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DESENVOLVIMENTO DE MÓDULO DE ENSINO PARA ESTUDO DE PERDA DE CARGA EM AULAS PRÁTICAS

DEVELOPMENT OF TEACHING MODULE FOR LOSS STUDY IN PRACTICAL CLASSES

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RESUMO
A perda de carga é um conceito de grande importância para estudantes de engenharia das mais diversas áreas, necessário no dimensionamento de sistemas de bombeamento e tubulações. O presente trabalho teve como objetivo o desenvolvimento de um módulo didático que torne mais prático o aprendizado desses estudantes, possibilitando a aquisição de dados para a criação de experimentos e roteiros de aula. Com este módulo foi possível estudar a perda carga em tubulações, cálculos de altura manométrica, potência e rendimento de bombas e discussões sobre cavitação.
Palavras-chave: Vazão. Rendimento. Bombas.

ABSTRACT
Pressure drop is a concept of great importance for engineering students from a wide range of fields, which is required when sizing pumping and piping systems, for example. The present work aimed to develop a teaching module that makes more practical the learning of these students, enabling the acquisition of data for the creation of experiments and class scripts. With this module it was possible to study the pressure drop in pipes, head calculations, pump power and yield and discussions about cavitation.
Key words: Flow. Yield. Pumps.

1. INTRODUCTION

The process of building the teaching module took place under the undergraduate education program PROAE 2018 – Programa de Apoio ao Ensino de Graduação –, a program that encourages projects that result in concrete actions for the improvement of teaching at the Federal University of Jequitinhonha and Mucuri Valleys (UFVJM). After initial studies, the module was designed and later built using low-cost materials aiming to make the Project easily replicable.

The teaching module represents a prototype of a system that transports a fluid between tanks in different heights, similar to the process of water supply from artesian wells and water and effluent treatment plants [1]. In this sense, the fluid, when flowing through a pipeline, suffers some resistance to its movement due to the combined effect of viscosity and inertia.

Such resistance is overcome by the moving fluid by dissipating part of its energy acquired during pumping.

Water or any other fluid can be pumped, but generally the manufacturer's specifications refer to water as the working fluid. According to Gomes (2013) [2], in fluids such as sulfur, where the viscosity is higher than that of water, the parameters as the optimum pump operating point should be corrected. More viscous fluids can reduce the pump efficiency and increase the absorbed Power, as well as reducing the head and the flow.

To perform the correct sizing of pumping systems it is necessary to develop calculations such as pressure drop. Pressure drop is the dissipation of the energy from flowing fluid due to accidents present in the pipelines, which causes reduction on fluid speed [3]. Also defined as a measure that is influenced by a variety of factors such as temperature, viscosity, and pipe roughness, pressure drop gives a flow resistance, increasing with the fluid viscosity and particle inertia present in the fluid under study [4]. For most pipes, accessories and fittings used in hydraulic installations, there is no analytical treatment for the pressure drop calculations because it is an eminently experimental field [5].

Several equations allow us to estimate the pressure drop in small diameter polyethylene pipes and, among them, the Darcy-Weisbach equation has been established [6]. The pressure drop may be distributed or localized, depending on the cause. In distributed one, the walls of the rectilinear ducts cause a pressure loss, distributed along the length of the pipe, causing the total pressure to gradually decrease over the length.

This pressure drop depends on the diameter, tube length, wall roughness, fluid properties, specific mass, viscosity and flow. The localized pressure drop is caused by the pipe fittings, that is, the various parts required for pipe assembly and flow control, which cause sudden variation in speed, modulus or direction, intensifying the pressure drop where they are located [7].

In addition, it is indispensable to determine which pump is suitable for the purpose of the system, involving knowledge of the optimal operating point obtained through the pump curve. Working at the optimum point indicates higher efficiency and lower operating costs. Net Positive Suction Head Available (NPSHA) indicates whether the pump cavitation phenomenon will occur when compared to NPSHR (Net Positive Suction Head Required), which is presented by the pump manufacturer [3, 8].

Thus, the main objective of this work is the design of a pressure drop teaching module, and its study, including calculations of head, NPSHA, pump power and yield for the design of experiments and scripts for laboratory use in the institution.

2. METHODS

This study was carried out in the Laboratory of Engineering, from the chemical engineering course at UFVJM, where the teaching module was developed, considering, above all, the possibility of inserting students in situations common to different industries.

In industrial environment, plumbing systems consist of rectilinear pipes of various diameters and various accessories such as fittings, valves, registers, flowmeters, restrictions and expansions, as well as many others.

Initially, a bibliographic survey on hydraulic pressure drop was carried out, seeking to understand the specifications, fittings and pipelines according to technical standard for PVC (Polyvinyl chloride). From this study, the teaching module was designed, as illustrated in Figure 1.

After the construction of the module, six triplicate tests were performed in the didactic module, varying the flow rate during the experiment. Different valve openings (¼; ½; ¾; 1; 1 ¼ and 1 ½ turns) during 10 seconds created 6 different flow rates for the experiment.

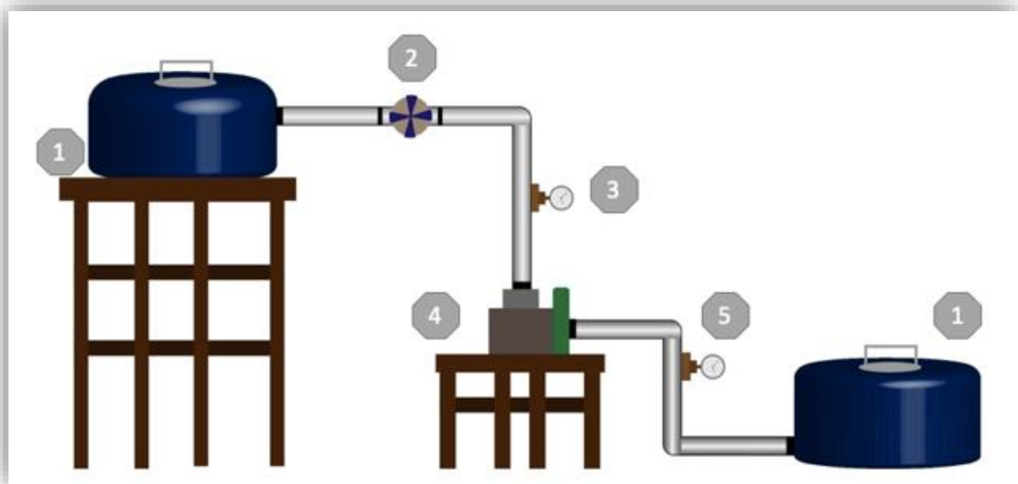

Figure 1 - Design of the teaching module for load loss study; 1: water tanks. 2: valve, 3: manometer, 4: pump, 5: vacuometer

After determining these parameters, data were obtained to calculate the located pressure drop in each accessory and the distributed pressure drop throughout the module. Thus, it was possible to detect which accessories contribute the most to the pressure drop. Moreover, with the obtained results it was possible to validate the efficiency of the built module, by determining the NPSHA, power and construction of the pump curve.

In distributed pressure drop, the walls of the rectilinear ducts cause a pressure loss along the tube, causing the total pressure to gradually decrease along its length. This pressure drop depends on the diameter, pipe length, wall roughness, fluid properties, specific mass, viscosity and flow rate of the fluid. Distributed pressure drop can be calculated according to Equation 1.

$$h_l=2f\frac{u^2}{g}\frac{Leq}{D} \quad (1)$$

In Equation 1, Leq is defined as an equivalent pipe length that causes the same pressure drop as the fitting, calculated according to Cremasco (2012) [8] . The roughness has the value of 0.0000015 m according to NBR5626. The symbols u and g are the fluid speed and the acceleration of gravity, respectively. The friction factor f is expressed as a function of roughness, pipe diameter and flow rate, and in turbulent systems this factor can be determined according to Equation 2, wher Re represents the Reynolds number, through which it is possible to affirm the flow regime.

$$f=\left\{\left(\frac{64}{Re}\right)^8+9{,}5.\left[\ln\left(\frac{\varepsilon}{3{,}7.D}+\left(\frac{2500}{Re^{0{,}9}}\right)^6\right)\right]^{-16}\right\}^{0{,}125} \quad (2)$$

Localized pressure drop is caused by plumbing fittings. Experimentally, it is observed that the pressure drop in accessories is constant when the regime is turbulent and can be determined by Equation 3, where k is a constant that can be found in tables or graphs in Fluid Mechanics or Unit Operations books.

$$h_p= k\frac{u^2}{2g} \quad (3)$$

To specify a pump for a given application it is of fundamental importance to determine the head, parameter that can be calculated according to Cremasco (2012) [8]. In addition, it is also of paramount importance to determine the power of the pump as it is associated with the energy expenditure required to displace the fluid. The ratio between the useful power of a pump and the power consumed gives the yield obtained according to Equation 4.

$$\text{Yield} = \frac{W_u}{W_{consumed}} \qquad (4)$$

In pumping operations the NPSHA indicates the ideal condition for fluid suction to occur. Since, there is a vacuum pressure limit that can be reached in the suction of a pump, so that, below this limit, the cavitation phenomenon occurs [9] . NPSHA is calculated according to Equation 5.

$$NPSH_D = \frac{PA\text{-}Pvapor}{\rho g} + H_s \qquad (5)$$

In equation 5, Pvapor is the vapor pressure of the liquid, which depends on temperature; Patm is the atmospheric pressure, defined as 1 atm; "ρ" is the specific mass and Hs is the suction head. This parameter is provided by the manufacturer as a function of flow and when the NPSHA is less than or equal to the NPSHR, cavitation will occur ([8], 2012) . In addition to the above parameters, there is also the pump curves, which aims to describe the operating conditions, specifically centrifugal pumps. These curves are diagrams that usually contain the head and the workflow.

3. RESULTS AND DISCUSSION

The module was constructed using four tees, three knees, eight fittings, a gate valve, a check valve and a pipe outlet, including a straight length of approximately 223.5 cm. All components have a diameter of 1 ¾ inches, except for the valve, which is 1 inch. The ready module can be seen in Figure 2.

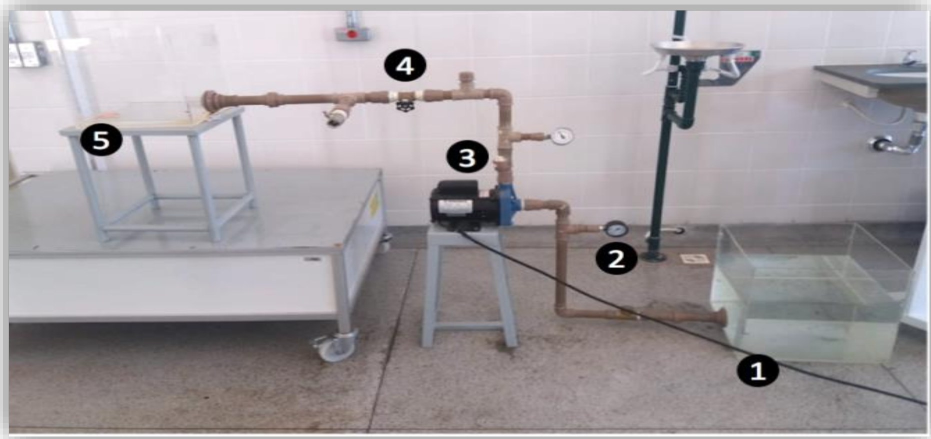

Figure 2 - Teaching module built. 1: water tank; 2: vacuometer; 3: pump, 4: globe valve; 5: discharge tank.

Table 1 shows the values for localized and distributed pressure drop found through Equation 1 and 2, considering that the pipe diameter is 1 ¾ in. The graph in Figure 3 shows the relation between total load loss and flow. Table 2 shows the values for power and yield in each flow studied.

Table 1 - Load loss associated to flow in the experiment.

Flow (10^{-4} m^3/s)	Load Loss (m)		
	Localized	Distributed	Total
0,58	0,01	0,08	0,09
2,67	0,02	1,97	1,99
5,92	0,11	10,27	10,38
8,57	0,22	22,06	22,29
10,10	0,31	30,73	31,04
12,20	0,46	45,66	46,12

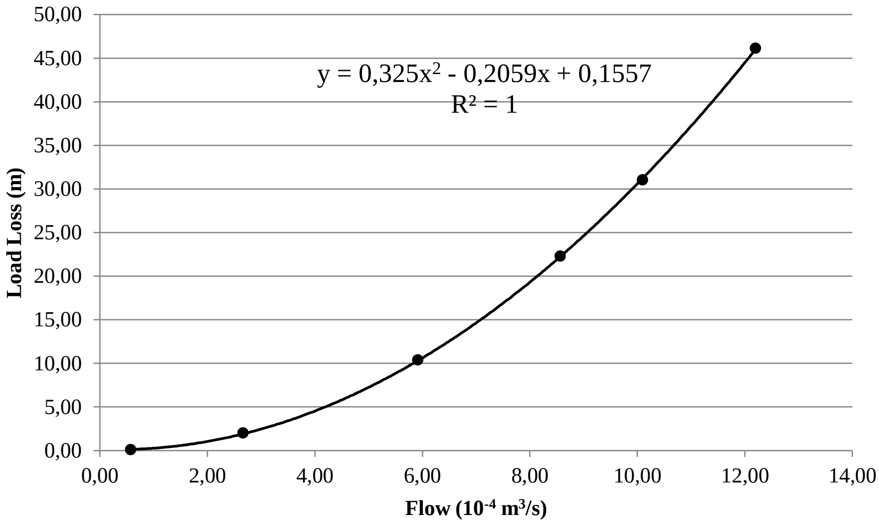

Figure 3 - Relation between load loss and flow in the teaching module.

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Table 2 - Power and yield to each flow in experiment

Flow (10^{-4} m^3/s)	Power (W)	Yield (%)
0,58	9,57	2,59
2,67	40,5	10,95
5,92	84,02	22,71
8,57	106,78	28,86
10,10	111,17	30,05
12,20	108,24	29,25

The head calculations are listed in Table 3, separated by suction (Hsuc) and discharge head (Hdis) and total head (H) can also be better visualized by the graph in Figure 4.

Table 3 - Suction, discharge and total head related to the flow.

Flow (10^{-4} m3/s)	HSUC (m)	HDIS (m)	H (m)	NPSHA
0,58	0,015	16,896	16,881	10,027
2,67	0,06	15,524	15,463	10,073
5,92	0,213	14,688	14,475	10,226
8,57	0,735	13,452	12,717	10,748
10,10	1,149	12,43	11,281	11,162
12,20	2,083	11,153	9,07	12,096

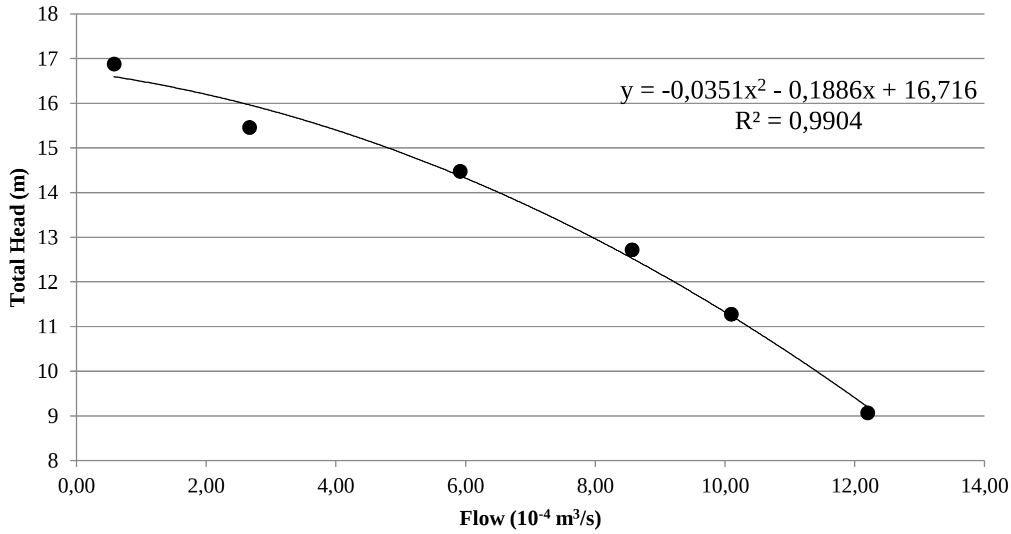

Figure 4 - Relation between Total head and Flow in the teaching module.

Since pressure loss is dependent on several factors, using equations to estimate it is a difficult task that often does not represent reality [10]. To confirm the feasibility in practical classes, studies of distributed and localized pressure loss were performed, relating flow data and NPSHA.

According to the study by Provenzano and contributors (2016) [11], based on measured friction losses and effective pipe diameters, it was found that the relationship between the Darcy-Weisbach, f, and the Reynolds number, R, can still be described with a power equation in which, assuming a value of -0.25 for Exponent 50, the coefficient was smaller than the theoretical and equal to c = 0.285. Thompsom and contributors (2011) [12], conducting experiments with Reynolds Number ranging from 1,500 to 10,000 and flat tubes with different wall thicknesses, obtained systematically higher friction factor values and characterized by greater variability than those obtained in the current investigation, even if differences in the values of f tend to decline with the increase of R. In this sense, as discussed, it is noteworthy that the incidence of measurement errors increases in decreasing R. In addition, these authors evaluated f values based on effective tube diameters.

In general, the equations overestimate the pressure losses, considering studies where the pipes used are PVC. In the present work, the relationships between flow and distributed pressure drop and localized pressure drop were performed in pipes with only two diameter variations: 1 ¾ in and 1 in.

Note that the smaller the diameter, the greater the associated pressure drop is. This occurs because the fluid will have to perform contraction and expansion when passing through the accessories. Since there is a discrepancy between the diameter of the pipe and the accessory, these phenomena are responsible for swirls that cause potential energy dissipation and consequently lead to an associated load loss [13]. The flow of liquid dissipates part of its energy, mainly in the form of heat, which generates the so-called pressure drop.

In addition, the elastic behavior of the tube, recently investigated by Rettore and contributors (2014) [14], occurs only with operating pressure higher than the upper limit suggested by the manufacturer and only in pipes characterized by a very small wall thickness.

According to Provenzano and contributors (2016) [11], the vertical height of the pipe increases rapidly and the horizontal width decreases with hydrostatic pressures varying from 0 to 30 kPa, also confirming that the cross-sectional area of the pipe tends to inflate rapidly, until it reaches its complete roundness. A model was proposed to represent the effective pipe diameter as a function of water pressure to be used to assess friction loss.

The increase in pressure drop values also tends to cause an increase in the power used by the pump, as can be seen in Table 2, which shows the values found for pump power and performance at different flow rates. The power consumed was considered to be 370 W, this value being provided by the manufacturer.

The results obtained in Table 2 show a low pump performance, which can be justified because the pump operated at a power lower than its capacity. The tanks present in the didactic module have a small volume, which limits the use of the pump at higher flow rates.

Naturally, the type of fluid and, consequently, its pressure drop in pipes, are fundamental in the sizing of pipes and pumps of such systems, since the head represents the energy supplied to the liquid, which should be sufficient for overcome the geometric unevenness and the pressure losses that occur along the way [15].

The head represents the amount of energy a fluid will need to pass from the suction tank to the discharge tank at a given flow rate. The head must be able to overcome the geometric difference, the pressure drop and the pressure difference in the tanks.

In Figure 4, it was observed that the head height decreases with the flow increasing, in a parabolic behavior. This behavior is consistent with the results obtained for the pressure drop (Figure 3), since the increase in pressure drop, caused by the increased flow, decreases the available energy in the fluid, thus reducing the head.

Like the pressure drop, the NPSHA increases proportionally with the flow, which indicates that the higher the flow rate, the closer the pump will cavitate. In conducting the experiment, the phenomenon was not observed, which can also be characterized by both the sound emitted by the pump and the theoretical calculations, relating NPSHR data, commonly provided by the manufacturer. In the present work, given the use of donated bombs, such information could not be obtained. However, it is possible to make comparisons with previous studies.

Carvalho and contributors (2009) [16], in their study, stated that the wastewater dilution (peeling and demucilage) promoted a proportional reduction of the flow resistance; consequently, less pressure drop in the pipe compared to the original concentration.

Coelho and contributors (2018) [17], in their study, concluded that the estimation of pressure drop by the Swamee and Jain method overestimated the values determined in the mercury column. Until the flow rate of 5.15 $m^3.h^{-1}$ using the Hazen-Williams method, it presented the smallest variation and, consequently, the highest efficiency of pressure drop estimation in relation to the values determined for the polyethylene pipe with diameter of 25 mm. Thus, it is possible to say that the practical results obtained in the built module are in accordance with the theoretical knowledge, being another learning tool for the students.

FINAL CONSIDERATIONS

From the development of the load loss teaching module, it was possible to study concepts as important in industrial as in the academic area. As observed, during the construction of the module and the experiments, in order to confirm the theory, it was concluded that the pressure drop changes proportionally with the flow rate and that the head decreases with the increase in flow, indicating the amount energy the fluid will need to be pumped.

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REFERENCES

[1]. DE SOUZA, A.I.; HENRIQUE, P. **Apresentação dos cálculos para seleção de bomba para sistema de reaproveitamento de água de poços artesianos**. Universidade Federal do Rio de Janeiro, Departamento de Engenharia Mecânica, Rio de Janeiro, 2014.

[2]. GOMES, G.A.P.M. **Seleção de Bomba Centrífuga Vertical para Operação em um Sistema de Transferência de Enxofre Líquido**. Projeto de Graduação, Rio de Janeiro, UFRJ/Escola Politécnica, 2013.

[3]. SILVA, P.; TELLES, C. **Tubulações Industriais**. 4 ed., Rio de Janeiro, Livros Técnicos e Científicos, 1976.

[4]. AZEVEDO NETTO, J.M.; FERNADEZ Y FERNADEZ, M.; ARAUJO, R. de, ITO; A.E.. **Manual de hidráulica**. 8ª ed, São Paulo, Edgard Blucher, 1998.

[5]. PORTO, R.M. **Hidráulica Básica**. 3ª ed., São Paulo, EESC – USP, 2004.

[6]. VILELA, L.A.A.; SOCCOL, O.J.; GERVÁSIO E.S., et al. Alteração no diâmetro e na perda de carga em tubos de polietileno submetidos a diferentes pressões. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v.7, n.1, p.182-185, 2003.

[7]. PERRY, R.H., & CHILTON, C.H. **Manual de Engenharia Química**. 1980.

[8]. CREMASCO, M.A. **Operações unitárias em Sistemas particulados e fluido mecânicos**. 2ª. ed. Blucher, 2012.

[9]. BRUNETTI, F. **Mecânica dos Fluidos**. 2 ed, Pearson Prentice Hall, 2008.

[10]. ALAZBA, A.A.; MATTAR, M.A.; ELNESR, M.N.; AMIN, M.T. Field assessment of friction head loss and friction correction factor equations. **Journal of Irrigation and Drainage Engineering**, v. 167, 2012.

[11]. PROVENZANO, G.; ALAGNA, V.; AUTOVINO, D.; et al. Analysis of Geometrical Relationships and Friction Losses in Small-Diameter Lay-Flat Polyethylene Pipes. **Journal of Irrigation and Drainage Engineering**, v.142, n. 2, pp.1-9, 2016.

[12]. THOMPSON, E.; MERKLEY, G.; KELLER, A.; BARFUSS, S. Experimental determination of the hydraulic properties of low-pressure, lay-flat drip irrigation systems. **Journal of Irrigation and Drainage Engineering**, v. 137, n.1, pp. 37-48, 2011.

[13]. FOX, R.W.; MCDONALD, A.T.; PRITCHARD, P.J. **Introdução a Mecânica dos fluidos**. 7 ed., LTC, 2010.

[14]. RETTORE NETO, O.; BOTREL, T.A.; FRIZZONE, J.A.; CAMARGO, A.P. Method for determining friction head loss along elastic pipes. **Irrigation Science**, Apr. 2014.

[15]. CARVALHO, J. A.; AQUINO, R. F.; PEREIRA, G. M.; et al. Desempenho de uma bomba centrífuga operando com água residuária do processamento do café. **Revista Engenharia Agrícola**, v.28, p.86-94, 2008.

[16]. CARVALHO, J. A.; AQUINO, R. F.; PEREIRA, G. M.; et al. Perda de carga em tubos de PVC conduzindo água residuária do processamento de café. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v.13, (Suplemento), p.811–817, 2009.

[17]. COELHO, A. P; ZANINI, J. R; FARIA, R. T. de; et al. Comparação de equações para estimativa da perda de carga em tubulação de polietileno. **Pesquisa Aplicada & Agrotecnologia**, v.11, n.1, p.25-31, Jan-Abr., 2018.