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SOFTWARE FOR CALCULATION OF LOAD LOSSES

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Abstract: Among the areas of civil engineering, none of them receives as little importance as the design of hydraulic projects, given that, for a good design, a detailed and delicate analysis is necessary, which takes time. This way, professionals resort to oversizing so that they can meet all demands, thus generating high project, execution and maintenance costs. With this, the purpose is to develop a functional and easily accessible software, in order to assist the user of hydraulic projects in the calculation of head losses in building pipes and sizing of hydraulic pumps, thus contributing to the diffusion knowledge about hydraulic problems. The software was developed from the Java programming language, having its interface created with the help of the NetBeans 8.0.1 IDE, with data entries for solving localized and distributed load loss formulas; where the pressure drop in the pipes will be calculated through the Darcy-Weisbach equation; in order to allow the user to choose a compatible hydraulic pump, thus generating savings in labor, maintenance and even reductions related to energy and water consumption, aiming at more sustainable hydraulic systems. The executable document has satisfactory performance in solving the distributed and localized head loss equations and will be registered at the National Institute of Industrial Property (INPI), guaranteeing its authenticity.

Keywords: Loss of Load, Software for Loss of Load, Universal Equation.

INTRODUCTION

An article published in G1 (2019) points out that the world population will reach about 9.7 billion people in the year 2050, according to a study carried out by the UN. This estimate raises the worldwide concern about population growth and its impacts related to excessive water consumption.

One of the main consequences of the

accelerated and disorderly growth of metropolises is the lack of infrastructure in large centers. The city of São Paulo can be cited as an example. According to data provided by Instituto Trata Brasil (2019), in 2017, losses in water distribution totaled 35.4%.

Furthermore, Filho (2015) emphasizes that real losses; those caused by leaks in branches, distribution networks and water mains; are the ones that most demand attention in loss reduction actions. He also says that the main cause of these losses comes from the poor quality of water infrastructure. In addition, weak investments in this area together with low rainfall end up intensifying the water crises in the country (AGÊNCIA NACIONAL DE ÁGUAS, 2019).

Given the size of the data, the need for investments in correctly dimensioned hydraulic projects is evident. Thus, a precise engineering study is necessary to analyze the existing problems in the supply systems and the procedures to be used, as well as their impacts on the lives of the resident population (SOARES; PALO; BATISTA, 2015).

Therefore, the present work seeks to develop a software in Java language that is capable of calculating the pressure drop in building pipes, focusing on the sizing of pipes and pumps.

That said, head losses in a pipeline can be defined as the difference between the initial energy and the final energy of a liquid, which flows from one point to another (CARVALHO JR, 2017). The difference in energy is caused by the friction between the particles when the fluid flows, being dissipated in the form of heat.

For the transport of water, pipes assembled in sequence are used, composed of accessories with the function of joining, such as curves, derivations, registers or connections of any type and possibly a hydraulic machine as a pump (PORTO, 2006). These components

cause pressure loss in the system, which is classified as localized pressure drop. In the straight sections, the head losses are classified as distributed, being caused by the friction of the fluid with the layer of the inner wall of the tube.

In relation to the development of the software, programming in Java was chosen, because according to Indrusiak (1996), Java is a simple language that presents a reduced number of constructions, which, consequently, lead to a reduction of programming errors, making programming in Java more efficient. In addition, in the Java environment, there is a large number of libraries available, which contribute to the development of the application.

In order to facilitate the construction of software in Java language, several development environments were created, called Integrated Development Environment (IDE), which have tools and libraries, being the NetBeans IDE one of the most popular among developers (OLIVA, 2014).

Knowing this, when analyzing NetBeans, it was possible to perceive a solid base for visual applications, through the development of graphical interfaces, due to the resources of modeling tools of easy understanding, access and application, facilitating the creation of the source code.

METHODOLOGY

The development of this work was based on a literature review on pressure drop, distributed and located, and design of hydraulic pumps. From a theoretical deepening of the basic concepts of fluid mechanics, a software was developed that allows the calculation of head losses in a given pipe.

At first, it is necessary to calculate the kinematic viscosity, which is given by the ratio between the dynamic viscosity and the density of the fluid, where the higher the viscosity, the

greater the friction of the fluid with the inner walls of the tube. This way, kinematic viscosity is a property that directly influences the flow behavior (IZOLA, 2017).

The kinematic viscosity can be obtained from the fluid and its temperature. For simplification purposes, it was determined that the fluid would be water, as the application in question aims to calculate head losses in building pipelines. However, the temperature will be an input value of the software, that is, the user must enter the temperature so that the application can perform the calculations.

Table 1 was obtained from the graph of kinematic viscosity versus temperature for water, contained in the book Introduction to Fluid Mechanics (Fox; McDonald; Pritchard, p.456 and 457).

With the help of the Excel tool, it was possible to create a graph of the kinematic viscosity as a function of temperature.

That way, when the user enters the temperature, the application will calculate the kinematic viscosity of the fluid from the equation below:

$$y = -3E - 06x^3 + 0,0006x^2 - 0,0469x + 1,7517$$

In graph 1, it is possible to observe the water viscosity curve as a function of temperature, and the graph equation obtained from Excel.

Again, for standardization purposes, it was decided to limit the pipe diameters used by the user. This way, the most common diameters in building piping installations were maintained.

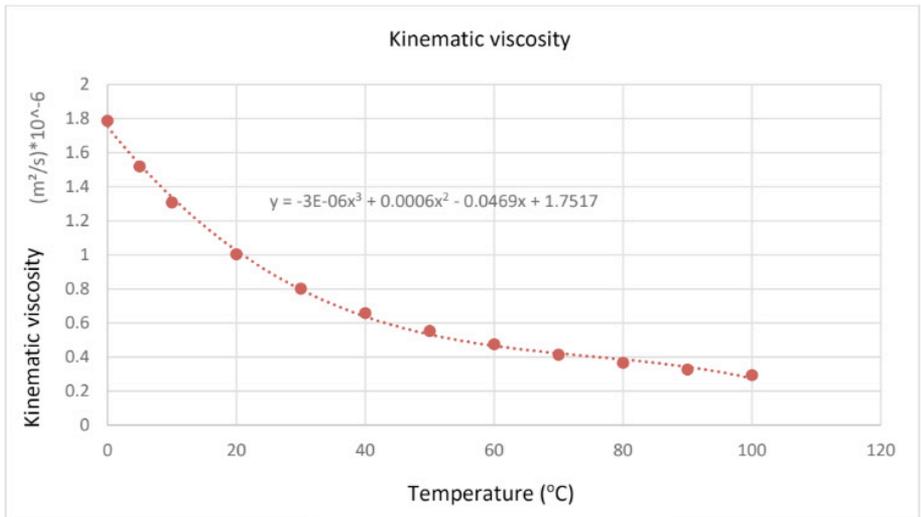
However, when ordering PVC cylindrical pipe from a hardware store, the clerk will consider the outside diameter of the pipe. However, the distributed head loss calculations are performed taking into account the internal diameter, as the liquid is in contact with the internal wall of the tube. Due to this, it was necessary to verify the corresponding internal diameters.

For this, the TIGRE catalog was used as a basis, Items of the Weldable Line, which are

Temperature (°C)	Kinematic viscosity (m ² /s)x10 ⁻⁶
0	1,787
5	1,519
10	1,307
20	1,004
30	0,801
40	0,658
50	0,553
60	0,475
70	0,413
80	0,365
90	0,326
100	0,294

Table 1 - Kinematic viscosity as a function of temperature

Source: Author himself.



Graph 1 - Kinematic Viscosity as a function of temperature

Source: Author himself.

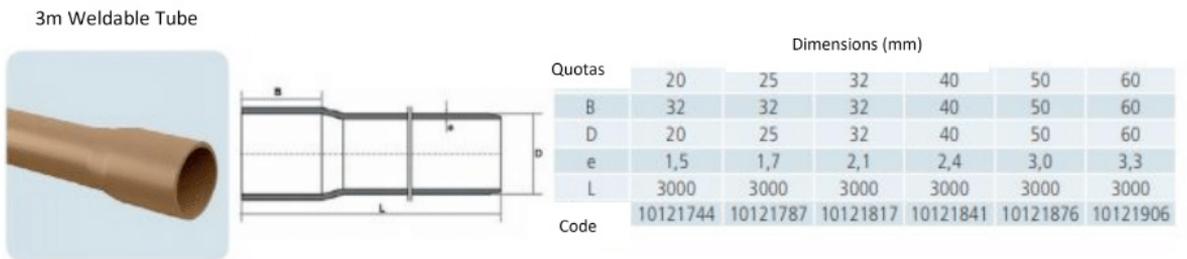


Figure 1 - TIGRE 3m weldable tube

Source: Tigre Catalog - Weldable Line Items

widely marketed for Cold Water Installations, in residential, commercial and industrial works.

In figure 1, there is the 3m Weldable Tube, with its dimensions, and a sketch that facilitates the visualization. This way, the inner diameter of the tube can be defined as:

$$Di = D - 2 * e$$

Where:

D – External diameter of the tube (m);

e – Thickness of the inner wall of the tube (m);

In the case of calculating localized head losses, it is also necessary to define the internal diameter of the accidents, which are valves, valves, curves, elbows and tees, present throughout the route.

For standardization purposes, the types of accidents that the user can choose when performing the load loss calculations in the software were limited. That is, the user can choose any one of these accidents: gate valve, ball valve, straight through tee, side exit tee, 45° elbow, 45° bend and 90° bend.

In this specific case, each accident has an internal diameter. Figure 2 shows a 90° bend, while Figure 3 shows a 45° knee. For example, for the 90° curve of 32mm in diameter, we have an internal diameter of 32mm. As for the 45° knee with 32mm in diameter, there is an internal diameter equal to 29.5mm.

Thus, when the user chooses a diameter in the selection box, the software will select the corresponding internal diameter, both in straight sections and in accessories.

Then it is necessary to calculate the velocity of the water in the pipe. For this, the user must enter the volumetric flow rate of the system in question. With that, we have:

$$V = \frac{Q}{A} = \frac{Q}{\frac{\pi * D^2}{4}}$$

Where:

V – Velocity of the water in the tube (m/s);

A – Tube area (m²);

Q – Volumetric flow (m³/s);

D – Internal diameter of the tube (m).

From this, it is possible to calculate the Reynolds number and classify the flow. The Reynolds number is given by:

$$Re = \frac{V * D}{\nu}$$

Where:

Re – Reynolds number;

V – Velocity of the water in the tube (m/s);

D – Internal diameter of the tube (m);

ν – Kinematic viscosity of the fluid (m²/s).

The Reynolds number is responsible for defining the type of flow. If Re < 2000, the flow is classified as laminar and the friction factor will be calculated as follows: $f = \frac{64}{Re}$

Where:

f - Friction factor;

Re – Reynolds number.

If Re > 4000, the flow will be classified as turbulent, so the friction factor is defined by the equation defined by Darcy-Weisbach:

$$f = \frac{0,25}{\left[\log \left(\frac{\epsilon/D}{3,7} + \frac{5,74}{Re^{0,9}} \right) \right]^2}$$

f – Darcy's friction factor;

D - Pipe diameter;

ε – Absolute roughness;

Re – Reynolds number.

In addition, a selection box was also used to define the type of material for the inner wall of the tube. Again, for standardization purposes, the type of material that the user can choose was limited, thus maintaining the most usual in water building installations, PVC.

This way, it was possible to define the absolute roughness of the inner wall of the tube. The absolute roughness values were obtained from the table below:

Finally, the distributed head loss was calculated from the Darcy-Weisbach equation:

$$\Delta h = f * \frac{L * V^2}{D * 2 * g}$$

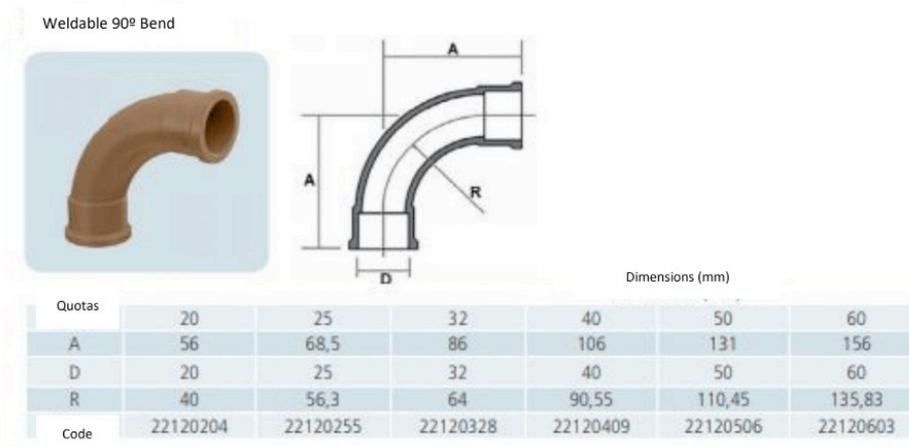


Figure 2 - TIGRE Weldable 90° Curve
Source: Tigre Catalog - Weldable Line Items

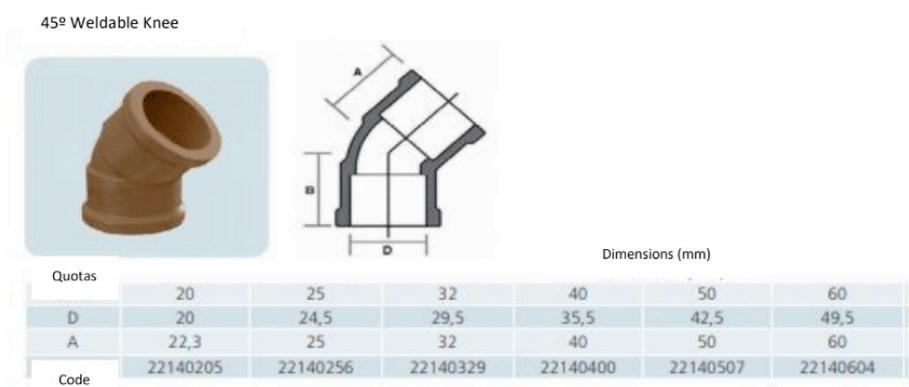


Figure 3 - TIGRE Weldable 45° Knee
Source: Tigre Catalog - Weldable Line Items

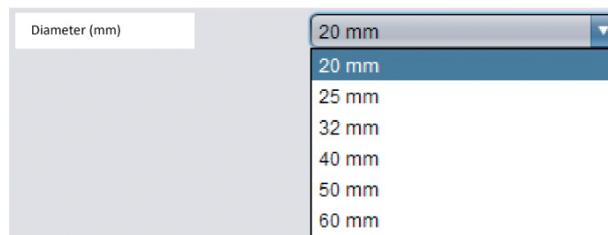


Figure 4 – Diameter selection box.
Source: Author himself.

Where:

Δh – Distributed load loss;

f – Darcy friction factor;

L – Tube length (m);

D – Tube diameter (m);

g – Gravity (m/s²).

The tube length will be an input value, entered by the user in a text box. As for the acceleration due to gravity, the default value will be 9.81 m/s².

The total distributed head loss in the system is given by the sum of the distributed loss in each straight stretch present.

According to Porto (2006), valves, curves, registers, connections are necessary for the operation of the system, however, their presence produces load losses due to the increase in turbulence. This type of pressure drop, generated by accessories, is called localized pressure drop. The localized pressure drop can be calculated as follows:

$$\Delta h_{loc} = K * \frac{V^2}{2 * g}$$

Δh_{loc} – Localized load loss;

K – Localized head loss coefficient;

V – Velocity of the water in the tube;

g – Gravity (m/s²);

Each accessory present in the pipe has a value of K . In the table below, it is possible to obtain the values of K . Remembering that, in the software in question, the user can choose between the following accessories: gate valve, ball valve, direct passage tee, side outlet tee, 45° elbow, 45° bend and 90° bend, selecting up to a maximum of 6 times each accessory.

The total localized head loss in the system is given by the sum of the localized loss in each accessory present.

Finally, the total head loss can be defined as the sum of the distributed and localized head losses.

RESULTS

For the purpose of comparing results, the

calculation of the total pressure drop in a system of pipes and accessories will be carried out and, soon after, the software will be fed with the same data. Below is the information necessary for the comparative calculation.

Material: PVC;

Temperature: 20°C;

Gravity: 9.8 m/s²;

Volumetric flow: $Q = 0.045 \text{ m}^3/\text{min}$;

Diameter: $D = 40\text{mm}$.

It started with the calculation of the distributed load loss, that is, the one that occurs in straight stretches. As stated earlier, it is necessary to use the internal diameter due to the thickness of the tube, therefore, the diameter chosen was 20mm, however, 17mm will be used. In addition, the flow must be in the unit of measurement in m³/s. Thus, for the calculation of the distributed head loss, we have:

$$D_i = D - e = 20 - 2 * 1,5 = 17,0 \text{ mm}$$

$$V = \frac{Q}{A} = \frac{Q}{\frac{\pi * D^2}{4}}$$

$$V = \frac{\left(\frac{0,045}{60}\right)}{\frac{\pi * (0,017)^2}{4}} = 3,3043 \text{ m/s}$$

$$Re = \frac{V * D}{\nu}$$

$$Re = \frac{3,3043 * 0,017}{1,004 * 10^{-6}} = 55.949,30$$

$$f = \frac{0,25}{\left[\log\left(\frac{\varepsilon/D}{3,7} + \frac{5,74}{Re^{0,9}}\right)\right]^2}$$

$$f = \frac{0,25}{\left[\log\left(\frac{(0,0015)}{3,7} + \frac{5,74}{(55949,3)^{0,9}}\right)\right]^2} = 0,0956$$

tube material	Roughness - ϵ
	(mm)
Glass	0,0001
copper and aluminum	0,001-0,002
PVC pipes	0,0015-0,007
epoxy resin	0,005
Stainless steel	0,015
Carbon steel	0,045-0,090.
calendered plain steel	0,015
welded steel with splice	0,046
plain galvanized steel	0,15
steel with rust	0,15-4
plain cast iron	0,25-0,8
worn cast iron	0,8-1,5
Corroded cast iron	1,5-2,5
smooth cement	0,3
common concrete	0,3-1
thick concrete	0,3-5
planed wood	0,18-0,9
unfinished concrete	1 a 3
asbestos cement	0,025
common wood	5
smooth concrete	0,2 a 0,3

Figure 5 – Roughness in tubes for different materials.

Source: Laboratory Practices: Fluid Mechanics, p. 24.

Accessory	K	Accessory	K
Short radius 90° elbow	0,9	open gate valve	0,2
90° long radius elbow	0,6	open angle valve	5
45° elbow	0,4	open globe valve	10
90° curve, $r/D = 1$	0,4	Foot valve with sieve	10
45° curve	0,2	Retention valve	3
Te, direct passage	0,9	Return curve, $\alpha = 1800$	2,2
tee, side exit	2,0	float valve	6

Figure 6 - K coefficient values for various accessories.

Source: (Porto, 2006).

Component	Quantity
Straight piping	15,0 m
Curve 90°	5
Drawer valve	2
Elbow 45°	3

Table 2: Components present in the pipeline

Source: Author himself.

$$\Delta h = f * \frac{L * V^2}{D * 2 * g}$$

$$\Delta h = 0,0956 * \frac{15 * (3,3043)^2}{0,017 * 2 * 9,81} = 46,9418$$

To calculate the localized pressure drop, the calculation was separated according to each accessory. In this specific case, the diameter of all accessories considered in the calculation does not change, therefore, 20mm is the internal diameter. Therefore, it is necessary to calculate the speed again.

$$V = \frac{Q}{A} = \frac{Q}{\frac{\pi * D^2}{4}} = \frac{(\frac{0,045}{60})}{\frac{\pi * (0,020)^2}{4}} = 2,3873 \text{ m/s}$$

$$\Delta h_{loc_{curve\ 90}} = K_{c90} * \frac{V^2}{2 * g}$$

$$\Delta h_{loc_{curve\ 90}} = 0,4 * \frac{(2,3873)^2}{2 * 9,81} = 0,1162$$

$$\Delta h_{loc_{drawer}} = K_{gav} * \frac{V^2}{2 * g}$$

$$\Delta h_{loc_{drawer}} = 0,2 * \frac{(2,3873)^2}{2 * 9,81} = 0,0581$$

$$\Delta h_{loc_{elbow\ 45}} = K_{cot45} * \frac{V^2}{2 * g}$$

$$\Delta h_{loc_{elbow\ 45}} = 0,4 * \frac{(2,3873)^2}{2 * 9,81} = 0,1162$$

At the end of the calculation, the value of

the localized pressure drop must be multiplied according to the number of times the accessory appears in the system. In this case, we have:

$$\Delta h_{loc_{curve90}} = 5 * 0,1162 = 0,5810$$

$$\Delta h_{loc_{drawer}} = 2 * 0,0581 = 0,1162$$

$$\Delta h_{loc_{coto45}} = 3 * 0,1162 = 0,3486$$

$$\Delta h_{loc} = 0,5810 + 0,1162 + 0,3486 = 1,0458$$

Therefore, the total loss in the system in question is given by:

$$h_{TOT_{cal}} = \Delta h + \Delta h_{loc}$$

$$h_{TOT_{cal}} = 46,9418 + 1,0458 = 47,9876$$

For comparison purposes, the data used in the previous calculation were entered into the application. The user must enter the design flow in m³/s, select a diameter from those available, inform the length of the tube of the straight part, and select which accessories and their respective quantity.

When finishing entering all the necessary information, the user must click on "CALCULATE", and the software will calculate the load losses, presenting the results on the screen. Remembering that the result shown on the screen corresponds to the total loss in the system, that is, the software calculates the distributed and localized load loss.

This way, one has:



Figure 7 – Image of the software developed with the input and selection boxes.

Source: Author himself.

To verify the efficiency of the analysis obtained with the software, the experimental error was calculated. Therefore, there is:

$$E = \frac{h_{TOT_{cal}} - h_{TOT_{soft}}}{h_{TOT_{cal}}} * 100$$

$$E = \frac{|47,9876 - 47,9992|}{47,9876} * 100 = 0,024\%$$

Through the calculations above, it is possible to observe that the developed software performs the pressure drop calculations accurately. The error is probably due to rounding to decimal places.

Below is the project flowchart.

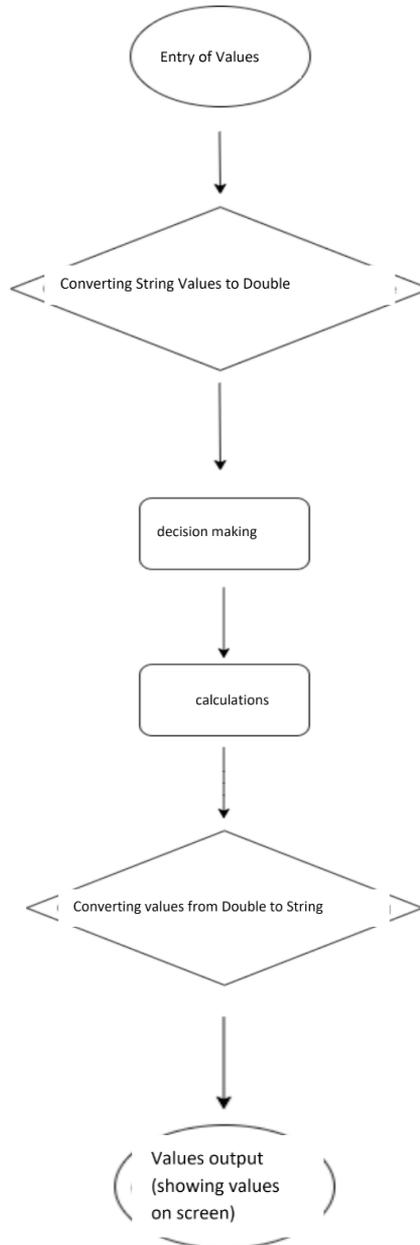


Figure 8 - Project flowchart.

Source: Author himself.

CONCLUSION

With the completion of this work, it is possible to conclude that the developed software has satisfactory performance and allows the calculation of load losses, distributed and located, according to the particularities of the system, quickly and accurately. In addition, the checkboxes and value entries are objective, making it easier for users who have little knowledge of the subject to understand.

The choice of NetBeans facilitated the creation of the software due to the functions present in the platform, reducing the possibility of programming errors. In addition, the use of Java as a programming language made the development of the software more precise, since several articles, materials and tutorials are available on the internet due to its great

usability.

For future work, it is interesting to implement in the application the option for the user to be able to change the diameter of pipes and accessories present in a single system. Currently, the software does not allow this change, that is, the software makes the calculation with the diameter selected initially, and in practice, changes in diameters happen frequently. To circumvent this issue, there is in the software the possibility of performing the calculation of distributed and localized load losses independently.

It is also interesting to include other types of accidents, such as reductions, globe valves, foot valves with sieve, among others. In addition, it is important to adapt the application to the mobile version, allowing it to be accessed with greater ease and practicality.

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