Pumping yield of a PVC hydraulic ram prototype

Gustavo Eiji Ykeda[1]
Fernando da Silva Barbosa[2]
Miguel Angel Isaac Toledo del Pino[3]

Abstract

The use of hydraulic rams has increased due to energy problems in rural environments and to the need for irrigation of crops, even in small properties. These pumps work on the principle of water hammer to pump water without the use of external energy; however, they present low efficiency, considering the pumping yield as a function of the pumping height. Thus, the objective of the present study was to evaluate the efficiency gain of a hydraulic ram through the addition of pressure retaining valve at its inlet. The valve has the function of forming a physical barrier to the water that returns after the blowing with the suction valve. The prototype was tested using a randomized block design, with 4 blocks. A conventional PVC hydraulic ram and a hydraulic ram with a pressure retaining valve were installed and evaluated at the same time and with the same pumping height, which increased one meter every four days, with four replications for each height. The water output flow, system inlet and outlet pressure, inlet flow, pumped water volume, and number of beats per minute were evaluated to assess the efficiency of the hydraulic ram prototype. The hydraulic ram with the valve presented lower pumping yields in most evaluated heights; it presented better pumping than the conventional hydraulic ham only for the height of nine meters, denoting a poor cost/benefit ratio.
Keywords: Water hammer. Pumping efficiency. Retention valve.

Introduction

Hydraulic rams had been widely used in the past and are again being used due to the search for alternative energy sources to replace electrical energy or fossil fuels. These pumps are easily handled and does not require specialized workmanship for their use or maintenance; in addition, they do not demand electric power nor emit polluting gases, and their maintenance and operational costs are relatively low (ABATE, 2000).

Hydraulic ram has been used extensively for nearly a century in rural areas to pump water to heights greater than 100 meters. It is the ideal machine for pumping at certain conditions because the system works with only the force of falling water directed by a pipe. The system is automatic and has an exceptional history of absence of problems (WATT, 1975).

1 Instituto Federal de Educação, Ciência e Tecnologia do Sul de Minas Gerais, *Campus* Inconfidentes, discente do curso superior de Engenharia Agronômica. gustavo.e.ykeda@gmail.com. Rua Rio de Janeiro, 37, Atibaia (SP), CEP: 12942-270.

2 Instituto Federal de Educação, Ciência e Tecnologia do Sul de Minas Gerais, *Campus* Inconfidentes, professor EBTT. fernando.barbosa@ifsuldeminas.edu.br.

3 Instituto Federal de Educação, Ciência e Tecnologia do Sul de Minas Gerais, *Campus* Inconfidentes, professor EBTT. miguel.toledo@ifsuldeminas.edu.br.

Hydraulic rams should be installed at lower levels than the water source, at least 1.0 m and preferably at the lowest possible altitude (AZEVEDO NETO et al., 1998). According to the description of Azevedo Neto et al. (1998), the water that reaches the hydraulic ram exits through an external valve until reaching a high speed, then, the valve suddenly closes, causing an overpressure in the interior of the pump, called water hammer, which makes pumping the water possible.

Water hammer is the effect of the abrupt interruption of a continuous water flow into a pipe resulting in an increase in pressure; this is observed by abruptly closing the water outlet of a hose (TIAGO FILHO, 2002). The overpressure can be high, causing rupture and damages when it is not controlled; hydraulic rams use this overpressure to pump water of a reservoir to a higher point (CARVALHO; OLIVEIRA, 2008).

The ram prototype was developed considering that after an abrupt interruption of the water there is a potential energy generated within the hydraulic ram, and this energy causes the water to be pushed to an upper height (CARVALHO; OLIVEIRA, 2008), but there is a loss of energy during this process, because some of this energy is dissipated when the water that has suffered the blow meets the water that enters the system. Therefore, the inclusion of a physical barrier, such as a horizontal retainer in the lower tee fitting of the hydraulic ram, could minimize the dissipation of this energy.

In this context, the objective of this work was to evaluate the efficiency gain of a PVC hydraulic ram prototype through the addition of a retaining valve at its inlet and compare it to a conventional PVC hydraulic ram, considering this addition would increase the pumping height, and the constructive material would resist the internal pressure increase, increasing cost/benefit ratio.

Material and methods

The study was conducted at the Farm School of the Federal Institute of Education, Science and Technology of South of Minas Gerais, Inconfidentes campus, Minas Gerais, Brazil. The water source was a reservoir built near the nursery of that institution (22°18’42.05”S, 46°20’1.63”W). The topography of the study site was analyzed to measure the height at which the hydraulic rams were installed, reaching a maximum height of 5 meters.

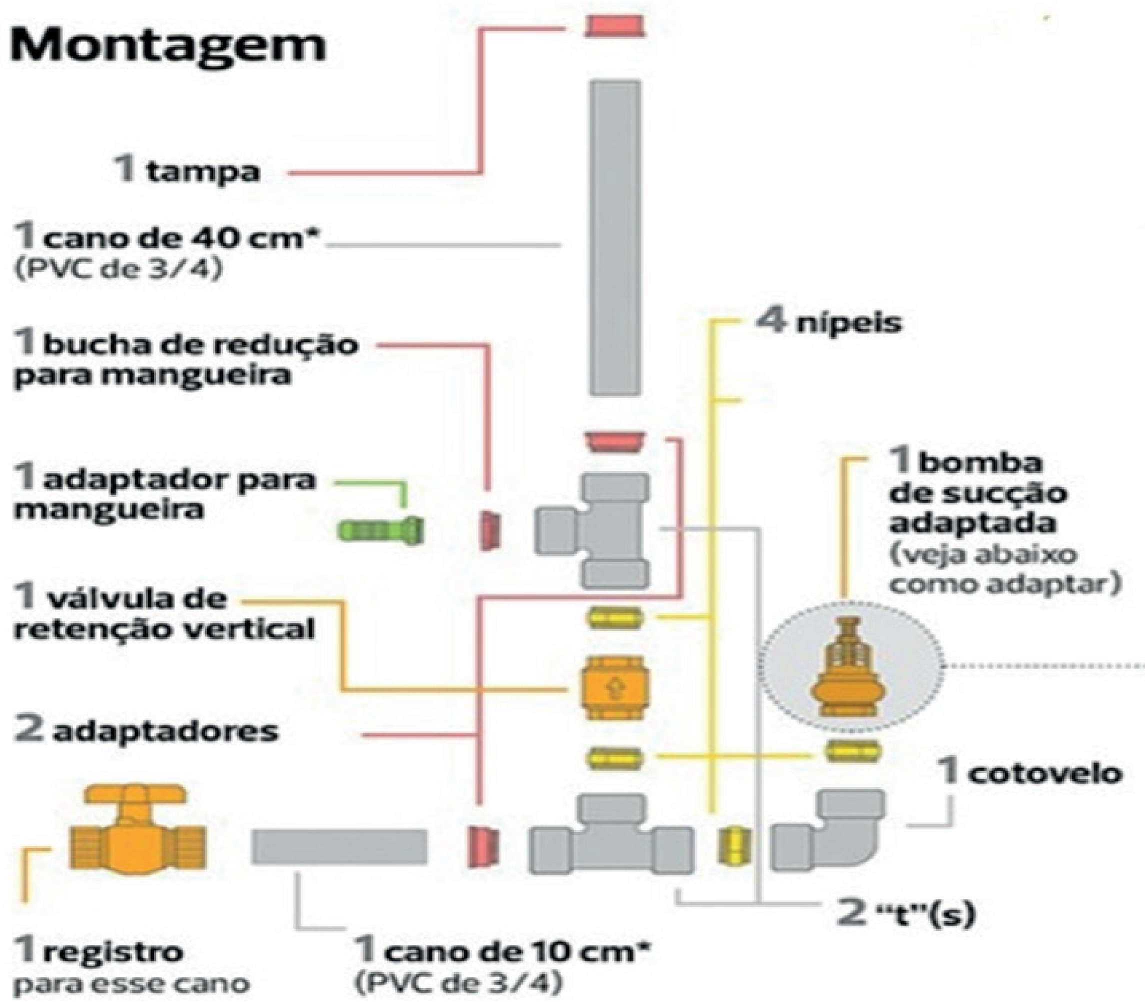
The experiment was conducted in a randomized block experimental design, using a 2×4 factorial arrangement, consisting of 2 pumping systems (PVC hydraulic ram prototype with additional valve and conventional PVC hydraulic ram without additional valve) and 4 pumping heights (8.0 m, 9.0 m, 10.0 m and 11.0 m), with 4 replications (TABLE 2). The available flow rate at the site was 0.7 L s^{-1} and the ram operating time was 8 hours a day.

The variables evaluated were: water pressure at the inlet of the system with the ram in operation (mca); water pressure at the output of the system in operation (mca); water flow (liters per hour); number of beats (beats per minute) and economic yield (EY).

The economic yield (EY) was calculated using the equation *EY = amount pumped (L day*$^{-1}$*) / hydraulic ram cost (Brazilian Real - R$)*, considering R$ 110.00 for the conventional ram and R$ 163.00 for the ram prototype.

The assembly of the hydraulic ram followed the model presented in the Globo Rural magazine of May 14, 2015 (FIGURE 1).

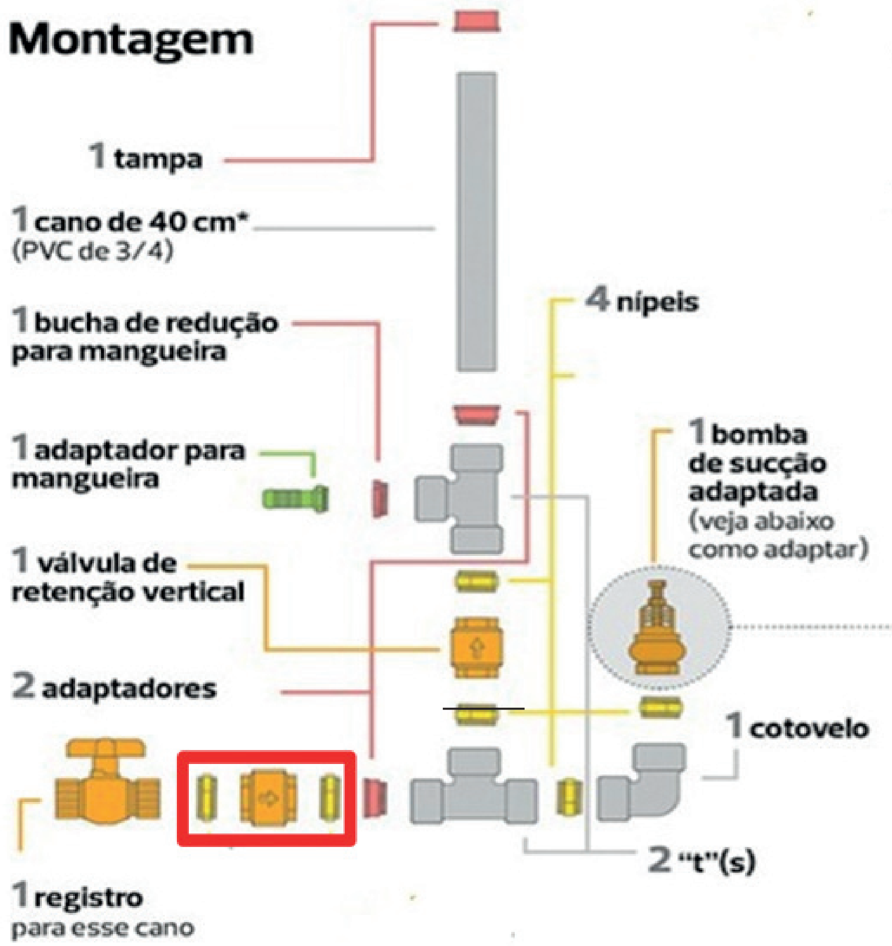
Figure 1. Assembly scheme of the parts for the conventional PVC hydraulic ram.



Source: Adapted from Globo Rural (2015).

The same parts were used for the PVC hydraulic ram prototype; however, two 3/4-inch niples and one 3/4-inch vertical retainer were added (FIGURE 2).

Figure 2. Assembly scheme of the parts for the PVC hydraulic ram prototype.



Source: Adapted from Globo Rural (2015).

An adapter for the pressure manometer was developed to measure the water pressure using 1 tee fitting with 2 hose connectors with diameter of 1 inch; 1 tee fitting of 1/2 inch; 1 female output adapter of 1 inch and another of 1/2 inch; 1 adapter of 1 inch, and another of 1/2 inch; approximately 5 cm of a PVC tube of 1 inch, and another of 1/2 inch; 1 cap of 1 inch, and another of 1/2-inch; and 1 tire inner tube valve. Pressure was measured using a tire pressure measurer (FIGURE 4).

An adapter for the pressure manometer of 1 inch was developed to measure the pressure at the hydraulic ram inlet as well as an adapter for the manometer of 1/2 inch to measure the pressure at the outlet. A filter was developed using a wooden box and the suction hoses were attached to it. 2 jute sacks were used as a filter to trap physical impurities and filter the water.

The water suction of each hydraulic ham was performed through 25 meters of 1-inch polyethylene hose. The water outlet of each hydraulic ram consisted of 20 meters polyethylene hoses of 1/2 inch. A hydrometer (Unimag - Monojato Class B) with nominal diameter of 1/2 inch – 3/4 inch was installed at each ram outlet to measure the pumped water volume during the study period. The hoses were adjusted to the desired heights using a meter graduated rope fixed in the suspension support of the ram.

The rams were kept at a fixed suction height of 5.0 m for evaluation, varying the vertical fall up to 11 meters (TABLE 1).

Table 1. Pumping heights evaluated.

Suction height	Vertical fall height
5.0 m	8.0 m
	9.0 m
	10.0 m
	11.0 m

Source: Elaborated by the authors (2017).

The heights were evaluated according to Table 2; each replication corresponded to one day of evaluation. The operating and evaluation times were approximately 8 hours a day (8h to 16h).

Table 2. Distribution of the replications/blocks of the experiment.

Replication	Height			
	8.0 m	9.0 m	10.0 m	11.0 m
1	01/19/2017	01/23/2017	01/27/2017	01/31/2017
2	01/20/2017	01/24/2017	01/28/2017	02/01/2017
3	01/21/2017	01/25/2017	01/29/2017	02/02/2017
4	01/22/2017	01/26/2017	01/30/2017	02/03/2017

Source: Elaborated by the authors (2017).

The results were subjected to analysis of variance by the F test, and significant means were compared by the Scott-Knott test at 5 % significance level, using SISVAR program (FERREIRA, 2014).

Results and discussion

Table 3 shows the analysis of variance of the factors related to pressure and volume evaluated.

Table 3. Analysis of variance of the water pressure with the ram in operation (WPR) in mca; water pressure at the ram outlet (WPO) in mca; pumped water flow (PWF) in L h^{-1}; number of beats per minute (NBM), in beats min^{-1}; economic yield (EY), in L day^{-1} R$$^{-1}$.

Source of variation	WPR	WPO	PWF	NBM	EY
Block	0.641 ^{ns}	2.326 ^{ns}	0.469 ^{ns}	1.130 ^{ns}	0.324 ^{ns}
Height (H)	14.829**	39.509**	22.419**	13.373**	16.897**
Treatment (T)	4.841*	53.182**	0.005 ^{ns}	3.225 ^{ns}	33.533**
H × T	1.668 ^{ns}	0.0031*	3.330*	2.750 ^{ns}	1.883 ^{ns}
CV (%)	6.28	4.46	16.97	5.25	18.77
Overall mean	13.957	15.987	95.064	43.135	0.723

* = significant at 5%; ** = significant at 1%; ns = not significant
Source: Elaborated by the authors (2017).

The water pressure with the ram in operation (WPR) was significantly affected by the heights ($p < 0.01$) and treatments ($p < 0.05$) (TABLE 3). The heights of 10 and 11 meters presented higher pressures (TABLE 4), as expected, since higher pressures are required to pump water to higher heights. The conventional ram presented a higher outlet pressure than the prototype ram (TABLE 5 and FIGURE 3). The WPR of the ram prototype was lower, as expected, since the horizontal retention valve retained part of the pressure, causing a localized pressure loss.

Table 4. Mean water pressure at the inlet of the ram in operation (WPR) for the 4 pumping heights evaluated, in mca.

Treatments	Means
8.0 m	13.17 b
9.0 m	12.78 b
10.0 m	14.51 a
11.0 m	15.36 a

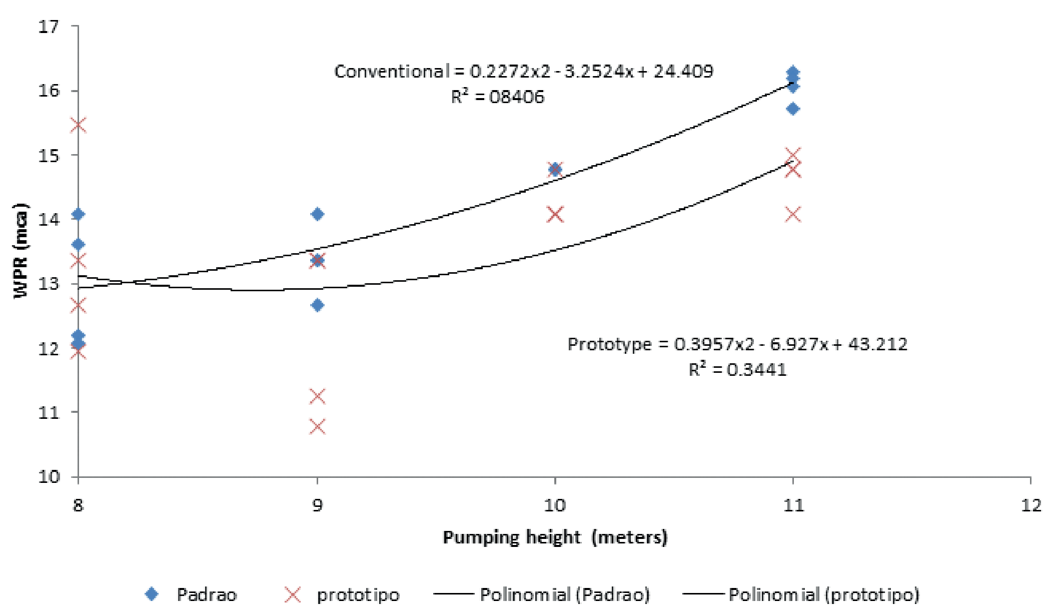
Means followed by the same letters in the column do not differ by the Scott-Knott test ($p < 0.05$).
Source: Elaborated by the authors (2017).

Table 5. Water pressure at the inlet of the ram in operation (WPR) for the conventional ram and for the prototype ram, in mca.

Treatment	Mean
Prototype	13.61 b
Conventional	14.29 a

Means followed by the same letters in the column do not differ by the Scott-Knott test ($p < 0.05$)
Source: Elaborated by the authors (2017).

Figure 3. Water pressure at the inlet of the ram in operation (WPR) as a function of the pumping height for the conventional and prototype rams.



Source: Elaborated by the authors (2017).

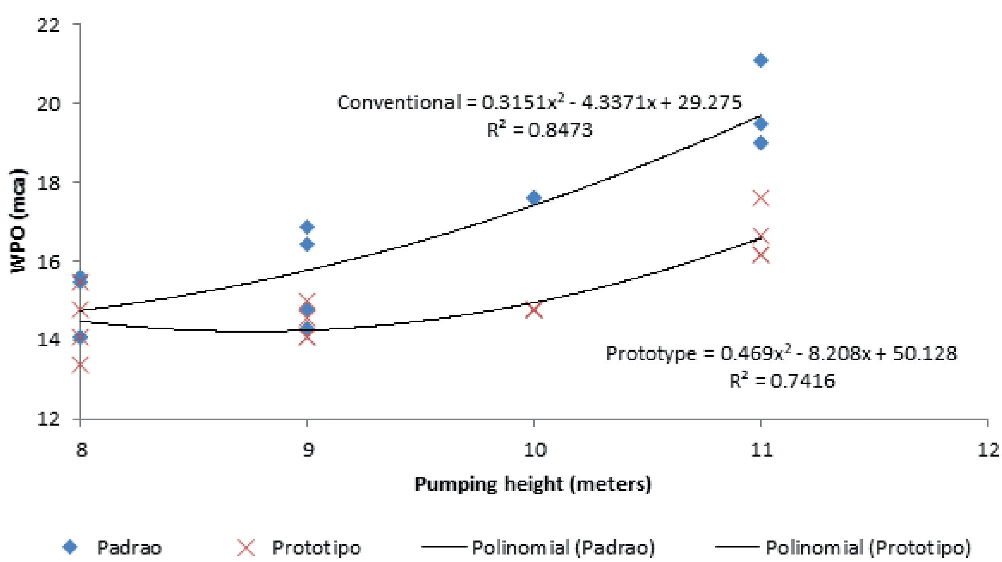
Water pressure at the ram outlet (WPO) was significantly affected by the heights and treatments ($p < 0.01$) and by the interaction between height and treatment ($p < 0.05$) (TABLE 3). The conventional ram presented better results for almost all heights evaluated, it was not significantly different from the prototype ram only at the height of 8 meters (TABLE 6, FIGURE 4). The output pressure of the prototype ram was expected to be higher, with the horizontal retention valve redirecting the water hammer pressure at the inlet to the outlet of the ram, but it was not found in the experiment.

Table 6. Mean data of the interaction between height and treatment for the pumping pressure at the outlet of the rams (WPO), in mca.

Treatment	8.0 m	9.0 m	10.0 m	11.0 m
Prototype	14.422708 Ba	14.422705 Bb	14.774480 Bb	16.650603 Ab
Conventional	14.803793 Ca	15.595285 Ca	17.588670 Ba	19.640678 Aa

Means followed by the same uppercase letter in the row and lowercase letter in the column do not differ by the Scott-Knott test ($p < 0.05$)
Source: Elaborated by the authors (2017).

Figure 4. Pumping pressure at the outlet of the ram (WPO) as a function of the pumping height for the conventional and prototype rams.



Source: Elaborated by the authors (2017).

The pumped water flow (PWF) was significantly affected by the heights ($p < 0.01$) and by the interaction between height and treatment ($p < 0.05$) (TABLE 3). The ram prototype had higher flow when using the height of 9 meters (TABLE 7). The beat frequency of the ram is directly related to its pumping performance, however, the beat frequencies of one ram may not be ideal for the other. This explains the best performance of the ram prototype at height of 9.0 meters height, indicating the beating frequency of 44 b min^{-1} (TABLE 8) may be favored over the conventional ram. Nevertheless, the ram prototype may have worked under unfavorable conditions in the other heights. Therefore, further studies should be carried out to find the best beat frequencies of each ram and evaluate them at their maximum efficiency, instead of evaluating them with similar beat frequencies, which was the aim of this study.

The pumped volume (TABLE 7) was lower than that found by Cararo et al. (2007), who found pumping volume of 115.2 L h^{-1} to 481.2 L h^{-1} with a vertical fall of 10 m; however, the suction pipe used by them was a galvanized steel pipe of 50 mm at 4.37 meters height. Abate and Botrel (2000) found higher pumping yields when using steel pipe at the height of 4.7 meters. Polyethylene suction pipes were used in the present study; thus, a lower pumped volume was expected.

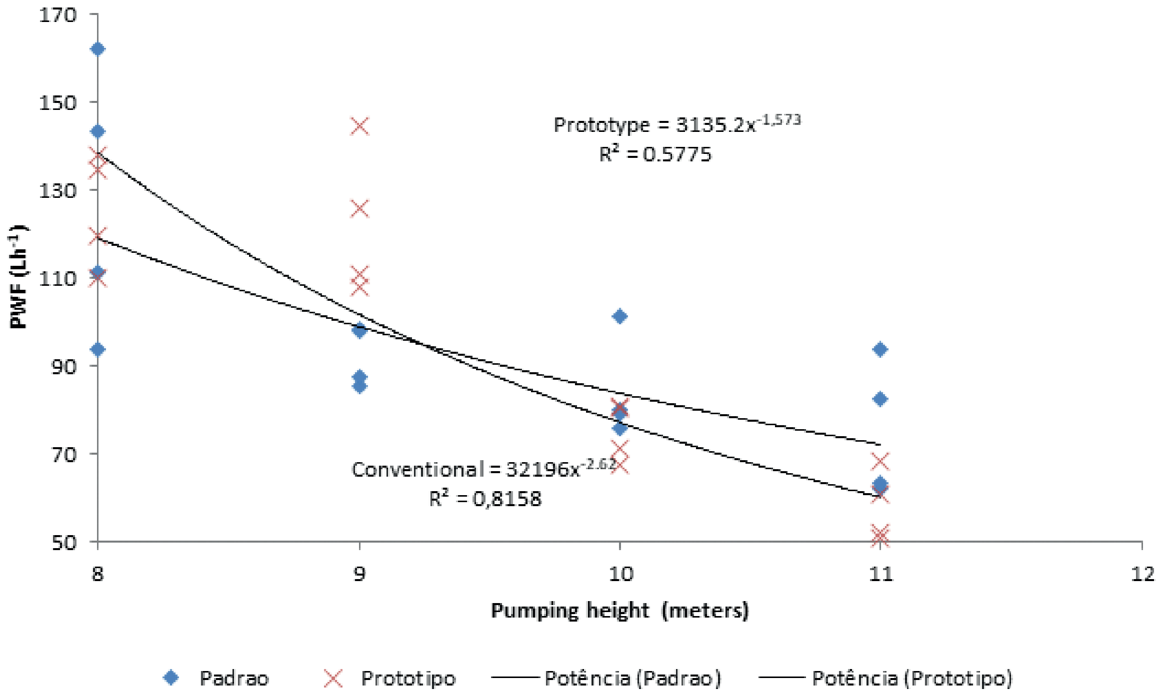
A more pronounced decrease in the flow of the ram prototype was found with increasing pumping height (FIGURE 5).

Table 7. Interaction between height and treatment for pumped water flow (PWF), in L h^{-1}.

Treatment	8.0 m	9.0 m	10.0 m	11.0 m
Prototype	125.59Aa	122.39 Aa	75.02 Ba	58.02 Ba
Conventional	127.623 Aa	92.25 Bb	84.13 Ba	75.46 Ba

Means followed by the same uppercase letter in the row and lowercase letter in the column do not differ by the Scott-Knott test ($p<0.05$)
Source: Elaborated by the authors (2017).

Figure 5. Pumped water flow (PWF) as a function of the pumping height for the conventional and prototype rams.



Source: Elaborated by the authors (2017).

The number of beats per minute (NBM) was significantly affected ($p<0.01$) by the height (TABLE 3). The higher flow rate found by Cararo et al. (2007) may have been affected not only by the galvanized steel pipe, but by the NBM, since their rams were set to a beat frequency, in general, above 60 beats min^{-1}, which may also have affected their efficiency.

Table 8. Mean number of beats per minute for the 4 pumping heights evaluated, in beats min^{-1}.

Treatment	Means
8.0 m	45.87 a
9.0 m	44.87 a
10.0 m	39.29 c
11.0 m	42.50 b

Means followed by the same letters in the column do not differ by the Scott-Knott test ($p<0.05$).
Source: Elaborated by the authors (2017).

The economic yield (EY) was significantly affected by the heights and treatments ($p<0.01$), but not by the interaction between them (TABLE 3). EY was higher at the height of 8 meters for both rams, mainly because of the higher pumped water volumes at that height (TABLE 9; FIGURE 6). The prototype ram had higher production cost due to the additional valve and presented lower pumping efficiency, resulting in an unfavorable cost/benefit ratio when compared to the conventional ram (TABLE 10).

Table 9. Economic yield (ER) for the 4 pumping heights evaluated, in L day^{-1} R$$^{-1}$.

Treatment	Mean
8	0.965354 a
9	0.794751 b
10	0.612591 c
11	0.521010 c

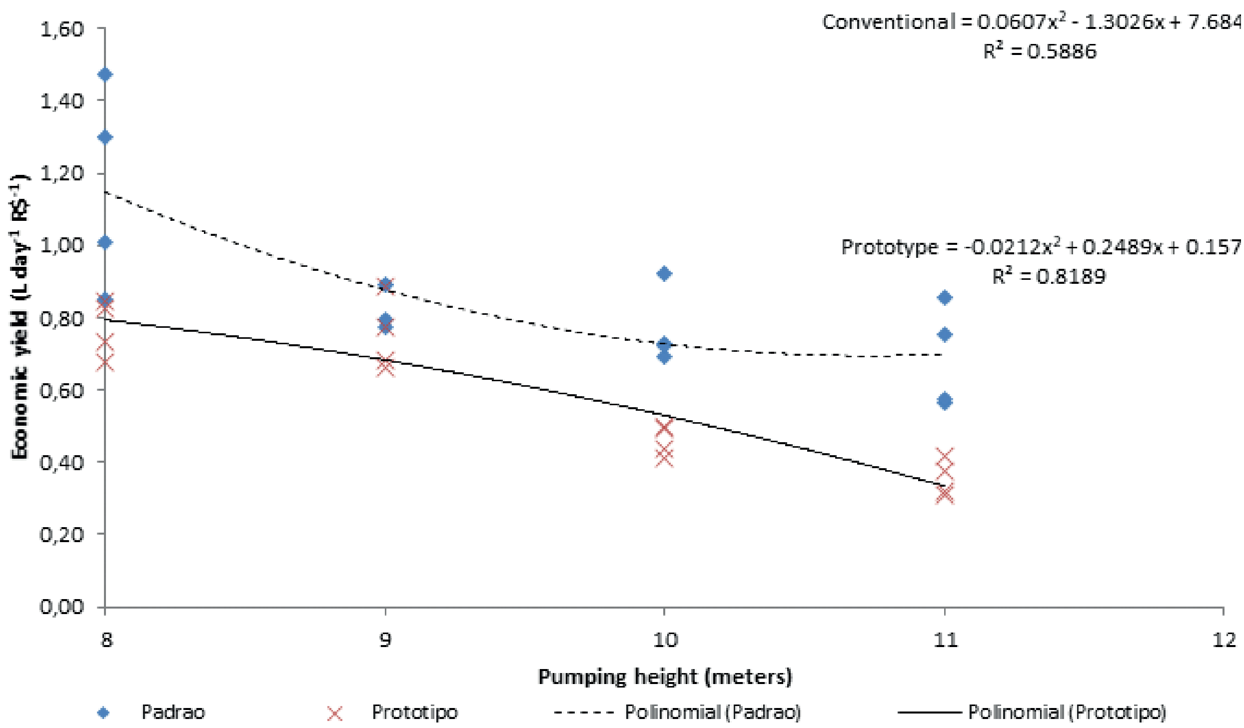
Means followed by the same letters in the column do not differ by the Scott-Knott test ($p<0.05$).
Source: Elaborated by the authors (2017).

Table 10. Economic yield (EY) for the conventional ram and prototype ram, in L day^{-1} R$$^{-1}$.

Treatment	Mean
Prototype	0.584401 b
Conventional	0.862452 a

Means followed by the same letters in the column do not differ by the Scott-Knott test ($p<0.05$).
Source: Elaborated by the authors (2017).

Figure 6. Economic yield (L day^{-1} R\$$^{-1}$) as a function of the pumping height for the conventional and prototype rams.



Source: Elaborated by the authors (2017).

Conclusion

Considering the evaluated conditions, the inclusion of à retention valve in the ram prototype does not increase yield in pumping height, and there is no increase in internal pressure or variations in the operation leading to the occurrence of mechanical problems or leaks in the ram.

The increase of approximately R$ 53.00 for the assembly of the prototype ram did not improve the system's performance, decreasing the cost/benefit ratio for the conditions evaluated.

The setting in the number of beats per minute should be specific to each ram to reach the best performance. Thus, each ram should be set with specific adjustments to work within their maximum efficiency.

Estudo do rendimento de bombeamento para um protótipo de carneiro hidráulico de PVC

Resumo

Devido à dificuldade energética no meio rural e à necessidade de irrigação, mesmo em pequenas propriedades, tem aumentado o uso do carneiro hidráulico, o qual por meio do princípio do golpe de aríete bombeia água sem o uso de energia elétrica. Contudo, seu rendimento em função da altura bombeada não é tão eficiente. Por meio deste estudo, objetivou-se com a adição de uma

válvula retentora na entrada do carneiro ter um ganho de eficiência. A válvula tem a função de formar uma barreira física para a água que retorna, após seu golpe, com a válvula de sucção. O projeto foi desenvolvido com delineamento em blocos casualisados, com 4 blocos. Foram instalados 1 carneiro hidráulico de PVC (convencional) e 1 carneiro hidráulico com retentor que foram avaliados ao mesmo tempo. A altura de queda foi a mesma, variando 1 metro da altura bombeada a cada 4 dias. Foram realizadas 4 repetições para cada altura analisada e avaliou-se a vazão de saída por meio de hidrômetros, pressão de entrada e saída do sistema, vazão de entrada, volume de água perdida e número de batidas por minuto, sendo possível medir sua eficiência. O carneiro hidráulico com válvula apresentou um rendimento inferior na maioria das alturas estudadas, o bombeamento foi superior ao convencional somente aos 9 metros de altura, o que prejudica a relação custo-benefício.
Palavras-chave: Golpe de Aríete. Eficiência de bombeamento. Válvula de retenção. Choque de Aríete.

References:

ABATE, C.; BOTREL, T. A. Avaliação do desempenho de um carneiro hidráulico com tubulação de alimentação em aço galvanizado e PVC. **Scientia Agricola**, Piracicaba, v. 59, n. 1, p. 197-203. Disponível em: http://www.scielo.br/pdf/sa/v59n1/8095.pdf Acesso em: 12/04/2017

AZEVEDO NETO, J. M.; FERNANDEZ, M. F. y; ARAÚJO, R.; ITO, A. E. **Manual de hidráulica**. Capítulos A11 e A12. 8. ed. São Paulo. Ed.Edgard Blücher, 1998. p. 225-308p.

CARVALHO, J. A.; OLIVEIRA, L. F. C. de. In.:__ **Instalações de bombeamento para irrigação.** Lavras/MG: Editora UFLA, 2008.Capitulo 25, p. 347-362

CARARO, D. C.; DAMASCENO, F. A.; GRIFFANTE, G.; ALVARENGA, L. A. Caracterísitcas construtivas de um carneiro hidráulico com materiais alternativos. **Revista Brasileira de Engenharia Agrícola e Ambiental**, Campina Grande, v. 11, n. 4, p. 349-354, 2007.

FERREIRA, D. F. **Sisvar**: a Guide for its Bootstrap procedures in multiple comparisons. **Ciência e Agrotecnologia**, Lavras, v. 38, n. 2, p. 109-112, 2014. Disponível em: http://dx.doi.org/10. 1590/S1413-70542014000200001. Acesso em: 12 abr. 2017.

COMO fazer um carneiro hidráulico. **Revista Globo Rural**, Rio de Janeiro, p. 1, maio, 2015. Disponível em: http://revistagloborural.globo.com/vida-na-fazenda/noticia/2015/05/como-fazer-o-carneiro-hidraulico.html. Acesso em: 20 maio 2016.

TIAGO FILHO, G. L. **Carneiro Hidráulico**: o que é e como produzi-lo. Itajubá: Centro Nacional de Referência em Pequenos Aproveitamentos Hidro energéticos, 2002. 8p. Disponível em: https://www.slideshare.net/CelsoFerreiradePaula/carneiro-hidraulico-56859971 Acesso em: 12 abr. 2017.

WATT, S. B. **A manual on the hydraulic ram for pumping water.In:___Introdução** Londres: Intermediate technology. 1975. p. 6.

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