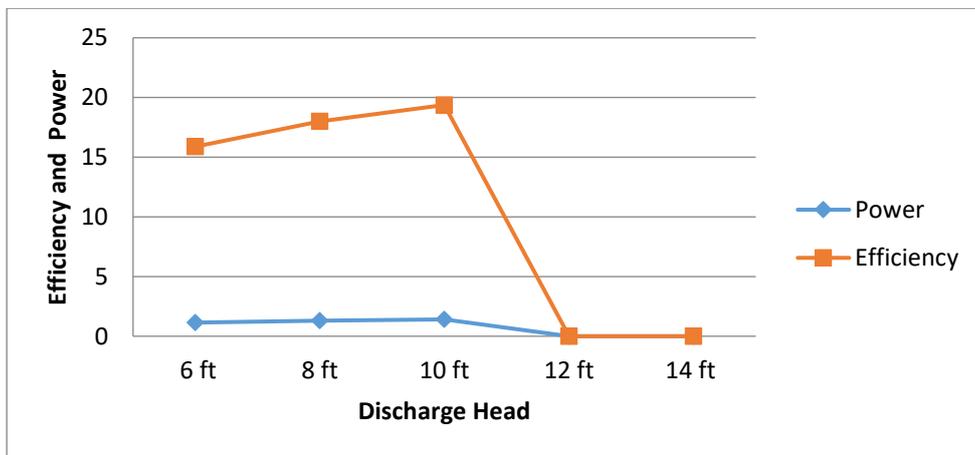


Figure 7: Plot of power and efficiency at 2.8 ft supply head against varying discharge head

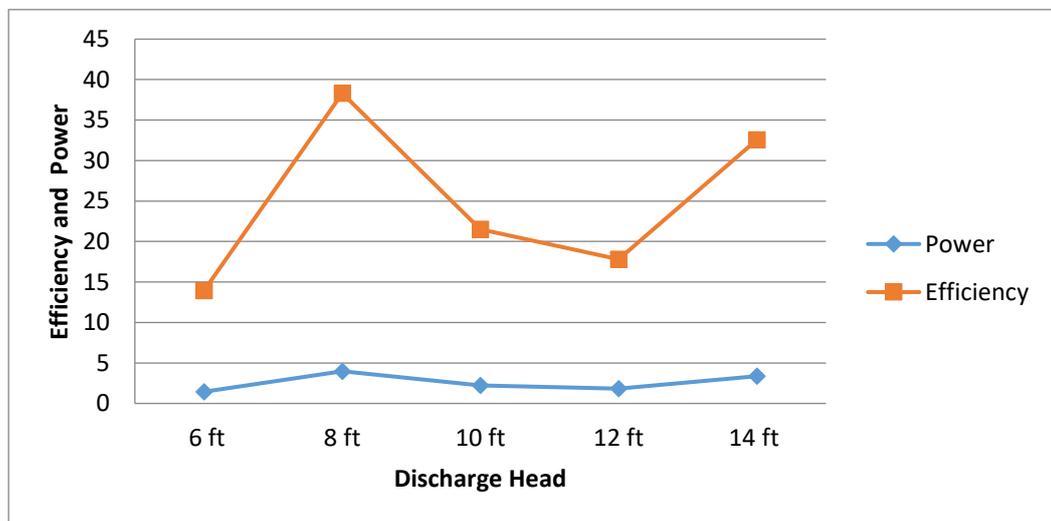


Figure 8: Plot of power and efficiency at 4.0 ft supply head against varying discharge head

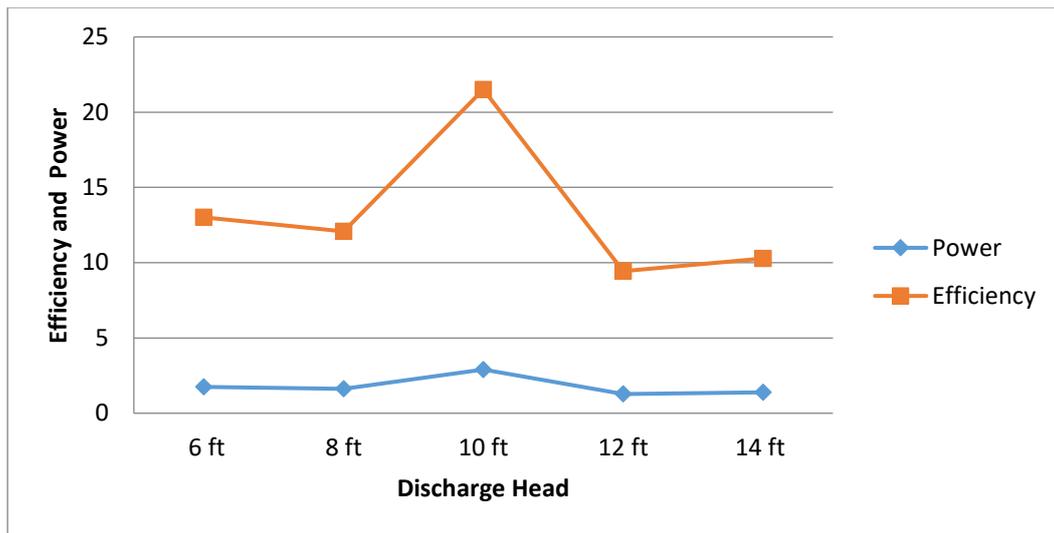


Figure 9: Plot of power and efficiency at 5.2 ft supply head against varying discharge head

From Figure 4, it is seen that for a constant supply head, the volumetric flow rate generally increases as the increasing supply head and decreases steeply as the discharge head increases. This could be attributed to loss in mechanical energy in the fluid. The greatest volumetric flow through the pump was 14,364 L/day and was obtained at 4ft supply head, when discharging to a delivery height if 8 ft. The hydraulic ram pump produced by [14] and [15] produced 3, L/day and 15,279 L/day for a delivery to supply height ratio of average 1.5 respectively. The hydraulic ram pump developed by [16] and [17] produced above 7,000 L/day while corresponding to an average delivery to supply height ratio of 2. Thus the flow rate produced is in a reasonable range.

From Figure 5-9, it is observed that the efficiency of the system drops drastically for a supply head below 2.8 ft and for delivery heights above 12 ft. This is attributed to the increase in the head difference. This agreed with [17] that concluded that the efficiency will increase, if the head difference is reduced. The greatest efficiency of 39.40% was obtained from a supply head of 2ft and a delivery head of 8 ft as shown in Figure 4. This corresponds to a head difference of 6 ft (1.823m). According to results from [17], the maximum efficiency was obtained at a head difference of 2.28 m. Also, [11], [15] and [16] had maximum efficiency above 30%. From Figure 5-9, it observed that the power produced usually peaks between delivery heads of 8 ft and 12 ft. This corresponds to head ratios ranging from 1.92 to 4. This is attributed to the fact that at greater delivery heights above, 10 ft, the flow rate generally decreases. From Figure 8, it is seen that the greatest power developed was 3.977 watts, which corresponds to a supply head of 4 ft and a discharge height of 8 ft. The hydraulic ram pump developed by [16] generated 23.9 kW for a discharge head of 20 m.

#### 4.0 Conclusion

This paper has presented a study on the effects of the discharge head (height) on the performance of a mini-hydraulic ram pump for possible applications in mini-hydro turbine systems. The hydraulic ram pump was modelled and fabricated. The pump was subjected to various experiments by varying the supply heads varying supply head of 2ft, 2.4ft, 2.8ft, 5.2ft, and 7ft against various delivery/discharge heads of 6 ft, 8 ft, 10 ft, 12 ft and 14 ft. Results showed that the pump does not function at certain discharge heights, because of insufficient gravitational force for low supply head to meet a high delivery head; and (or) excessive pressure head for high supply heads as well as when the supply head was increased to 7ft.

The maximum volumetric flow through the pump was 14,364 L/day and was obtained at 4ft supply head, when discharging to a delivery height of 8 ft. efficiency of the system drops drastically for a supply head below 2.8 ft and for delivery heights above 12 ft. The maximum efficiency of 39.40% was obtained from a supply head of 2ft and a delivery head of 8 ft. This corresponds to a head difference of 6 ft (1.823m). The hydraulic ram produced a maximum power of was 3.977 watts, which corresponds to a supply head of 4 ft and a discharge height of 8 ft. It is observed that the power produced usually peaks head ratios ranging from 1.92 to 4.

## Normenclature

$Q_s$	Supply flow rate
$V_s$	Supply Velocity
$t$	Time
$A_s$	Cross sectional area of Supply
$Re$	Reynolds number
$\nu$	Kinematic viscosity
$d$	Pipe diameter
$f$	Blasius frictionless factor
$H_l$	Head loss
$V_d$	Discharge velocity
$P$	Power
$\rho$	Density
$h$	Height
$H_a$	Length of air chamber
$g$	Acceleration due to gravity
$H_d$	Delivery/Discharge head/height
$Q_d$	Delivery/Discharge flow rate
$H_s$	Supply head/height
$\eta$	Efficiency
$\frac{P}{w}$	Pressure head
$\frac{v^2}{2g}$	Velocity head
$z$	Gravitational head

## Conflict of Interest

The authors wishes to state that there is no conflict of interest in this paper.

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