The use of hydraulic ram pump for increasing pump head-technical feasibility

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Abstract
The combined pump and hydraulic ram pump (HRP) was presented to evaluate the technical feasibility for increasing pump head. This method was used to demonstrate a possible low-cost alternative solution to supply water in remote areas. It illustrated the case where energy in rivers was not enough to drive HRP and a pump alone could not lift water to the required head. The HRP was connected in series with the pump. The experiment on the combined system operation was investigated. The system was working only at a certain range of flow rates for a power supply by the pump. Therefore, HRP was adjusted to pump water in the range that the waste valve was functioning. The combined system can operate at a low flow rate with a high head without extra energy and no overloading. It reveals that the more discharge head is required, the less flow can be lifted which results in a high number of valve beats per minute of the waste valve. Experimental determination of the optimal values for these parameters will make it possible to provide for a feasible design of HRP in the given pump. The optimal HRP will make it possible to ensure the required performance (delivery, head, efficiency) of the combined system.

KEYWORDS
application of HRP, combined pump and hydraulic ram pump, experiment, increasing pump head, valve beats per minute of the waste valve

1 INTRODUCTION

Ideally, a pump should deliver flow at a pressure or head efficiently and reliably over a wide range of operating conditions. Installed water pumps in some cases are insufficient to meet head or lift fluctuations. This can occur during a drought when water levels in rivers or canals fall, and the head or lift increases. A variety of workable solutions to the problem exist, such as adding another pump in series, or installation of an over-design pump, but the added pump will generally cost. This is a real and serious problem in many places, especially in the north-east of Thailand where the people live in poverty and remote rural areas. A possible low-cost alternative solution to supply water in remote areas is required. Despite many different pump designs and installations, the purpose of this paper is to increase the pump head in those remote areas of limited use of pumps. In a situation where the people could not afford to buy a new pump. This came across when we learned that the people in Pachan village, Ubon Ratchathani Province, Thailand, tried to increase the...
pump head by using the twin column which was placed close to the pump exist as shown in Figure 1. The experiment on the twin column was conducted at King Mongkut’s University of Technology Thonburi (KMUTT). The results did not show any improvement in the pump head. However, the installation of the twin column is working as the air chambers that can avoid damage to the pump system due to water hammer and smooth the flow rate. Therefore, we searched for a similar invention which could increase a pump head and found that hydraulic ram pump (HRP) might be interested. It is one of the simplest and the most environmentally friendly devices for such applications.

The idea of using HRP is exquisite and many studies have been done, mostly about the use of a flowing stream for pumping water to a higher altitude than the point of water supply without an external energy source. Recently, the interest in HRP for water supply has been renewed due to the awareness of the adverse impact of climate change and the needs of sustainable technology, especially in remote areas of developing regions. 2,3 Comparisons and reviews dealing with HRP systems can be seen in Watt, 4 Eric, 5 Browne, 6 and Matthias et al. 7 A comprehensive study on operation and performance in HRP has been published by Young, 8 Mbiu et al, 9 Suarda et al, 10 and Asvapoositkul et al. 11 Several studies have been done to investigate HRP especially the effect of impulse or waste valve on the pump performance. The opening and closing of the waste valve are due to the flow velocity under the action of the supply head. As the flow velocity increases, the disc of the waste valve rises since the drag of the plate overcomes the weight of the valve. The waste valve will close at some flow velocity. The closure will be very rapid. This means that the flow in HRP is unsteady flow with complex behavior. Viccione et al 12 developed a technique to capture the propagating celerity of the developed pressure waves. Unsteady pressure profiles at the impulse and delivery valve were detected using pressure transducers. The displacements at impulse and delivery valves were detected using video recorders. Suarda et al. 12 also investigated the flow pattern and waste valve displacements of various designs via a high-speed video camera to analyze the flow structure and reveal the transport mechanisms in the flows of fluid.

Januddi et al. 2 presented computational fluid dynamics (CFD) simulations to determine the velocity and pressure profile for different valves design. The results show the influence of the waste valve on HRP performance. The new design of HRP with springs system was invented by Rajaonison and Rakotondramiaraana. 13 Many variables are involved in the operation of the system. The influence of supply head, air chamber pressure, and waste valve beats per minute on HRP performance was experimentally determined by Asvapoositkul et al. 11 The results reveal that the HRP characteristics are functions of the waste valve beats per minute and the supply head. It was recommended that the development of innovative design and application of HRP should be done for further investigation. To the best of our knowledge, HRP is applied for seawater desalination. 14,15

This study focuses on the use of a simple and reliable device to increase pump head, which requires a higher lift than can be achieved with a pump. A HRP is installed into the path of the pump exit. The key difference between a conventional pump and a HRP is that a conventional pump is the provider of force to a fluid stream and a HRP uses the force of the stream to do its work. There is currently no experience in the development and operation of a combined pump and HRP for the situation where the pump cannot provide sufficient head. This study is also focused on the technical feasibility, power consumption, and the limitations of such applications.

The present study is to perform an experimental investigation of the operation of a combined pump and HRP (connected in series) and to make a rational analysis with that of a single pump. It illustrated the case where energy sources in rivers or streams were not enough to drive HRP and a pump alone could not lift water to the required head. Many variables are involved in the operation of the pump and HRP, but the ones of primary interest to the designing or operating engineer apart from pump efficiency are the rate of pumping and the head. Therefore, the analysis herein was to determine the rate of pumping and the head for any conditions of operation.
2 | EXPERIMENTAL SETUP

The experimental setup used a pump driven by an electric motor along with a measurement setup as shown in Figure 2. It was assembled with a centrifugal pump, ZUZUMI model ZH-2007 (flow rate range: 0-60 L/min, hydraulic head range: 0-7 m) equipped with a built-in motor at a constant speed of 1450 rpm. The water was drawn by the pump and its flow rate was varied by a valve at the discharge pipe. The polyvinyl chloride (PVC) pipe was used with a nominal diameter of 25 mm (1 in.) and a length of 5 m. The flow at the supply pipe was rated by an Ultrasonic flow meter. The flow at the discharge pipe was gathered in a storage tank during the test. Water pressure at the discharge pipe was read by a pressure transducer. The total head at the discharge pipe was calculated from the measured flow rate and pressure. Power utilization in the pump was rated by using a single-phase multi-meter.

The combined pump and HRP was set up as shown in Figure 3. The HRP used in this study was the same as the one used by Asvapoositkul et al.11 It was made of the PVC pipe and fittings. The HRP drive pipe of a nominal diameter of 25 mm was connected to the centrifugal pump discharge. The pump sucks in water from a water tank and adds energy to the water with a supply head, $H_s$, and a flow rate, $Q_s$. Water from the pump accelerates along the pipe and flows out around the open of the waste valve with a flow rate, $Q_w$. A simple weighted waste valve as shown in Figure 4 was used. It was made of stainless steel with a diameter of 40 mm. The opening and closing of the valve are due to the dead weight on the valve stem. In this experiment, the dead weight of 116 g was applied. The drag of the accelerating water closes the waste valve, creating a back surge (water-hammer effect) and an increase in pressure, forcing water to flow through the check valve, the air-chamber, and the delivery pipe with a delivery head, $H_d$ and a flow rate, $Q_d$. A drop in pressure in a supply pipe opens the waste valve and the cycle repeats. It should be noted that the HRP utilizes the energy from the supply head, $H_s$, and a flow rate, $Q_s$ to a delivery head, $H_d$ which is higher than $H_s$ with a small amount of water $Q_d$ by swift closure of the waste valve. Typically, a small amount of water will be delivered to the storage tank. Therefore, the nominal diameter of the delivery pipe was reduced to 12 mm. The measuring devices were the same as those used in the pump testing. The water pressure at the supply (or drive) pipe and that at the delivery pipe were measured by pressure transducers. The pressure at the air chamber was read by a Burdon-tube gage. The waste valve motion was recorded with a video recorder in a smartphone (HUAWEI, model Y7 Pro 1080p@30fps). The video was imported to the computer for processing, editing, and saving. The waste valve beats per minute were counted. The measuring device specifications are given in Table 1.

3 | PROCEDURE

The pump performance was tested first. The following procedure was followed. After reaching steady-state conditions, all data were recorded at every 5-minute interval. A total of three readings were recorded for each measured data and then the mean value was calculated. The water level in the tank was kept constant in this experiment while the water flow rate was varied. These data were used to characterize the performance of the pump.
After finishing the pump test, the HRP was installed as shown in Figure 3. The pump is started with the flow control valve fully closed. By slightly opening the flow control valve at the delivery pipe, the waste valve was pressed to let the water flow through it. Adjusting the turning of the control valve until the waste valve started beating. It should be noted that the waste valve was functioning only at a certain range of flow rate ($Q_d$) during this experiment. It is due to the pump capacity was over the HRP capacity. For each delivery flow rate ($Q_d$) reading, all data were recorded. Increasing the flow rate, $Q_d$ until the waste valve stopped functioning. The data were used to characterize the performance of the combined pump and HRP. It should be noted that the waste valve will function only at a certain range of flow rate, $Q_d$. The flow rate $Q_w$ varies according to the waste valve features, for example, design of disc, weight. These features were unchanged in this experiment. A characteristic curve for the combined system is presented to assist in the determination of the design characteristics of the device.

## 4 SYSTEM PERFORMANCE

The flow pattern in HRP is not constant in time but exhibits fluctuation. Thus, all the measured parameters are averaged and used for determination system performance. The efficiency of the pump is defined as

$$\eta_{\text{Pump}} = \frac{\rho g Q_s H_s}{W_{in}}$$  (1)
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**FIGURE 5** H-Q curve for the pump and combined pump and HRP

The efficiency of the HRP is defined as

\[ \eta_{HRP} = \frac{Q_d}{Q_s} \frac{H_d}{H_s} = Q \ast H \ast \]

The efficiency of the combined pump and HRP is defined as

\[ \eta_{Pump + HRP} = \frac{\rho g Q_d H_d}{W_{in}} \]

where \( H' \) = head ratio = \( \frac{H_d}{H_s} \)

\( Q' \) = flow rate ratio = \( \frac{Q_d}{Q_s} \approx 1 - \frac{Q_w}{Q_s} \)

\( W_{in} \) = input power

The head ratio (H’) is the ratio of discharge head (H_d) to supply head (H_s) and the flow rate ratio (Q’) is the ratio of discharge flow rate (Q_d) to supply flow rate (Q_s). In these experiments, the efficiency of the combined system (\( \eta_{Pump + HRP} \)) is the ratio of the power added to the fluid to the power used to drive the pump.

5 | RESULTS AND DISCUSSION

The variation of the head with capacity for pump and that for combined pump and HRP are shown in Figure 5. H-Q curve of the pump is shown with triangular marks. The head developed by the pump decreases with the flow rate. The maximum head of 11 m is obtained at a flow rate of 0.42 L/min, while the minimum head of 7 m is obtained at a flow of 31 L/min. The power consumption for this operation is shown in Figure 6. The pump efficiency curve is shown in Figure 7. The best operating point with the efficiency of 21% is at the flow of about 30 L/min and the head of 7.5 m. These results represent a benchmark for comparing the pump and the combined system performance.

In the pump, the flow in the supply pipe can be approximately the same as the delivery pipe. In HRP, the flow in the supply pipe (Q_s) is higher than that in the delivery pipe (Q_d) due to loss (Q_w) at the waste valve. Therefore, the flow rate of the combined system should be specified clearly. The total head of the combined system, in Figure 5, was plotted against the discharge flow rate (Q_d, shown with circular marks). It is high at low Q_d and decreases rapidly at high Q_d. We can see that the developed head by the combined system is higher than that by the pump in all range of flow rate. The respective heads are also plotted as a function of the supply flow rate (Q_s, shown with square marks). It must be emphasized that the
curves presented in Figure 5 delineate the operating points for the pump and the combined system with \( Q_d \) and \( Q_s \). The flow differential \((Q_s - Q_d)\) is reflected in quantity wasted, \( Q_w \). As a result of this mass flow rate lost, the combined system performance should be presented in terms of \( Q_d \) (the actual amount of fluid flowing through the system), and its supply flow rate, \( Q_s \), to see how the energy conversion in the system. Its overall performance is considered in terms of \( Q_d \) and \( H_d \), and efficiency dropped with lower delivery flows. However, higher delivery flows \( Q_d \) could not be achieved at this experiment and permitted only about 7 L/min. This is a drawback that needs to be discussed in the following.

The power consumption of the combined system, in Figure 6, was plotted against \( Q_d \) and \( Q_s \), which are shown in circular marks and square marks, respectively. The power consumption of the combined system as a function of the quantity delivered \( Q_d \) (shown in circular marks) was high compared to that of the pump for the same flow rate. However, the respective power consumption of the combined system as a function of supply flow rate, \( Q_s \) (shown in square marks) did not exceed the power consumption of the pump for the same flow rate. This meant that the pump was not overloaded when the HRP was added.
A similar observation may be made for efficiencies of both cases in Figure 7. It looked like that the combined system as a function of Qd (shown in circular marks) was improved the efficiency of the pump. The corresponding values as a function of Qs (shown in square marks) were substantially low when compared to the pump efficiency. Variations in these values may be explained by quantity wasted, Qw at the waste valve.

Power supply from the pump (in terms of Hs and Qs) is used by HRP to lift part of water to another level (in terms of Hd and Qd). It allows us to deal with the higher pressure rise at a less discharge flow rate. The efficiency of the HRP and that of the combined system are given in Equations (1)-(3). The performance of the machine is best presented in terms of dimensionless coefficients. These coefficients are the head ratio H’ (the ratio of discharge head to supply head), the flow ratio Q’ (the ratio of discharge flow rate to supply flow rate), and the efficiency. The relationship between H’ and Q’ is shown in Figure 8 where Q’ < 1 and H’ > 1. H’ is high at low Q’. The more head is required, the less flow can be lifted. The overall efficiency of the combined system was also shown in Figure 8. These points are discussed further in another section of the present review.

Different characteristics for the quantity delivered Qd, source capacity Qs, and quantity wasted Qw were shown in Figure 9. The results showed that the parameter Qw trended to vary inversely proportional to Qd. The parameter Qs did not appear to be greatly influenced by Qd. Therefore, the less flow in delivery pipe Qd means a high flow rate through the waste valve. All recorded data of Qs were in the range of 30.53 ± 0.22 L/min with a confidence limit of 95%. This meant that the pump was operated around its best operating point during the test of the combined system (as shown in Figure 7).

The parameter Qw was affected by its beat frequency in terms of beats per minute. This was shown in Figure 10 where an increase in quantity wasted trended to increase its beats per minute due to the drag of the disc. The beats per minute were in the range of 197-230 times/min during this experiment. However, an increase in Qw meant low Qd and η (as shown in Figures 7-10). Therefore, an increase in waste valve beats per minute value tended to decrease the overall efficiency of the system. This is in contrast with previously described\textsuperscript{11} that HRP must be adjusted to pump the maximum quantity of water possible (Qd), and this normally happens when the waste valve beats per minute value are the highest. In this experiment, the highest value in the waste valve beats per minute could not be obtained since the pump capacity was over the HRP capacity. The control valve at the delivery line cannot be varied independently. It must be adjusted to a certain range of flow rates where the waste valve was functioning. Therefore, the waste valve beats per minute were measured at a certain flow rate Qd instead. It should be noted that the results from this experiment demonstrated the potential use of HRP to increase the discharge head of the pump in case of a shortage of lift.

This study focuses on the technical feasibility of combining the pump and HRP for increasing pump head. The application illustrates the case where energy sources in rivers or streams are not enough to drive HRP and the pump alone cannot lift water to the required head. This means that both are required to accomplish the case. The study addressed three primary research questions.
The first question focused on the feasibility of combining the pump and HRP for increasing pump head. The results indicate that the combined system (pump + HRP) can boost the head ratio of 2.4-7, but at the expense of the flow rate ratio (eg, 0.23-0.02). This means that the output head is 2.4-7 times the input head where only 23%-2% of the water flowing through the system will be delivered to the storage tank. The results also indicate that the combined system efficiency is low compared to the pump efficiency as a function of supply flow rate $Q_s$ (square marks in Figure 7). We noticed that HRP could smooth the pressure from the pump during the test run.

The second research question evaluated the power consumption of the combined system and that of the pump. Again, it should be considered in terms of the supply flow rate ($Q_s$). The results indicated that the hydropower from the pump was used by HRP to increase discharged head but at a lesser flow rate. It did not overload the pump and continuously works if the hydropower from the pump was available.

The third research question addressed the limitation of the combined system. Normally, in each supply head condition, the HRP is adjusted to pump the maximum flow $Q_d$ in the delivery pipe with an approximately constant value of waste.
valve beats per minute.\textsuperscript{11} However, this could not be done during this experiment because the pump capacity was over the HRP capacity. The waste valve was functioning only at a certain range of flow rate (Q_d). Therefore, the waste valve beats per minute were measured at a certain flow rate Q_d instead. This indicates that the pump and the HRP should be matched for optimal work output and waste valve beats per minute.

The efficiency of the HRP is appreciably lower than that of the electric pump. The comparatively low value of efficiency should not be considered prejudicial to the HRP, because the power sources of the two systems are different. The input power of the electric pump is the electricity which is normally much more valuable and expensive. The input power of the HRP is the hydropower from the stream or the pump in this case study and does not need other power sources to operate. The HRP is used because of its simplicity of construction, inexpensive, and no harmful effects on the environment.

6 | CONCLUSIONS

The possibility of using HRP to increase head for the pump in case of a shortage of lift or work as a booster pump has been investigated. The experimental results show that this simple device can be used to increase water-lift with a high head (2.4-7 times the input head) at a less flow rate (23%-2% of the supply flow rate). The pump was working normally, and no overloading was found. The combined system efficiency is lower than the pump efficiency in terms of supply flow rate since most of the water is wasted at the waste valve. The required head and water flow rate influence the combined system performance. These parameters were considered in terms of head ratio (H') and flow rate ratio (Q'). There is a limitation that the system can be used. The pump and the HRP should be matched for optimal work output and waste valve beats per minute. Optimum pump efficiency is governed by H' and Q'. The impact of these parameters on such applications comes with a trade-off. Finally, the system could be applied to increase the pump head. Potential future applications for climate change and sustainability technologies for developing areas. The combined system works with relatively low system efficiency. Therefore, an investigation of potential improvement is required. It must be determined for the water demands where it is applicable since more than 75% of the supply water is wasted at the waste valve. The authors suggest that future research should be focused on assessment methods in matching the pump and the HRP for optimal work output and waste valve beats per minute. Investigation on the new design of HRP, as suggested by Rajaonison and Rakotondramiarana\textsuperscript{13} and Obermoser,\textsuperscript{16} could be done in eliminating the loss of flow rate in the waste valve. Numerical analysis of the complex behavior of HRP systems also recommended especially of the opening and closing condition of the wasted valve. As already pointed out in the introduction, flow visualization techniques combined with measured pump performance results help to get a better understanding of flow patterns inside HRPs.

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CONFLICT OF INTEREST
The authors declare no potential conflict of interest.

AUTHOR CONTRIBUTIONS
Wanchai asvapoositkul: Writing-review and editing. T Nimtipaitoon: Data curation; resources. S. Rattanasuwan: Formal analysis; resources. P Manakitsirisuthi: Data curation; resources.

DATA AVAILABILITY STATEMENT
The data that support the findings of this study are available from the corresponding author upon reasonable request.

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REFERENCES

1. Brikké F, Bredero M. Linking Technology Choice with Operation and Maintenance in the Context of Community Water Supply and Sanitation: A Reference Document for Planners and Project Staff. Geneva, Switzerland: World Health Organization; 2003.

2. Januddi FS, Huzni MM, Elfeny MS, Bakri A, Mohammad Z, Ismail Z. Development and testing of hydraulic ram pump (Hydram): experiments and simulations. The International Fundamentum Sciences Symposium. Vol 440. Bristol, England: IOP Publishing Ltd; 2018.

3. Viccione G, Immediata N, Cava R, Piantedosi M. eA preliminary laboratory investigation of a hydraulic ram pump. Paper presented at: The 3rd EWaK International Conference on “Insights on Water-Energy-Food Nexus; 27–30 June 2018; Lefkada Island, Greece.

4. Watt S. A Manual on the Automatic Hydraulic Ram for Pumping Water. London, UK: Intermediate Technology Publications; 1975.

5. Eric J. Proceedings of a Workshop on Hydraulic Ram Pump (Hydram) Technology Manuscript Report; May 29–June 1, 1984; Arusha, Tanzania.

6. Browne D. Design, Sizing, Construction and Maintenance of Gravity-Fed System in Rural Areas, Module 6: Hydraulic Ram Pump Systems Action. Paris, France: Contre la Faim, Hermann; 2005.

7. Matthias I, Suchard S, Johannes FJM, Johannes M, S W. Hydraulic ram pumps for irrigation in northern Thailand agriculture and agricultural. Sci Procedia. 2015;5:107-114.

8. Young B. Design of Homologous ram Pump. J Fluids Eng Trans ASME. 1997;119:360-365.

9. Mbiu RN, Maranga SM, Mwai M. Performance testing of hydraulic ram pump. Paper presented at: Proceedings of the Sustainable Research and Innovation (SRI) Conference; 6–8 May 2015. ISBN: 2079-6226.

10. Suarda M, Ghrurra A, Sucipta M, Kusuma IGBW. Investigation on characterization of waste valve to optimize the hydraulic ram pump performance. Paper presented at: AIP Conference Proceedings 1984; 2018:020023.

11. Asvapoositkul W, Juruta J, Tabtimhin N, Limpongsa Y. Determination of hydraulic ram pump performance: experimental results. Adv Civil Eng. 2019;2019:1-11.

12. Suarda M, Sucipta M, Dwijana IGK. Investigation on flow pattern in a hydraulic ram pump at various design and setting of its waste valve. Paper presented at: International Conference on Design, Energy, Materials and Manufacture; 2019:539.

13. Rajaonison A, Rakotondramiarana HT. Theoretical study of the behavior of a hydraulic ram pump with springs system. Am J Fluid Dynam. 2019;9(1):1-12.

14. Sawyer RA, Maratos DF. An investigation into the economic feasibility of unsteady incompressible duct flow (water hammer) to create hydrostatic pressure for seawater desalination using reverse osmosis. Desalination. 2001:138:307-317.

15. Sawyer RA. Technical feasibility of wave power for seawater desalination using the hydro-ram (Hydram). Desalination. Vol 153. Amsterdam, Netherlands: Elsevier BV; 2003:287-293.

16. Obermoser K. Hydraulic ram pump. USA Patent US 6,234,764 B1, 2001.

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