PERFORMANCE OF A HYDRAULIC RAM PUMP

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DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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ABSTRAK

Hidraulik ram pam merupakan sejenis peranti tenaga yang boleh diperbaharui dan mengunakan tenaga potensi air untuk pam air dengan aplikasi kesan tukul air. Perubahan dalam ketinggian bekalan, penghantaran dan geometri tangki tekanan udara akan menjejaskan prestasi hidraulik ram pam.

Kesan-kesan daripada faktor-faktor tersebut akan diujikan melalui eksperimen. Beberapa eksperimen telah dijalankan dengan menggunakan ketinggian bekalan 1.0m, 1.5m dan 2.0m, ketinggian penghantaran daripada 2.0m ke 7.5m dan tangki tekanan udara yang bersaiz 0.515L, 1.030L, 1.544L, 2.059L dan 2.574L.

Keputusan eksperimen tersebut menujukkan bahawa penambahan dalam ketinggian bekalan akan memperbaiki prestati hidraulik ram pam manakala penambahan dalam ketinggian penghantaran akan menyebabkan penjatuhan dalam prestasi pam. Pada ketinggian bekalan 1.0m, hidraulik ram pam mempunyai volumetrik kecekapan daripada 0.855% ke 6.022% pada ketinggian penghantaran daripada 2.0m ke 5.5m dan tangki tekanan udara dengan 1.030L mempunyai prestasi keseluruhan yang terbaik. Pada ketinggian bekalan 1.5m, hidraulik ram pam mempunyai volumetrik kecekapan daripada 2.550% ke 5.925% pada ketinggian penghantaran daripada 2.0m ke 5.5m dan tangki tekanan udara dengan 1.544L mempunyai prestasi keseluruhan yang terbaik. Pada ketinggian bekalan 2.0m, hidraulik ram pam mempunyai volumetrik kecekapan daripada 1.064% ke 2.790% pada ketinggian penghantaran daripada 4.0m ke 7.5m dan tangki tekanan udara dengan 1.544L mempunyai prestasi keseluruhan yang terbaik. Di samping itu, hidraulik ram pam yang mempunyai tangki tekanan udara yang lebih kecil menunjukkan prestasi yang lebih baik tetapi penambahan dalam ketinggian bekalan pam perlukan tangki tekanan udara yang lebih besar. Keputusan penyelidikan ini boleh membekalkan satu rujukan dalam membina hidraulik ram pam yang mempunyai prestasi yang lebih baik bersekutu dengan aplikasinya.

ABSTRACT

Hydraulic ram pump is a renewable energy device used to pump water using potential energy of falling water based on water hammer effect. The changes in supply head, delivery head and air vessel geometry of hydraulic ram pump will affect its performance.

The effects of these factors on the pump performance were studied experimentally. Several sets of experiments were conducted under supply heads of 1.0m, 1.5m and 2.0m, delivery heads from 2.0m to 7.5m and air vessels with volume of 0.515L, 1.030L, 1.544L, 2.059L and 2.574L.

The results showed that the increase in supply head improved the pump performance whereas the increase in delivery head caused a decrease in the performance. At supply head of 1.0m, hydraulic ram pump operated at volumetric efficiency of 0.855% to 6.022% at delivery head of 2.0m to 5.5m and air vessel with 1.030L had the overall best performance. At supply head of 1.5m, hydraulic ram pump operated at volumetric efficiency of 2.550 % to 5.925% at delivery head of 2.0m to 5.5m and air vessel with 1.544L had the overall best performance. At supply head of 2.0m, hydraulic ram pump operated at volumetric efficiency of 1.064% to 2.790% at delivery head of 4.0m to 7.5m and air vessel with 1.544L had the overall best performance. Besides, hydraulic ram pump with smaller air vessel performed better in high delivery heads but bigger air vessel was required when the supply head increased. The findings of this research also provide a guideline in developing a hydraulic ram pump with better performance associated with its application.

CHAPTER 1: INTRODUCTION

In this section, brief introduction on hydraulic ram pump and its applications are discussed.

1.1 Research background

For decades farmers irrigate their crops using water from the nearby stream or lake via electrical water pumping system. The water pumping devices pump water to the fields by means of conversion of electrical energy to mechanical energy. Petroleum, gas and coal are burned to generating electrical energy for different applications. In future the world will be confronted with the crisis of fossil fuel depletion and the energy cost will increase significantly. This could affect the agriculture field especially in the rural agriculture areas.

There are still remote areas may not be accessible to electrical power supply where water is still needed to be transferred from one location to another. Therefore, an alternative solution is needed to help the people in remote areas to get the water supply.

Hydraulic ram pump, in short also referred to as hydram was created by John Whitehurst of Cheshire, U.K. in 1772 [1]. Hydraulic ram pump can be a viable and appropriate renewable energy water pumping technology in delivering water by using potential energy of water based on water hammer effect. The hydraulic ram pump consists of two moving parts, the waste and delivery valves and also an air chamber. The construction consists of pipe fittings of suitable size making it reliable, cost saving, less maintenance and sustainable. Figure 1.1 and Figure 1.2 show two different types of hydraulic ram pump. Therefore, hydraulic ram pump could be applied in the remote areas to transfer the water.

Output performance of a hydraulic ram pump is highly dependent on its design, air vessel geometry, supply head and delivery head. In other words, the design of hydraulic ram pump should take into account the basic geometry of pump, location of water reservoir and tank. The relationship between these factors can be investigated experimentally in term of their correlation which provide a guideline in achieving the optimum performance of a hydraulic ram pump.

Figure 1.1: Hydraulic ram pump used in rural area

Figure 1.2: Hydraulic ram pump made by Pu-Quan Enterprise Co. Ltd. in Taiwan

1.2 Water hammer effect

Water hammer effect is a pressure surge or wave produced when a fluid in motion is forced to stop or change its direction suddenly. A water hammer commonly occurs in the pipeline system when a valve closes suddenly, the generated pressure wave will propagate along the pipe. This pressure wave can lead to major problems, such as, noise, vibration and pipe collapse as shown in Figure 1.3. The effects of water hammer can be reduced using accumulators, surge tanks, expansion tanks and other features. Although water hammer effect is undesirable in the pipeline system, its principle can be used to create a simple water pumping device called hydraulic ram pump.

Figure 1.3: Pipes broken from water hammer

1.3 Problem statement

There is limited literature available on hydraulic ram pump performance and the performance is highly dependent on supply head, delivery head and air vessel geometry. By varying these factors, the volumetric flow rate delivered by the pump changes accordingly. Therefore, the effects of these factors on hydraulic ram pump performance are to be studied experimentally, aiming for a better understanding of the influences of these factors on hydraulic ram pump performance. Besides, the correlation between the related factors can provide a guideline in hydraulic ram pump development.

1.4 Research objectives

1) To study the effect of diameter and volume of air vessel on the hydraulic ram pump performance.
2) To study the correlation of air vessel volume, supply head and delivery head of hydraulic ram pump.
3) To design a hydraulic ram pump laboratory.

1.5 Scope of the project

In this project a medium-sized hydraulic ram pump will be designed and fabricated. Different sets of experiment are then conducted using the hydraulic ram pump to obtain relevant experimental data. The experiment will involve several parameters of hydraulic ram pump, such as, supply head, delivery head, diameter and volume of air vessel of hydraulic ram pump. The obtained data is plotted into graphs and analyzed to study the effects of the parameters on the hydraulic ram pump performance. The correlation between these parameters will be determined and used to create formulations which will able to define the hydraulic ram pump performance.

CHAPTER 2: LITERATURE REVIEW

In this section, relevant resources are reviewed in order to obtain sufficient knowledge about hydraulic ram pump.

2.1 Drain valve

Nuttakit Saenthong [2] in Thailand had done a research to study the effects of drain valves on flow rate of the hydraulic ram pump. The study was conducted using hydraulic ram pump as shown as Figure 2.1. Three sizes of drain valves of 25, 38 and 50 mm were used in the experiment and connected to an air chamber with 102 mm diameter, and 450 mm height. In addition, three mass pressures of 800g, 900g and 1100g were used to push the valve in the experiment. From the results of the experiment, it was shown that the flow rate of ram pump is dependent on the diameter and mass pressure of the drain valve. However, the dependency is not linear where there is a limitation on the diameter and mass pressure of drain valve in order to produce the maximum flow rate. The results showed that drain valve with 38mm diameter and mass pressure on the valve of 900g showed the highest flow rate of 25 liters per hour. Consequently, the hydraulic ram pump optimum design for the highest flow rate should take into account the size of the diameter of the drain valve and mass pressure to push valves.

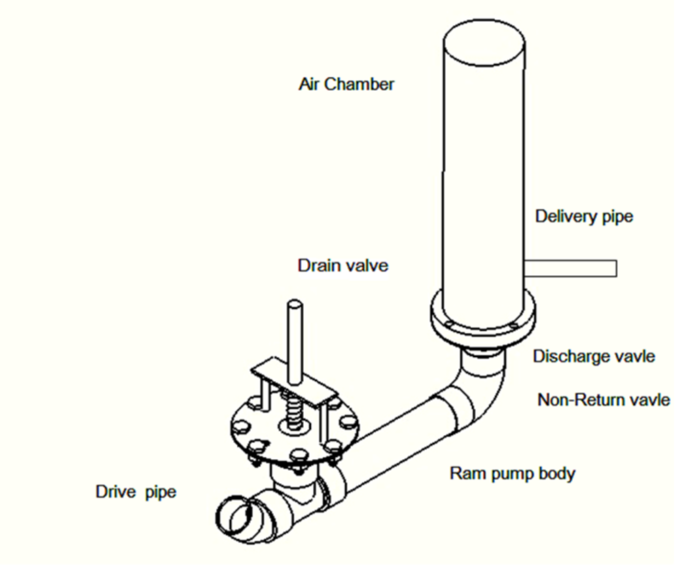


Figure 2.1: The body and parts of hydraulic ram pump [2]

2.2 Method of improving efficiency

Poonam Diwan, Aman Patel and Lavish Sahu [3] had designed and fabricated a hydraulic ram pump to improve the efficiency by using of air vessel, multiple ram set-up, small drive pipe diameter, lighter mass of the waste valve plunger and PVC drive pipe. The final design is shown in Figure 2.2. Then, the ram pump had a higher efficiency of 31.05% compared to the design developed earlier by using 1-1/4 inch valve with efficiency of 25.81%.

Figure 2.2: Final assemble hydraulic ram pump [3]

2.3 Inner diameter of pipes

Sumio Saito [4] and his team claimed that the performance of hydraulic ram pump could be evaluated based on the basic hydrodynamic characteristics, such as, pump head and flow rate. The study focused on understanding the basic hydrodynamic characteristics of hydraulic ram pump and experimentally examined how the hydrodynamic characteristics are affected by the inner diameter of the drive and lifting pipes, capacity of the air vessel and the angle of the drive pipe, which represent the geometry of the hydraulic ram pump. The results showed that the drain flow rate and number of water hammer occurrences increased when the drive pipe inner diameter increased while the lifting pipe diameter was fixed. Besides, the capacity of the air vessel was found to have negligible effect on its performance. On the other hand, the ratio of delivery head to supply head decreased as the drive pipe angle increased.

2.4 Head ratio

Sakhare Mayur Mahadev [5] had designed a ram pump and tested it with different head difference and ratio of delivery head to supply head. The experiment was conducted using suppy height of 2.29m, 2m and 1.63m above the ground level, and each inlet height was tested with different delivery height of 20ft, 18ft and 15ft. Based on the experiment, the maximum efficiency was obtained at head ratio of 2. The pump gave 450litre per hour water discharge for maximum efficiency of 41.25% and 98litre per hour water discharge for minimum efficiency of 18.65%. [5] The assembly of experiment is shown in Figure 2.3.

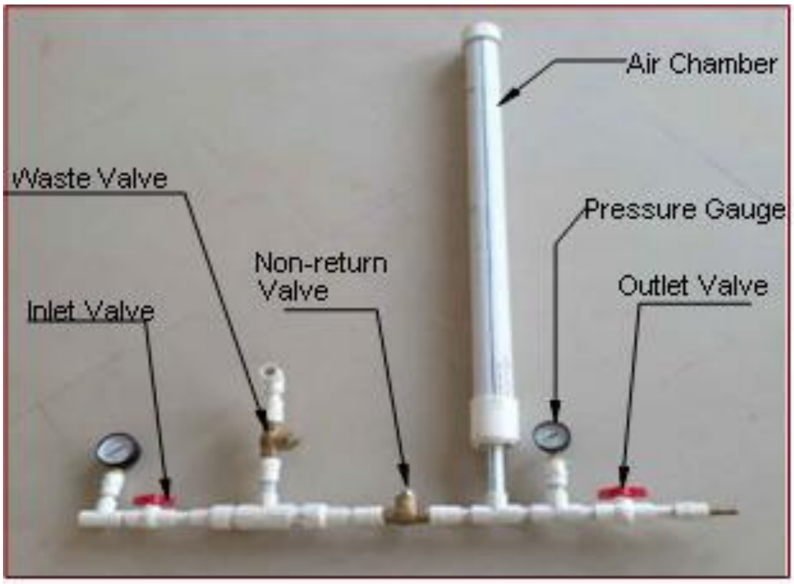


Figure 2.3: Assembly of automatic hydraulic ram pump [5]

2.5 Water recirculation system

Sampath S S [6] and his team designed a hydraulic ram pump with water recirculation system to avoid wastage of water. The ram pump was then tested with different length of inlet pipe to study its effects to the outlet water flow rate, pressure and supply pipe length. The experiment was repeated by using different head and lift height to study its relationship. It was observed that by maintaining the head constant and increasing the lift height there was a drop in the volume of water delivered with respect to the time period. Their work emphasized in the calculation of the discharge, power and the efficiency of the ram pump and then compare them with other research paper. The configuration of the ram pump is shown in Figure 2.4.

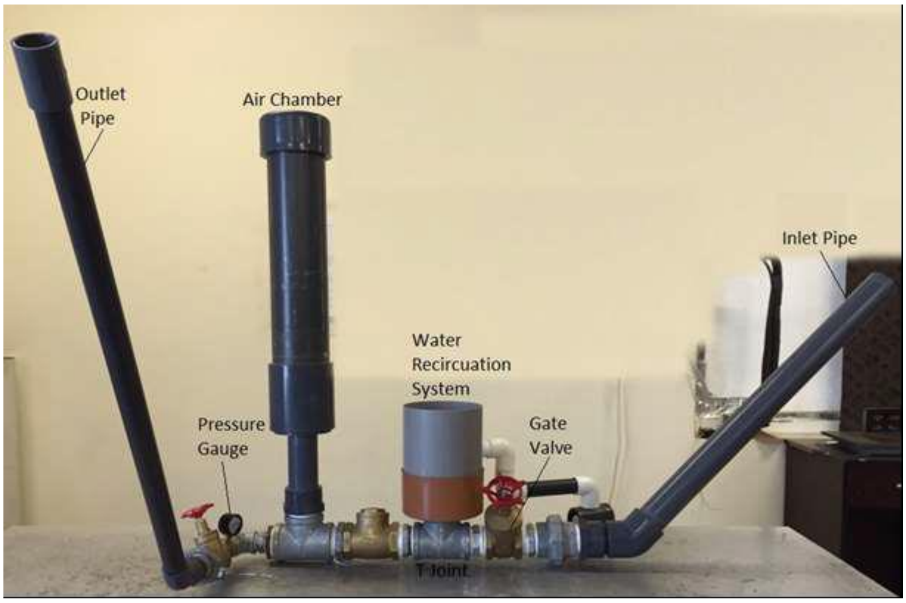


Figure 2.4: Fully constructed hydraulic ram pump with water recirculation system [6]

2.6 Air vessel size and types of valve

Matthias Inthachot [7] and his team had designed a ram pump and connected to an automatic low pressure irrigation system to irrigate a small plot of coffee trees. Besides, they tested the ram pump by changing some of its components and configuration to look for the most efficient ram pump as shown in Figure 2.5and Figure 2.6. At the test stand different trials were carried out:

- Different air vessel sizes
  - A small one with a volume of 0.6 litres (made of 250mm length, 50mm pipe diameter and analogous end cap and reducer fitting).
  - A medium sized one, volume 2.3 litres (made of 450mm length, 75mm pipe diameter, analogous end cap plus reducer fitting).
  - Big air vessel with a volume of 3.6 litres (made of 700mm length, 75mm pipe diameter plus end cap and reducer fitting).
- Different valve types as impulse valve
  - Clap check valve
  - Inlet valve (1” brass brazen, ¾” PVC and 1 ½” PVC)

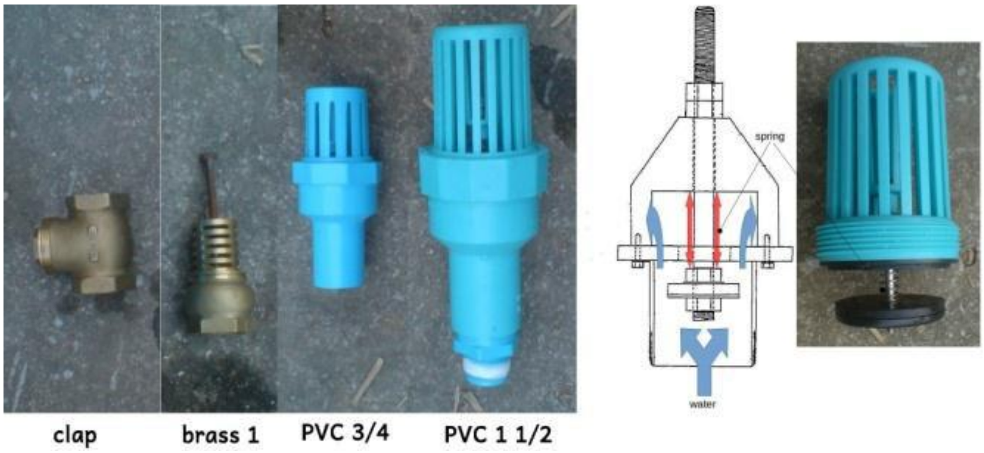


Figure 2.5: Different valves tested as impulse valve in the construction of hydraulic ram [7]

- Different valve configurations

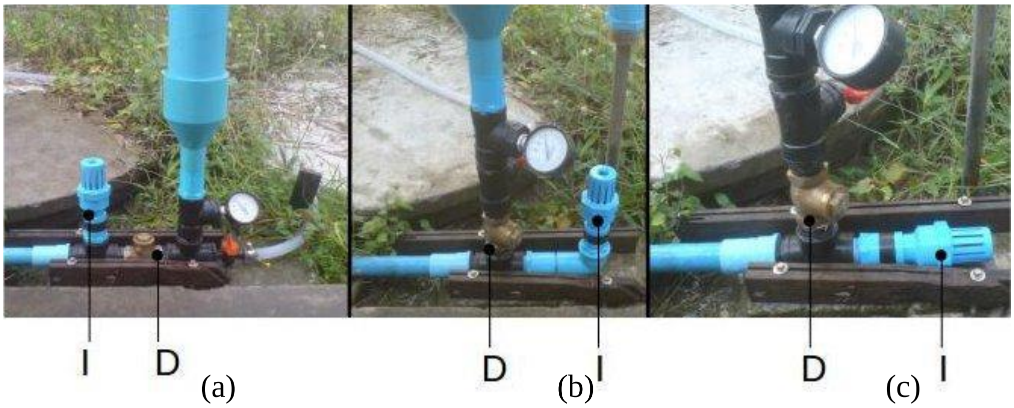


Figure 2.6: Different valve configurations in the construction of hydraulic ram with I impulse valve; D delivery valve) [7]

The experimental results indicated that the ram pump with the smallest air vessel attached did not work and strokes caused harder shocks on the system because the pressure chamber was full of water. From 2.3litres on, air vessel volume was found not crucial for operation of the ram pump. Best results were achieved with the 1½" PVC inlet valve but its durability is a concern as it is made of plastics. It was claimed that both valve configurations have their pros and cons. Configuration (a) produced more significant water hammer effect whereas (b) and (c) provided smoother water flow without disturbance.

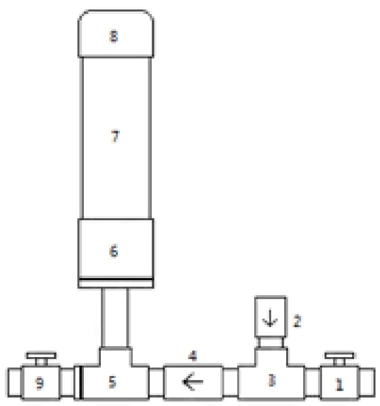
In summary, there are limited literature focussing on the effect of geometry of air vessel on the performance of hydraulic ram pump. Sampath S S [6] only studied the effects of different length of drive pipe to the performance of hydraulic ram pump with water recirculation system. Besides, the water recirculation system can actually be removed because the water comes out from the waste valve will flow back to the stream or river and it is not considered as wastage. Poonam Diwan [3] did mentioned that the above stated variables of pump could improve the ram pump performance. However, he did not study in detail how these variables could affect the ram pump performance.

CHAPTER 3: METHODOLOGY

A complete hydraulic ram pump system was built for the experiment. Several parameters were investigated, which were, supply head, delivery head and air vessel geometry. Thus, the hydraulic ram pump system used in the experiment was designed in such a way which allowed the variations in the parameters. In this section, the content is presented in the following broad area to explain the details of the experiment:

3.1 Hydraulic ram pump design

A 19mm diameter, medium-sized hydraulic ram pump was developed based on configuration as shown in Figure 3.1. The pipe fittings and polyvinyl chloride (PVC) pipes were prepared and jointed together using PVC cement to form the parts of hydraulic ram pump. The complete hydraulic ram pump is shown in Figure 3.2.



1. 3/4" PVC ball valve
2. 3/4" brass swing check valve
3. 3/4" PVC tee
4. 3/4" spring check valve
5. 3/4" PVC tee
6. 2" x 3/4" reducing socket
7. 2" x 10" PVC pipe
8. 2" PVC cap
9. 3/4" PVC ball valve

Figure 3.1: Design configuration of hydraulic ram pump

Figure 3.2: Hydraulic ram pump (19mm diameter)

3.2 Air vessels

In order to study the effects of air vessel geometry on performance of hydraulic ram pump, air vessels with different diameter and volumes were required in the experiment.

Therefore, air vessels with same diameter but different volumes were fabricated using PVC caps, PVC pipes and PVC reducers as shown in Figure 3.3. Air vessels volumes used in the experiment were 0.515L, 1.030L, 1.544L, 2.059L and 2.574L. The volumes were determined based on the ratio of height to diameter of air vessels with an interval increment ratio of 5, so that the difference in air vessel volumes was big and its effects on the pump performance were significant which simplified the subsequent result analysis.

In addition, air vessels with same volume but different diameters were fabricated using PVC caps, PVC pipes and PVC reducers as shown in Figure 3.4. The air vessels have the same volume of 1.030L but diameters of 50mm, 75mm and 100mm.

Figure 3.3: Air vessels with same diameter but different volumes (from left: 0.515L, 1.030L, 1.544L, 2.059L and 2.574L)

Figure 3.4: Air vessels with same volume but different diameters (from left: 50mm, 75mm and 100mm)

3.3 Waste water collector

A tray was used as collector of waste water released by the hydraulic ram pump during its operation. Figure 3.5 showed the waste water collector with hydraulic ram pump.

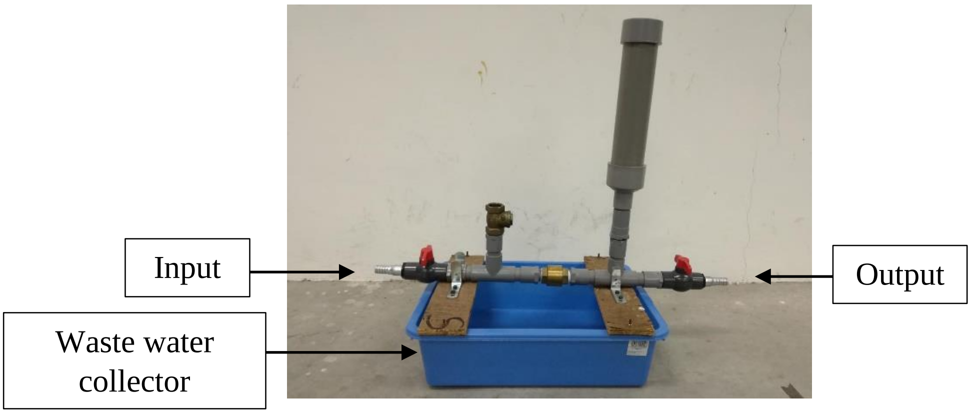


Figure 3.5: Waste water collector with hydraulic ram pump

3.4 Supply head

Different heights of supply head was required in the experiment to manipulate the input volume flow rate of the hydraulic ram pump. Plastic table was used as the supply head supporter because it was obtainable and able to withstand the weight of water tank. The tables were stacked up to achieve different height as shown in Figure 3.6. The excess water remover port was used to maintain the supply head by circulating the excess water to the waste water collector.

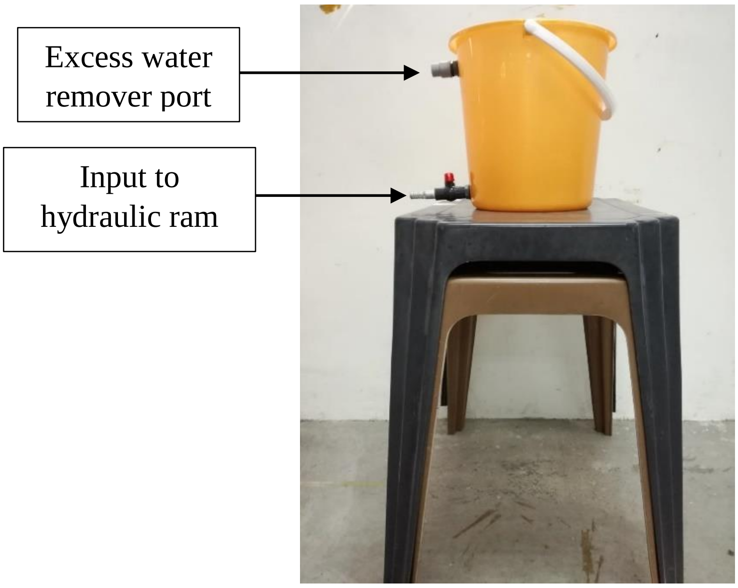


Figure 3.6: Supply head supporter

3.5 Delivery head

The delivery head support frame was made of PVC pipes to hang the delivery pipe to higher elevation. The PVC pipes were assembled together with PVC connectors which allows its height to be extendable to desired height, thus making it to be height adjustable. The support frame was supported by a heavy base as shown in Figure 3.7. It was placed at different floors of building to further increase the delivery head, such as, first floor of building to achieve higher delivery heads.

Figure 3.7: Delivery head support frame

3.6 Complete experimental setup

The complete system setup is shown in Figure 3.8 and 3.9. The hydraulic ram pump system consists of a 5m head submersible water pump to recirculate the drained water from the hydraulic ram pump back to the water supply bucket so that the supply head can always be maintained at the same water level. The submersible water pump was shown in Figure 3.10.

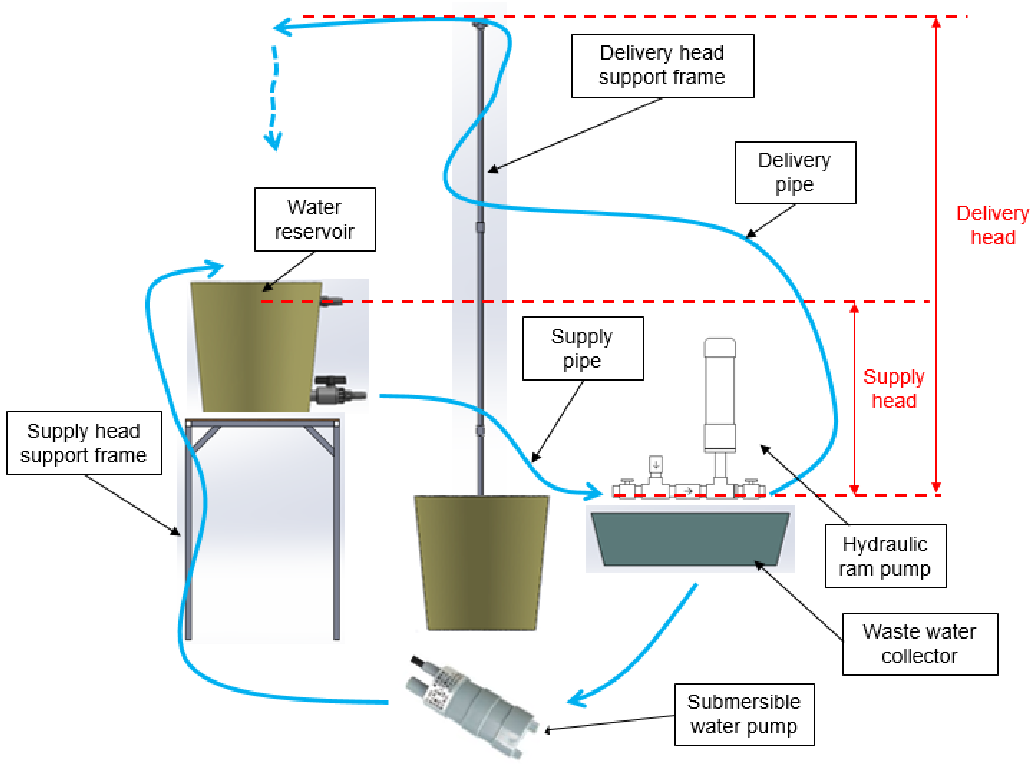


Figure 3.8: Illustration of complete hydraulic ram pump system setup

Figure 3.9: Complete experimental setup

Figure 3.10: Submersible water pump (12V, 5m head)

3.7 Experiment procedures

Two different parts of experiments were conducted to achieve the research objectives by acquiring sufficient experimental data, which was, constant air vessel diameter but different volumes and constant air vessel volume but different diameters. At the same time, different supply heads and delivery heads were included in the experiment.

3.7.1 Constant air vessel diameter but different volumes

The experiment was set up as shown in Figure 3.8 with supply head of 1.0m, delivery head of 2.0m and air vessel with 0.515L shown in Figure 3.3. The submersible water pump was connected to the power supply and turned on. Then, the ball valves of the supply head and pump input were turned on fully. After that, the brass swing check valve was primed by tapping its flap until the hydraulic ram pump started to operate continuously. The output ball valve was opened slowly until it was fully opened (If the output ball valve cannot be opened fully, open it to the maximum where the hydraulic ram pump still able to operate). Let the system run for three minutes to achieve steady condition. The time taken for the hydraulic ram pump to deliver 1L of water to the measuring beaker was measured using a stopwatch. The measurement was repeated three times to get an average value. The experiment was repeated by changing the delivery head to 2.5m until 5.5m with an interval of 0.5m. After that, repeated the entire experiment with air vessel volume of 1.030L, 1.544L, 2.059L and 2.574L. (When changing the air vessel, turn off all the ball valves and dismantle the assembled air vessel slowly to prevent the water burst out of the air vessel suddenly due to high pressure accumulated.) The results were tabulated and plotted into graphs.

3.7.2 Constant air vessel volume but different diameters

The experiment was set up as shown in Figure 3.8 with supply head of 1.0m, delivery head of 2.0m and air vessel with 50mm diameter as shown in Figure 3.4. The submersible water pump was connected to the power supply and turned on. Then, the ball valves of the supply head and pump input were opened fully. After that, the brass swing check valve was primed by tapping its flap until the hydraulic ram pump started to operate continuously. The output ball valve was opened slowly until it was fully opened. (If the output ball valve cannot be opened fully, open it to the maximum where the hydraulic ram pump still able to operate) Let the system run for three minutes to achieve steady condition. The time taken for the hydraulic ram pump to deliver 1L of water to the measuring beaker was measured by a stopwatch. The measurement was repeated three times to get an average value. The experiment was repeated by changing the delivery head to 2.5m until 5.5m with an interval of 0.5m. After that, the entire experiment was repeated with air vessel with diameter of 75mm and 100mm. (When changing the air vessel, turn off all the ball valves and dismantle the assembled air vessel slowly to prevent the water burst out of the air vessel suddenly due to high pressure accumulated.) The results were tabulated and plotted into graphs.

CHAPTER 4: RESULTS AND DISCUSSION

In this chapter, the results of this research work are presented for experimental results of constant air vessel diameter with different volume, constant air vessel volume with different diameters, formulation of hydraulic ram pump and designing hydraulic ram pump experiment set up for undergraduate program students.

4.1 Constant air vessel diameter but different volumes

Air vessel with same diameter of 50mm but different volumes were used in the experiment. There were five different volumes of air vessel used, which was, 0.515L, 1.030L, 1.544L, 2.059L and 2.574L.

4.1.1 Supply head = 1m & inlet volume flow rate = 0.26 L/s

Below is the results obtained from the experiment of hydraulic ram pump system with supply head of 1.0m.

Table 4.1: Time taken to collect 1L of water for different delivery head with different volume of air vessels at 1.0m supply head

Volume (L)	Delivery head (m) / Aspect ratio (h/D)	Time taken to collect 1 Litre of water (s)							
		2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5
0.515	5	70.00	72.93	102.50	125.66	134.79	180.63	277.02	344.43
1.030	10	64.21	65.76	88.39	119.27	135.78	175.63	265.62	341.67
1.544	15	63.87	67.55	91.78	118.49	136.52	177.85	258.70	353.79
2.059	20	64.89	67.28	94.27	125.35	150.56	207.42	293.59	515.34
2.574	25	68.48	69.70	96.93	131.40	142.23	209.44	329.18	449.79

Table 4.2: Volume flow rate of hydraulic ram pump for different delivery head with different volume of air vessels at 1.0m supply head

Volume (L)	Delivery head (m) / Aspect ratio (h/D)	Volume flow rate (L/s)							
		2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5
0.515	5	0.01429	0.01371	0.00976	0.00796	0.00742	0.00554	0.00361	0.00290
1.030	10	0.01557	0.01521	0.01131	0.00838	0.00736	0.00569	0.00376	0.00293
1.544	15	0.01566	0.01480	0.01090	0.00844	0.00733	0.00562	0.00387	0.00283
2.059	20	0.01541	0.01486	0.01061	0.00798	0.00664	0.00482	0.00341	0.00194
2.574	25	0.01460	0.01435	0.01032	0.00761	0.00703	0.00477	0.00304	0.00222

Table 4.3: Volumetric efficiency of hydraulic ram pump for different delivery head with different volume of air vessels at 1.0m supply head

		Volumetric efficiency (%)							
Volume (L)	Delivery head (m) / Aspect ratio (h/D)	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5
0.515	5	5.49477	5.27400	3.75235	3.06076	2.85344	2.12930	1.38839	1.11666
1.030	10	5.98996	5.84848	4.35135	3.22466	2.83264	2.18988	1.44799	1.12570
1.544	15	6.02216	5.69379	4.19047	3.24588	2.81735	2.16258	1.48670	1.08714
2.059	20	5.92749	5.71664	4.07993	3.06825	2.55457	1.85425	1.31003	0.74634
2.574	25	5.61674	5.51842	3.96797	2.92706	2.70418	1.83643	1.16840	0.85511

$$\text{*Volumetric efficiency} = \frac{Volume\ flow\ rate}{Inlet\ volume\ flow\ rate} \times 100\%$$

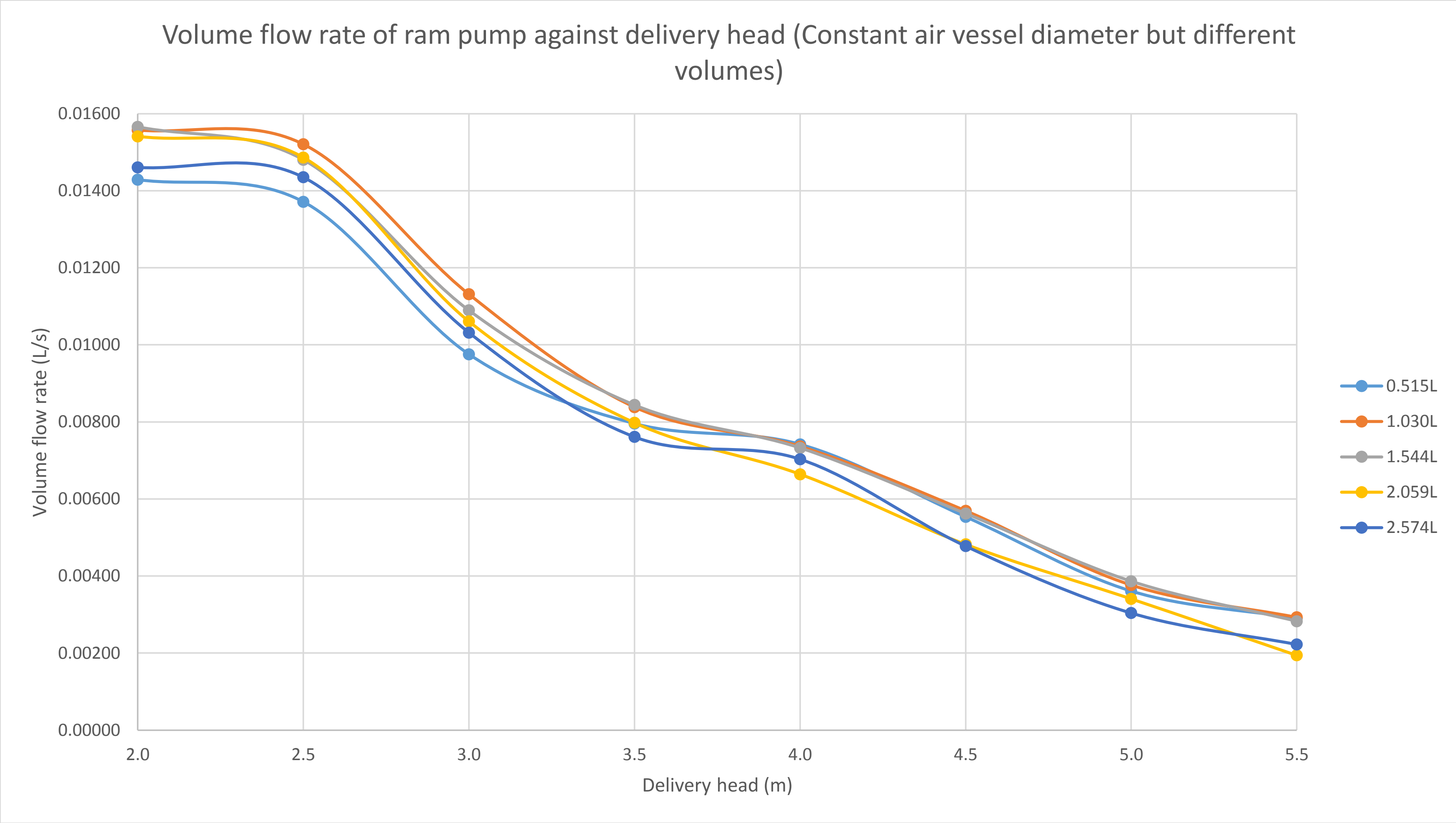


Figure 4.1: Volume flow rate of hydraulic ram pump for different delivery head with different air vessel volumes at 1.0m supply head