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Matlab-Based Program for the Parametric Study of Piping Systems

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Abstract

Educative computational tools for education in Chemical Engineering has been increasing in the last decade due to the advance in technology. This branch of engineering has many subjects that make it difficult to have only one robust software that contains all the main subjects. It involves the creation of special programs dedicated to specific areas of study. One of the main subjects in Chemical Engineering programs is fluid mechanics. This study presents the application of a graphical user interface developed in Matlab for the study of piping systems where the flow rate, pump power, and pressure drops are determined as a function of the material, diameter, length, and elevation of the pipe, as well as the number and type of pipe couplings. The software is based on an algorithm that allows the solution of piping systems with elevation using energy balances, specific equations of fluid mechanics, and specific geometric parameters. Three relevant case studies were developed, showing the behavior of the energy expenses of the pumps. It was found an increase in the pump power from 91.4% to 3713.4% when a pipe diameter of 2½ inches is increased from 20% to 60%. It was observed that the effect of the length of the pipe on the energy consumption of the pump is not significant for flows lower than 8 L/s. When the flow rate in the pipeline is 15 L/s and a change of pipeline is made from a 2-inch pipe - PVC schedule 40 to one of PVC schedule 80 of the same size, a 26.5% increase in pump power is needed. For steel pipes with schedule 40 and schedule 80, a rise of 30% and 67.8% was required, respectively.

Keywords: Pump power, graphical user interface, Pipe diameter, Pipe length.

1. Introduction

Every day engineers have multiple challenges imposed by society in many engineering areas, and one of the most common is the distribution of fluids in a pipe. Frequently, many interesting phenomena affect the supply of fluid inside a pipe which have to be considered during a detailed design of piping systems for instance heat transfer [1][2], corrosion [3], vibration [4], as well as many important risks [5]. Fluid transport systems in pipe networks are exposed to multiple factors that negatively affect their operation. Some of these factors are vibration caused by fluid pulsation, external excitation, and two-phase gas-liquid flow; This phenomenon, although intrinsic during the transportation process, requires control, since its mitigation depends in many cases on the excess energy expenditure of the pumping systems and the damage to the pipeline networks [6]. To achieve vibration control, a mathematical theoretical study is required with dynamic models that accurately describe the distribution of fluids. These models often have complex solutions based on iterations of numerical models; Therefore, integrating mathematical models with technology facilitates the learning and analysis of engineering designs. Some of the actions taken to minimize pulsations in the pipes are adding dampers, and acoustic filters and changing the pipe configuration.

Another factor that affects the lifespan and correct functioning of piping systems is flow-accelerated corrosion (FAC), whose wear action destroys the pipes and their accessories. This mechanism includes electrochemical reactions with subsequent chemical erosion that dissolves the protective oxide film on low-alloy steels. In this phenomenon, the mass transfer between the fluid and the surface of the pipe determines the hydrodynamic behavior of the fluid. The flow, speed, and shear stresses accelerate this phenomenon, increasing the danger and turbulence in the flow [7]. Many of the accessories suffer from FAC; However, the 90° elbow, an unavoidable accessory of transport systems, is the most prone to this phenomenon due to the enormous directional change of the flow. For these reasons, designing models that adequately describe the behavior of fluids in a pipe network is complex. Important simulation software has been designed with multiple toolboxes; However, these software are not easy to use, and the cost of licenses is high. Software such as COMSOL MULTIPHYSIC offers a wide range of physical phenomena in their integrated modules, especially for the simulation of processes where heat and momentum transfer are decisive. Research has been done on improving heat transfer in materials such as ceramics with the help of this software [8], On the other hand, in the case of analyzing hydrocarbon transport systems, ANSYS is generally the computational tool used, which contains a large number of thermophysical properties of fluids and can exchange data with other software [9], other computer tools could be mentioned.

The are other phenomena that affect the piping design which involves the fluid momentum on the surface of the pipes caused by the multiple fittings such as valves, pipe couplings, etc., [10]. Must piping systems spend a high amount of energy because of the use of pumps or when implementing heat transfer to the fluids.

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The energy-saving for the care of the environment, together with the economic savings make it necessary to analyze a design process before its execution carefully. Hence, when designing a piping system with elevation, it is essential to observe not only the flow behavior but also the mathematical development involved in these processes [11]–[14]. One of the most critical variables is the diameter since its proper selection can help to obtain a significant minimum expense due to the substantial investment required in piping systems [15]–[19]. It is necessary to analyze the effect of the different pipe diameters together with the other variables that are part of the design of the system in the energy costs required in a pump [20]–[23]. For the reasons mentioned above, proper preparation of the engineers in their professional training is essential.

To ensure that engineers have fast and assertive learning and can solve multiple problems including those of piping design during their undergraduate time, they must complement the knowledge acquired in the theoretical classes with all the fundamental equations with the help of computer tools so that they receive the necessary educational competencies [24] that help them make an adequate analysis of the effects that different input variables can cause on one or several output variables [25], mainly energy requirements in a pump or volumetric flowrate inside a pipe.

Software such as Ansys, COMSOL Multiphysics, and Sigma pipe [22][26]–[28], can be used to analyze by pipe section the internal behavior of the fluid and its effect on the surroundings. Excellent results of the phenomena that govern the system can be obtained with these programs. However, the physics that governs the system is very complicated because of the multiple variables and the complex differential equations used that need numerical methods to be solved [29]. To teach engineering students the way to solve all the differential equations used in the mentioned software result complicated. Thus, it is necessary to create simple software that gives undergraduate students the possibility to have a more robust knowledge about the effects that multiple input variables have on some output variables in systems such as pipe flow distribution.

This article presents an interactive graphical user interface for the study and design of piping systems with elevation, where users can handle different variables such as type of fluid, pipe diameter, pipe length, pipe schedule, pipe elevation, pipe fitting, pipe material, pump efficiency, and Flow. Three essential cases of studies were developed that involve the effect of length, diameter, material, and flow in the pipes as well as their interactions on the energy expenditure of the pump. The software lets to analyze the behavior of specific parameters using plots based on multiple variables to achieve an adequate selection of pipe fittings and their dimensions to obtain an excellent cost-benefit ratio. Section II shows the methodology of this research, beginning with the presentation of the algorithm and ending with the fundamental governing equations such as the general equation of energy. Section III shows the main results and discussion of the paper, where different patterns of the pump power were found depending on the input variables selected in the piping system studied. Finally, the conclusions of the paper are presented, showing the pertinent variables with the highest effect on the pump power.

2. Description of the computational coding.

FluidSoft DL.1 program is an easy-to-use creative interface that allows students and recent graduates in engineering to have significant support and learning experience through the study of piping systems with elevation. It was designed so that the user can work with different variables such as length, diameter, altitude, etc., to observe their effect on the power of the pump, the pressure drops, and the flow in the pipes. The software has educational components to improve the knowledge and learning process of engineering students. When making decisions about choosing the best operating conditions of a system, the software is beneficial because it allows multiple parameters to be used quickly and easily. It also allows the teacher to change the methodology of teaching in the subject of fluid mechanics, specifically in the theory-practice relationship, since it adds the simulation component to the learning process. It makes the student understand in a faster way all the phenomena happening in a piping system.

Figure 1 shows a screen capture of one of the multiple views of the software, which shows the inputs given by the user. Plots of the relevant variables emerge on different screens.

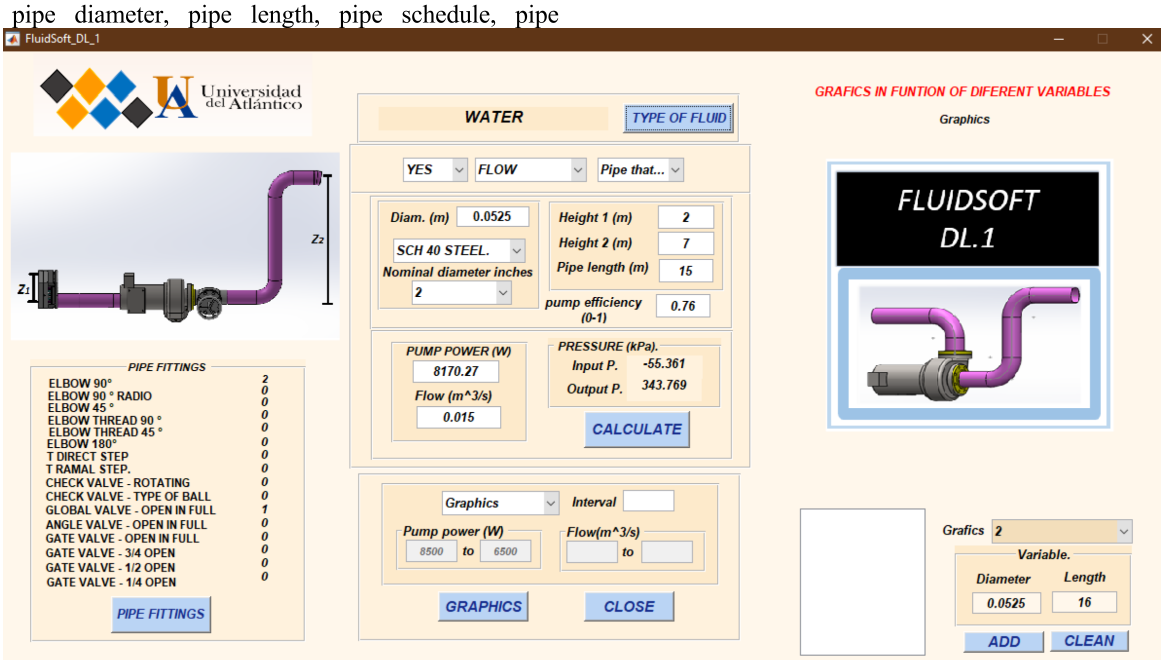


Fig. 1. Main view of the Graphical User Interface.

FluidSoft D.L 1 was developed in the Matlab® R2015a version and can work on all computers with the corresponding MATLAB Compiler Runtime (MCR) version. The software can run on any PC with Microsoft Windows 32/64 bits.
The mentioned software was registered in the D.N.D.A. Dirección Nacional de Derechos de Autor (National Leadership Copyright), with register number 13-76-178 on October 16-2019.

The programming algorithm on which the software is based is shown in Figure 2.

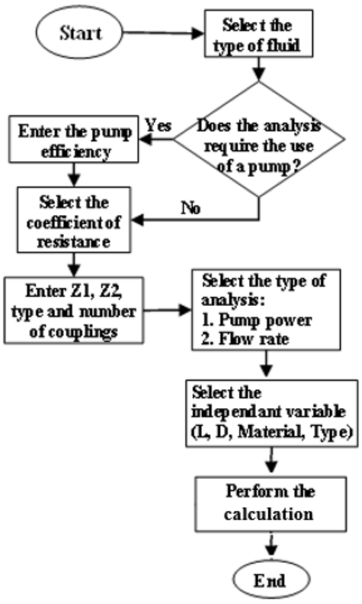
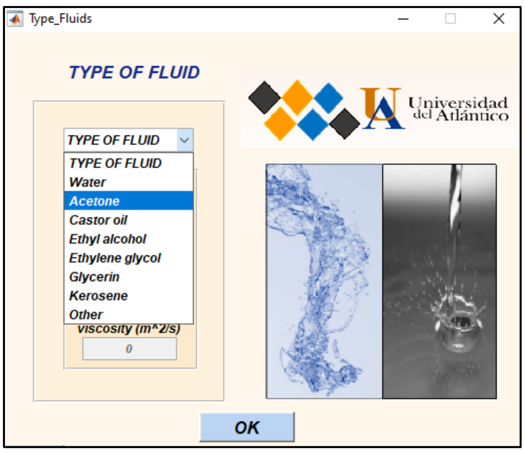


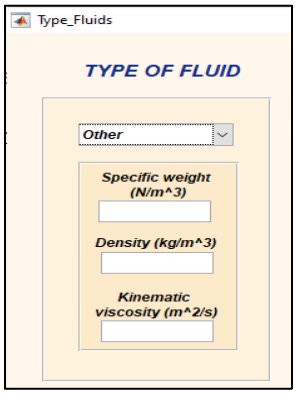
Fig. 2. Flowchart of Fluidsoft DL.1

The computational coding of the mathematical models performs iterative techniques until reaching the exact solution of the studied problem. Fig. 2 shows one of the multiple algorithms used to obtain the outcomes.

Figure 3a shows that the software has a drop-down list of multiple fluids that can be selected to work with, and each of them has physical properties that were included in the software. Some of the working fluids are water, glycerin, ethylene glycol, and kerosene and once the fluid is selected a dialog box will be presented showing all its properties. If the fluid is not included in the list, there is an option called others where the user can enter the requested properties of the fluid to be studied (see Figure 3b).



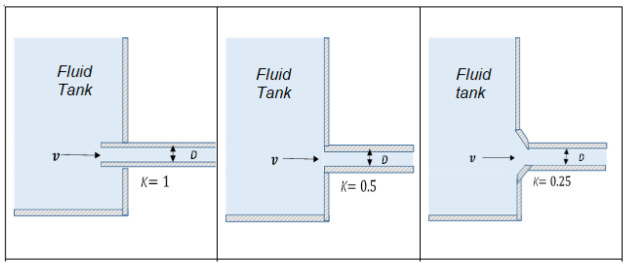
(a)



(b)

Fig. 3. Types of fluid in the Software. a) drop-down list of multiple fluids. b) properties of the different fluids

The coefficient of resistance at the pipe inlets is a value that must be considered when moving the fluid from the tank to the pipe for subsequent distribution. The fluid inside the tank has a negligible velocity which increases considerably when entering the pipe, causing a high energy loss that is highly significant when determining the total energy losses. The resistance coefficient is directly related to the geometry of the tank entrance to the pipe, and there are established values in the literature. Some pipes penetrate the tank into its interior (reentrant), other pipes are connected to the tank using sharp edges, and there are pipes connected with chamfered inlets and with well-rounded inlets, each of these connections has different resistance coefficients, see Figure 4.

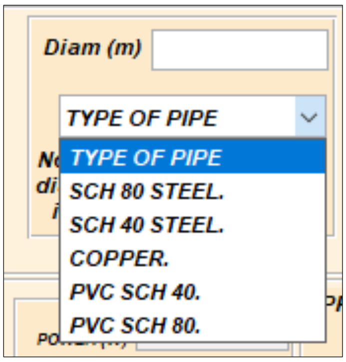


(a) (b) (c)

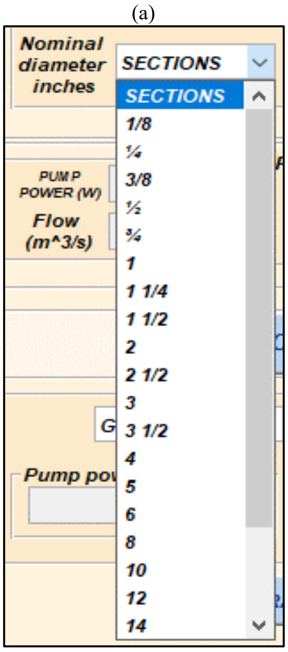
Fig. 4. The coefficient of resistance at the pipe inlets, a) reentrant pipe inlet, b) sharp-edged pipe inlet, c) chamfered pipe inlet.

As it is well known, one of the most important variables when designing fluid distribution systems is the total energy losses along the pipe section. Its magnitude is highly related to the type of pipe material, couplings, flow rate, pipe diameter, among others. It is important to identify all losses when designing the system and choosing the appropriate pump; The software presents a list of different types of pipes and couplings so that the user can make comparisons and make a correct decision when making a design. Among the different types of materials that can be selected are copper, PVC, iron, and different types of steel. On the other hand, various types of couplings can also be selected such as elbows, valves, tees, and multiple pipe diameters, as can be seen in Figure 5 a, b, c.

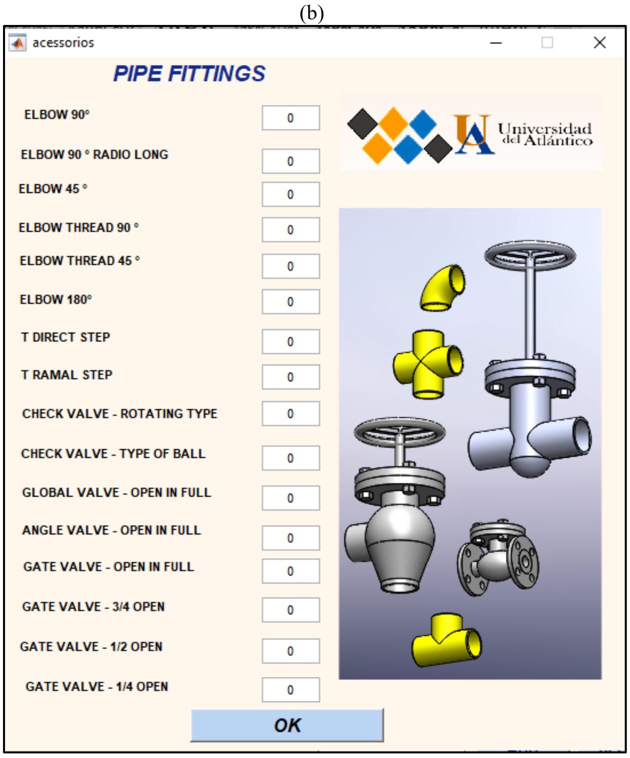
FluidSoft DL.1 software allows the user to make a graphical comparison of the effect of fluid types, pipe size and length, and pipe material on the flow pattern and power output of the pump, allowing the user to have greater understanding and guidance when selecting an optimal system configuration that meets the energy and flow needs, achieving economic savings and an efficient process.



(a)



(b)



(c)

Fig. 5. Generator of pipeline losses. a) Pipe material. b) Pipe diameter. c) Couplings in the piping system.

The algorithm for graphical analysis in the software is shown in Figure 6,

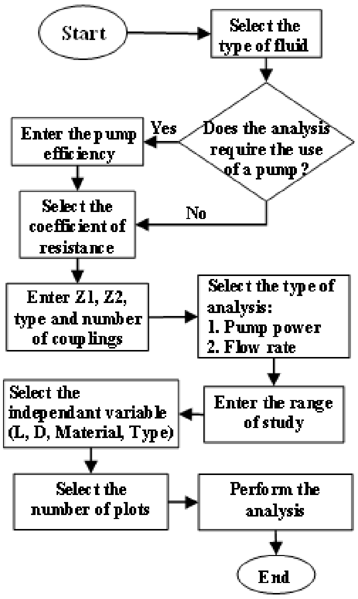


Fig. 6. Algorithm for graphical analysis in the software FluidSoft DL.1

Figure 6 shows that multiple variables such as diameter, length, type of fluid, and pipe material can be studied as a function of flow and pump power, by entering data ranges on the selected input variable. The interval condition refers to the divisions between the study intervals, as can be seen in Figure 7. The patterns obtained in the graphs let to select the best working ranges of the system.

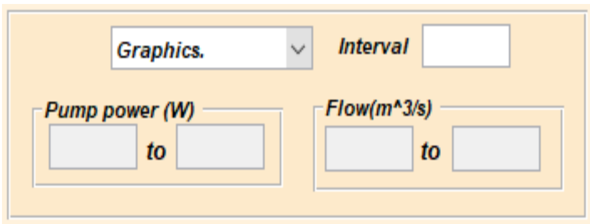


Fig. 7. Input data ranges for pump power and volumetric Flow rate.

As soon as the working ranges are entered in the dialog box shown in Figure 7, the desired study graph can be selected as shown in Figure 8. It is shown that both the pump power and the Flow rate can be a function of other parameters. The patterns obtained in the graphs let the user select the best working ranges of the system.

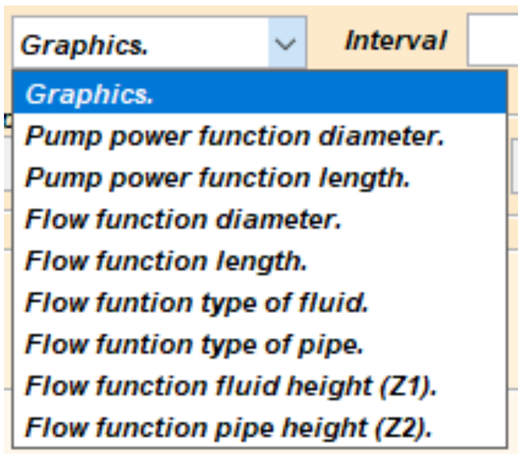


Fig. 8. Drop list of the multiple types of plots.

As soon as the two variables are selected for the graphical analysis, such as pump power vs flows, a third variable to study can also be selected, in this case, the diameter was selected. For this third variable, up to a maximum of five values can be studied to avoid excess information, see Figure 9. The third additional variable that can be selected is displayed in a drop-down menu called graphs. To prevent the software from crashing, several boxes are disabled and only the boxes for the variables to be analyzed remain enabled, as shown in Figure 9. The gray boxes correspond to the data that remains fixed for the third variable; These data are entered with the ADD button and are removed with the CLEAN button to enter new values.

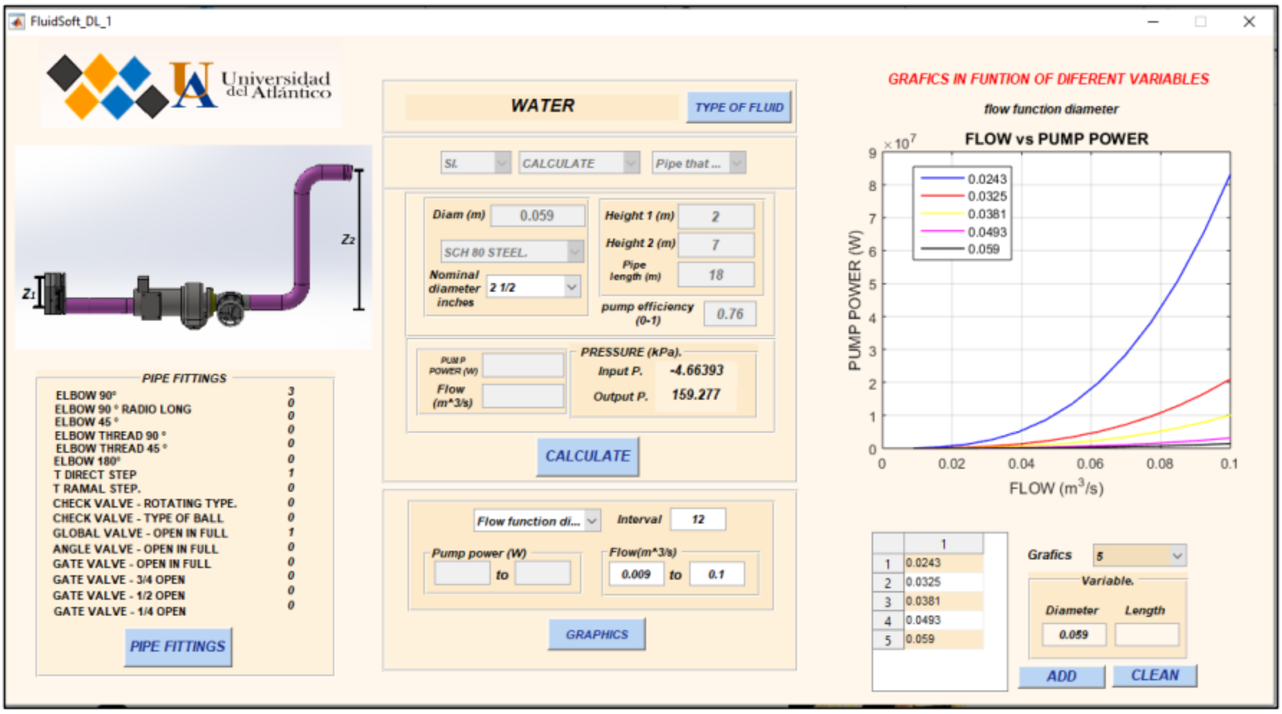


Fig. 9. Graphical analysis interface of the software Fluidsoft DL.1.

3. Equations

The fundamental equations used for the development of the software are organized as follows:
General energy equation, see Equation 1.

$$\Delta\left(\frac{1}{2}\frac{\langle v^3\rangle}{\langle v\rangle}+gZ+\frac{P}{\rho}\right)w=W-E_c-E_v \tag{1}$$

where $\langle v\rangle$ is the average velocity, Z is the elevation above the reference point, P is the pressure, ρ is the density of the fluid, and g is the gravitational acceleration.

The term P/ρ is the pressure energy per unit mass, gZ is the potential energy per unit mass and $\langle v^3\rangle/\langle v\rangle$ is the kinetic energy per unit mass, W is the work done by the surroundings on the fluid, E_C is the compression term, and Ev is the friction loss term or viscous dissipation which includes the losses of pipe fittings.

The last two terms are determined as follows in equations 2 and 3,

$$E_c=-\int_{V(t)} p(\nabla\bullet v)dV \tag{2}$$

$$E_v=-\int_{V(t)}(\tau:\nabla v)dV=f(h_L) \tag{3}$$

where equation 2 is the part of the continuity equation that establishes that if two sections of pipes are taken, the flow that passes through them is constant regardless of the point taken between these two sections. Equation 3 refers to the energy losses in the pipe section and h_L is the term related to hydraulic losses caused by the friction between the fluid flow and the surfaces of the pipe. The equation used due to its high precision to calculate the losses is the equation of Darcy, see Equation 4.

$$h_L=f\frac{L}{D}\frac{v^2}{2g} \tag{4}$$

When fluids are transported through pipes, they present certain disordered behaviors that result in a high interaction between the inertial forces and the viscous forces of the fluid. There are other cases in which the fluid moves in a perfectly ordered manner, with the same speed between its parallel plates. According to the given situation, fluids can move in a laminar or turbulent flow regime. Each flow regime presents an equation for calculating the friction factor, which is essential for calculating losses in the pipes.

To calculate the friction factor for laminar flow ($\mathrm{Re}\leq 2000$), equation 5 is used.

$$f = \frac{64}{\mathrm{Re}} \quad (5)$$

Equation 6 is used to calculate the friction factor for turbulent flow ($\mathrm{Re} > 4000$).

$$f = \frac{0.25}{\left[\log\left(\frac{1}{3.7\left\{\frac{D}{\varepsilon}\right\}} + \frac{5.74}{\mathrm{Re}^{0.9}}\right)\right]^2} \quad (6)$$

For fluids with a specific viscosity, shear stresses will appear on the walls of the pipe, which makes it necessary to use the Hagen-Poiseuille equation to determine the energy losses due to friction in laminar flow, see Equation 7.

$$h_L = \frac{32\eta L v}{\gamma D^2} \quad (7)$$

Equation 8 is used to calculate the energy losses due to the inlet of the fluid to the tank.

$$h_L = K\left(\frac{v^2}{2g}\right) \quad (8)$$

where the parameter K depends on the geometry, the type of pipe entry in the tank, and the type of pipe couplings. K is determined with equation 9.

$$K = \left(\frac{L_e}{D}\right) f \quad (9)$$

4. Results and Discussion

Three critical case studies were developed to make use of the best energy requirements of the pump. These cases considered the effects of the diameter, length, material, and pipe flow on the energy requirements of the pump.

4.1. Effect of the diameter and pipe flow on the pump power

For the following case study, it was used a Schedule 40 steel pipe with a length of 15 m, a fluid height in the storage tank of 2m, a pipe elevation of 7m, a pump efficiency of 0.76, entries square-shaped, two standard elbows of 90º, and a globe valve completely open. Pipes with nominal diameters of 1 inch (2.540 cm), 1¼-inch (3.175 cm), 1½-inch (3.810 cm), 2 inches (5.080 cm), and 2½ inches (5.715 cm) were analyzed.

As shown in Figure 10, the lower the diameter of the pipe, the higher the energy required by the pump to transport the fluid. When the volumetric flow is 15 L/s, 4.18 kW of power is needed for a 2½-inch pipe. When the diameter is reduced to 2 inches (20% decrease), the energy requirements of the pump increase by 91.4%, needing 8 kW. When the pipe diameter decreases from a 2½-inch pipe to 1¼ inches (50% reduction), the necessary energy requirements increase by 963.3%, demanding 44.45 kW. If the diameter is decreased to 1 inch (60 % reduction), the energy requirements increase abruptly by 3713.4%, requiring 159.41 kW. Increasing the diameter of the pipe will generally reduce the frictional losses within the pipe. Practically, pipes with large diameters require less power to maintain a given flow rate compared to pipes with small diameters. Large-diameter pipes result in low flow velocity as well as low friction losses, which decreases the power required by the pump. Conversely, using small-diameter pipes increase frictional losses because of the high flow velocities, which will require the pump to work harder to maintain the same flow rate. As a result, small-diameter pipes demand more power from the pump. The previous effect is increased exponentially with the increase of the flow as can be seen in Figure 10 where the separation among the pump power lines becomes more evident at higher flows.

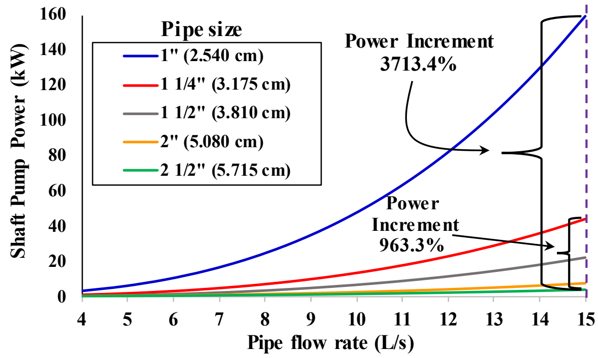


Fig. 10. Effect of the pipe diameter on the energy consumption of the pump for a Schedule 40 steel pipe with a length of 15 m.

Also, this kind of information is essential at the moment of choosing the right diameter in a pipeline because of the maximum strength it can stand. Many bad decisions are taken on many occasions when engineers build a net of pipes with the wrong diameter causing liquid escapes from pipes in lots of constructions. This is a general problem that can be avoided easily by running some simulations in specific software like Fluidsoft DL.1 resulting in saving money and time.

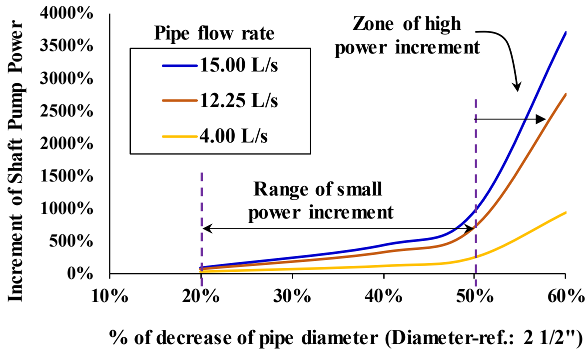


Fig. 11. Behavior of the increment of the pump power as a function of the percentage of decrease of the pipe diameter and flow rate, for schedule 40 steel pipe, 15 m length.

Based on a pipe diameter of 2½-inch, when the percentage of reduction in pipe diameter increases from 20 to 50%, the percentage of energy rise increases from approximately 70% to 600 %, see Figure 11. On the other hand, when the percentage of reduction in pipe diameter is higher than 50% and the pipe flow rates are higher than 12.25 L/s, the percentage of energy rise increases steeply from approximately 800% to 3000%. For pipes with low flow rates (4 L/s), the percentage of energy rise goes from 245% to 935%. These results confirm the need to make several simulations of a pipeline system before choosing the correct one since these values are directly related to the economic cost of the pumps and their maintenance. In summary, the right choice of a pump depends on many factors like the pipe diameter and the volumetric flow rate, to guarantee cost-effective operations with high efficiency. Besides, the type of pump such as centrifugal, positive displacement, axial flow, etc., and the specific requirements of the system also play a significant part in determining the shaft pump power requirements. It is essential to use an appropriate hydraulic design that involves pipe sizing and pump selection to achieve optimal performance and energy efficiency in a pumping system.

4.2. Effect of pipeline length and pipe flow rate on the energy requirements of the pump.

For the present case study, it was used schedule 40 steel pipes with diameters of 2 and 1½ inches, a fluid height in the storage tank of 2 m, a pipe elevation of 7 m, a pump efficiency of 0.76, inlets with square edges, two standard 90º elbows, and a fully open globe valve. The study was done with five different pipeline lengths in the range [10m; 19m], see Figure 12.

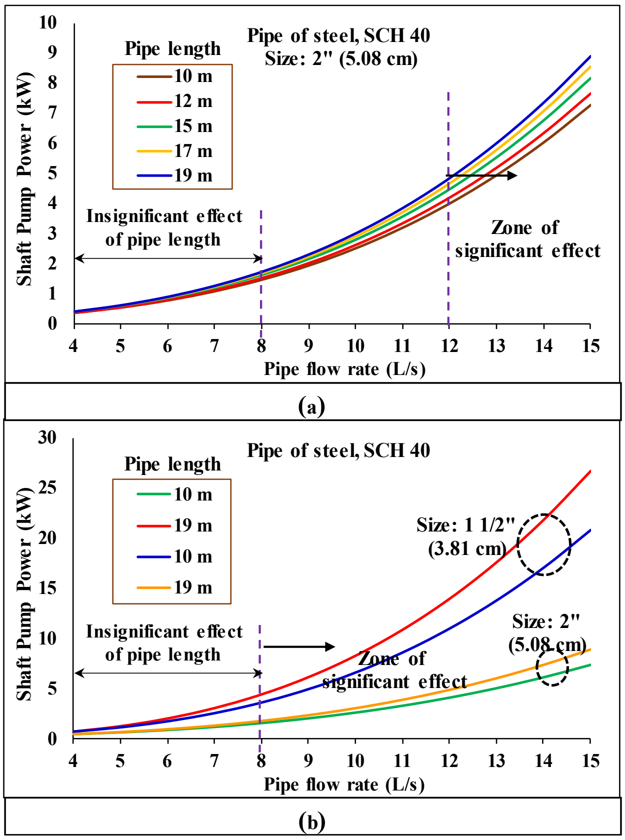


Fig.12. Behavior of the energy consumption of the pump as a function of the pipe length, (a) D=2 inches, L= [10,12,15,17,19]m, (b) D=[2 inches, 1 ½ inches], L=[10m,19m]

In Figure 12a, for a 2-inch pipe with a flow rate in the range between 4 and 8 L/s, the energy consumption of the pump is insignificant for any length of pipe between 10 and 19 m long, only requiring a power increase of approximately 1.5 kW. However, for high flow rates in the range between 12 and 15 L/s, the energy requirement is around 5.1 kW, with a significant effect on the pipe length which is obvious due to the high frictional loss for large pipe lengths. The larger the length of the pipe, the higher the energy consumption of the pump.

The flow zone between 8 and 12 L/s is an intermediate zone where the effect of the pipe is barely emerging but on a small scale.In Figure 12b, when the diameter of schedule 40 steel pipes with lengths of 10 and 19 m are reduced from 2 inches to 1½ inches, the energy consumption of the pumps increases considerably up to 190%. Both the diameter and length have significant effects on the power of the pump; however, this effect is remarkably higher for pipe flow rates higher than 8 L/s.

As fluid goes through a pipeline, friction between the moving fluid and the pipe interior wall surfaces causes energy losses. Commonly, long pipelines result in high frictional losses; hence, the longer the pipeline, the more power the pump needs to beat these losses and maintain the wanted volumetric flow rate. On the other hand, the pump is required to provide additional energy to overcome the total head in a pipeline system which includes several components, such as elevation head, velocity head, and pressure head. In long pipelines, the cumulative head losses are normally high, which demands more shaft pump power.

In summary, the use of long pipelines with high flow rates leads to an increase in the power requirements for a pump. The selected pump must overcome the high frictional losses and provide more shaft pump power to conserve the required flow under these conditions. Engineers must consider all the mentioned factors during the design stage to warrant that the pump selected can meet the system requirements efficiently.

Optimizing the pipeline design, using properly sized pipes in length and diameter, and selecting the right type of pumps with the appropriate characteristics for the system are essential steps in decreasing the energy spent and improving the overall efficiency of fluid transport systems.

4.3. Effect of pipe material and volumetric flow rate on pump power

For this case study, we used a 2-inch diameter pipe with a length of 15 m, fluid height in the storage tank of 2m, pipe elevation of 7m, pump efficiency of 76%, square shape inlets, two standard 90º elbows, and a fully open globe valve. Five different types of pipes were selected, SCH 40 steel, SCH 80 steel, copper, SCH 40 PVC, and SCH 80 PVC pipes, see Figure 6.

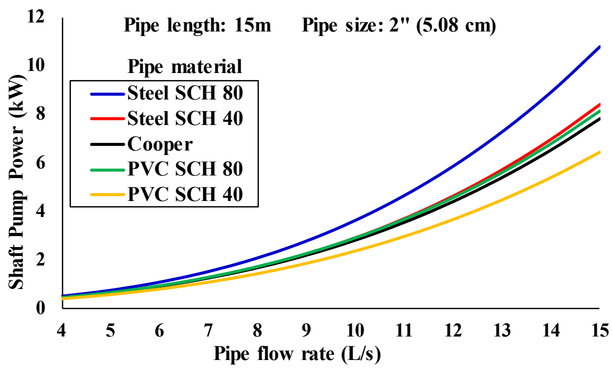


Fig. 13. Behavior of the energy consumption of the pump as a function of the pipe material.

As can be seen in Figure 13, for flow rates less than 7 L/s, the effect of the pipe material is insignificant; however, for flow rates higher than 8L/s, the effect of the material changes and becomes significant. For an SCH 40 PVC pipe with a flow rate of 15 L/s, the energy consumption of 6438 kW is required, which is low compared to the other types of pipes used. Changing this pipe for a PVC SCH 80 of the same size required an increase of 26.5% more power. When making the change for a copper pipe, a 21.7% increase in pump power was needed. For an SCH 40 steel pipe, an increase of 30% was required, and finally, for an SCH 80 steel pipe, the increase was 67.8%. As the schedule of a pipe increases, its inner diameter decreases, causing an increase in pressure, and increasing the energy consumption of the pump. With this result, the effect of the friction factor of the pipe material is evidenced. This type of simulation helps to select the best material type of pipeline to work since a comparison of the energy power spent can be linked with the economic expenses.

On the other hand, it can be seen that the SCH 80 steel pipe is the one that causes the highest energy consumption in the pump; however, this pipe has high external resistance letting it be located at great depths where high resistance to the ground is needed. Due to the large width, this pipe also has high internal resistance allowing it to be strong to wall shear stress distribution [30] [25]. Those are factors to consider when selecting the right pipe. This type of study is quite easy to perform with the help of the presented software, which helps the engineer quickly choose the right kind of pipe.

When it is compared the roughness (e) of steel, copper, and PVC pipes, steel pipes (e=0.0450-0.0900mm) generally have higher roughness compared to copper (e=0.0020mm) and PVC (e=0.0015mm). Steel has a high roughness which affects the friction losses as well as the turbulence of the flow, resulting in a high loss of energy.

Copper pipelines have smoother interior surfaces compared to steel pipelines, resulting in lower friction losses. PVC pipes have especially low roughness, like copper pipes, making them favorable for hydraulic systems where reducing frictional losses is important.

The software lets engineers perform detailed hydraulic calculations considering factors such as the pipe material, the type of fluid being transported, and the required level of smoothness for optimal fluid flow when designing piping systems to ensure efficient and cost-effective operation.

5. Conclusions

An informatics tool for engineers focused on the design and analysis of piping systems with elevation called Fluidsoft DL.1 was presented. Three case studies were developed where the user can perform a simple analysis of the different variables using energy balances with a set of data such as length, diameter, pipe material, and height of the liquid storage tank in output variables such as the power of the pump and the flow in the pipe.

When the volumetric flow rate is 15 L/s, 4.18 kW of power is required in a 2½ inches pipe. When this diameter decreases to 2 inches (20% decrease), the energy requirements of the pump increase by 91.4%, requiring 8 kW. When the pipe diameter decreases again to 1 inch (60% decrease), the requirements increase by 3713.4%, requiring 159.41 kW. Pipes with larger diameters will require less power to maintain a given flow rate compared to pipes with smaller diameters. Larger pipes will result in lower flow velocity and lower friction losses, which decreases the power required by the pump. The type of pump such as centrifugal, positive displacement, axial-flow pumps, etc., and the specific requirements of the system play a significant role in determining the power requirements of the pumps.

When the pipe flow rate goes from 4 to 8 L/s, the effect of the pipe length on the pump energy consumption is insignificant. The increase in pump power is approximately 1.5 kW. However, if higher flow rates are used in the range between 12 and 15 L/s, the rise in energy consumption is about 5.1 kW (240%). In addition, a significant effect of the length of the pipe can be seen. The larger the pipeline, the higher the energy consumption of the pump. Long pipelines generally result in high frictional losses. Therefore, the longer the pipeline, the more energy the pump needs to overcome these losses and maintain the desired flow rate. In addition, in longer pipelines, the cumulative head losses which include various components, such as elevation head, velocity head, and pressure head are typically higher, demanding more energy from the pump.

When the flow rate is less than 7 L/s for pipes 2 inches in diameter and 15m long, the effect of the pipe material is not significant; however, for a pipe flow rate higher than 8L/s the effect is significant. For an SCH 40 PVC pipe with a flow rate of 15 L/s, a pump power of 6438 kW is required. Changing this pipe for a PVC SCH 80 of the same size results in an increase of 26.5% more power. For steel pipes, SCH 40 and SCH 80, an increase in energy consumption of 30% and 67.8%, respectively, was required. When the schedule of a pipe increases, its inside diameter decreases, causing an increase in pressure drop. Pipes with high roughness such as steel pipes affect the friction losses as well as the turbulence of the flow, resulting in high loss of energy.

Copper pipes offer a smoother interior surface compared to steel, resulting in lower friction losses. PVC pipes have very low roughness, similar to copper, making them favorable for applications where minimizing frictional losses is important.

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Nomenclature

P	Pressure [N/m^2]
Z	Elevation [m]
h_L	Energy losses due to couplings [m]
W	Work done on the system [kW]
v	Velocity of the fluid [m/s]
L	Pipe length [m]
D	Pipe diameter [m]
f	Friction factor [Dimensionless]
Le	Equivalent length [m]
w	Mass flow rate [kg/s]
E_v	Friction loss term or viscous dissipation [kW]
ε	Relative roughness [Dimensionless]
γ	Specific weight [kg/(m^2·s^2)]
η	Dynamic viscosity [kg/(m·s)]
ρ	Density [kg/m^3]