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LAB-SCALE SYSTEM FOR SMALL RAM PUMP'S TESTING AND PERFORMANCE EVALUATION

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ABSTRACT

Ram pumps employ renewable energy in the form of water head to pump water, but they have performance issues that require difficult on-site testing and tuning, hence limiting their application. The current research developed a low-cost lab-scale testing system for small ram pumps' performance evaluation, tuning and leak testing. The developed system is made from available, low-cost, sensors and components. It conserves test water by setting the supply head through continuous circulation of water. The system was tested on a low-cost small sized ram pump, specially built using plumbing components. Test results demonstrated the capacity of the developed testing system.

Keywords: *Ram pump, performance test, flow rate measurement, supply head, leak test*

1. INTRODUCTION

Ram pumps use the potential energy of water flowing from springs, streams or rivers to lift a fraction of that water up to a higher level, compared to the head of supply water. This is achieved by means of water hammer action developed by sudden closure of a valve (ram pump's impulse valve) that interrupts water flowing inside a pipe (ram pipe) from the supply (Abate and Botrel, 2002). The kinetic energy of the moving water trapped in the ram pipe is converted into a potential energy on the water delivery side.

Ram pumps do not require any traditional energy source to operate (Yussupov *et al.*, 2020), and they operate continuously with minimal need for maintenance. An installed ram pump delivers 1000 to 50000 liters of water a day to a reservoir of a village (Anonymous, 2007). Accordingly, ram pumps have the potential to solve problems of water supply shortage for households and agriculture in rural areas (Alkouhi and Lashkarara, 2017; Yussupov *et al.*, 2022).

Ram pumps suffer from sensitivity to running conditions and need for on-site testing. This is due to ram pumps output; the delivery head and flow rate, being function of a number of parameters. A ram pump's performance is affected by the supply head, diameter and length of ram pipe, size and pressure of its air chamber, and diameter, mass and stroke length of its impulse valve's disc. A number of researches were conducted to evaluate the interdependent effects of these parameters on the performance of a ram pump.

Young (1998) formulated three non-dimensional parameters to define ram pump characteristics. These parameters are function of ram pump's supply and delivery heads, flow rate and beating frequency of its impulse valve. The upper and lower bounds of these non-dimensional parameters would define the feasible area of ramp pump's design. Salins *et al.* (2015) investigated the effect of ram pipe length on the delivered flow rate. They found a peak of delivered flow rate at 2 m ram pipe length. De Carvalho *et al.* (2016) studied the effect of air chamber's size on the delivery flow rate at different delivery heads. Other studies investigated development of ram pump designs to increase its performance such as Yang *et al.* (2014) whom demonstrated that placing a diffuser before the impulse valve would increase delivered flow rate and the delivery head.

A number of systems were developed, and reported in literature, for testing the performance of ram pumps. Alkouhi *et al.* (2019) presented a neat system, yet it has a room for development. Apparently, it would waste water and its falling output column would suffer from siphon effect and would need to have an opened top. Also, flow rates measuring technique is not described. The system reported by Mbiu *et al.* (2015) circulates water and employ reservoir and a tank for fixing the delivery head. However, it is a large system and they have not described their flow rates measuring technique. The system demonstrated by Asvapoositkul *et al.* (2019) is an easy to implement system, yet it would waste test water. Flow rate measuring technique and supply head fixation technique are not described.

The current research aims at developing a lab-scale low cost system for small ram pumps testing, tuning and performance evaluation. This system would facilitate testing a ram pump at given running conditions. Objectives include developing a, simple to control, water supply source with the capacity to change the supply head, developing a variable delivery head arrangement and developing a ram pump output assessment system. The system would assess the pump's performance parameters such as supplied and delivered water flow rates at different supply and delivery heads. For the purpose of testing the system's capacity, a small 2" diameter ram pump was designed and built from specially selected plumbing components.

2. TESTING SYSTEM CONSTRUCTION

The developed ram pump testing system consists of a tank, a basin, an electric pump, delivery head arrangement, electronic flow meters, pressure gauges, auxiliary valves, pipes, flow control valves and air trap, connected as shown in Fig. 1.

2.1 The Supply Tank

The supply tank (T) of the system is a PVC tank of 200 liters, without cover. It is fitted with two ports; the first is a 2 inch diameter output port fitted with a ball valve, near its bottom to feed water to the ram pipe (RP). The second port is a 1 inch input port near tank's top. This port is connected to reinforced hose H1 that feeds water to the supply tank during the runs to maintain its water level.
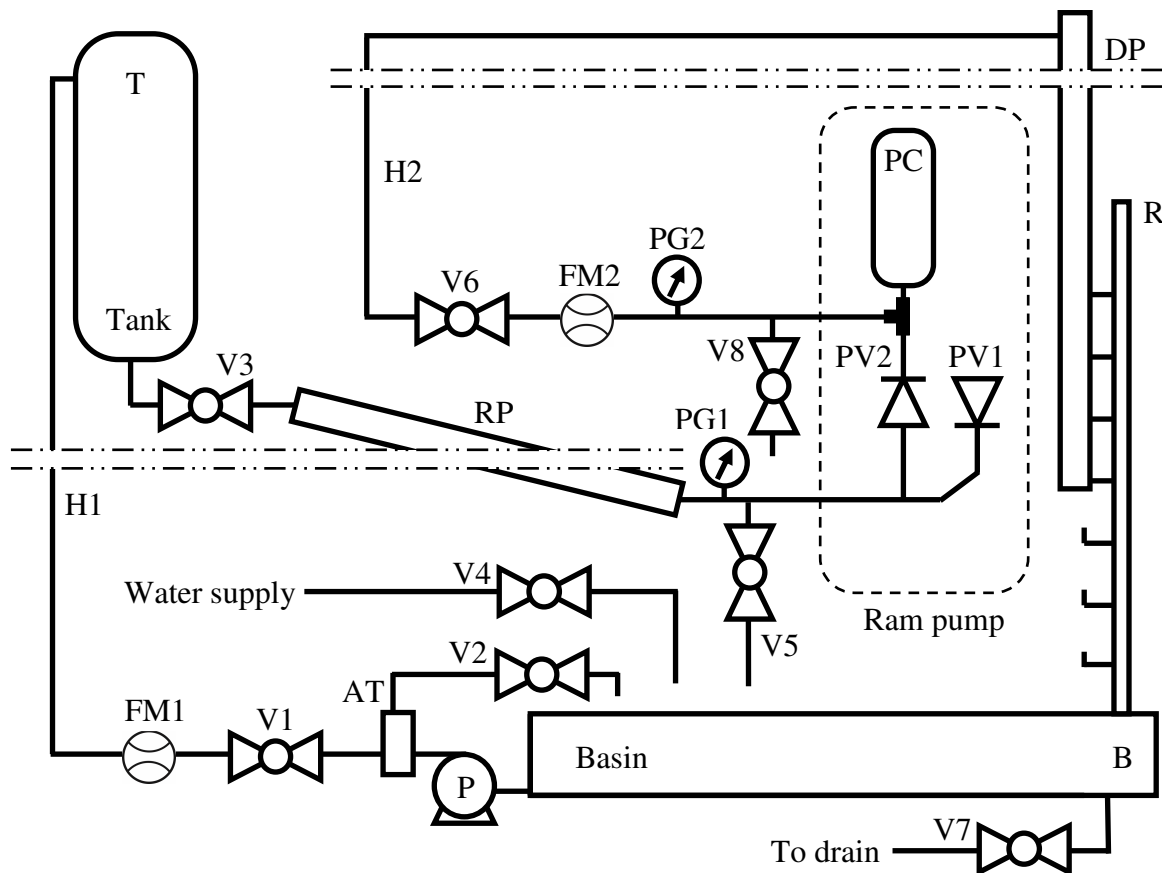
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Fig. 1 Schematic diagram of the testing system fitted with the ram pump

2.3 Ram Pipe

The system is fitted with a ram pipe (RP). RP represents the input port of the ram pump. For the current work it is a 2 inch inner diameter PVC pipe of 4 meters length. It is fitted with two threaded ports at each end. It receives the water from the supply tank and delivers it to the ram pump body. RP could be replaced with pipes of other materials, diameters and lengths or could be extended with similar pipe segments to any required length. RP is inclined from the supply tank downward to the ram pump body, with few degrees. This inclination allows the trapped air in the ram pump's body to escape to the supply tank during initial system preparation for a run.

2.4 Delivery Head Arrangement

A dedicated delivery head arrangement is developed to adjust the ram pump's delivery head. It consists of a reinforced hose (H2), PVC drain pipe (DP) of two inch inner diameter, and a specially developed rack (R). The ram pump, pumps the water through its, half inch of inner diameter, delivery port to the, three quarter inch of inner diameter, H2 whose tip's center elevation from the ram pump's base represents the delivery head. The hose tip is supported by and attached to a port next to top end of the vertical drain pipe. The attachment allows the pumped water to fall free from the hose tip into the drain pipe, without trapping air inside the drain pipe.

The specially developed rack has a number of 25 cm spaced hinges that are used to seat the drain pipe. For the current work a drain pipe of 150 cm length is employed, which, in conjunction with the rack and its hinges, allows delivery heads from 175 cm up to 325 cm, in 25 cm increments, given that 325 cm is the highest possible delivery head inside our lab. However, a longer drain pipe could be employed in labs with higher ceilings and would allow evaluation of ram pumps' performance at higher delivery heads using the current system.

2.5 The Basin

The basin (B) is made of a half metal barrel that was cut vertically and laid horizontally on a supporting metal structure. The supporting structure is featured with fixtures that support the tested ram pump's body, the end of the ram pipe and the delivery head rack as well as different control, adjusting and testing devices. Basin's main function is to collect the water falling from the ram pump's impulse valve and the pumped water falling inside the drain pipe. It is featured with an output port at its lowest point.

2.6 The Electric Pump

An electric water pump (P) of 370 watts power is employed to continuously pump all the water falling in the basin to the supply tank. The electric pump's input port is fitted to the output port of the basin, located at the lowest point in the basin, to drain all its water. Due to required fast emptying of the basin, some air is sucked alongside the sucked water. Therefore, the pump's output is fitted with an air trap (AT) and a system of valves (V1 and V2) to vent the air from pumped water stream. To measure the flow rate of the pumped water an electronic flow meter (FM1) is fitted on the line. Finally, the water is pumped through a flexible hose (H1) to the supply tank's input port.

2.7 Pressure Gauges

The ram pump's body and the delivery side pipe (output port) are fitted with identical 1 bar bourdon pressure gauges, (PG1) and (PG2) respectively. PG1 measures the input head before starting the pump while PG2 measures the pressure during testing ram pump for leak. They have accuracy of ±1% of their full scale. It is considered that the current system will test small sized ram pumps and will not be operated at pressures higher than 1 bar. However, replacing the pressure gauges with higher rate pressure gauges would enable testing larger pumps.

2.8 Auxiliary Valves

The system is fitted with a number of stainless steel ball valves to facilitate the control of system's priming, operation, drainage and pump leak testing. Valve V4 is used to fill the water to the system at the start of the run. Valve V3 opens the supply source to start feeding the ram pump with water under pressure equivalent to the height of water inside the supply tank from the ram pump body's base. At the end of the run valve V5 drains the water of the supply tank, the ram pipe and the ram pump's body into the basin. Also, valve V8 drains the delivery side piping and the ram pump's pressure chamber into the basin. Valve V7 is used to drain all the system's water from the basin at the end of operation. Valve V6 facilitates ram pump's leak test.
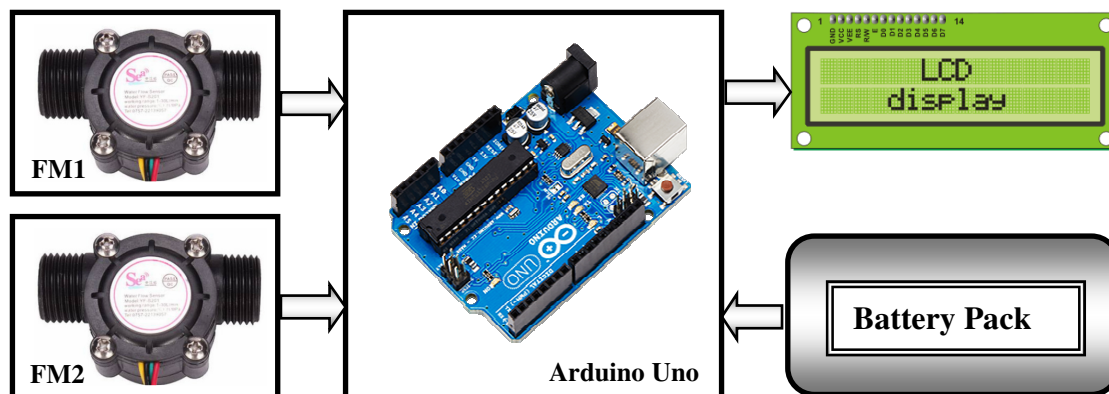
2.9 Electronic Flow Meters

The system is fitted with two electronic flow meters; FM1 and FM2. The electronic flow meters are "Sea" brand of model number "YF-S201", with 1 to 30 Liter/min measuring range. They are based on mechanical rotary flow meter principle and are fitted with electronic circuits, based on Hall-effect, to output one digital pulse per rotor turn. The two flow meters' output signals are fed to a microcontroller development board (Arduino UNO) and the development board is fitted with a battery pack and LCD for results display. The development board is programmed to read flow meters' signals, process them and display the flow rates on the LCD in liters per minute, as shown in Fig. 2. It also feed the results to a spreadsheet on a PC for results recording.

Fig. 2 Schematic diagram of water flow rates measuring system

2.10 Flow Control Valves and Air Trap

The air trap is fitted to the output of the electric water pump. It splits the pumped water into two streams. The first stream is water that is fed to the supply tank through control valve V1, electronic flow meter FM1 and hose H1. The second stream is air bubbles with small percentage of water. It is delivered back to the basin through control valve V2, where the bubbles are released to atmosphere and the accompanying water joins the water flowing to the basin output port. The air trap and the partial opening of V1 and V2 ensure that the water pumped back to the supply tank does not contain large air bubbles. This is important due to relying on measuring the flow rate of water pumped back to the supply tank in evaluation of the supply water flow rate.

The flow meter (FM2) is responsible for measuring the flow rate of ram pump's pumped water. It is located on the delivery line next to the ram pump's output port. The flow meter (FM1) is responsible for indirectly measuring the total water flowing from the supply tank. It is fitted on the line of water heading back to the supply tank. This arrangement makes use of the fact that the supply line flow rate is equal to the return line flow rate, as long as the head inside the supply tank is fixed at steady sate operation. This head fixation is induced by the electric pump's continuously draining all the water from the basin. This technique benefits from the fixed amount of water occupying the system as well as the water being circulated through the system, at steady sate operation. The arrangement allows indirectly measuring the net flow rate of water flowing from supply tank to the ram pump without throttling its pipe.

Flow meters were calibrated through diverting their output water to a container with known volume, recording the filling time, calculating flow rate and comparing the calculated flow rate with the corresponding flow meter readings. It should be noted that electronic circuit of the flow meters were programmed to collect flow representing signals for a complete minute before reporting the reading as a moving average of 1 minute period, to ensure high accuracy, given fluctuating nature of ram pump's flow.

3. RAM PUMP CONSTRUCTION

The ram pump's body was made from 1.5 inch steel water pipes and fittings arranged to support the two check valves of the ram pump; impulse valve PV1, and delivery valves PV2, delivery T connector, as well as the ram pump's pressure chamber (PC).

3.1 Check Valves

The most critical part of the ram pump is the impulse valve PV1. Normal check valves would not function as impulse valves without varying degrees of modification. Some check valves would require machining and some would require simpler modifications. After testing a range of check valves available locally, an Italian made 1.5 inch check valve, "YOURK itap", was employed. This valve was found more suitable due to its high build quality. It required two modifications; removal of the spring that keeps valve's disc closed in all orientations, and adjusting its disc mass.

The water flow rate passing through ram pumps depend, chiefly, on their inlet side water head and the overall pump's characteristics especially ram pipe's diameter and length, and impulse valves' parameters such as valve's disc travel and mass. To tweak pump's flow rates, valve's disc travel or mass is tailored. Some commercial ram pumps are equipped with an adjustable supporting spring for the valve's disc to tweak its performance.

The same type of check valve, "YOURK itap", was employed for the delivery side check valve PV2 due to its smooth operation and low disc mass, allowing faster opening and closing actions without the supporting spring. The valve's spring was removed and a delivery side leak test result was satisfactory due to valve's high build quality and delivery head support of the valve's closure action. Also, the large diameter of valve's disc would allow larger amount of water to cross the valve during the ramming pressure surge with minimal throttling pressure losses. The large diameter would also ensure higher disc closure force for the same delivery head pressure.

3.2 Pressure Chamber

A pressure chamber PC was made from a 60 cm length PVC pipe of 4 inch diameter. The pipe was sealed with an end cup at the top and an adapter to connect to the 1.5 inch delivery valve PV2 and its fittings at the bottom. Delivery pipe is connected to a T connector joining the check valve PV2 below it to the pressure chamber PC above it.

4. SYSTEM OPERATION

4.1 Setting Input Head

In the current work the input head is measured as the vertical distance from the ram pump's base up to the water level in the supply tank T, during pump's steady state operation. The procedure to set the input head of the ram pump could be summarized as following: -

- Fully open valve V4 that supplies water to basin.
- Start the electric pump with V3 closed, V1 opened and V2 closed to pump the water from the basin to supply tank T.
- When required head is reached valve V3 is fully opened and the ram pump will start and the water level in tank T will drop.
- Valve V4 is partially opened until the head reaches the desired input head then closed.
- If the supply head reached a higher than required, valve V7 is partially opened to drain some water from the system until the head reaches the desired input head value, then V7 is closed.

4.2 Setting Output Head

The output head is evaluated as the vertical distance from the base of the ram pump up to the center line of hose H2's higher end. The output head of the ram pump is adjusted by supporting the DP on the corresponding rack hinge that would elevate the H2's end, supported at DP tip, to the required elevation.

4.3 Starting Ram Pump Test

As V3 is opened with V5 and V8 closed, and V6 opened, most ram pumps would start automatically. However, some models of ram pumps running at certain water head ranges would require manually tapping the impulse valve PV1 opened few times before the ram pump would start running.

Steady state ram pump operation is identified by its impulse valve stable beating rate and constant pumped water flow rate, measured by flow meter FM2. After the pump reaches steady state, its performance parameters are measured. That including flow rate of circulating water measured by FM1, flow rate of pumped water measured by FM2 and wasted water rate measured as difference between FM1 and FM2 readings.

Our pump was adjusted to deliver 3 liters of pumped water per minute at delivery head of 1.75 m using two meters of input head. This was achieved by increasing the mass of its impulse valve's disc to 80 grams.

4.4 Ram Pump Leak Test

One of the biggest problems of the ram pumps is leaking especially in the pressure chamber (PC) and check valve PV2. The pressurized air in pressure chamber PC has a pivotal role in ram pump's performance and sustaining its operation. Leak in the pressure chamber would reduce ram pump's performance and would stop it. Also, any leak in valve PV2 would reduce the ram pump's output head and flow rate as the pumped water is leaked back to the ram pump's body. The current system has the capacity to check PC and valve PV2 for leak at its maximum delivery head using the following procedure: -

- During ram pump's operation at delivery head of 3.25 m, valve V6 is closed to seal the chamber output

- When pressure gauge PG2 stop increasing, valve V3 is closed to stop the pump, given that the pump might stop on its own after closing V6, depending on operating conditions.
- Valve V5 is opened to drain the ram pipe and ram pump's body.
- As pressure chamber is pressurized and closed by PV2, pressure gauge PG2 readings are recorded periodically, as its readings' reduction indicates leak in either PC or PV2.

4.5 End of Ram Pump Test

To take off the ram pump from the test system, V3 is closed to stop the ram pump's supply water and pump P is stopped. Then, V5 is opened to drain the ram pipe and ram pump's body and V8 is gradually opened to empty the pressure chamber PC as well as the delivery side pipes and hose. Water in tank T and basin is used for the next pump's runs. At the end of all testing, all water is sent to the drainage by opening V3, V5, V8, V1 and drain valve V7.

5. RESULTS AND DISCUSSION

5.1 The Characteristic Parameters of the Ram Pump

The ram pump's testing system performance was evaluated through setting the input supply head, setting the delivery head, running the testing ram pump and recording its performance results. The parameters that were used to characterize the ram pump performance, as described by Young (1996) and Young (1998), are given in Eq. (1). These parameters were evaluated for each run. Collected run results and evaluated efficiencies are given in Table 1. The tested ram pump was also evaluated for leak.

$$\zeta = 100\ (q\ h) / (Q\ H) \tag{1}$$

Where: -

H	Supply head (m)
h	Delivery head (m)
Q	Total water flow rate (L/min)
q	Delivered water flow rate (L/min)
ξ	Efficiency of the pump (%)

Table 1 Testing parameters and results of the ram pump

h (m)	Q (L/min)	q (L/min)	q/Q	ξ (%)
1.75	19.50	3.02	0.1549	15.5
2	18.14	2.42	0.1334	13.3
2.25	18.42	2.12	0.1151	11.5
2.5	18.21	1.81	0.0994	9.9
2.75	18.33	1.56	0.0851	8.5
3	18.02	1.29	0.0716	7.2
3.25	16.78	0.92	0.0548	5.5

5.2 Ram Pump Performance Curves

The current test investigates the functionality of the ram pump testing system through evaluation of testing ram pump's performance at two meters supply head and different delivery heads. The effects on supplied and delivered water flow rates as well as efficiencies are evaluated.

Figure 3 shows the variation of the delivered water flow rate at different delivery heads h. The figure shows the characteristic relation of q decrees as h increase.

Figure 4 shows the variation of the supply water flow rate Q at different delivery heads (h). The figure shows that Q does not change greatly when delivery head h is changed within the system's test range of 1.75-3.25 m.

Figure 5 illustrates the change of the efficiency of the ram pump with the variation of the delivery head. The figure shows the characteristic relation of efficiency ξ decrees as h increase.

The ram pump's pressure chamber PC and PV2 were checked for leak by trapping pressure inside pressure chamber, by closure of valve V6, and monitoring trapped pressure using PG2. For an hour, PG2 did not show measurable pressure reduction, indicating no leak.

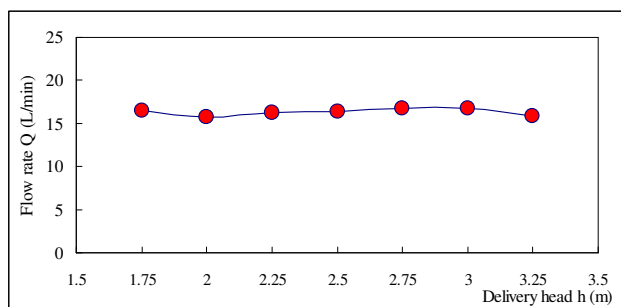**Fig. 3** Delivered water flow rate q at different delivery heads

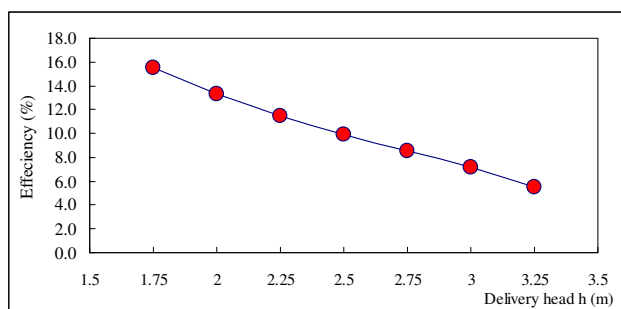**Fig. 4** Supply water flow rate Q at different delivery heads

Fig. 5 Efficiency of the ram pump at different delivery heads

6. CONCLUSIONS

The current work presented the design and function of a newly developed low-cost lab-scale testing system for testing, tuning and performance evaluation of small ram pumps. Importance of the work stems from ram pump's performance being highly affected by instillation site's parameters such as input and output heads and ram pipe's material, length and diameter. Accordingly, it requires tuning, but in-situ tuning of the ram pump for all site's variable conditions would require capacity to test full scale of fluctuating site's parameters such as supply head, which would be a river water level, which is not

practical. Accordingly, a ram pump would need to be tested and tuned for specific site's variable running conditions before being installed there.

The developed testing system has the capacity to adjust supply head using a novel technique that conserves testing water. It also has the capacity to adjust the delivery head using easy to produce arrangement. It measures, electronically, supply and delivery flow rates. It would also allow testing the ram pump against different ram pipes' parameters. The testing system is also able to check ram pumps' pressure chamber (PC) and delivery side check valve (PV2) for leak at ram pump's maximum delivery head.

For purpose of system testing, a ram pump was built from locally available plumbing components. It was tested using the testing system. The testing system proved its effectiveness through its success in facilitating ram pump testing, tuning and evaluating its performance at different running conditions. The system facilitated tuning the tested ram pump to deliver a specific flow rate, three liters per minute, to a specific head, 175 cm, using a specific supply head, 200 cm, by changing impulse valve disc's weight, to 80 grams. Using this disc weight, the ram pump was able to start automatically in response to application of supply head without need for tapping the impulse valve open. The ram pump performance was also evaluated at different delivery heads. Finally the ram pump was tested for leakage of its pressure chamber and delivery side check valve and it passed the test. Accordingly the current system proved to have the capacity to facilitate future employment of ram pumps.

It is recommended that the system would be equipped with digital pressure sensors and Data Acquisition System (DAQ) for further capacity for thorough investigation of ram pumps' performance issues and to help develop newer, more efficient, ram pump designs.

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