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CONSTRUCTION AND DIMENSIONING OF A DIDACTIC EXPERIMENT FOR HYDRAULIC ANALYSIS

Adimar da Costa Nunes Neto
Carlos Henrique de Paula Jr
Luiz Carlos Cordeiro Jr
Rafael Costa Da Silva
Raniery Mendes Antônio
Universidade do Estado do Rio de Janeiro – Faculdade de Tecnologia
Rodovia Presidente Dutra, Km 298, s / n - Industrial Polo, Resende - RJ, 27537-000, phone: (24) 3381-3889
costarafaelprod@gmail.com

ABSTRACT: *Student's perception and visualization of the hydraulic dimensioning for analysis of the characteristic length in pipes is not always performed in a clear and effective way. Experimental activities aim at physical contact, the practical use of the concepts which are approached in classroom. From this perspective, the experimental activities carried out aim to overcome these difficulties in theoretical disciplines, considering that the contribution of these circuits is very enriching for the course content and since the students are stimulated to develop experimental analysis in the solution of the proposed practical problem. To achieve this goal, a workbench was built with two hydraulic circuits (PVC and Galvanized Iron), being recycled most part of the material used.*
Furthermore, through a partnership with companies, a second (high pressure) workbench was built which enabled the development of studies and mapping of didactic activities. The experiments were designed to be very understandable and have a good area of tabular interaction, in order to give a better understanding and allow comparative analysis between the same circuits of different materials submitted to the same conditions. It is also possible to explore the most varied functions of the valves in a high pressure experiment.

Keywords: Hydraulic Circuits, head loss, manometric height

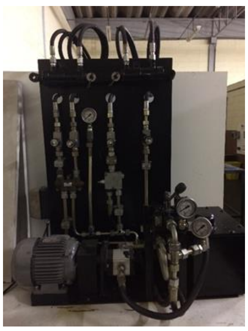
1. INTRODUCTION

The study of the pressure drop in pipes is very important for the correct design of pump systems. The fluid flowing in a conduit is subjected to strong forces exerted by the walls of the pipe and by a region of the liquid itself, called the *boundary layer*. Thus, shear forces (friction) arise that dissipate energy mainly in the form of heat. This energy is no longer recovered, being called head loss (ΔH). The head loss occurs along the pipeline (distributed) and singularities (located).

In the first workbench analyzed (Picture 1), the hydraulic circuits are pressurized through a centrifugal water pump, and both circuits are analyzed through the measurements recorded in pressure gauges, types of connections, characteristic lengths, total head, in the various accessories that form the circuits, and in the appropriate analysis of roughness of the walls of these tubes and loss of the load that this represents.

The second workbench (Picture 2) differs from the other hydraulic system because it is a high pressure system and a high viscosity hydraulic fluid, which transmits force to the hydraulic actuators in order to promote the movement of feed or return. Through these practical activities, students can develop a better understanding and application of theoretical concepts.

(Picture 1- Hydraulic stand "1")



(Picture 2- Hydraulic stand "2")

2. METHODOLOGY

2.1 Materials and methods

This work was conducted in the Laboratory of Motors, Hydraulics and Pneumatics of University of the State of Rio de Janeiro (Resende Campus). In the experiment 1, the following equipment was used on the first workbench: A centrifugal pump, two hydraulic reservoirs, PVC and galvanized iron pipes, 90° elbows, a direct exit and side exit, reductions, spherical valves, unions, check valves, valves foot with sieve, all with ¾" diameter. In addition, 1" PVC tubes were used to replace ¾" tubes to have the differential in the diameters in the Venturi Tube, and it was also used a pipe in a “T” form with 1” and pressure gauges to register pressures.

It is possible to calculate the flow per gallon and pressure difference (exerted by the Venturi Tube) in the first workbench. The pressure gauge registers the pressures and then they are compared to the calculated values. These results are combined between head loss from accessories and linear length of the circuit to calculate a total height of energy, the volume of energy that the system requests to transport fluid from the suction reservoir to the discard reservoir with a given flow rate. The energy is used as a parameter and it is fundamental to the specification power of the pump.

The following equipment was used on the second workbench: a gear pump, high pressure hydraulic hoses, flow regulating valves, sequential valve, piloted check valve, directional valve, straight through and side outlet, union, 90 ° curves, 90 ° elbows, linear pressure gauges and hydraulic actuators, as well as a hydraulic reservoir. All the accessories used in the countertop are in the diameter of 5/8. In this second workbench was analysed the fluid standart velocity, the Reynolds number, the friction factor, the head loss in the pressure line and in the system. It is possible to compare the results measured in the manometers with the theoretical values.

2.2 Experimental procedure

The transfer of a fluid through a pipe requires the analysis of the variation of its properties (pressure, flow, viscosity, etc.). In the Hydraulics activity, a Circuit is analyzed (see picture below) and divided into two parts: one in PVC and the other in galvanized iron, both being pressurized through a centrifugal pump. To compose this study the circuits are analyzed through the registered measurements in the pressure gauges and through mapping the various connection types, valves and accessories. Four different conditions were considered:

a) Simple circuit in which the fluid is pumped from the lower reservoir and after that, being poured right after the first gauge (upper reservoir).
b) With the fluid being pumped from the lower reservoir and after that, being poured in the upper reservoir, while it runs all over and only the PVC installations.
c) With the fluid being pumped from the lower reservoir and after that, being poured in the reservoir itself, while it runs all over and only the PVC installations.
d) With the fluid being pumped from the lower reservoir and after that, being poured in the reservoir itself, while it runs all over and only the galvanized iron installations.

a) 

b) 

(Picture 3- Hydraulic Workbench 1 "case a") (Picture 4- Hydraulic Workbench 1 "case b")

c)  d) 

(Picture 5 - Hydraulic workbench 1 "case c") (Picture 6 - Hydraulic workbench 1 "case d")

In all proposed cases the fluid is pumped by the centrifugal pump, passing through the suction part of the circuit. After this process, the fluid is pumped up, running through the PVC or galvanized iron pipes (depending on the current situation) to reach the last reservoir. The gauges along the way register the pressures in the system.

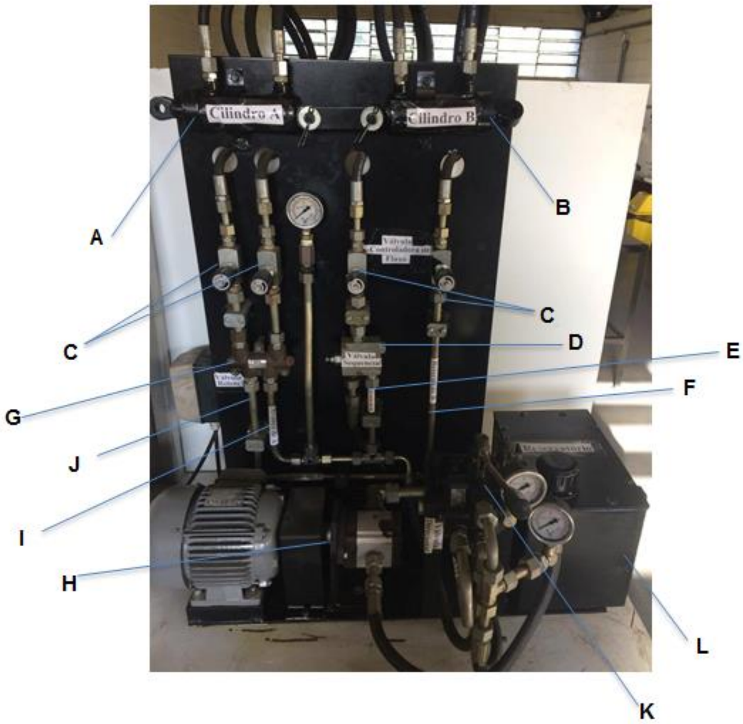
In search of a precise value for the mass flow rate in the circuit, the Venturi Tube was designed and additioned to the system. It is an equipment that indicates the pressure variation of a flowing fluid in regions with different transverse areas. It consists in a tube with a constriction (narrowing) in the middle of its length. The constriction effect causes a change in the drop pressure of the fluid moving in the tube. Pressure gauges connected in the tubes arranged in the different diameters, allow measuring the pressure variation, which is used to calculate the mass flow rate and the velocity of the fluid. Where the area is smaller, there will be higher velocity, so the pressure will be higher. Using the pressure drop is possible to calculate the fluid velocity and the flow successively, using the Bernoulli equation.

With the use of spherical valves, it is possible to direct the flow to the part where the Venturi Tube was added, in order to evaluate the velocity and fluid flow for the analysis of the experiment, as shown in Picture 7 below.

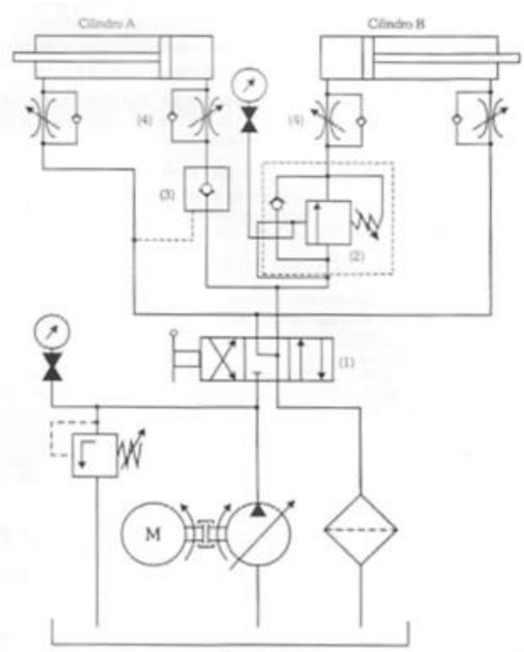
Picture 7 – Venturi Tube

In the second workbench, a hydraulic vehicle application circuit model is shown, which is based on the model presented by Bustamante (Hydraulic Automation-2003) and can be observed in figures 8 and 9. The actuators (hydraulic cylinders) operate under high pressure and working under actuation of a sequential valve, they allow the application of these circuits in series. In this proposed hydraulic workbench, the conceptual development for the dimensioning of hydraulic lines of suction, pressure and return is applied. When using the workbench, the gear pumps the oil from the reservoir (suction part), pumping it to the directional valve (pressure line). By actuating the valve for the advance, it will release the fluid to the system. The released fluid will put pressure on B (so-called the part where the system for advancement and return of cylinder B is located), but it does not exceed the sequential valve, because it does not have enough pressure. Thus, the fluid flows to A (so-called the part where the system for advancement and return of cylinder A is located), passing through the germinated piloted check valve. When the fluid completes the advance at (A), it reaches the desired pressure to bypass the sequential valve at (B). This activates the cylinder in (B). Finally, when the return control is triggered, both actuators (A) and (B) return at the same time, due to the absence of a sequential valve in the hydraulic return circuit.

By means of studies and research it could be seen that another hydraulic fluid type "B " would meet the same specifications as the current fluid used "A", specifications referring to standard DIN 51524-3 2006-9. Thus, a theoretical analysis varied the type of oil used and consequently the viscosity, the density and the loss of charge. The aim was to theoretically assess the effects that the change from fluid A to B would have on that circuit regarding to the reduction of the loss of charge.



(Picture 8- Hydraulic Workbench "2")



(Picture 9- Workbench Model, Bustamante)

Circuit layout:

A- Cylinder A (actuator A);
B- Cylinder B (actuator B);
C- Flow Control Valve: This circuit is composed of four valves located on the feed and return lines of actuators A and B. These valves allow control with high precision flow in one direction. They also allow you to completely close the flow in one direction and at the same time release the flow from the opposite direction;
D- Sequential Valve: Located in the lead line of actuator B, having a "bypass" connected to it. It is a directly operated valve. It is used to sequence a second system according to the set pressure;
E- Actuator fluid feed pipe B;
F- Actuator fluid return pipe B;
G- Check valve: Located in the forward and return line of actuator A, these valves are used for the blocking of operational circuits that are under pressure, such as safety against falling of a load in case of rupture in piping or against discontinuous movements of hydraulically tensioned consumers;
H- Gear Pump;
I- Actuator fluid feed pipe A;
J- Actuator fluid return pipe A;
K- Directional valve: Located in the pressure line, it has the function of guiding the direction the flow must follow, in order to carry out a proposed work (double acting actuators);
L- Hydraulic Reservoir.

3. Mathematical equations

The two governance rules presented by Bustamante (Hydraulic Automation-2003) are used in the first workbench. First, to calculate the flow using the experimental feature of the Venturi Tube, and one more Bernoulli equation, as shown below:

Equation (1):

$$\boldsymbol{P1} + \frac{\boldsymbol{V1}^{\mathbf{2}}}{\mathbf{2}\boldsymbol{g}} = \boldsymbol{P2} + \frac{\boldsymbol{V2}^{\mathbf{2}}}{\mathbf{2}\boldsymbol{g}} + \mathrm{K}\left(\frac{\boldsymbol{V2}^{\mathbf{2}}}{\mathbf{2}\boldsymbol{g}}\right) \qquad (1)$$

If "K" is the load loss coefficient, "V" is the velocity at points 1 and 2, "A" is an area at point 1 and 2, "g" is a gravity, "P" and "2".

For the calculation of the total head, the value of the effect of the correction is equal to that applied:

Equation (2)

$$\boldsymbol{H} = (\boldsymbol{Hs} + \boldsymbol{Hr}) + (\boldsymbol{Cls} \times \boldsymbol{Fc}) + (\boldsymbol{Clr} \times \boldsymbol{Fc}) + \boldsymbol{Pca} \qquad (2)$$

Considering "H" as the total gauge height, "Hs" as the suction head, "Hr" as the discharge head, "Cls" as the linear length of suction head, "Clr" as the linear length of discharge head, "Fc" as the correction factor to the mas flow rate found and "Pca" as the head loss of the accessories.

Due to greater complexity of the second hydraulic circuit ("2" workbench), a greater range of governing equations is required. It is possible to emphasize among them the design and analysis of the recommended velocity for the flow rate for different pipe dimensions, Reynolds number, friction factor, head loss lines suction, pressure and return and total head loss of the system presented by Macintyre (1997) and by Munson, Okiishi, Young (Fundamentals of Fluid Mechanics -1997).

Equation (3) When finding the speed it is possible to calculate the Reynolds number with the following equation, considering “V” as the velocity, “Di” as the pipe diameter and “υ” as a cinematic viscosity.

$$\mathrm{Re} = \frac{V \times Di}{v} \qquad (3)$$

Equation (4) Considering a model of rigid tubes and constant temperature, the appropriate friction factor to this mass flow regime (laminar), for this workbench model was:

$$\Psi = \frac{\mathbf{64}}{\boldsymbol{Re}} \qquad (4)$$

Equation (5) To calculate the pressure loss in the pressure line, use the friction factor found previously, applying it in the following equation:

$$\Delta\boldsymbol{P} = \Psi \times \frac{\mathbf{5} \times \boldsymbol{LT} \times \rho \times \boldsymbol{v}^{\mathbf{2}}}{\boldsymbol{dt} \times \mathbf{10}^{\mathbf{10}}} \qquad (5)$$

Equation (6) In order to determine the total head loss system, we add the pressure drop of the "Dp" valves to the pressure drop in the pressure line, that is:

$$\Delta\boldsymbol{PT} = \Delta\boldsymbol{P} + \boldsymbol{Dp} \qquad (6)$$

4. Results, Figures and tables

When using the Venturi Tube (Figure 7), in practice, for workbench "1", with the values measured based on the pressure difference made by the pressure gauges, we adopted an average of registered values to avoid any parallax errors. From the Bernoulli relation, the velocity and the flow in this pipe are analyzed analytically.

To define the velocity values, we considered the ratio of diameters D1 (1 ') = 0.025m and D2 (3/4) = 0.019m which involve Venturi tube tracking. The coefficient of load loss "K" was based on the comparison between the tube diameters and the model presented by Fox and Mcdonald (1988), according to the table below.

Table 1. Head Loss Coefficient

K	1,1	1,2	1,4	1,6	1,8	2	2,2	2,5	3	4	5	10	∞
D/d	0,15	0,25	0,34	0,38	0,41	0,44	0,46	0,48	0,48	0,49	0,49	0,49	0,5

When the value of the head loss coefficient "K" is identified, the equation "1" is used to define the velocities (V2 = 2.6684m / s) and the flow rate (Q = 2.8 m³ / h). The total manometric height calculated and registered by gauge for the highlighted proposals is presented in the table below:

Table 2. Total Manometric Height x Pressure (manometers)

	Flow Rate	Total Manometric Height	Pressures (Gauges)
Case a)	2,85 m³/h	8,68 PSI	9 PSI
Case b)	2,85 m³/h	13,65 PSI	14 PSI
Case c)	2,85 m³/h	14,83 PSI	15 PSI
Case d)	2,85 m³/h	15,49 PSI	16 PSI

Unlike the previous procedure, in which all the basement was developed from the Venturi Tube, another evaluation of the same hydraulic circuit was made, in the definition of the flow by the galling method, and thus the values as shown below and consequently a new manometric height. The new values obtained were:

Table 3. Total Manometric Height x Pressure (manometers)

	Flow Rate	Total Manometric Height	Pressures (Gauges)
Case a)	3,5 m³/h	11 PSI	9 PSI
Case b)	3,5 m³/h	17,86 PSI	14 PSI
Case c)	3,5 m³/h	19,30 PSI	15 PSI
Case d)	3,5 m³/h	20,80 PSI	16 PSI

It is possible to see that the galling method is more susceptible to human error, parallax. With the introduction of the Venturi Tube in the experiment, the calculated values are much closer and more satisfactory for the pressures calculated and recorded on the gauges. The experiment could be proved with a small margin of error of 0.5 PSI that can be explained by visual failures when observing the pressures recorded in the gauges.

The same technical solution base was developed for workbench “2” (fig 8), as presented by Bustamante (Hydraulic Automation- 2003), although known the flow rate. In carrying out the proposed calculations for the high pressure workbench, theoretical values were obtained close to those recorded in the gauges, both for the Hydraulic Fluid “A” and for the “B”, and a variation in the pressure drop due to the density and viscosity of each fluid. As shown in the tables and represented in the charts below.

Table 4. Results - High Pressure workbench (Hydraulic Fluid A)

	Advance A	Advance B	Return A	Return B
Reynolds Number	1191,471	1191,471	551,47	551,47
Friction Factor	0,063	0,063	0,136	0,136
Load Loss on Pressure line (bar)	3,568	3,801	1,766	1,824
Total Calculated Head Loss (bar)	13,533	22,237	10,174	8,37
Pressures Registered on the Gauges (bar)	11	20	10	10

Graph 1. Head Loss Calculated (Hydraulic Fluid A) x Pressures recorded in Gauges

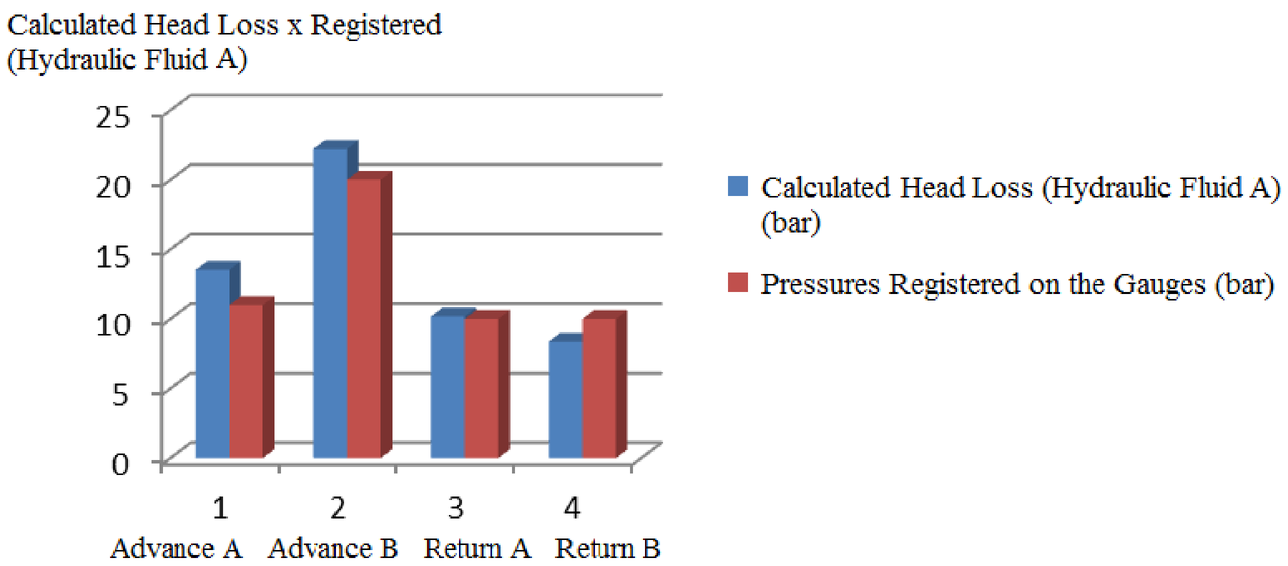
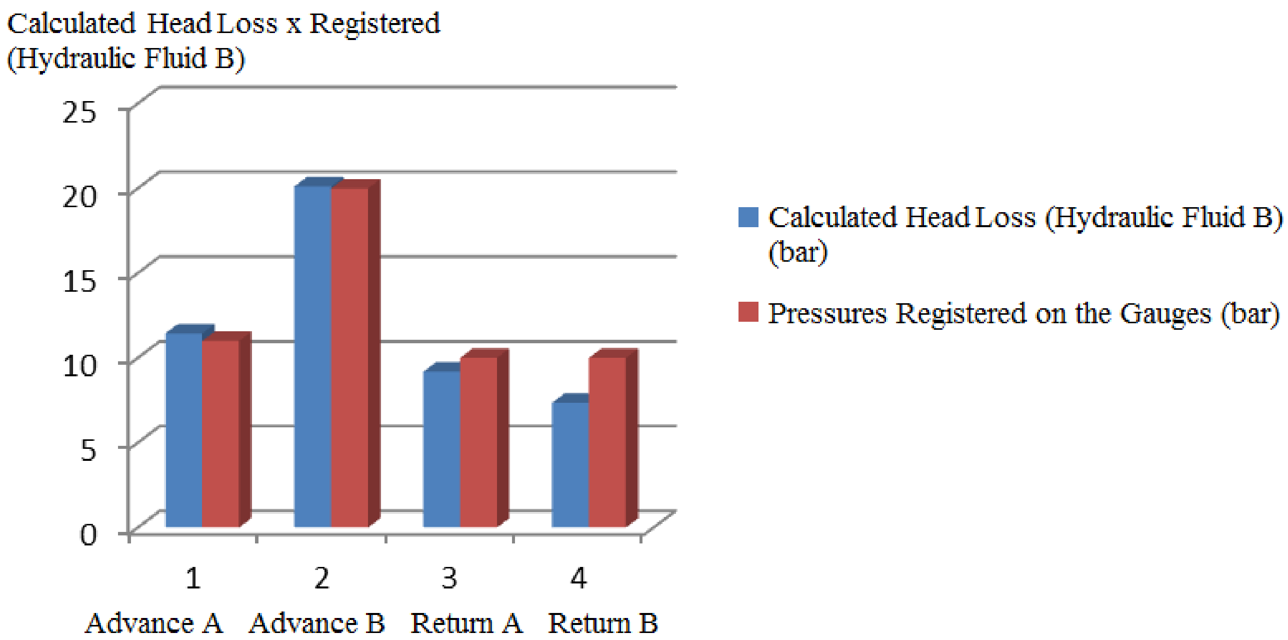


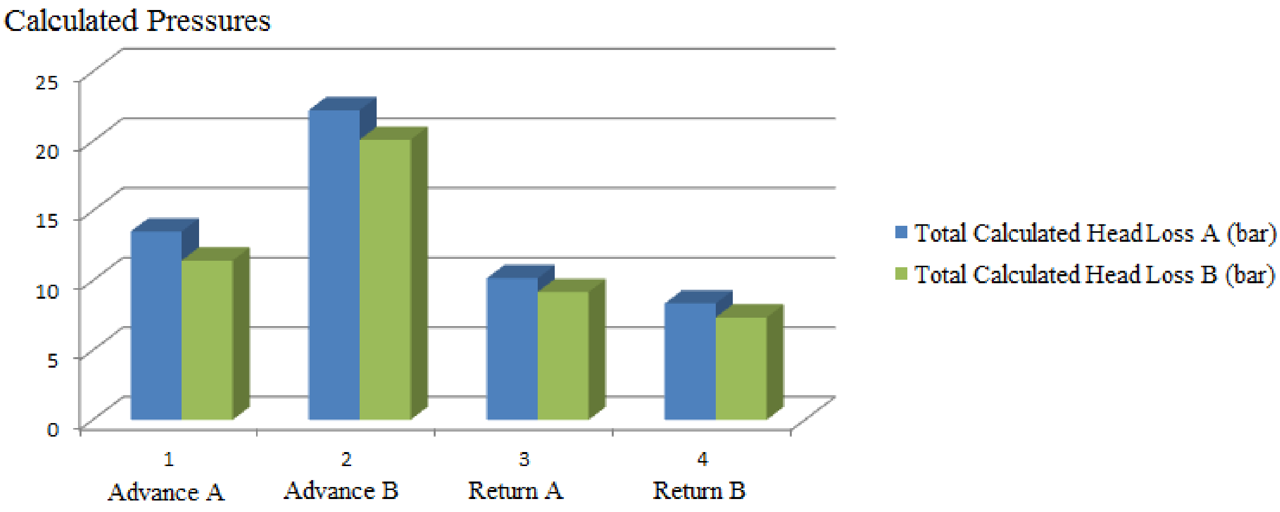
Table 5. Results - High Pressure Hydraulic Workbench (Hydraulic Fluid B "46")

	Advance A	Advance B	Return A	Return B
Reynolds Number	1761,304	1761,304	815,217	815,217
Friction Factor	0,043	0,043	0,092	0,092
Load Loss on Pressure line (bar)	2,392	2,548	1,184	1,222
Total Calculated Head Loss (bar)	11,445	20,115	9,194	7,358
Pressures Registered on the Gauges (bar)	11	20	10	10

Graph 2. Calculated head losses x Pressures Recorded on Gauges



Graph 3. Head Loss (Hydraulic Fluid B) X Head Loss (Hydraulic Fluid A)



5. CONCLUSION

From the planning, construction and dimensioning of the hydraulic circuits, it was possible to conclude that the work accomplishes the objective of developing hydraulic circuits in didactic workplaces in the Laboratory of Motors, Hydraulics and Pneumatics of the Technology College. These groups, as well as other experiments already presented, will have great importance for the faculty, because they can perform practical activities of the literary subjects studied in the classroom. With the hydraulic workbenches, faculty and trainees can take dynamic and practical classes to the graduates in engineering, with appropriate equipment.

Initially after the construction and analysis of the hydraulic workbench "1", we concluded with the hydraulic circuit (with centrifugal pump) that when we used the Bernoulli equation to calculate the flow in the system using the Venturi tube reached a higher accurate value for it and consequently for the final result of the total manometric height. When comparing tables "2" and "3", it is possible to conclude that the use of the Venturi Tube method to calculate the flow rate is more accurate than the galling method due to the values shown. It is also important to highlight that the effects of the system degradation are negligible for PVC pipes. However, the effects of this degradation through internal corrosion increase susceptibly the roughness and consequently the head loss for the galvanized iron pipes. This finding is clear when compared the circuits (PVC x Galvanized) because they are dimensionally similar.

After constructing and analyzing a high pressure system, "2" hydraulic workbench (with gear pump), the entire workbench and its various types of accessories and valves were mapped according to the proposal developed by Bustamante. The theoretical model proposed proved to be efficient and robust when compared to the experimental analysis of this work. In an analysis of the fluid to be used it was possible to demonstrate through theory and calculations a reduction of up to 2 bar in the pressure drop of the circuit with the replacement of a fluid A to the B. The result of all this development is reflected in the practical class formatting model, with the Engineering students, in the experimental analysis of all the hydraulic design of the system, such as head loss, mass flow, velocity, friction factor among others, experimentally validated through manometers.

Analyzing the work developed in both hydrological bases, it is possible to understand how important it is to the theoretical and experimental conciliation in the intellectual development of the student. The opportunity to think, execute, check and validate brings the responsibility, maturation and consequently the feeling of being right thing for self-knowledge and also as a legacy for other Engineering students. In continuity as a contribution to future activities, the following suggestions are recommended, such as: inserting a rotameter at the centrifugal pump outlet (hydraulic workbench 1) combined with a by-pass circuit, to allow the study of the pressure drop and coefficient of friction under variation of the flow and to continue the development of know-how in the mobile area that allows to map and to detail not only a workbench referring to this one as well as an equipment on a complete vehicle. In addition, practical tests were carried out with pressure measurements at different points along the circuit seeking to validate the calculations performed with the conclusion of hydraulic fluids analysis and the challenge of building an electro hydraulic workbench.

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7. References

Bustamante, 2003, “AUTOMAÇÃO HIDRÁULCA – Projetos, Dimensionamento e Análise de Circuitos”, Érica Ltda., 2ª Ed, São Paulo, Brasil.

Fox, McDonald,1988, “INTRODUÇÃO À MECÂNICA DOS FLUIDOS”, Editora Guanabara S.A., 3ª Ed, Rio de Janeiro, Brasil.

Macintyre,1997, ”EQUIPAMENTOS INDUSTRIAIS E DE PROCESSO”, Livros Técnicos e Cientificos Editora S.A., Rio de Janeiro, Brasil.

Munson, Okiishi, Young, 1997, “FUNDAMENTOS DA MECÂNICA DOS FLUIDOS”, Editora Edgard Blucher Ltda., Vol.2, 2ª Ed, São Paulo, Brasil.

Zorzan, Daronch, Dal Molin, 2013, “DESENVOLVIMENTO DE UMA BANCADA DIDÁTICA DE HIDRÁULICA”, Horizontina-RS, Brasil.

ŞCHEAUA, 2016, “THEORICAL APPROACHES REGARDING THE VENTURI EFFECT”, Galați, Romênia

https://www.comsol.com/blogs/exploring-the-venturi-effect/

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