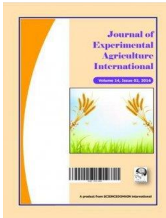

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Efficiency of Hydraulic Ram Pumps Made with Alternative Materials

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Authors' contributions

This work was carried out in collaboration between all authors. Authors IRB, PAVLM, IRH and HTB designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors IRB, PAVLM and GHSV managed the analyses of the study. Authors IRB, GHSV, VR and ACN managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

This study evaluates the effect of different angles of inclination of air chamber and ratios of fall/elevation heights (h/H) on the efficiency of hydraulic ram pumps made with alternative materials. The experiment is divided in two stages. In the first, an entirely randomized design is used, with five replications, in a 3×2 factorial scheme, considered in the composition of the treatments, with combinations of three alternative materials of the air chamber (polyethylene terephthalate bottle, polyvinyl chloride tube and the cylinder of a fire extinguisher) at two angles of inclination (45° and 90º). In the second stage, the experiment is again conducted with an entirely randomized design, with five replications, in a 2×4 factorial scheme, considered in the composition of the treatments, with combinations of two angles of inclination of the air chamber (45° and 90°) in four h/H ratios (1/3, 1/4, 1/5 and 1/6). The alternative material of the air chamber provides the highest efficiency in the first stage. The variables studied are subjected to normality analysis

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(Shapiro-Wilk) and homoscedasticity (Bartlett), with the T test being performed with the correction of Bonferroni ($P < 0.05$). The hydraulic ram with a PET bottle camber, inserted at an angle of 90º, submitted to an h/H ratio of between 1/4 and 1/6, provided the highest efficiency.

Keywords: Alternative pump; small farm; natural resources; field technology.

1. INTRODUCTION

A hydraulic ram is a simple and practical machine used to pump water in farms using the water hammer effect [1]. This stroke is an overpressure wave that occurs in a pipe with water where the flow is abruptly interrupted by the closing of the exhaust valve.

According to Abate and Botrel, [2], hydraulic rams present, as advantages, the lack of a need for external sources of energy, such as petroleum-derived fuels or electric energy, simple maintenance and operation, not requiring skilled labor, low cost of acquisition and/or assembly, and the possibility of use for 24 h a day, emphasizing water without the emission of pollutants or gases. Horne and Newman, [3] notes that the efficiency of these rams is determined by local conditions, with the water hammer producing noise and there being a need for a waterfall and the use of clean water, in addition to elevating only a small fraction of the flow rate available in the inlet.

Lately, hydraulic rams have been less used because of their low water lifting efficiency, instead being replaced by centrifugal pumps, which require energy to work. However, hydraulic rams can still be favored on farms, especially when positioned in running water, where uncharged water returns to the watercourse.

Considering the scarcity of financial resources for a farm, it is possible to manufacture hydraulic rams in a non-industrial way, using materials alternative to cast iron, such as polyvinyl chloride (PVC) piping [2], fire extinguisher pressure chambers [4] or bottles of polyethylene terephthalate (PET) [5]. However, none of these studies evaluated the performance of the hydraulic rams by varying the air chamber positioning angle, nor the different fall/elevation height (h/H) ratios.

Normally, the air chambers are positioned on a hydraulic ram at a 90° angle. However, it is believed that when positioned at an angle of 45°, they can provide less head loss, and consequently, greater mechanical efficiency.

In relation to the different h/H ratios, it is known that the higher this ratio, the lower the efficiency, making it essential to obtain the ratio that provides the highest mechanical efficiency, when using alternative materials for air chamber.

In view of the above, it is of utmost importance to develop research that increases the efficiency of this machine in order to optimize the use of water in small farms and to reduce the acquisition costs of a hydraulic ram for the farmer. Thus, the objective of this study is to evaluate the effect of different inclination angles of the air chamber and the h/H ratio on the efficiency of hydraulic ram pumps made from alternative materials.

2. MATERIALS AND METHODS

The experiment was implemented and conducted in a rural farm at the Municipality of Santa Teresa, Espírito Santo state, Brazil. The following materials were used to make the hydraulic ram: a fire extinguisher cylinder; PVC pipes, a 2-L PET bottle; two galvanized pipe junctions of 45° with a 1-inch diameter, two 1-inch diameter galvanized tees; a 1-inch brass nipple, a 1-inch vertical check valve, a 1-inch well valve, a 1-inch brass bushing for 0.75 inch, a 0.5 to 0.75-inch hose adapter, 2-inch nuts, a spring, sealing tape thread and glue for the PVC pipes. Table 1 shows the volumes and dimensions of the air chambers for the different materials used in the experiment.

Table 1. Volumes and dimensions of the air chambers for the different materials used in the experiment

Material	Volume (cm^3)	Internal Diameter(cm)	Length (cm)
PET bottle	2,000	9.3	33.0
Fire extinguisher	1,200	7.1	30.5
PVC pipe	100	2.8	16.3

(a) (b) (c)

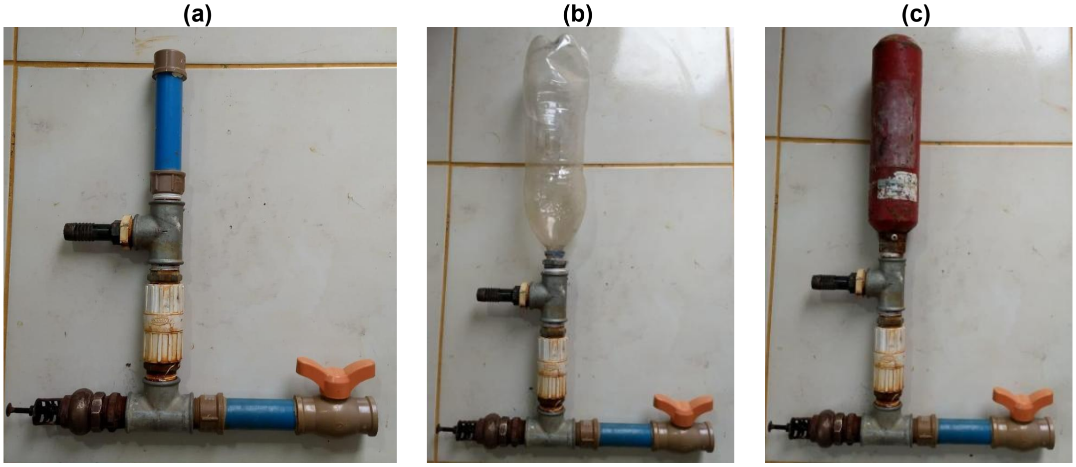

Fig. 1. 90° air chamber inclination using (a) PVC, (b) PET and (c) fire extinguisher cylinder

(a) (b) (c)

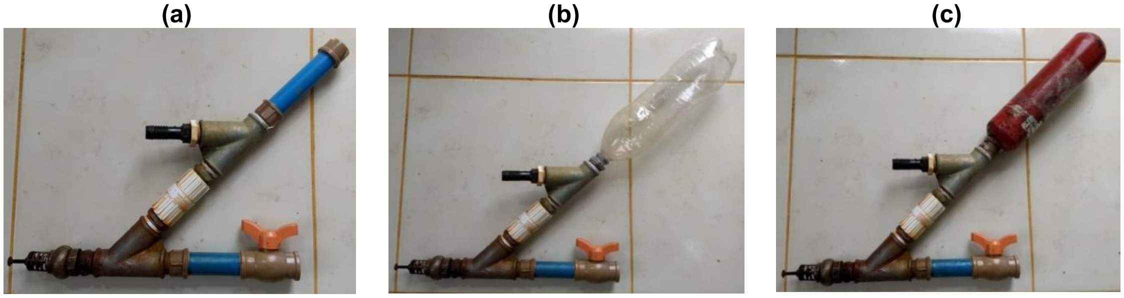

Fig. 2. 45° air chamber inclination using (a) PVC, (b) PET and (c) fire extinguisher cylinder

The experiment was divided in two steps: a) the yield of the hydraulic ram when varying the angle of inclination of the air chamber, with different reusable materials, and b) the yield of the hydraulic ram when varying the h/H ratio, with different inclinations of air chamber.

2.1 Yield of Hydraulic Ram with Variation of Angle of Inclination and Reusable Materials

Two angles of inclination of the air chamber, 90° and 45°, according to Figs. 1 and 2, respectively, were used, and these were combined with three reusable materials, namely, a PVC tube (Figs. 1a and 2a), a PET bottle (Figs. 1b and 2b) and a fire extinguisher cylinder (Figs. 1c and 2c). All combinations between the materials and the angles were performed, and these were evaluated with h/H = 1/4. Five replicates were performed for each treatment.

The water used to feed the ram was taken from a small reservoir of watercourse, whose water level was kept constant. From the reservoir, the water was transported by 1-inch PVC tubing, corresponding to the equipment feed tubing, while the pressurized water was transported by a flexible 0.75-inch diameter hose.

In order to determine the mechanical yield of the hydraulic ram (Rm), the proportions of the elevation (H) and fall (h) heights were determined, as well as the discharge (q) and feed rates (Q), as given in Equation 1.

$$Rm = \left[\frac{(H\,q)}{h\,Q} \right] 100 \quad (1)$$

Where,

Rm - Mechanical yield, %
H - Elevation height, m;
q - Boom flow rate, $m^3\ s^{-1}$;
h - Height of waterfall, m;
Q - Feed flow rate, $m^3\ s^{-1}$.

Both the feed and recharge rates were quantified by directly measuring the collected volume through a graduated container, in a time of 30 s.

This experiment was conducted with a completely randomized design, with five replications, in a 3×2 factorial scheme, considering the combinations of three alternative materials for the replacement of the industrial hydraulic ram air chamber (PET bottle, PVC tube and cylinder of fire extinguisher), for two angles of inclination, making a total of six treatments and 30 experimental units. The studied variables were submitted to normality analysis (Shapiro-Wilk) and homoscedasticity (Bartlett). After these assumptions were met, the t-test was performed for multiple comparisons, with the Bonferroni correction at a 5% probability level.

2.2 Yield of Hydraulic Ram with Variation of Angle of Inclination and h/H Ratio

The yields of the hydraulic ram with different angles of inclination, submitted to the different ratios of fall and elevation heights of the water (1/3, 1/4, 1/5 and 1/6), were evaluated in order to obtain the best result in the variation of the alternative material of the air chamber obtained for (a).

The determination of the mechanical yield was the same as that used in item (a). The experiment was conducted with a completely randomized design, with five replications, in a 2×4 factorial scheme, considering the combinations of two angles of inclination of the air chamber, in four ratios between the heights of fall and of elevation of the water (1/3, 1/4, 1/5 and 1/6), making a total of eight treatments and 40 experimental units.

The variables studied were submitted to normality analysis (Shapiro-Wilk) and homocedasticity (Bartlett), not taking into account the second assumption (very heterogeneous variances), in this case a non-parametric evaluation was used at a 5% probability level (Signals test), following a binomial distribution.

3. RESULTS AND DISCUSSION

3.1 Yield of Hydraulic Ram Varying the Inclination Angle of the Air Chamber with Different Alternative Materials

Table 2 and Fig. 3 show the different alternative materials used as air chamber, at two angles of inclination.

According to Fig. 3, it is observed that for the 45° angle, the three materials differed statistically from one another at the 5% probability level, with the PET bottle air chamber having the highest yield (~18%), followed by the PVC (~17.5%) and the extinguisher (~15.7%). For the 90° angle, the PET bottle provided statistically higher yields than the extinguisher and PVC, and these did not differ from each other. Such PET superiority can be explained by its structural properties.

Table 2. Yield of hydraulic ram varying the inclination angle of the air chamber with different alternative materials

Material	Inclination	Yield (%)	Variance (%)	Std deviation (%)
PET	45°	17.99	0.02	0.15
PET	90°	22.84	0.20	0.44
Extinguisher	45°	15.86	0.10	0.32
Extinguisher	90°	19.84	0.09	0.30
PVC	45°	17.38	0.01	0.08
PVC	90°	19.13	0.66	0.81

Table 3. Yield of the ram with the PET bottle, at two angles of inclination and different ratios between the heights of fall (h) and elevation (H)

Ratio h/H	Inclination	Yield (%)	Variance (%)	Std deviation (%)
1/3	45°	17.44	0.80	0.89
1/3	90°	18.69	0.27	0.52
1/4	45°	17.99	0.02	0.15
1/4	90°	22.84	0.20	0.44
1/5	45°	17.24	0.54	0.73
1/5	90°	22.17	0.26	0.51
1/6	45°	16.74	0.08	0.29
1/6	90°	22.56	0.06	0.24

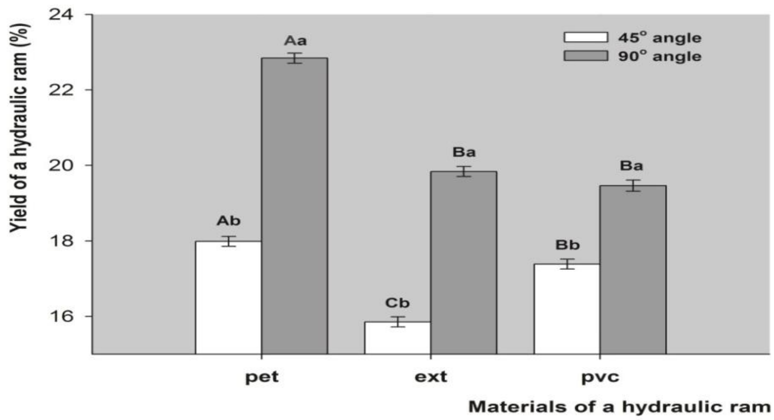

Fig. 3. Different materials used as air chambers at two angles of inclination

Equal letters do not differ statistically from each other by the t test with the Bonferroni correction at 5% probability. Capital letters compare the different materials within their respective inclinations. Lowercase letters compare the angle of the ram within each material

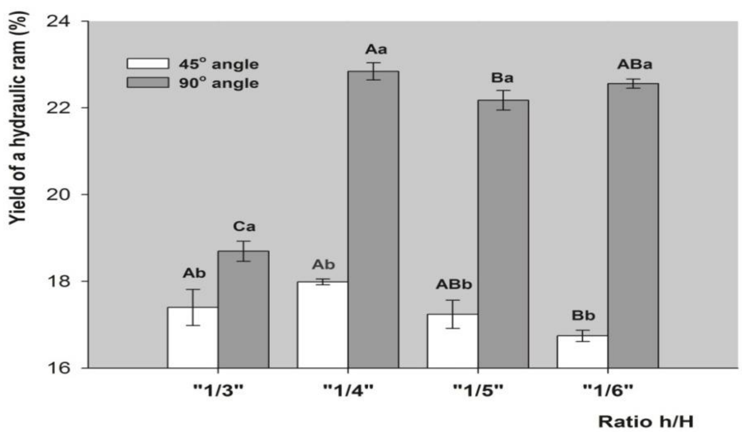

Fig. 4. Evaluation of the ram with PET bottle, at two angles of inclination and different ratios between the heights of fall (h) and elevation (H)

Equal letters do not differ statistically from one another by the test of the signals at 5% probability. Capital letters compare the different height/fall ratios within the angles of inclination. Lowercase letters compare the angle of the ram within each ratio

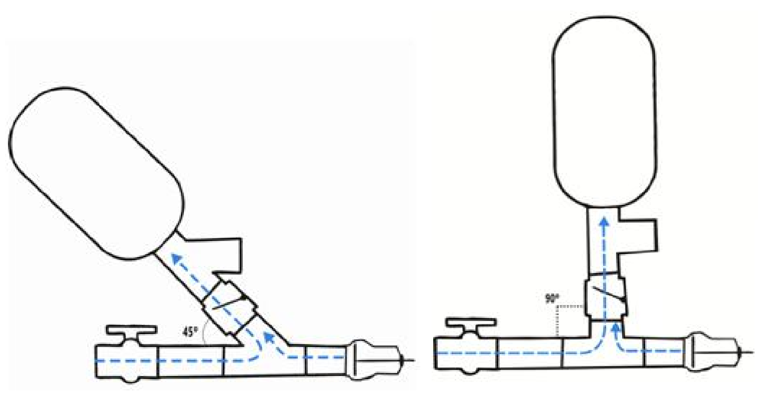

Fig. 5. Possible water flow inside hydraulic ram with angles of 45 and 90º

According to Bastos, [6], polyethylene terephthalate is a semicrystalline polymer composed of crystalline regions and amorphous regions, which gives it, through the biorientation process, an increase in the properties of impact resistance, fatigue and stretching, highlighting resistance to high internal pressures (608–710 kPa). Once the ram air chamber is pressurized, the PET acts by expanding and contracting so that it represses the water contained within the air chamber. Yield values close to those described by Bastos, [6], who found values between 19.76 and 35.47% for 2.5-L PET bottles, a volume close to that used in the present study.

It is worth considering that the volume of the air chambers were different for the different materials. The PVC had smaller volume than the others, with this, a smaller volume stored between the entrance and exit phases, which may explain the lower yields.

3.2 Yield of Hydraulic Ram with PET Bottle Varying the Inclination Angle of the Air Chamber with Different h/H Ratios

Table 3 and Fig. 4 show the evaluation of the ram with the PET bottle, at two angles of inclination and different ratios between the heights of fall (h) and elevation (H).

It can be seen in Fig. 4 that when the PET bottle was used with the angle of 45°, the highest yield was obtained for the ratio of 1/4, not statistically differing from the ratios of 1/3 and 1/5. The lowest yield was obtained for the ratio of 1/6, not statistically different from the 1/5 ratio. The lower yield for the 1/6 ratio was already expected, since the higher the h/H ratio, the higher the resistance will be offered to the flow.

Using the PET bottle with the 90° angle, the highest yield (~23%) was obtained for the ratio of 1/4, not statistically different from the 1/6 ratio, which in turn, did not differ from the 1/5 ratio. The ratio 1/3 provided the lowest yield (~17.4%), differing from the other relationships evaluated.

During the tests, it was observed that the relief valve was closed with less strength with the ram mounted with PET bottle for a ratio of 1/3 when compared to the other ratios. As the volume of its compression chamber is relatively large, when compared to the other types of chambers, in the 1/3 ratio less resistance to water displacement occurred due to the lower water column and, possibly, there was no sufficient compression inside the air chamber to ensure adequate water elevation.

Jennings, [7] shows that the length of the discharge pipe is considered to be of little importance to the installation, since friction loss is reduced as a function of the small flow rate. Thus, the 1/6 h/H ratio can be used for water retention in the 90° ram.

For the three evaluated air chambers (PET bottle, extinguisher and PVC) and all ratios (1/3, 1/4, 1/5 and 1/6), the 90° inclination was statistically superior to the 45° inclination. The hydraulic ram is based on the use of the potential energy of the water for its elevation, through the water hammer [8]. According to Azevedo, [1], the blow is characterized by a violent shock that is produced on the walls of the conduit, when the movement of the liquid is interrupted immediately. The velocity variation creates a disturbance wave in the liquid, called the pressure wave, which propagates through the liquid in one direction as well as the other, until it is damped.

At the moment the exhaust valve is closed by the liquid thrust, a pressure surge occurs, causing the valve to open and water to enter the valve [2]. A possible explanation for the best results for the 90º ram is that most of the water entering the air chamber comes from the feed pipe and not from the water that returns from the closure of the relief valve. Assuming this hypothesis, the ram with an inclination of 45º, in relation to the feed pipe, is disadvantaged, since the water needs to make a more pronounced curve, which causes greater head loss when the water moves of the feed pipe into the air chamber, as shown in Fig. 5.

In this way, it is believed that if the 45° part was inverted, it could cause less head loss as the water moves from the feed pipe into the air chamber.

The yield values obtained in steps 1 and 2 did not exceed values greater than 23%, indicating a yield below those reported by [8] and [9], which report yields of 30 to 60%. This fact may also be associated with the plastic parts used to build the ram, as well as the feed pipe, which was PVC. According to Cararo, [5], the hydraulic ram yield is not high since much of the water supplied to the equipment is not repressed and also by the use of plastic parts, which cushion the water hammer. With the later reason, the authors recommend the use of metal pipes in the feed.

It is worth mentioning that, in this study, we tried to use materials that would be discarded, regardless of their volume, aiming at reducing the cost of making the alternative hydraulic ram when compared to those manufactured industrially.

4. CONCLUSION

According to the results, a hydraulic ram with a PET bottle air chamber, inserted at a 90º angle, with an h/H ratio between 1/4 and 1/6 is recommended as it provides a higher mechanical yield.

New studies using air chambers with the same volume/dimensions and placing them at a 45° angle in the opposite direction to the one studied in this work are necessary, in order to prove the increase in the operating efficiency of the hydraulic ram.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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