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

S. Sarip1, A. Q Mohd Radzi2, T. S. Hong3, R. Mohammad4, M. F. Yakub5, M. A. Suhot6, H. M. Kaidi7
1,3,4,6,7Razak Faculty of Technology and Informatics, UTM Kuala Lumpur, Malaysia
2Kelana Jaya Community College, Jabatan Pendidikan Politeknik Kolej Komuniti, Malaysia
3Malaysia-Japan International Institute of Technology, UTM Kuala Lumpur, Malaysia

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.

Keywords:
Fabrication
Hydraulic Ram Pump
Remote Area
Water Supply

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 workshop 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 subcomponents 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 in thickness 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 1 mm 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  | 3½ | 4  | 5  | 6  |
|---------------------------|----|----|----|----|----|----|----|
| Internal diameter (bore)  | mm | 32 | 38 | 51 | 63.5 | 76 | 101 | 127 |
| Supply discharge Qs (liters/min) | From 7 | 12 | 27 | 45 | 68 | 136 | 180 |
| Maximum height to which ram pump will pump water (h<sub>d</sub>) | meters | 150 | 150 | 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]](image)

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) H<sub>s</sub>, the difference in height between the pump location and tank storage or usage location (delivery head) H<sub>D</sub>, the quantity of flow from the source or supply per minute Q<sub>s</sub>, the length of the drive pipe, the quantity of water required (pumping flow rate) Q<sub>D</sub>, 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 H<sub>s</sub> of 2 m and the delivery head H<sub>D</sub> 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 H<sub>s</sub> is 2 m and the delivery head H<sub>D</sub> 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:

\[ 150 < \frac{L}{D} < 1000 \]  
(1)

Design, analysis and fabrication of UTM hydraulic ram pump for water supply in remote areas (S. Sarip)
\( \frac{L}{D} = 500 \) as recommended by Watt [5], when \( D = 3" = 0.075m \), then \( L = 0.075m \times 500 = 37.5m \)

Minimum of drive pipe length of 4 or 5 times supply head \( H \) [5].

\[ L = 4H \quad (2) \]

Supply head \( H = 2m \), \( L = 4 \times 2m = 8m \).

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.

\[ Q_S = \frac{7000}{79} = 88.6 \text{ L/min} \quad (3) \]

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](image)

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                                                           |
| 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.

**ACKNOWLEDGEMENTS**

This study was funded by IEEE Humanitarian Activities Communities (HAC) with project no. R.K130000.7356.4B357 and DPUTMRAZAK, project no. R.K130000.7740.4J299.

**REFERENCES**

[1] “Technical notes: Hydraulic Ram Pumps,” in Agriculture, US Department :Natural Resources Conservation Service, no. 26, 2007
[2] K. Yang, “Design And Hydraulic Performance Of A Novel Hydraulic Ram Pump,” 2014.
[3] B. W. Young, “Generic design of ram pumps,” *Procedia Inst. Mech. Eng.*, vol. 212, no. Part A, pp. 117-124, 1998.
[4] D. GRYGO, “Proposal For Build A Test Stand To The Study Water Ram Based On The Recommendations Construction,” *J. Civ. Eng. Environ. Archit.*, vol. 63, pp. 137-147, 2016.

Design, analysis and fabrication of UTM hydraulic ram pump for water supply in remote areas (S. Sarip)
BIOGRAPHIES OF AUTHORS

Shamsul Sarip is an academic staff of Razak Faculty of Technology and Informatics, Universiti Teknologi Malaysia Kuala Lumpur. He received Diploma of Mechanical Engineering in 1995, Bachelor of Mechanical Engineering in 1998, and Master of Mechanical Engineering in 2002 from the Universiti Teknologi Malaysia. He then obtained his PhD in Mechanical Engineering from University of Bradford, United Kingdom in 2012. He has been involved in the area of engineering design including lightweight disc brake, macro hydro turbine, ram pump, marine current turbine and product development. He also involved in university motor sport activities which required him to expand the knowledge to finite element analysis, heat transfer, computational fluid dynamics and structure analysis.

Abdul Qoiyum Mohd Radzi holds a Bachelor in (Mechanical-Automotive) Engineering from Universiti Teknologi Malaysia in 2007. He is currently studying Master of Science in Engineering Design at Razak Faculty Technology and Informatics, UTM Kuala Lumpur. His interest is in Renewable Energy, Mechanical Design Process and Analyzed, Design Optimization for Wind Turbine and Fluid Power.

Tung Siew Hong holds a Bachelor Degree in Electrical & Electronics Engineering from Universiti Tenaga Nasional (UNITEN), Malaysia in year 2010. He is a practicing engineer registered with BEM, member of IEM and IET. In year 2018, he was appointed as Regional Technical Manager in a Singapore-based company, focused on Factory Automation & Intelligence solution, Robotics and Vision Inspection Systems.
Roslina Mohammad is an academic staff at Razak Faculty of Technology and Informatics, Universiti Teknologi Malaysia, Kuala Lumpur. She received Diploma Mechanical Engineering in 2000, Bachelor Engineering (Hons) Mechanical Engineering in 2003 and Master Science Mechanical Engineering, from Universiti Teknologi Malaysia in 2007. She then obtained Ph.D. of Mechanical Engineering from University of Adelaide, South Australia, Australia in 2011. She has an expertise in the area of solid and impact mechanics and risk assessment and management. She has also been involved in the area of mechanical fatigue particularly in analytical, numerical and experimental of fatigue of pipeline.

Fitri Yakub received his Dip Eng., and BEng. degrees in Mechatronics Engineering and Electronics Engineering from University of Technology Malaysia in 2001 and 2006 respectively. He obtained MSc. in Mechatronics Engineering from International Islamic University Malaysia in 2011. His field of research interest includes intelligent control, automatic and robust control, and motion control, which related to applications of positioning systems, vehicle dynamics system, and vibration and control system.

Mohamed Azlan Suhot is an academic staff of Faculty of Technology and Informatics Razak, UTM Kuala Lumpur. He received his bachelor and masters education in Materials Engineering from University Science Malaysia in 1996 and 2000 respectively. He then pursued and finished his PhD in Composite Materials from University of Southampton, United Kingdom in 2008. He has been involved in the area of renewable energy especially involving installation of sustainable pumps and turbines in remote and rural area. He is also very passionate in activities involving UTM students which also required him to be close with communities and NGOs.

Hazilah Mad Kaidi received her B.Eng (Horns) in Electrical Engineering in Teleommunication, Universiti Teknologi Malaysia, the M.Sc. degree in Telecommunication and Information Engineering at Universiti Teknologi MARA and the Ph.D. degree from the Universiti Teknologi Malaysia. She is currently a senior lecturer at Razak Faculty of Technology and Informatics, Universiti Teknologi Malaysia Kuala Lumpur. Her research interests include mobile and wireless communications, error control coding, relay networks, cooperative communications, Hybrid ARQ Cross Layer Design and iterative receiver.

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$^3$s$^{-1}$ | Qd $(10^{-3})$ m$^3$s$^{-1}$ | Qw $(10^{-3})$ m$^3$s$^{-1}$ | 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

$$Q_s = \frac{N \pi L}{60}$$  \hspace{1cm} (3.0)

When N=49 beat cycle/minute, then

$$Q_s = \frac{49 \times 3.142 \times 37.5 \text{ m}}{(0.035)^2/60} = 135.3 \times 10^{-3} \text{ m}^3\text{s}^{-1}$$

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

$$V_s = \sqrt{\frac{2gH}{C}}$$ \hspace{1cm} (4.0)

$$= 0.96 \sqrt{2 \times 9.8 \times 2} = 6.01 \text{ m/s}$$

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

$$V_d = \sqrt{\frac{2gH}{C}}$$ \hspace{1cm} (3.0)

$$= 0.96 \sqrt{2 \times 9.8 \times 20} = 19.02 \text{ m/s}$$

Discharge through delivery pipe is given by

$$Q_d = A_d V_d$$ \hspace{1cm} (4.0)

$$= \frac{\pi}{4} \times 0.025 \times 19.02 = 9.336 \times 10^{-3} \text{ m}^3\text{s}^{-1}$$

Discharge through waste valve is given by

$$Q_w = Q_s - Q_d$$ \hspace{1cm} (7.0)

$$= (135.3 - 9.336) \times 10^{-3} = 125.96 \times 10^{-3} \text{ m}^3\text{s}^{-1}$$

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

Design, analysis and fabrication of UTM hydraulic ram pump for water supply in remote areas (S. Sarip)
Velocity of fluid flow in elbow is given by

\[ V_e = \frac{Q_w}{A_w} \quad (6.0) \]

\[ = \frac{125.96 \times 10^{-3}}{\frac{\pi}{4} \times 0.075^2} \]

\[ = 28.51 \text{ ms}^{-1} \]

Velocity of fluid flow diffuser before the air chamber

\[ V_{diff} = \frac{Q_D}{A_t} \quad (7.0) \]

\[ = \frac{9.336 \times 10^{-3}}{\frac{\pi}{4} \times 0.05^2} \]

\[ = 4.75 \text{ ms}^{-1} \]

Head losses

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

\[ H_1 = \frac{V_{diff}^2}{2g} \quad (8.0) \]

\[ = \frac{(4.75)^2}{2 \times 9.81} \]

\[ = 1.15 \text{ m} \]

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

\[ H_2 = K \frac{V_e^2}{2g} \quad (9.0) \]

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

\[ = 0.5 \frac{(4.75)^2}{2 \times 9.81} \]

\[ = 0.113 \text{ m} \]

3. Head loss at inlet gate valve

\[ H_3 = K \frac{V_e^2}{2g} \quad (10.0) \]

\[ = 0.5 \frac{6.01^2}{2 \times 9.81} \]

\[ = 0.92 \text{ m} \]

4. Head loss at outlet of delivery valve

\[ H_4 = K \frac{V_e^2}{2g} \quad (11.0) \]

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

\[ = 0.29 \frac{46.51^2}{2 \times 9.81} \]

\[ = 5.3 \text{ m} \]

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

\[ H_3 = K \frac{V_e^2}{2g} \quad (12.0) \]

\[ = 0.5 \frac{21.1^2}{2 \times 9.81} \]

\[ = 0.268 \text{ m} \]

6. Head loss due to the galvanized elbow connector pipe

\[ H_3 = K_e \frac{V_e^2}{2g} \quad (13.0) \]

\[ K_e = 1.129 \text{ refer to [10] page 127 for loss factor for elbow (θ = 90°)} \]

\[ = 1.129 \frac{28.51^2}{2 \times 9.81} \]

\[ = 46.77 \text{ m} \]

7. Reynolds number is given by

\[ Re = \frac{4V_d}{\pi} \quad (14.0) \]

According to ASTM standard for water viscosity

at 20°C, \( \mu = \frac{0.001002 \text{ kg}}{\text{ms}} \), \( \rho = \frac{1000 \text{ kg}}{m^3} \)

\[ Re = 4.5 \times 10^5 \]

8. Coefficient of friction is given by

Referring to [10] pages 116 for PVC as smooth pipe for the equation of Nikuradse

\[ f = 0.0032 + 0.221 \times Re^{0.25} \text{ for} \]

\[ \text{Indonesian J Elec Eng & Comp Sci, Vol. 17, No. 1, January 2020 : 213 - 221} \]
Design, analysis and fabrication of UTM hydraulic ram pump for water supply in remote areas (S. Sarip)

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

\[ H - \frac{f}{D} \left( \frac{\pi}{2} \right) - \frac{\sum (K_r \omega^2)}{2g} \frac{d^2v}{dt^2} = 0 \]  

(15.0)

\[ \frac{d^2v}{dt^2} = 0.13 \text{ m}^2\text{s}^{-1} (-\nu e) \]

10. Drag force is given by the equation

\[ F_D = C_D A_D \frac{\rho}{2g} \frac{v_e^2}{2g} \]  

(17.0)

\[ = 1.12 \times 2 \times 4 \times 0.075^2 \times 1000 \times \frac{28.51}{289.81} \]

\[ = 7.2 \text{ N (-ve)} \]

11. The pressure at the waste valve is obtained by

\[ P_3 = \frac{F}{A_x} \]  

(18.0)

\[ = 7.2 \times 0.075^2 \]

\[ = 1.63 \text{ kNm}^{-2} \]

12. The power required can be calculated using this expression

\[ P = pgHQ_s \]  

(19.0)

\[ = 1000 \times 9.81 \times (20.2) \times 135.3 \times 10^{-3} \]

\[ = 23.9 \text{ kW} \]

13. The efficiency of the hydraulic ram pump is given by [5], \( h = H_d - H_s = 20 - 2 = 18 \text{ m} \).

\[ \eta = \frac{Q \times H}{Q_s \times H_s} \times 100\% \]  

(20.0)

\[ = \frac{9.336 \times 10^{-3} \times 9}{135.3 \times 10^{-3} \times 2} \times 100\% \]

\[ = 6 \]