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Review of Hydraulic Ram Pumps (Hydram) and Recommendations for Revival

Shamsudeen A. Sodangi

Mechanical Engineering Technology, Federal Polytechnic Nasarawa, Nigeria

ABSTRACT

Green technology is often only adopted when it becomes economically viable or even advantageous to do so. Advancements in technology means continually innovating to tackle new and old problems. However, some solutions albeit it older are becoming more relevant in the wake of the green revolution. The hydraulic Ram pump (Hydram) is one such solution. The Hydram is a 200-year-old device that has fallen out of favour in recent times. Hydrams are mechanical devices that use the kinetic energy in the flow of a fluid to pump a fraction of the fluid to a higher head. Major recent works on Hydrams are presented and summarised here. An attempt is made to cover the breadth of the field to expose the reader to the major areas of research in Hydrams while avoiding the inclusion similar works. The potential of Hydrams for use as a green solution to pumping water for irrigation is highlighted.

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I. INTRODUCTION

Hydraulic pumps (Hydram) are mechanical devices that use the kinetic energy in the flow of a fluid to pump a fraction of the fluid to a higher head. The fraction of fluid from which the energy has been extracted is released back into the flow. A sample setup is to extract some of the kinetic energy from 80% of the fluid flow by volume and transfer said energy to the remaining 20% of the flow. This is all achieved with only two valves, and no external fuel or power is required.

The energy is extracted by utilising the hammer effect. Hammer effect is a pressure surge that is generated due to a sudden change is the momentum of water. In Hydrams the hammer effect is achieved by snapping shut a valve.

What follows in this work is a brief description of the working principle of a Hydram. The next section is a history of Hydram technology, examples of early works in the development of Hydrams, and a brief of the different trends in the field. Another section is a review of a collection of works that this author thinks can be very helpful and exemplary in the design of Hydrams. It is followed by another section on the works dedicated to analysing the performance of Hydrams. Finally, a conclusion is drawn on the potential and localisation of Hydram technology in Nigeria and by extension similar socio-economic countries.

II. WORKING PRINCIPLE OF HYDRAM

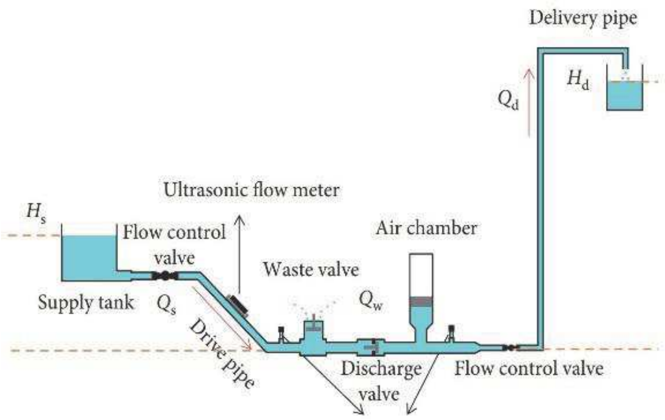

Figure 1: Hydram Illustration [1]

Figure 1 shows an illustration describing the principle of operation of Hydrams. Descriptions of the working principle in this section is in reference to figure 1, with water assumed to be the fluid. The flow control valves are simply taps used to start and stop the operation of the Hydram. The diagram is that of a Hydram built for demonstrative purposes. The flow from a river is therefore replaced by a supply tank.

Stage 1 - Operation starts with the 'discharge valve' closed and the 'waste valve' open. The discharge valve is designed such that it remains shut during this stage, i.e. the force required to open it will be greater than the flow under gravity can exert. Water therefore flows from the supply tank and out through the waste valve. The waste valve is initially held (artificially) open as a way of priming the device.

Stage 2 - As the flow increases through the waste valve, it eventually overcomes the weight (other configurations also possible) of the valve and closes the waste valve, thereby creating a water hammer. The surge in pressure is enough to force the discharge valve open and water to flow out the discharge valve and to the delivery head at a higher elevation.

Stage 3 - The pressure (from the water hammer) decreases as water flows out, the pressure is eventually low enough that the discharge valve closes, and the waste valve opens. This cycle repeats itself.

Stage 4 - The air chamber is used to smooth out the cyclical flow of water and produce a more uniform flow. At the start of operation, it may be required to tap open the waste valve by hand before the operation becomes automatic. The valves also need to be properly calibrated to work in sync.

III. HISTORY, TIMELINE AND DEVELOPMENT TRENDS

A report: "Proceedings off a Workshop on Hydraulic Ram Pump (Hydram) Technology" [2] was released in 1984 subsequent to a conference held at ARUSHA, Tanzania. This Paper in many ways seeks to achieve the same objectives of said conference but in Nigeria.

In said conference E.J Schiller presented a paper [3] he noted that Hydram technology is 200 years old. Its invention is credited to John Whitehurst in 1775, it was subsequently automated by joseph Montgolfier and patented in 1797. Several improvements and advancements were recorded up to the early 1930's when development shifted squarely to fossils and steam. Several companies still manufactured hydrams for rural off-grid usage or developing economies. The paper also described performance characteristics of a Hydram including an early work of employing a computer model. The references in this paper span between 1918- 1984, indicating continuous interest in this old technology mostly employed for rural irrigation purposes.

In the same conference [4] presented work centred on management and economic overview of employing Hydram technology. The paper highlighted the advantages of Hydram to include easier training of the residents to maintain and service Hydrams and generally lower cost of maintenance compared to fossil engines. Hydrams also do not remove the necessity of transporting fuels to remote locations. Hydrams are were also reported to have favourable economies of scale compared to large projects that perhaps require heavy machinery to be transported to remote areas, these large projects are also likely to only serve the immediate environs. The paper finally recommended an extended survey of areas suitable for Hydram applications be mapped out.

"Ref. [5]" highlighted the need for renewable energy devices was reiterated. The paper recommended Hydrams be design for durability and efficiency using steel casts rather than lightweight materials. It was also noted that a lack of awareness of the technology was a limiting factor in its adoption. Machinery is also so often imported from developed economies to low-income economies, this means when adoption fades in those developed economies production and therefore access to the technology is reduced for all even when the environment in low income economies are favourable to the technology. The paper further noted only one manufacturer of Hydrams in Tanzania and falling number of producers in Europe in America.

Similar conclusions and recommendations similar were presented in [6] and [7] as per studies carried out in Kenya and Zambia respectively. E. J Schiller presented [8]; where the daily operation of a Hydram as affected by the site it is situated, the type of Hydram and the required maintenance operation is considered. Several other papers were presented at the conference that tackled some of the same problems faced today regarding Hydram design and adoption. These papers laid foundations that ensure solutions are not etched from scratch.

An influential work in recent times [9] presented a design methodology calculating basic parameters and explanation the working principles of a Hydram. The paper is highly cited and gives an excellent introduction to the field for researchers.

"Ref. [10]" presented a work that uses an actual functioning Hydram which is rare as most publications in the field tend to have small experimental platforms. The Hydram used was an installation in China institute of water resources. They used a new diffuser (variable area) after the drive pipe to reduce resistance in the flow. The design allowed for a more compact assembly to reduce the weight of large hydrams. No performance change was recorded but the reduction in size alleviates transportation logistics to remove areas when dealing with larger Hydrams.

A typical design approach of Hydrams can be seen in [11], they built a demonstration scale Hydra and changed parameters like drive pipe length and valve beats per minute while recording the change in performance. However, [11] also included a fluid flow simulation modelled using COMSOL 5.3. Others works that present similar approaches to this design approach include [12], [13] and [14]. "Ref. [15]" is another example but they also employed computer simulation using CATIA and ANSYS.

A mathematical model for the inner workings of a Hydram may be called a work in progress, [16] built a mathematical model for predicting some performance parameters using statistical extrapolative methods employed on MATLAB. The results presented were however only valid for that particular setup because independent variables used were not dimensionless.

"Ref. [17]" described a method to analytically predict the performance of a ram pump given certain input parameters. This an example of a rare analytical approach in the field as opposed to statistical and empirical approaches. The analytics used is however shallow and employs several empirical relations.

A Novel application of hydrams in water distribution networks [18] used an energy redistribution device. There are areas of intermittent high pressure in a water distribution system and corresponding areas of low pressure due to changes in demand. Water may then be rerouted through hydrams to simultaneously increase and decrease pressure as required in different zones. This work is truly a new an innovative application of Hydram technology to a solve a problem that is not irrigation or remote location domestic water supply.

IV. WORKS ON DESIGN OF HYDRAM

A. Manual of Information on the Automatic Hydraulic Ram for Pumping Water

"Ref. [19]" published an instructional manual on how to design, build, tune and maintain a Hydram. The Hydram was built and installed in Bedfordshire, England. The Hydram was operated for only operated for hours of testing and therefore reliability was not tested. The ram was built to be used with an input head of 1m or greater and an input flow of 5L/min.

Notes:

1. Manual is detailed and instructional to allow one to rebuild and modify a Hydram.
2. Maximum efficiency was attained with a supply head three times (X3) the output head.
3. The report uniquely highlighted the importance of input pipe. A length to diameter ratio (L/D) of 500 was reported as optimal. Length of the drive pipe should however be less than four times the input head. Steel or iron is recommended as the material. This was presented from testing and empirical findings without analytical justification, but this author strongly suspects the effect on flow regime i.e. controlling turbulent and laminar flow as the reasons for the effect on performance.
4. In contrast the material of the output pipe was reported to have minimal effect on the performance of the Hydram. Considerations of material should be for reliability concerns.
5. It was recommended that the input diameter be smaller than the main body of the Hydram and to limit any sudden changes in the size or direction of flow of water.
6. Two designs for the impulse (waste) valve were presented. Both designs were such that they can be manufactured from simple components without relaying on professional manufacturers. The designs centre around bending a thin plate of steel and using bolts to keep the plate bent thereby maintaining tension. This spring action is used to return the valve to the closed position. This spring the design also has the advantage of allowing easy tuning of the waste valve beats per minute simply by adjusting tightening a bolt which increases the tension stored in the plate.
7. There is also a list of diagnostic steps to troubleshoot a faulty Hydram.

B. Others

"Ref. [20]" designed a setup where two Hydrams were setup in parallel. This meant the two hydrams shared the same input pipe and also merged their output flows. It was found that this setup produced a lower output flow rate than if the two Hydrams were operated independently with their output summated.

V. WORKS ON PERFORMANCE ANALYSIS

A. Determination of Hydraulic Ram Pump Performance: Experimental Results.

"Ref. [1]" built a Hydram which was used as a platform for comparing the effect of different parameters on the performance of a Hydram. The primary parameter evaluated was efficiency.

$$Power = Pressure \times Volume\ Flow\ Rate \quad (1)$$

$$P = Q\left(p + \frac{1}{2}\rho v^2 + \rho g h\right) \quad (2)$$

Where P= Power, Q= Volume flowrate, p= pressure, ρ = density, v= velocity, g= gravity and h = height (head)

$Pow = \rho g h Q$ (3)

$$\eta = \frac{(Q\rho gh)_{output}}{(Q\rho gh)_{input}} = \frac{(Q\times h)_{output}}{(Q\times h)_{input}} \quad (4)$$

Equation (1) is the start of the assumed derivation from first principles. The work uses an equation of power that removes the first two terms in equation 2, and is shown in equation 3. The terms in the bracket of equation 1 is an expression of pressure from Bernoulli's equation. The static pressure remains unchanged from the inlet to the outlet, and the velocity must have been assumed to remain unchanged.

The efficiency of the pump was then obtained by the ratio of 'power input' and 'power output'. An expression of efficiency was obtained as shown in equation (4).

An experimental rig was built to perform experiments by changing the inlet flow rate. Some mundane relationships were shown including: 'Increase in delivery head with increase in supply' and 'increase in delivery flow rate with increase in delivery head'.

Efficiency was shown to increase with an increase in the ratio of 'delivery flow rate' to 'supply flow rate' $(\frac{Q_{output}}{Q_{input}})$. Max efficiency of 61 – 65% was obtained, this is because the efficiency also varied with supply head, for 2.5m supply head efficiency was max at $\frac{Q_o}{Q_i} = 0.18$.

While for a 2 supply head efficiency was maximum (65%) at = 0.25.

Notes From paper:

1. Efficiency of hydrams is usually less than 70%.
2. Hydrams should be designed for specific delivery heads. Alternatively design a Hydram that can vary parameters like intake and waste flow based on required delivery head. Add an instructional chart to the user manual.
3. Efficiency was unchanged by changes in pressure in the air chamber.
4. Tuning the Waste Valve beats (WVB) is very important. Increasing the (WVB) per minute allows a smaller supply head to output a similar delivery flow rate. Example 2.5L/min of delivery flow rate may be achieved by either '18.5 L/min supply at 208 WVB/min' or '13 L/min supply at 285 WVB/min'.
5. Efficiency was consistently higher at the maximum the highest WVB/min tested for different $\frac{Q_o}{Q_i}$. Again $\frac{Q_o}{Q_i}$ = 0.25 for 285 VWB/min yielding the maximum efficiency of 65%, efficiency decreased with decreasing WVB/min. It is expected there is a maximum beyond which this relationship will change.

Notes for Future Designs:

6. The Ideal supposedly maximum allowed WVB/min is not studied. As WVB/min is increased the efficiency must plateau or even decrease at some point. There also needs to be consideration based on the structural integrity of the Hydram, as WVB/min is increased, there will be increased oscillating pressure differentials.
7. When designing a Hydram use a high WVB/min.
8. One may expect about 70% efficiency for the Hydram. If significantly lower then there is room for improvement.
9. Design Hydrams for specific supply flow rates and delivery head.
10. The pipe length, width and inlet flow may be varied to maximise efficiency and therefore durability of machine

B. Predicting the Output of a Hydraulic Ram Pump [21]

This work developed a polynomial that may be used to predict the output flow rate from a ram pump given the input head and output head. The general form of the polynomial is given in equation 5.

$$y = Ax^2 + Bx + C \quad (5)$$

Where y = Output flow (m/min) rate, x = Input head (cm), A, B and C are constants.

A, B, C vary for different outlet heads. For example at 60cm output head (A= −0.22, B= 82.67 and C= 1360), while at 120cm output head (A= −0.32, B= 105.14 and C= −220).

The work further determined a general empirical relationship that includes the output head as a variable in the equation as presented in equation 6. This was achieved by plotting the constants A, B and C from equation 5 against the output heads and using the method of least squares.

$$= (0.0003h - 0.2529)\, x^2 + (0.0642h + 88.546)\, x - 15.887h + 1754 \quad (6)$$

Where = output flow, x = input head and h = output head.

The derived empirical equation (equation 6) was then used to predict the supply flow which was then contrasted with measured experimental values. An error rate ranging from -17% to +11.8% was found between predicted and measured value.

Notes:
1. The derived empirical equation was not tested outside the range of experimental values used to create the equation. This means the error rate obtained is only an indication of the analysis methods (least squares method). The error rate is simply a reflection of the curve being a best fit.
2. Testing simply needs to be extended to variables outside those used to derive the equation. This can perhaps be the basis of another work. The logic and analytical process used is sound.
3. The derived equation and hence the prediction it can make is very limited. The equation is limited to the hydrams of that specific dimensions, any change in length or width of the connecting pipes is bound to yield different performances as seen in other works. A change in material used albeit to a smaller extent will also affect performance due to friction.
4. The relationship between 'input head', 'output head', and 'output flow' is consistent with what is seen in other works.

C. Other Papers on Performance Analysis

"Ref. [22]" presented a follow up to [23] where they designed an experiment to study the cycle stages in ram pumps. They calculated forces acting on elements of the Hydram using Computational Fluid Dynamics (CFD), specifically ANSYS. The objective of calculating the closing force required by the impulse valve was to enable higher efficiency in design optimization of impulse valves. Due to the persistent transient nature of flow and the complex interaction in the state of a Hydram, an analytical method of calculating the closing force is generally avoided. Empirical approaches and blind tuning are the most common in Hydram literature despite the inefficiencies.

"Ref. [24]" presented an experiment to analyse the effect of supply head and delivery pipe length on the efficiency of a Hydram. The results showed no change in the delivery flow rate with changes in the input pipe length. The Efficiency of the Hydram was shown to increase almost proportionately with the supply head. The supply head was varied between 0.3m and 0.9m, which resulted in a Rankine efficiency of between 15% to 35%. This plot was used in a regression analysis to determine that 88.2 % of the efficiency of a Hydram is dictated by the supply head. This author strongly believes and as shown by other works that the efficiency tops off and stops increasing with further increases in the supply head. Essentially the range of data used is too small. The analytical process remains sound and could be beneficial if further works may use it to determine what percentage of the efficiency is truly dictated by the supply head.

"Ref. [25]" built a Hydram and recorded data that confirms the proportional relationship between (L/D) of the drive pipe and the efficiency of the Hydram. Using analytical and experimental results several relationships were developed for obtaining different pump parameters. The work is perhaps the most analytically inclined as opposed to the litany of empirical and statistical/experimental approaches in Hydram performance evaluation.

VI. RECOMMENDATION

Recommendations for design and performance analysis have already followed in their respective sections. A broader overview for the technology is presented in this section.

The primary use of Hydrams has always been in irrigation for small holder farmers and for domestic water pumping in remote areas.

Seasonal rivers can be difficult to use for irrigation. The rivers start to flow before the rains are fully established but slow after the rains have stopped. This limits the applicability of Hydrams because its operation requires a flowing river. However, it presents an opportunity to extend the farming season by using Hydrams to allow the cultivation of two or more crops. There is a need for a more extensive survey to map out rivers and streams suitable for Hydram technology.

Another huddle for Hydram adoption is an innate lack of awareness of the technology. This can be remedied by incorporating the technology into government agricultural development projects of which there are several. Introducing the technology to local communities through public demonstrations and providing samples to agricultural equipment distributors.

Perhaps the most important step that will encourage the adoption of Hydrams is addressing local design and production. Hydrams may be designed specifically for fabrication in local workshops which will encourage production and adoption. Heavy maintenance and customizations as per river flow conditions can also be easily carried out in these workshops. Polytechnics and universities can have a major role in designing, training and distributing design blueprints, while keeping all work open sourced. This work is meant to encourage and be a starting point for researchers who wish to address this problem.

CONFLICT OF INTEREST

The author declares no conflict of interest.

REFERENCES

[1] A. Wanchai, J. Jedsada, T. Nattapong and L. Osawat, "Determination of Hydraulic Ram Pump Performance: Experimental Results," Advances in Civil Engineering, 2019.

[2] International Development Research Centre, "Proceedings of a Workshop in hydraulic ram pump (hydram) technology," International Development Research Centre, Aruhsa, 1986.

[3] E. J. Schiller, "The Hydraulic Ram Pump (Hydram): It's History, Operating Characteristics and Potential Use," In Proceedings of a Workshop on Hydraulic Ram Pump (Hydram) Technology, 1986.

[4] A. Mzee, "The Application of Hydram Pumps in Rural Water Supply Schemes in Tanzania," In Proceedings of a Workshop on Hydraulic Ram Pump (Hydram) Technolgy, 1984.

[5] D. Tulapona, "The Use of Hydrams for Water Pumping In Tanzania," In Proceedings of A Workshop On Hydraulic Ram Pump (Hydram) Technoly, 1984.

[6] O. O. Mbeche, "The Hydraulc Ram Pump In Kenya," In Proceedings Of A Workshop On Hydraulic Ram Pump Technology, 1984.

[7] W. T. Weerakoon and V. Liyanage, "Hydraulic Ram Pump Technology and Practice in Zambia," In Proceedings of A Workshop on Hydraulic Ram Pump Technology, 1984.

[8] E. J. Schiller, "Practical Aspects of Hydram Operation," In Proceedings of a Workshop on Hydraulic Ram Pump Technology, Tanzania, 1984.

[9] S. Sheikh, C. C. handa and A. P. Ninawe, "Design Methodology for Hydraulic Ram Pump (Hydram)," International Journal of Mechanical Engineering anad Robotics Research, 2013.

[10] K. Yang, J. Li, Y. Guo, X. Guo, H. Fu and W. Tao, "Designed and Hydraulic Performance of A Novel Hydraulic Ram Pump," in 11t International Conference on Hydro informatics, New York City, 2014.

[11] F. Januddi, M. M. Huzni, M. S. Effendy, A. Bakri, Z. Mohammad and Z. Ismail, "Development and Testing of Hydraulic Ram Pump (Hydram):," in IOP Conference Series: Materials Science and Engineering, 2018.

[12] M. Inthachot, S. Saehaeng, J. F. J. Max, J. Muller and W. Spreer, "Hydraulic Ram Pumps for Irrigation in Nothern Thailand," in 1st International Conference on Asian Highland atural Resources Management, AsiaHiLand, 2015.

[13] K. Othman, M. A. Shamsuri, M. A. Safi'e, I. I. M. Asri, K. Ngadimon and H. M. Hassim, "Mechanical Water Pump Using Double," Multidisciplinary Applied Research and Innovation Vol. 2, pp. 124-131, 2021.

[14] Y. Y. MAW and Z. M. HTET, "Design of 15 meter Head Hydraulic Ram Pump," International Journal of Scientific Engineering and Technology Research, Volume. 03, Issue No. 10., pp. 2177-2181, 2014.

[15] N. S. M. Hussin, S. A. Gamil, N. Amin, M. Safar, M. Majid, M. Kazim and N. Nasir, "Design and Analysis of hydraulic Ram Water Pumping System," Journal of Physics: Conference Series 908 012052, 2017.

[16] A. RajaonisonandH. T. Rakotondramiarana, "Experimental Validation of a Mathematical Model of the Operation of a Hydraulic Ram Pump with a Springs System," Americal Journal of Applied Sciences, 2020.

[17] A. B. Mahajam, C. C. Handa and A. P. Ninawe, "Comparative Study of Analytical Treatment for HYDRAM," International Journal of Trend in Scientific Research and Development (IJTSRD), pp. 223-226, 2021.

[18] M. Zeidan and A. Ostfeld, "Hydraulic Ram Pump Integration into Water Distribution Systems fo Energy Recovery Application.," Water, pp. 14, 21, 2022.

[19] S. Watt, "A Manual of Information in the Automatic Hydraulic Ram for pumping Water," Intermediate Technology Development Group, 1974.

[20] E. d. R. Moreno and E. A. A. -P. Ruben D Muelas-Hurtado, "Analysis of Two Hydraulic Ram Pumps in Parallel Operating with Single-vertical Supply," Journal of Physics: Conference Series, doi: 10. 1088/1742-6596/2022/1/012028, 2021.

[21] K. Manohar and A. Anthony, "Predicting the Output of a Hydraulic Ram Pump," Current Journal of Applied Science and Technology, p. 7, 2019.

[22] W. Sobieski and D. Grygo, "Fluid Flow in the Impulse Valve of a hydraulic ram," Technical Sciences, pp. 205-220, 2019.

[23] W. Sobieski, Grygo D and S. Lipinski, "Measurement and analysis of water hammer in ram pump," Sadhana Vol. 41 No. 11, pp. 1333-1347, 2016.

[24] J. Muhamad and S. Arifin, "Analysis Effect of Supply Head and Delivery Pipe Length toward the Efficiency Hydraulic Ram 3 Inches," International Research Journal of Advanced Engineering and Science, Volume 4, Issue 2, pp. 263-266., 2019.

[25] R. Fatahi-Alkhouli and A. K. Babak Lashkar-Ara, "On the measurement of ram-pump power by changing in water hammer pressure wave energy," Ain Shams Engineering Journal, 2019.