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Special edition

Design of a hydraulic ram pump for irrigation of the UFSM campus in Cachoeira do Sul

Dimensionamento de um carneiro hidráulico para a irrigação do campus da UFSM em Cachoeira do Sul

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ABSTRACT

With the development of the Federal University of Santa Maria (UFSM) campus in the city of Cachoeira do Sul-RS, plans of arborization and landscaping were made, and the need of a constant and reliable water supply for irrigation appeared. Therefore, the hydraulic ram pump was selected to deliver water from the pond, present in the grounds of the campus, to a storage tank for the irrigation system. In this context, this paper addresses a review of studies about the design and manufacture of hydraulic ram pumps and, subsequently, presents the basic design and the fabrication steps of a PVC hydraulic ram pump that is capable of feeding the irrigation system.

Keywords: Hydraulic ram pump; Design; Manufacture

RESUMO

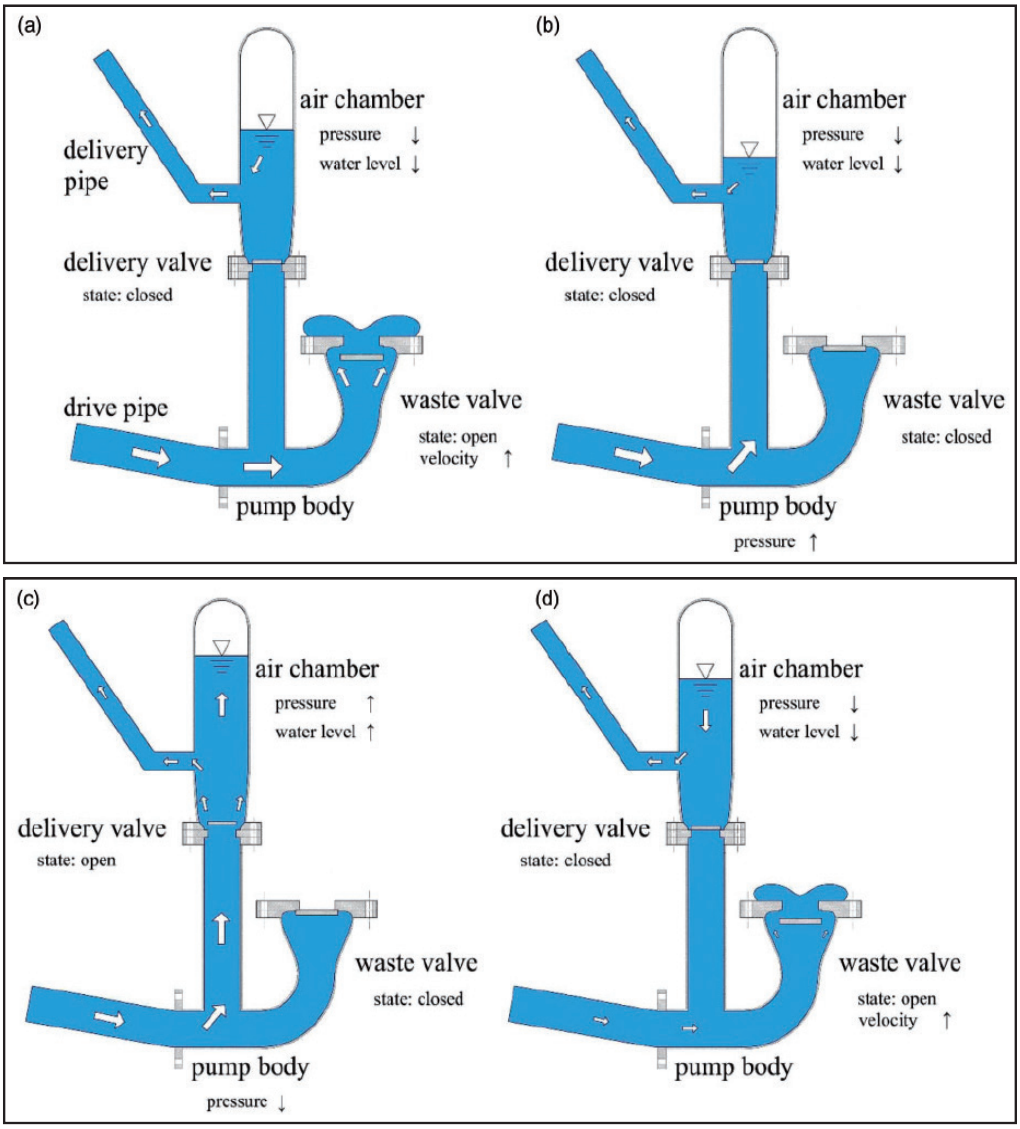
Com o desenvolvimento do Campus da Universidade Federal de Santa Maria (UFSM) na cidade de Cachoeira do Sul-RS, foram feitos planos de arborização e paisagismo, surgindo assim a necessidade de um abastecimento de água constante e confiável para irrigação. Desse modo, a bomba de carneiro hidráulico foi escolhida para bombear a água do açude, presente no terreno do campus, a um tanque de armazenamento para o sistema de irrigação. Nesse contexto, este trabalho aborda uma revisão de estudos sobre o dimensionamento e a fabricação de carneiros hidráulicos e, posteriormente, apresenta o projeto básico e as etapas de construção de um carneiro hidráulico de PVC capaz de alimentar o sistema de irrigação.

Palavras-chave: Carneiro hidráulico; Dimensionamento; Fabricação

1 DESIGN OF A HYDRAULIC RAM PUMP FOR IRRIGATION OF THE UFSM CAMPUS IN CACHOEIRA DO SUL

The hydraulic ram pump is a 200-year-old device that uses renewable energy to automatically pump water from lower heads to higher elevations with no need of external power (Kesharwani; Tripura; Singh, 2021), this device works due to a series of energy conversion processes, which can be separated into three phases (Young, 1997). According to Figure 1:

Figure 1 – Operation Cycles of the Hydraulic Ram Pump



Source: Xinlei *et al.* (2018)

In the first phase, the potential energy in the water is transformed into kinetic energy as the fluid flows through the drive pipe and its velocity rises. In the second phase, the liquid flows by the ram and through the waste valve until it reaches a critical velocity (Young, 1995), at this instant the valve closes and all of the kinetic energy is converted to positive pressure. In the third phase, the pressure increase in the pump propels the water through the drive valve, as the fluid enters the air chamber its pressure rises and is converted into potential energy as the water exits the chamber and flows upwards through the drive pipe (Rojas, 2002).

The first detailed account of a hydraulic ram is from J. Whitehurst, who used his machine, in 1774 (Xinlei *et al*., 2018), to deliver clean water to a brewery. Whitehurst's design is the first to utilize this set of principles to function, but his machine was manually operated, as the waste valve had to be physically opened and closed. It was only in 1797, that J.M. Montgolfier and Argant created a machine that operated in the same manner of Whitehurst's but was not hand-operated, as their design featured a mechanical waste valve that opened and closed automatically (Basfeld; Müller, 1984).

The Montgolfier's design of ram pump was popularized in the middle of the 19th century and was commonly used in rural areas as the main way to deliver water for domestic and agricultural use (Basfeld; Müller, 1984). But with the development of novel pumps that used electricity or fossil fuels as energy, the use of the ram pump declined (Young, 1995).

However, in the past 30 years the interest in a reliable, low-cost and environment friendly alternatives for pumping water grew. With this growth, the interest in research of the hydraulic ram was renewed, as the ram pumps are reliable and of low maintenance since in its basic design there are only two moving parts, the waste valve (or impulse valve) and the delivery valve (Sarip *et al*., 2020). These types of pumps are low-cost as well, considering that they can either be bought or made on site with only hardware store parts, whereas other alternatives, such as electric hydro-turbines, require expensive components and high maintenance (Kesharwani; Tripura; Singh, 2021). Another key aspect of the ram pumps is the lack of need to use external power to realize the work on the water, which makes this type of pump environmentally friendly since no polluting by-products are generated in its operation (SARIP *et al*., 2020).

With the development of the *Federal University of Santa Maria* (UFSM) campus in the city of Cachoeira do Sul-RS, plans of arborization and landscaping were made, and the need of a constant and reliable water supply for irrigation appeared. The campus has in its grounds a pond replenished by rainwater and in close proximity to the area of arborization, however it is at a lower level than the rest of the campus. Therefore, one of the best options to deliver water from the pond to the irrigation system in place is the hydraulic ram pump due to its low-cost, low-maintenance, reliability and operation without the need for electrical power.

Thus, this paper aims to conduct out a bibliometric analysis and review of current literature about the design of a PVC hydraulic ram pump. Also present the design and manufactured prototype capable of delivering water to the irrigation of the UFSM campus in Cachoeira do Sul, RS.

2 MATERIAL AND METHODS

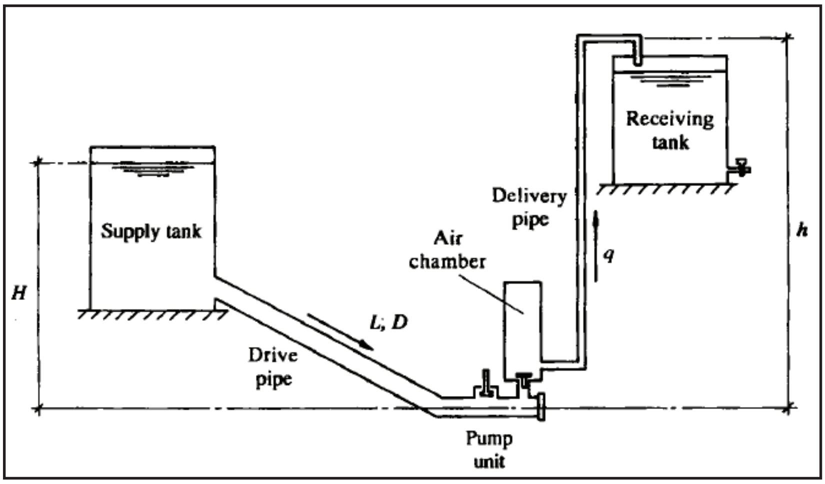
The bibliographic material utilized in the theoretical foundation of this review was found by searching the terms “HYDRAULIC RAM PUMP” AND (“MANUFACTURING” OR “DESIGN” OR “IRRIGATION”) in the Scopus, Web of Science and Google Scholar databases, between title, abstracts and keywords; in a search period ranging from 1960 to January of 2023.

The preliminary results of the searches in the three databases were analyzed and articles that were not deemed relevant to the research were excluded. The remaining articles were explored using the software’s “VOS viewer”, version 1.6.19, and “Microsoft Excel 2016” as a way to depict the growing interest and characterize the most important aspects of the hydraulic ram pumps.

2.1 Elements of the hydraulic ram pump

The hydraulic ram pump system is composed of: a) a water supply source at a higher level; b) a drive pipe connecting the supply source to the pump; c) the pump body that must have the impulse and drive valves; d) an air chamber to store the water cycles and e) a delivery pipe to direct the flow to higher altitudes (Young, 1997). The Figure 2 shows the system schematics.

Figure 2 – Hydraulic ram pump system schematics



Source: Young (1996)

2.2 Operating cycle of the hydraulic ram pump

Initially, as the water exists the supply source and flows through the drive pipe, its potential energy, due to gravity, is converted into kinetic energy as the water accelerates in the pipe (Sarip *et al*., 2020), at this stage the delivery valve is closed while the impulse valve is open under the action of the gravitational force and the elastic force of the spring present in the valve (Xinlei *et al*., 2018). Due to this factor, the water can flow through the body of the pump and out of the impulse valve increasing its velocity in the process, the impulse valve will only close when the flow velocity reaches a critical velocity in which the hydrodynamic force overcomes the forces that keep the valve open (Young, 1995).

At the instant in which the impulse valve closes the boundary conditions change abruptly (Xinlei *et al*., 2018) and a shock wave, induced by the water hammer effect, travels through the fluid (Young, 1995). As the water hammer effect takes place, the kinetic energy of the flow is converted into pressure, increasing the pressure in the body of the pump and causing a difference between the pressure in it and in the air chamber, due to this gradient, the delivery valve opens (Xinlei *et al*., 2018), allowing the water to enter the air chamber. It is valid to note that with the increase of the pressure after the water hammer effect, some of the fluid will reverse its flow orientation, recoil, dissipating energy as the reverse flow hits the incoming water for the next cycle (Ykeda; Barbosa; Pino, 2019).

As the water enters the air chamber, the pressure increases closing the delivery valve (Sarip *et al*., 2020), at this moment the pressure of the pump will decrease allowing the impulse valve to open and the next cycle to begin (Young, 1995).

As the water pressurizes the air chamber, the energy of the flow is stored as potential energy by the compression of the air, this energy will gradually be transferred to the water in the delivery pipe as the air expands (Basfeld; Müller, 1984).

2.3 Design considerations

For the proper operation of the ram pump, a minimal head high between the supply source and the pump must be followed, according to Abate (2000), this distance can vary between 0.5 up to 1 meter.

Some measures can be taken to guarantee the longevity of the system, one of them is the use of a supply valve, which is placed at the beginning of the drive pipe and contains a filter to keep the system free of debris (Sarip *et al*., 2020). Another measure that can be taken is the regulation of the frequency of the impulse valve as lower frequencies deliver higher pressures and a greater flow rate (Abate, 2000) and do not produce large impact forces that are detrimental to the pump life (Young, 1995).

The drive pipe must be straight and always full of water to not trap any air bubbles that increase the energy losses (Sarip *et al*., 2020), the utilized pipe can be of

PVC or a non-flexible material as galvanized steel. The use of a specific material causes a reflection of its properties in the acceleration of the water in the pipe. The material would be responsible for applying the friction force directly related to roughness to the fluid in displacement (Domingues *et al*., 2018). Furthermore, the water hammer effect causes significant increase in force against the tube wall, with a more elastic wall, the elasticity of the pipe will increase the energy losses, so a less elastic wall led to an increase in efficiency (Domingues *et al*., 2018). However, the use of PVC drive pipe can be recommended at supply heads less than 4.2 meters, as in higher supply heads the water hammer effect is stronger, due to its elasticity, the PVC pipe, absorbs a portion of the energy of the effect (Abate, 2000). In higher supply heads (4.2 meters or higher), the drive pipe must be made of non-flexible materials to minimize the energy losses, however in lower heads the PVC drive pipe is more efficient than its non-flexible counterparts since it has a lower roughness coefficient and the losses due to the elasticity of the material are insignificant (Abate, 2000).

The length of the drive pipe also holds major importance in the design process as longer pipes will result in a better performance provided that the length respects the boundary conditions imposed by Young (1996).

The hydraulic ram pump is considered a reliable way to pump water because it has only two moving parts, the impulse and the drive valves (Hussin *et al*., 2017). The impulse valve is a mechanical component fundamental to the operation cycle of the pump since it is the device that, when the water reaches a critical velocity, closes provoking the water hammer effect (Young, 1997). For the minimization of the energy losses in the system, the outlet diameter of the impulse valve must be equal or greater than the inlet diameter of the impulse valve (Xinlei *et al*., 2018).

Considering that the water hammer is a phenomenon correlated to the potential energy that will later be converted into an internal pressure, the implementation of a one-way valve to prevent the backflow of water would generate a localized head loss (Ykeda; Barbosa; Pino, 2019), resulting in lower inlet pressure and outlet pressure compared to the standard ram. It would largely affect the pumping of water, causing a smaller range as well as a smaller volume of the displaced fluid. Therefore, the use of a one-dimensional valve for the ram structure is not recommended due to its structural inefficiency as well as the reduced performance of the hydraulic ram itself.

The air chamber holds great importance in the ram pump as it absorbs the shocks of the water hammer effect (Young, 1995) and converts a pulsating flow of water to a steady delivery flow (Basfeld; Müller, 1984). It also is one of the key components to increase the performance of the ram pump since the smaller the diameter of the air chamber the higher the delivery pressure will be (Hussin *et al*., 2017). Sarip *et al*. (2020) suggests that the "size of the air chamber must be equal to the volume of the delivery pipe".

The delivery pipe holds little importance in the design processes since the low flow rate reduces the energy losses to the roughness of the internal walls of the pipe (Abate, 2000).

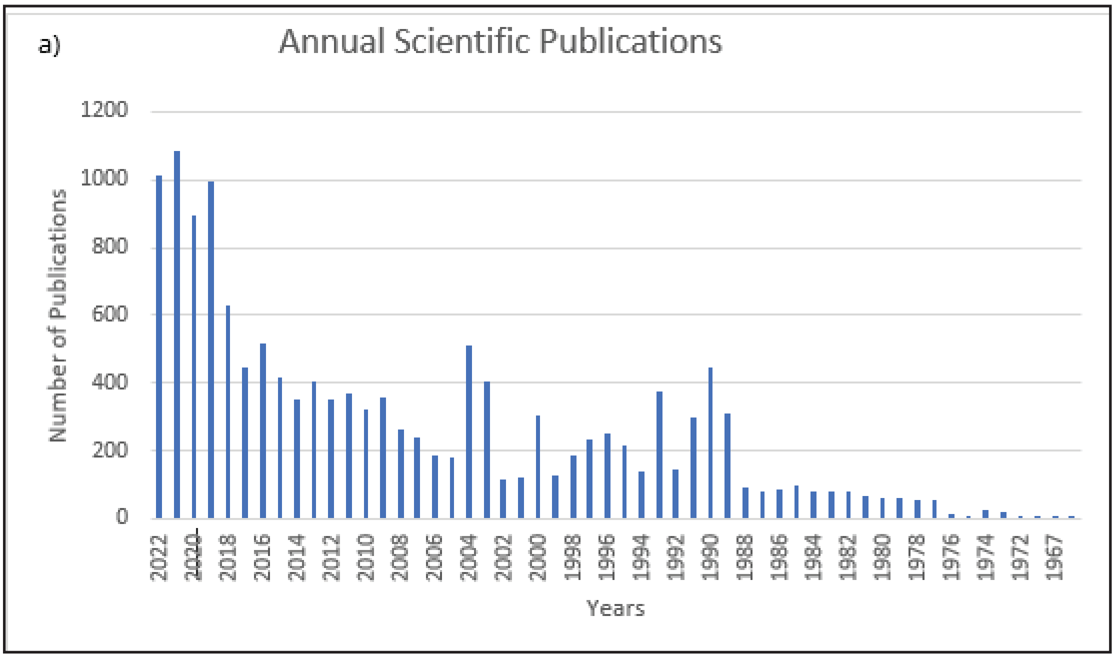
For its primary use in the UFSM campus in Cachoeira do Sul, the ram pump system has to be able to deliver enough water to feed the storage tank in the irrigation system. Since each irrigation cycle will use all the water in the 2000 liter tank the hydraulic ram pump will need to replenish the tank for a new cycle each day.

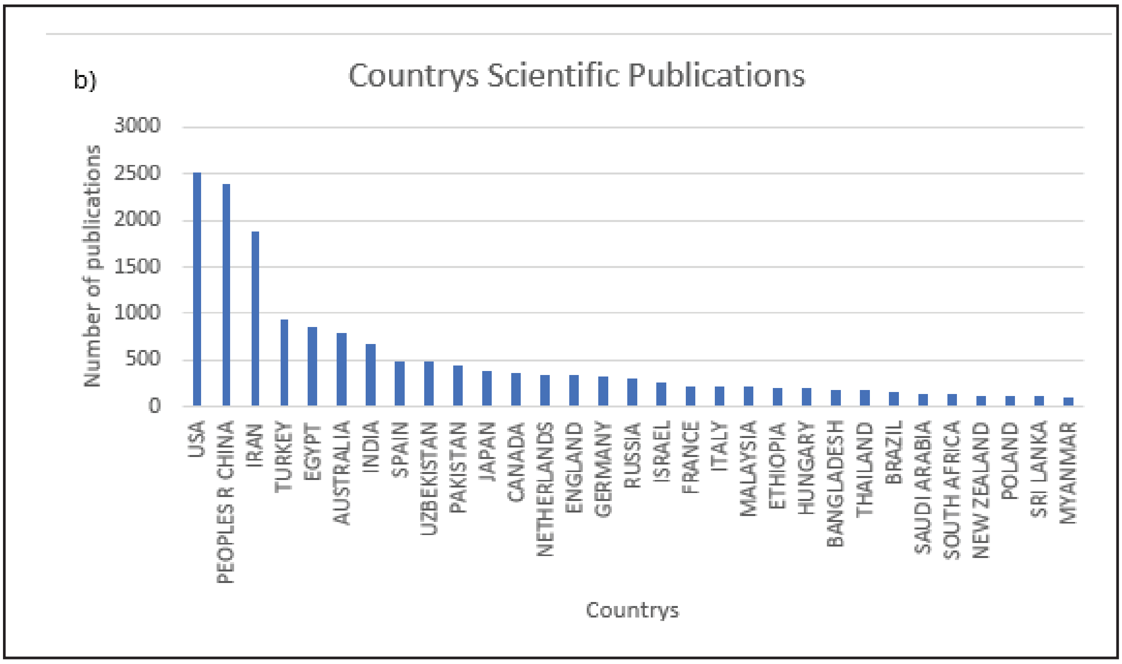
3 RESULTS AND DISCUSSION

3.1 Bibliometric analysis

According to the bibliometric analysis, realized a growth in the interest in the hydraulic ram pump, in the last 30 years, can be noticed worldwide. With a sharp growth from 1989 onwards, whereas the year 2021 had the greatest number of scientific publications. It is valid to note that the United States is the country with the most publications on the topic, being followed by China, Iran and Turkey.

Figure 3 – a) Annual Scientific Worldwide Publications; b) Countries Scientific Publications

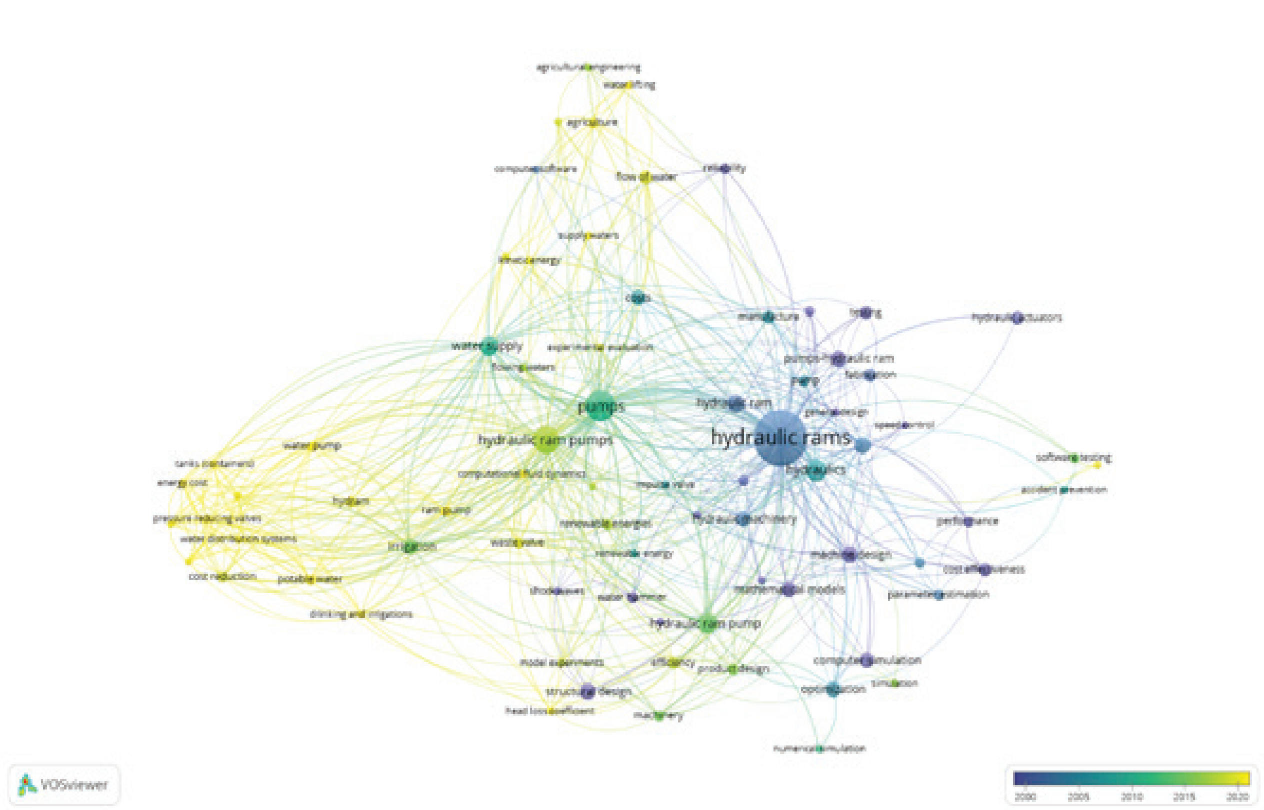




Source: Autorship(2023)

The evolution of the research focus with the keyword cloud cab be noted. In the late 1990s the research was focused on the hydraulic ram design and optimizations, but with the progression of time, a shift in the research focus can be noted as becoming centered in the uses of the ram pump in irrigation, delivery of potable water and renewable energy.

FIgure 4 – key-word cloud throughout the time



Source: Authorship (2023)

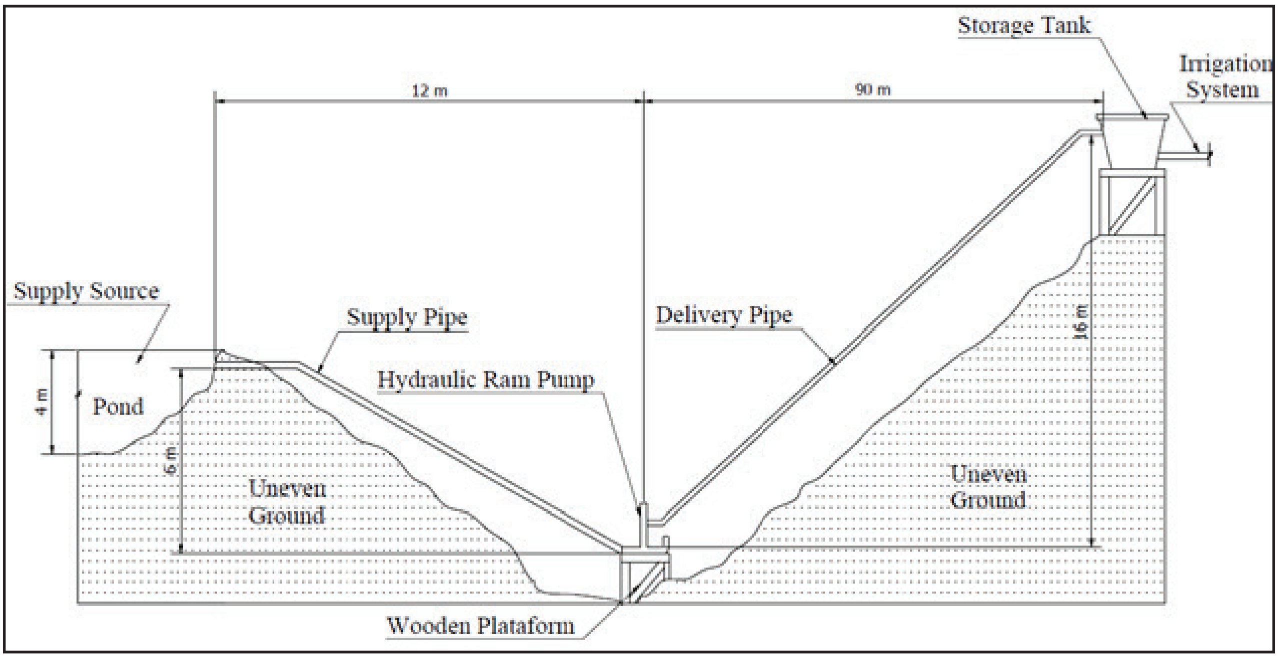
3.2 Parameters Analysis

3.2.1 Parameters measurements

Before the manufacture of the prototype, information about the location where the hydraulic ram pump would be installed was acquired by measuring procedures, and was determined that the flow rate of the pond, the supply source, with a 25 mm PVC drive pipe is 1800 liters per hour with a liquid column of 3.5 meters.

A wooden platform for the ram pump was built close to the pond so that the measured supply head is 6 meters with a distance of 12 meters between the supply source and the ram pump. The distance between the storage tank and the ram pump is 90 meters with a delivery head of 16 meters, as the water is going to be constantly pumped from the pond to a storage tank before being used in the irrigation system.

Figure 5 – Schematic drawing of the installation



Source: Autorship(2023)

Despite the design recommendations to utilize a stainless-steel drive pipe for supply head higher than 4.2 meters (ABATE, 2000) a PVC drive pipe was used in the system even though energy losses will occur, since it is not feasible to install a rigid pipe in the chosen location due to budget constraints and lack of accessibility for the installation.

3.2.2 Pump efficiency

According to the relations provided by Centro Nacional de Referência em Pequenos Aproveitamentos Hidroenergéticos (CERPCH) (2002) in an ideal situation, where the energy losses are not considered, for a supply head of 6 meters and a delivery head of 16 meters the efficiency of the hydraulic ram pump is expected to be of 60%.

3.2.3 Delivery flow rate calculation

The delivery flow rate can be determined by the equation 1 (CERPCH, 2002), and is, in ideal situations, 411 liters per hour. The delivery system used was a 12 mm flexible hose.

$$q = Q\left(\frac{h}{H}\right)R$$

Where:

q is the delivery flow rate;

Q is the supply flow rate;

h is the supply head high;

H is the delivery head high;

R is the efficiency of the pump.

The parameters *Q*, *h* and *H* were found by the analysis and measurements of the pond located at UFSM campus in Cachoeira do Sul. The parameter R can be calculated according to the section 3he .2.2 of this paper.

3.3 Prototype construction

The materials used in the manufacturing of the prototype hydraulic ram pump are listed as follows, in accordance with CERPCH (2002).

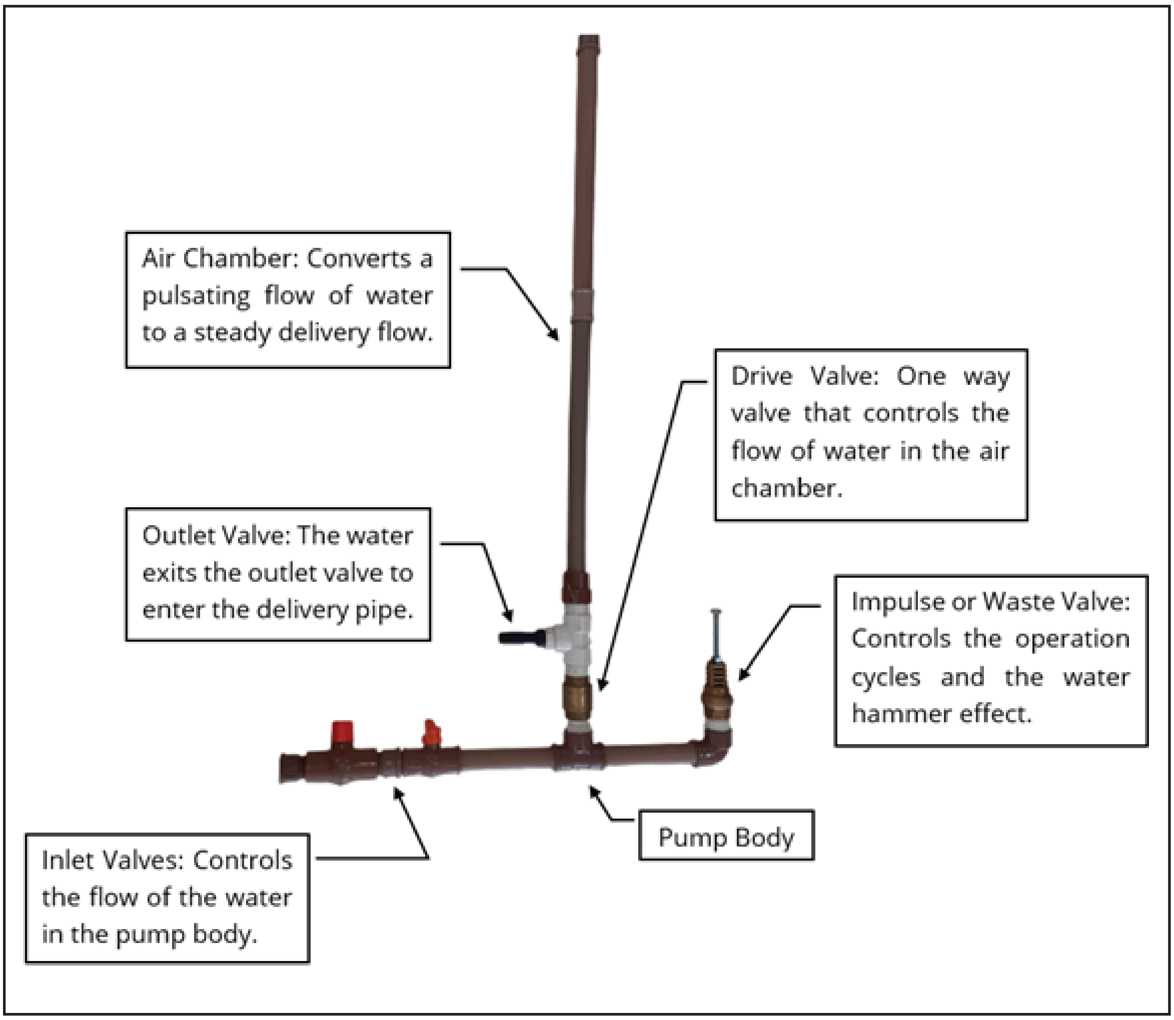
Table 1 – Bill of Material

Piece Number	Item	Quantity
1	PVC 25mm Valve Socket	7
2	PVC 25mm Ball Valve	2
3	PVC 25mm Socket	1
4	150 mm of 25mm PVC Pipe	2
5	PVC 25mm Tee Junction	2
6	PVC 25mm Elbow Junction	1
7	Brass Docol Suction Valve	1
8	Steel Hex Head M8 bolt	1
9	Steel M8 Nut	3
10	Steel M8 Washer	1
11	Compresion Spring	1
12	Brass Docol One Way Valve	1
13	PVC Hose Adaptor	1
14	625 mm of 25mm PVC Pipe	1
15	PVC 25mm End Cap	1

Source: Authorship (2023)

The impulse valve was assembled on site, the bolt was placed through the DOCOL brass suction valve, after that the spring was placed in the body of the bolt, being followed by a plain steel washer between two steel nuts and the assembly was tightened. All the valves used in the pump were connected to the PVC pipes through the valve sockets following the steps listed by CERPCH (2002). The finished prototype followed the design considerations addressed in this review and it is shown in the Figure 6.

Figure 6 – Final prototype



Source: Authorship (2023)

3.4 Experimental measurements

The flow rate and efficiency of the final prototype was measured in a period of drought in January of 2022 when the supply source was 103 liters per hour, which is 5.7% of total water disponible in a normal period. The real flow rate, in these conditions, is 33 liters per hour with a real efficiency of 32%.

4 CONCLUSIONS

This study addressed a compressive review of the literature about the design and manufacture of a hydraulic ram pump and used it to design and fabricate a prototype to be used in the irrigation system of the UFSM campus in Cachoeira do Sul. The objective of this work was accomplished as the prototype is capable of feeding the irrigation system, with a delivery flow rate of 33 liters per hour and a real efficiency of 32%. However, further studies are necessary to determine the various points of energy losses in the system.

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