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Design, analysis and fabrication of UTM hydraulic ram pump for water supply in remote areas

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ABSTRACT

This paper focuses on design, analysis and fabrication of hydraulic ram pump, which uses the force of gravity to deliver water to higher altitudes. It does not depend on electrical and fossil energy and robust, inexpensive, easy to install and maintain. All these qualities make it suitable for use in remote areas where water and electricity supply, especially in developing countries. The aim of this study is to construct a low cost UTM hydraulic ram pump for water supply in remote areas, provided that it must have a reliable design and made of materials available locally in Malaysia. The design must also be easy to assemble and dismantle, easy to maintain and durable with a long service life. In order to achieve these objectives, existing ram pump designs by other researchers were studied to provide the basics in designing the UTM hydraulic ram pump. The ram pump efficiency is 62%, based on drive pipe diameter of 3” and air chamber volume of 33.3 L. Referring to the guidelines and experimental data these design specifications allow a total of 7000 L/day (4.86 L/min) of water to be delivered to the storage tank. The power required is about 23.9 kW which is enough to overcome head losses of about 54.52 m. Through a test stand, the value of circulations is 49 cycle/minute and thus the overall performance of the ram pump can be calculated before installation in remote areas. Other factors such as the proper material selection and safety considerations were also prioritized.

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1. INTRODUCTION

The use of gravity and an environmental-friendly design makes the ram pump highly suited for agriculture and livestock watering systems [1]. As the ram pump does not depend on electrical and fossil energy [2], it is suitable for use in remote areas as a basic component in supplying water. It is also robust, inexpensive, easy to install and maintain [3]. The ram pump could also be used in households to improve energy usage, for free delivery of water, to irrigate gardens and as a component in water processing technology [4]. The ram pump works efficiently over a wide range of flow rates with proper tuning and can be made with simple work shop equipment [5].

Residents living in remote areas are known to face environmental and topographical limitations when it comes to water supply, especially those living near hills or in forestry zones far from urban areas. Therefore, the aim of this study is to construct a low cost UTM hydraulic ram pump for water supply in remote areas. It would have a reliable design and be made from materials available locally in Malaysia market. The design must also be easy to assemble and dismantle and be as simple as possible to allow for durability and a prolonged service life. Therefore, The Handbook of Ram Pump [5] and existing ram pump designs by other researchers were studied to provide the basic details in designing the UTM hydraulic ram pump. Several methods were employed during the design process, namely function analysis of the sub components in the hydraulic ram pump, a morphological chart for studying alternatives, a conceptual development using sketches, and weighted objectives [6-9].

This paper presents the design of a ram pump produced by the researchers using design process techniques, design objective and conceptual design. The results obtained from experiments and installations found that the height of the drive pipe greatly influenced flow rate and water delivery to storage tank.

2. RESEARCH METHOD

2.1. Design of UTM Hydraulic Ram Pump

The construction of a ram pump is simple where it consists of only two moving parts. The waste water valve, also known as an impulse valve, and a check valve (or delivery valve) intermittently pumps water without electrical energy from any source as it uses the free energy from the water hammer. Water from the supply head flows through the drive pipe into the valve box. The waste valve is initially open to release the water to the source and it quickly closes as the water flow increases. The closed valve causes the pressure to increase within the pump valve box, an effect also known as water hammer. This allows the water to flow through the delivery valve and delivers it to the storage box. At the same time, air enters the air valve to pass the delivery valve and pressurizes the air chamber to close the delivery valve and pumps the water through the delivery pipe to supply the storage tank. After the delivery valve is closed, the pressure in the valve box is reduced which causes the waste valve to open and water flows again into the valve box.

The ram pump must adhere to the criteria in design considerations outlined in The Ram Pump Handbook and also be comparable to existing and available products marketed in other countries [10-11]. Using the data of ram pump performance from Table 1, it was concluded that the Blake is the best suited for our purposes. More experimental data of the Blake ram are provided in Table 2. Both tables were referred to when calculating the pumping rate required in litres per day for the given head supply and delivery head values. The comparative data between the Blake ram and UTM hydraulic ram pump was calculated to get the pumping rate required as shown in Figure 1.

Table 1. Design Guidelines for Consideration in Hydraulic Ram Pump Design

Part	Consideration
Intake design	Intake will be a stream with a screen which must meet wildlife fish screen criteria set by the Department of Fish and Wildlife. Water must be free of debris, sand and sediments [16-17]
Drive pipe	Drive pipe must be made from a non-flexible material for maximum efficiency (last 20 feet of pipe is galvanized iron or steel pipe) with the length of drive pipe at least 4 to 5 times the vertical fall or supply head H. Drive pipe diameter will be used to obtain the size of hydraulic ram pump [18-19]. The pipe must be thick and straight, avoid any upward bends or humps (air trap), always submerged to avoid air entering the pipe as the bubbles will absorb the energy of pressure pulse [5]. A lower head supply and longer length drive pipe will require a supply tank to ensure the supply source is higher than the flow in the drive pipe.
Pump	The base foundation must be located above the 100-yard flood zone. The pump must be mounted to a solid concrete base to overcome the vibration and water impact loads by using stainless steel studs, nuts and bolts to prolong service life [20].
Delivery pipe	Minimize the distance to the storage tank to increase pumping rate. For a long delivery pipe, a smaller size is recommended to maintain the steady flow with less friction [21]. A house pipe hose with an internal bore of 20mm is strong enough and satisfactory for the delivery pipe selection.
Impulse valve	A heavy weight and a long stroke allow high flow rates as the waste water passes through the impulse valve. This will build up the impact of hammer pulse that is recommended for higher heads; while a small weight and short stroke is recommended for more ‘beat’ to quickly deliver larger volumes to lower heads [21-22].
Delivery valve	A large opening to allow the pumped water to enter the air chamber with less friction to flow. A simple valve such as clap check valve or clack valve can be used with one way directional valve type [21-22].
Air chamber	A larger air chamber makes it possible to compress and cushion the pressure pulse from the ram cycle, thus allowing for a steadier flow past the delivery pipe with less friction loss. Some suggest the size of air chamber be equal to the volume of the delivery pipe [22]. The air-filled pressure chamber creates a buffer, absorbing water hammer and turning the intermittent pumping into a steady flow [23-24].
Air valve	The air valve, or snifter valve, is a simple valve hole (eg: 1 mm before the delivery valve) with split pin type and it can be any valve to allow new air to top up the air in the air chamber. The available air will exist together with the turbulence of water entering the delivery pipe [5]. The size of the air valve does not have much effect and a hole size of less than 1mm is sufficient [8, 25].

The basic operation, and application of a hydraulic ram pump were discussed in the earlier sections and the design consideration factors for such pump are further reviewed in detail in section 2.2. The UTM hydraulic ram pump is required to supply water to a remote area with a head supply of 2 m and a delivery head of 20 m.

Table 2. Capacity of Blakes Ram [5]

Size of ram pump (Blakes)		1	2	3	3 ½	4	5	6
Internal diameter (bore)	mm	32	38	51	63.5	76	101	127
Supply discharge Q_s (liters/min)	From	7	12	27	45	68	136	180
	to*	16	25	55	96	137	270	410
Maximum height to which ram pump will pump water (h_d)	meters	150	150	120	120	120	105	105

*Note: The higher values of Qs are the volumes of water used by the ram pump at their maximum efficiency; the pumps do not have the capacity to pass larger amounts that those given.

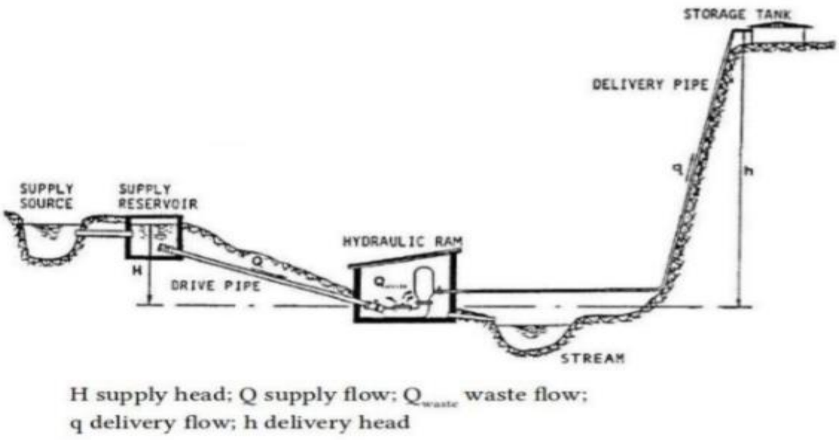

Figure 1. Hydraulic ram pump for use in remote areas [5]

2.2. Design Considerations

The main factors as recommended by pump manufacturers and the handbook are; the difference in height of water source and pump location (vertical fall as supply head) Hs, the difference in height between the pump location and tank storage or usage location (delivery head) HD, the quantity of flow from the source or supply per minute Qs, the length of the drive pipe, the quantity of water required (pumping flow rate) QD, and the length of delivery pipe to the storage [12-15]. The site condition of supply and delivery head and supply discharge Qs must first be measured before a ram size can be chosen to pump at the required rate.

The design parameters for a hydraulic ram pump according to Muhammed [6] are: volumetric discharge from the drive pipe, velocity of fluid flow in the driven pipe, Reynolds number, friction factor of the pipe, head loss in the pipe, velocity of fluid in T-junction, loss due to sudden enlargement at the T-junction, losses in pipe fittings, water acceleration in driven pipe, the drag force, pressure of fluid, power required and efficiency of hydraulic ram. In this study, the data were calculated and summarized in the ram pump specification section with most of the data obtained was from the experimental findings and results obtained from other researchers and from The Ram Pump Handbook [5]. From the given pump requirements, with the supply head Hs of 2 m and the delivery head HD of 20 m, and from required pumping capacity, the data for the supply discharge for the ram pump has been obtained.

To supply water to remote areas where the supply head Hs is 2 m and the delivery head HD is 20 m and using the discharge supply Qs of 88.6 litres per minute, the efficiency of the pump is 65% for parameters calculated using Table 1 as recommended by Watt [5].

The length of the drive pipe calculated according to Calvert's equation is as follows:

$$150 < \frac{L}{D} < 1000 \quad (1)$$

$\frac{L}{D} = 500$ as recommended by Watt [5], when D = 3” = 0.075m, then L= 0.075 m x 500=37.5m
Minimum of drive pipe length of 4 or 5 times supply head H [5].

$$L = 4H \tag{2}$$

supply head H = 2 m, L= 4 x 2 m = 8 m.

Hence, the value of 37.5 m was selected as the length of the drive pipe and as mentioned by Watt [5], the best efficiency of a ram pump when the supply head is one third of the delivery head is equal to 6.67m. The value of H (2 m), due to the remote area requirements, will be used in subsequent calculations as depicted in Appendix A which shows sample calculations of the Ram pump parameters (see section 2.2). If the efficiency of the pump is 65% and if the pumping rate is 7000 litres per day, the expected value of supply discharge for the ram pump is as follows:

From Table 3, with H_S of 2 m and the delivery head H_D of 20 m, and if the flow rate down the drive pipe is 1 litre/min, then 79 litres/min of water will be pumped each day to the header tank (supply tank). However, 7000 litres/day (4.86L/min) is the minimum requirement for the ram pump to supply water to remote areas.

$$Q_S = \frac{7000}{79} = 88.6\ L/min \tag{3}$$

Referring to Watt [5], the ram size No. 4 is satisfactory (Table 2), or in other words a ram with an internal bore greater than 76 mm can pump water more than 7000 litres/day (4.86 L/min). Therefore the 3” ram size was selected to meet the minimum requirement of pumping approximately 7000 L/day (4.86 L/min).

2.3. Conceptual Design

Figure 2 shows the prototype of the UTM hydraulic ram pump that was constructed using existing local products at a low cost. By using these materials, it will be easy to maintain, and will perform with high reliability.

Figure 2. UTM Hydraulic Ram Pump

Table 3 depicts the final specification for the UTM ram pump for supplying water to remote areas. The head supply of 2.0 m and delivery head of 20.0 m has been used to determine the pump size as detailed in section 2.2 and the calculated design parameters are detailed in Appendix A.

Table 3. UTM Ram Pump Specification

Part	Specifications
Head Supply H_S	2.0 m
Head Delivery H_D	20.0 m
Supply Discharge Q_S	88.6 L/min
Calculated Pumped Capacity Q_D	7000 liters/day (4.86 L/min).
Ram Pump Efficiency	62%
Beat cycle	49 cycle/min
Drive Pipe	PVC pipe, Diameter 3”, Length 37.5 m
Delivery Pipe	PVC pipe, Diameter 1”- 1 unit
Impulse Valve	Brazen metal check valve 3” -1 unit
Delivery Valve	Brazen metal check valve 1” -1 unit
Air Chamber	Modified LPG tank 16 kg -1 units Height =16” (24 cm) Diameter = 31.8 cm Volume= 33.3 L (Water)
NPT Thread Connecting Fitting Female T-Adaptor	Galvanized metal, Diameter 3” x 1 unit
Female Adaptor	PVC 3” -6 units
Female Adaptor	PVC 2” -1 units
Elbow Female Adaptor	Galvanized metal, Diameter 3” -1 unit
Reducer Fitting before air chamber	PVC 3” to 2”- 1 unit
Coupling T junction pipe for delivery pipe and air chamber	PVC Diameter 3” and 1” -1 unit
Total Head Losses	54.52 m

3. RESULTS AND DISCUSSION

Prior to installing the ram pump to supply water in a remote area, pilot tests were conducted in UTM KL to collect data and tune the ram pump for proper operation. During testing on the prototype, the tank was provided with 2 m supply head and the high flow rate into the tank is produced by using a water supply hose. The 20 m delivery head is produced by using a rubber hose connected to a higher floor of a building. The pump was found to meet the expected pumping requirement of 7000 L/min (4.86 L/min). However, a leakage has occurred at the welding joint that connects the air chamber and the T-junction PVC pipe due to the continuous pressure pulse absorption. Unsteady water delivery rate to the 1” hose delivery pipe was due to material failure in the welding finish especially in the modified LPG tank. Based on guidelines and experimental data by Watt [5], a ram pump size of 3”, drive pipe diameter of 3” and an air chamber volume of 33.3 L are sufficient to deliver water to the header tank at a rate of 7000 litres/day (4.86 L/min) with a calculated efficiency of 62%. The power required of about 23.9 kW is enough to overcome the head losses of 54.52 m as detailed in the appendixes and Table 2.

4. CONCLUSION

The modified LPG tank has able to provide enough air volume to absorb the pressure pulse to pump water to the delivery head as high as 20 m with a pumping requirement of 7000 litres/day (4.86 L/min). The leakage of air would reduce the continuous steady supply of water to the remote area. The material failure during testing should be rectified so that the design will improve. The efficiency of 62% obtained was an assurance that the ram pump with a size of 3”, drive pipe diameter of 3”, and air chamber volume of 33.3 L was sufficiently well designed to deliver water to the header tank at 7000 litres/day (4.86 L/min) according to the guidelines and experimental data from [5]. The power required of about 23.9 kW was enough to overcome the head losses of about 54.52 m as detailed in the appendixes.

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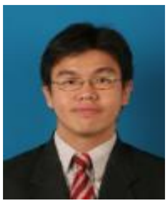

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APPENDIX A

Table A. Calculation of the Design Parameters of UTM Hydraulic Ram Pump

No.	L (m)	H (m)	h(m)	Ds (mm)	Dt (mm)	Vs (m/s)	Vd (m/s)	Qs (10^{-3} m^3s^{-1})	Qd (10^{-3} m^3s^{-1})	Qw (10^{-3} m^3s^{-1})	Vt (m/s)	P3 (kNm^{-2})	P (kW)	%
1	37.5	2	20	75	75	6.01	19.02	135.3	9.336	125.96	2.11	1.63	23.9	69

The volumetric discharge from the drive pipe is given by

$$Q_S = N\pi L r^2/60 \qquad (3.0)$$

When N=49 beat cycle/minute, then

$Q_S = 49 x\ 3.142\ x\ 37.5\ m\ (0.035)^2/60$

$= 135.3 \times 10^{-3}\ m^3s^{-1}$

The velocity of fluid flow in the drive pipe is given by

$$V_S = C_V\sqrt{2gH} \qquad (4.0)$$

$=0.96\sqrt{2x9.81x2}$

$=6.01ms^{-1}$

The velocity of fluid flow in the delivery pipe is given by

$$V_d = C_V\sqrt{2gh} \qquad (3.0)$$

$=0.96\sqrt{2x9.81x20}$

$=19.02ms^{-1}$

Discharge through delivery pipe is given by

$$Q_D = A_d V_d \qquad (4.0)$$

$=\frac{\pi}{4}x0.025^2x19.02$

$=9.336 \times 10^{-3}\ m^3s^{-1}$

Discharge through waste valve is given by

$$Q_W = Q_S - Q_D \qquad (7.0)$$

$= (135.3-9.336) \times 10^{-3}\ m^3s^{-1}$

$=125.96 \times 10^{-3}\ m^3s^{-1}$

Velocity of fluid flow in T-junction to air chamber is given by

$V_t = \frac{Q_D}{A_t}$ (5.0)

$= \frac{9.336\ x\ 10^{-3}}{\frac{\pi}{4} x 0.075^2}$

=2.11 ms^{-1}

Velocity of fluid flow in elbow is given by

$V_e = \frac{Q_w}{A_w}$ (6.0)

$= \frac{125.96\ x\ 10^{-3}}{\frac{\pi}{4} x 0.075^2}$

=28.51 ms^{-1}

Velocity of fluid flow diffuser before the air chamber

$V_{dif} = \frac{Q_D}{A_t}$ (7.0)

$= \frac{9.336\ x\ 10^{-3}}{\frac{\pi}{4} x 0.05^2}$

=4.75 ms^{-1}

Head losses

1. Head loss due to sudden enlargement at air chamber entrance

$H1 = \frac{(V_{dif})^2}{2g}$ (8.0)

$= \frac{(4.75)^2}{2\ x\ 9.81}$

=1.15m

2. Head loss due to sudden contraction of the brazen clap check valve

$H2 = K \frac{V_t^2}{2g}$ (9.0)

K=0.5 refer to [10] page 121 for inlet shape and loss factor

$= 0.5 \frac{2.11^2}{2\ X\ 9.81}$

= 0.113 m

3. Head loss at inlet gate valve

$H3 = K \frac{V_S^2}{2g}$ (10.0)

$=0.5 \frac{6.01^2}{2\ X\ 9.81}$

=0.92 m

4. Head loss at outlet of delivery valve

$H4 = K \frac{V_d^2}{2g}$ (11.0)

K=0.29 refer to [12] page 130 for pvc valve (cock valve data for 1")
with minimum possibility angle in closing angle (10°),
in most conditions the valve is almost always at maximum opening.

$=0.29 \frac{19.02^2}{2\ X\ 9.81}$

=5.3 m

5. Head loss due to the pipe fitting of the galvanized T junction pipe

$H3 = K_t \frac{V_t^2}{2g}$ (12.0)

$=0.5 \frac{2.11^2}{2\ X\ 9.81}$

=0.268 m

6. Head loss due to the galvanized elbow connector pipe

$H3 = K_e \frac{V_e^2}{2g}$ (13.0)

K_e=1.129 refer to [10] page 127 for loss factor for elbow ($\theta = 90°$)

$=1.129 \frac{28.51^2}{2\ X\ 9.81}$

=46.77 m

7. Reynolds number is given by

$Re = \frac{\rho V d}{\mu}$ (14.0)

According to ASTM standard for water viscosity
at 20℃, $\mu = \frac{0.001002 kg}{m.s}$, $\rho = \frac{1000 kg}{m^3}$

$= \frac{1000 x 6.01\ x\ 0.075}{0.001002}$

Re=4.5 x 10^5

8. Coefficient of friction is given by
Referring to [10] pages 116 for PVC as smooth pipe
for the equation of Nikuradse
f = 0.0032 + 0.221 x $Re^{-0.237}$ for

(Re = 10^5~3 x 10^6) (15.0)
= 0.0032 + 0.221 x (4.5 x 10^5)$^{-0.237}$
= 0.0133

9. Water acceleration in the driven pipe, this acceleration is given by

$$H - f\frac{L}{D}\left(\frac{V^2}{2g}\right) - \sum\left(K\frac{V^2}{2g}\right) = \frac{L}{D}\frac{dv}{dt} \quad (16.0)$$

$$2 - 0.0133\frac{37.5}{0.075}\left(\frac{6.01^2}{2x9.81}\right) - (1.15 + 0.113 + 0.92 + 5.3 + 0.268 + 46.77) = \frac{37.5}{0.075}\frac{dv}{dt}$$

$$\frac{dv}{dt} = 0.13\, m^2 s^{-1}\ (-ve)$$

10. Drag force is given by the equation

$$F_D = C_D A_t \rho \frac{V_e}{2g} \quad (17.0)$$

$=1.12\ x\ \frac{\pi}{4}\ x\ 0.075^2\ x\ 1000\ x\ \frac{28.51}{2x9.81}$
=7.2 N (-ve)

11. The pressure at the waste valve is obtained by

P3=$\frac{F}{A}$ (18.0)
$=\frac{7.2}{\frac{\pi}{4} x\ 0.075^2}$
=1.63 kNm^{-2}

12. The power required can be calculated using this expression

P=$\rho g H Q_S$ (19.0)
=1000 x 9.81 x (20-2) x 135.3 x 10^{-3}
=23.9 kW

13. The efficiency of the hydraulic ram pump is given by [5], h=Hd-Hs =20-2=18 m.

$\eta = \frac{Q_D\ x\ h}{Q_S\ X\ H}$ x 100% (20.0)
$=\frac{9.336\ x\ 10^{-3}\ x\ 18}{135.3\ x\ 10^{-3} x\ 2}\ x\ 100\%$
=6