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EENERGY REDUCTION ASPECTS USING 2D NUMERICAL SIMULATION FOR PUMPING STATIONS USED IN WATER COMPANIES

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The paper refers to a case study for the operation of a pumping installation, with hydraulic machines operating in parallel, equipped with a main collector. Unfortunately, the connections between the pump's discharge pipes and the main collector are designed and built in a T-junction, producing high energy losses. Proper system design is essential to minimize energy consumption. A well-designed system ensures that pumps are operating at their optimal duty points, minimizing energy waste. The results of this research present that changing the T-junction into a Y-junction can reduce energy consumption by 19.02 MWh/year. This means the reduction of operating costs by 1141.2 Euros/year.

Keywords: energy, optimization, pump, wastewater treatment

1. Introduction

The water companies operate a multitude of pumping stations, for drinking water supply, for wastewater transport in sewage systems, and for technological processes in wastewater treatment plants and water treatment plants. These pumping stations have a high energy demand. In the current context, the price of energy has increased a lot, and there is a need for hydrodynamic studies of pumping installations to identify the most appropriate ways to reduce energy consumption [1].

Energy consumption is a significant factor to consider when it comes to water pumps, as it directly impacts operational costs and environmental sustainability. Proper system design is essential to minimize energy consumption [2]. The design, capacity and dimensions of the pump vary in function and operate in a wide range of conditions as required. In the context of the actual number of certified criteria, the optimal project to be implemented is based on the fluctuating level of the load and the model of the load, the deterioration of the load, the

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modification of the operating pressure, the reduction of the load-bearing capacity, the introduction of gauge emissions with a view to the effect of the load [3].

These most recent studies show that pump placement methods were used to reduce energy consumption in the heating and distribution systems. The methods are the use of energy efficiency amplifiers that reduce energy consumption during the heating period, energy recovery and storage devices, and renewable energy sources. [4]. By mounting the pumps in parallel, operating costs was reduced by up to 15%, minimizing environmental impact, and contributing to sustainable water management [5]. The use of pump cascade systems can reduce energy consumption by up to 5.5% [6]. In all cases, the use of an increased efficiency pumping system is not sufficient. If a high yield was pursued, then there was high energy consumption. If the aim was to increase the flowrate, then the pump efficiency decrease. Thus, a balance was found between the operating conditions of the pumping system and the water distribution network.

A correct design can determine energy consumption savings. Operating a pump far from its best efficiency point can lead to increased wear and tear, potentially reducing the pump's lifespan and increasing maintenance requirements. The latest conclusions of Italian research encourage the exploration of supply networks by applying innovative solutions that consider sizing and control devices to further improve the efficiency of the systems, maintaining or even improving the quality of distributed water [7].

Minor pressure losses in a system directly influence a pump's energy consumption. By designing systems with minimized pressure losses (optimized pipe diameters, reduced fittings) and ensuring pumps operate near their best efficiency points, energy consumption and operational costs can be minimized. The energy consumed by a pump is directly proportional to the head it needs to overcome [8]. Therefore, the greater the pressure loss in a pumping system, the more energy the pump will consume to maintain a given flowrate. Higher energy consumption leads to higher operational costs [9]. By reducing pressure loss (using larger diameter pipes, minimizing the number of bends and fittings, choosing smoother pipe materials), it can reduce the energy requirements of the pump and, consequently, the operational costs [10].

One of the common configurations in both industrial and domestic applications is the T-junction [11]. Determining minor pressure loss for this type of junction was of paramount importance for multiple reasons [12]. Firstly, it aids in the accurate calculation of the pumping power required to maintain a desired flow rate. An inappropriate pump power can lead to pipe breaks in the network that determine the energy losses of up to 30-40% [13]. Secondly, understanding, and quantifying pressure loss can help in designing more efficient piping systems, thereby conserving energy, and reducing costs. Lastly, excessive pressure loss can lead to undesirable conditions such as cavitation, which can damage equipment and degrade system performance [14].

The Y-junction is also a common device in pipeline systems. Although research has shown the advantages of this type, it is less used in the field of water supply and more often used in the field of nuclear engineering [15],[16] and chemical engineering [17],[18]. Few studies showed the advantages of Y-junctions. The most recent studies show that as the angle of intersection increases in the range of 20°<θ<120, the pressure loss in the system increases. While θ increases in the range of 120°<θ<160° the pressure coefficient starts to decrease [19]. For example, when the angle of junctions is 60° the minor loss coefficient was 0.0884 and for the angle of junction 45° the minor loss coefficient was 0.0518 [20].

This paper has analyzed the complexity of minor pressure loss in T-junctions and Y-junctions in the water supply system. The method used basic mechanisms, empirical correlations, and advanced computational models to predict and mitigate these losses. The aim was to highlight the importance and advantages of the Y-junction for the future design and operation of more efficient and sustainable water systems.

2. Methodology

The paper presents a case study about the operation of a pumping installation with five hydraulic machines in parallel, equipped with a main collector. The research aim is to analyze the impact of the angle intersection between the discharge pipe and the main collector of the water network on the energy consumption of the system. In this case, two situations were analyzed: the T-junction, the real case presented in Fig. 1, and the Y-junction, for the analysis of the advantages of it. The difference between the two situations is the minor loss coefficient. According to the specialized literature, the minor loss coefficient of T-junction (angle of 90°) is ζ=1,5 and for Y-junction (angle of 45°) is ζ=0.5 [21],[22]. The Equation 1 was used to determine the minor head loss:

$$\Delta p = \zeta * \frac{v^2}{2g} \tag{1}$$

were, Δp $[m]$ - the minor head loss, ζ - the minor loss coefficient, *v [m/s]* - water velocity, *g = 9.81 [m/s²]*- gravitational acceleration.

Figure 1. Discharge pipe and main collector – pumping station RAJA, Constanta

The required flowrate of the system was $Q = 783.3$ m^3/h, the discharge pipe diameter was 300 mm, the main collector diameter was 600 mm and the required pressure in the network was $p = 2.05$ bar. The power required by the pump was calculated with Equation 2:

$$P = \frac{\rho g * H * Q}{\eta} \tag{2}$$

where: P *[W]* - power required by the pump, Q *[m^3/s]* – flowrate, H *[m]* - pumping head, which includes pressure loss, ρ *[kg/m^3]*- density of the fluid, $g = 9.81$ *[m/s]^2* is gravitational acceleration, $\eta = 85$ *[%]* is efficiency of the pump.

The research continued with modelling and mathematical simulations for the two situations. Their role was to improve the results obtained from calculations and measurements. When simulating the flow through a T-junction using computational fluid dynamics - Ansys-Fluent software, were taken into consideration the geometry, the fluid properties and boundary conditions.

The pipe system shown in Fig 1 was complex and difficult to model. There are many intersections and changes in the flowrate directions, which implies the analysis of several factors. To better understand the flow criteria, the system was divided into several sections, and the analysis was carried out for each section, separately. In this study, the punctual analysis of the pressure losses in the T-junction was presented to be compared with the Y-junction. In this case, according to the research in the literature, the 2D model was used to perform a comparative analysis.

The pipe geometry with CAD software and the real dimensions of the installation. The mesh was generated for the whole geometry to discretize the domain. Special attention was taken into consideration near the boundaries and areas of interest, such as the junction itself and regions where flow separation or recirculation may occur. The T-junctions mesh meets the quality criteria and has the following structure: number of nodes 10438, 10053 mixed cells, number of faces 20490 (Fig. 2).

The k-ε turbulence model was used for the mathematical modelling. It depends on the flow characteristics, Reynolds number, and any available experimental data for validation. The k-ε turbulence model is one of the most widely used turbulence models in computational fluid dynamics (CFD) simulations. It is a two-equation turbulence model that provides a closure for the Reynolds-averaged Navier-Stokes (RANS) equations by modelling the turbulent kinetic energy (*k*) and the turbulent dissipation rate (ε) [17].

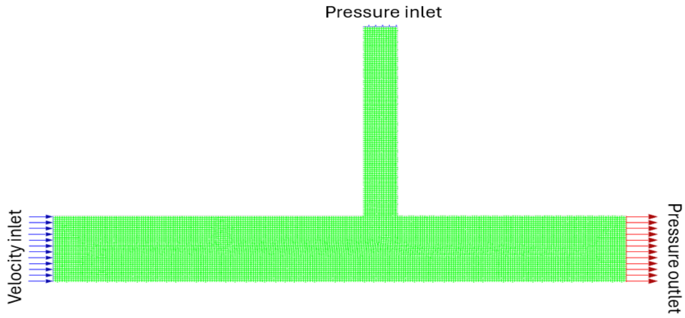

Figure 2. Geometry for T-junction pipe

The boundary conditions were specified as follows: discharge pipe was set as pressure inlet p = 2.10 bar, the main collector was set as velocity inlet v = 0.76 m/s, the outlet of the T-junction was set as pressure outlet p = 2.05 bar and the body of the pipe was set as a wall boundary. Also, were defined the water density ρ = 998.2 kg/m^3, and the water viscosity υ = 0.001 kg/m*s.

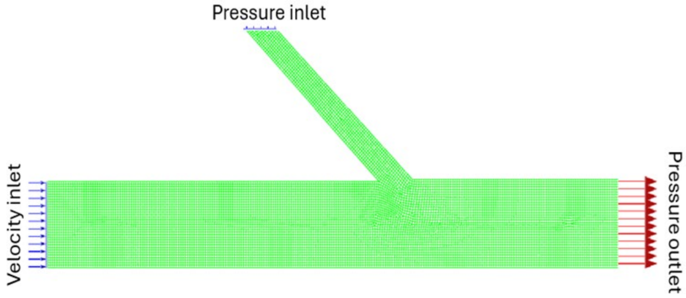

Figure 3. Geometry for Y-junction pipe

The second modelling was done for the Y-junction. The mesh meets the quality criteria and has the following structure: number of nodes 13736, 13250 mixed cells, number of faces 26985 (Fig.3.). Fluid properties were defined also for water and the same boundary conditions were specified. The second simulation also uses the k-ε turbulence model.

Following the mathematical models, the results of the simulation were analyzed such as the pressure in the pipes, the pressure loss, and the velocity magnitude.

3. Results and discussions

a. Experimental results

As a result of the experimental measurements, it was found that for T-junction, velocity water of 0.76 m/s and the pressure in the network of 2.05 bar, the minor pressure loss in the intersection was 0.07 bar and the pump power was 51.38 kW. In this situation, the energy consumption of the pumping station was 403.84 MWh/year. Applying the same methodology in the same operating conditions but for the Y-junction, a required pump power of 50.16 kW and a minor pressure loss of 0.02 bar were obtained. From the given values, the minor pressure loss at the T-junction is significantly higher than at the Y-junction. The minor pressure loss at the T-junction was 3.5 times higher than at the Y-junction. This could be due to the more abrupt change in flow direction in the T-junction, causing higher turbulence and energy dissipation compared to the more gradual flow redirection in the Y-junction.

In the Y-junction case, energy consumption would decrease to 394.32 MWh/year. If the type of intersection between the pipelines were replaced, there would be a reduction in energy consumption by 9.52 MWh/year. Because at the level of a pump, there are two such intersections, one in the suction area and one in the discharge area, there would be a decrease in energy consumption of 19.02 MWh/year. Within the water company, the price for one MWh is 60 euros. Thus, a decrease in operating costs can be registered by 1141.2 Euros/year. Considering the change of the intersection from the T-junction to the Y-junction, this implies a cost of 3020 euros. The amortization period of the investment will be 3-4 years, representing a brief period compared to the lifetime of the pipelines of at least 25 years.

b. Modelling results

Case 1 – simulation through T-junction

When the fluid flows through the discharge pipe, in this situation, the fluid hit the opposite wall with high velocity and created a vortex zone (Fig. 4). This situation is known as the "fluid wall impact" and has effects on the behavior of the fluid and the pressure losses (Fig 5). It can be observed how in the T-junction the pressure decreases by 0.06 bar. Comparing the mathematical results with the experimental results, an error of 10% was obtained. When the fluid hit the wall, it caused turbulence and local pressure peaks. These losses were considered as an additional form of resistance to the fluid flow which affected the flowrate in the pipe and caused high energy consumption for the pumps.

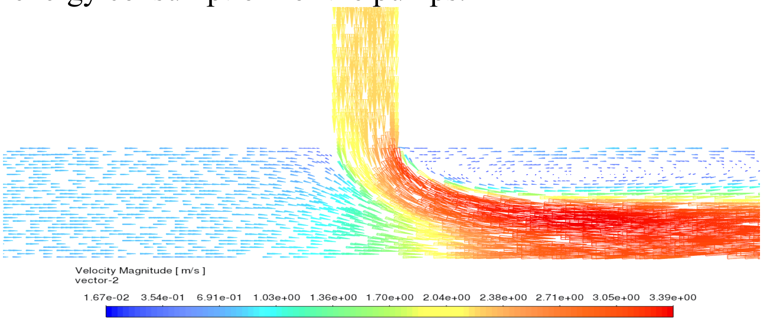

Figure 4. Velocity magnitude for T-junction pipe

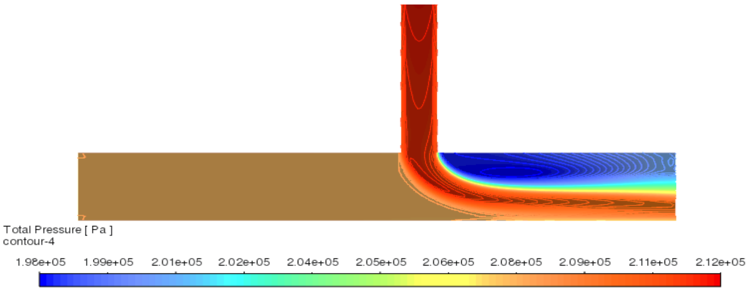

Figure 5. Total Pressure for T-junction pipe

The repeated impact of the fluid on the pipe wall can cause corrosion, especially for fluids containing solid particles or corrosive substances. This can lead to wear and deterioration of the pipe wall over time. In the case of intense fluid wall impact, it can generate noise and vibrations. These phenomena can be disruptive and may indicate design or operational issues in the pipe system.

Case 2 – simulation through Y-junction

In the case of the Y-junction, the intersection angle was 45^o. The graphic representation of the velocity magnitude shows that in the intersection the velocity was uniform, and a vortex was not created (Fig 6). Thus, the production of turbulences was avoided, and the risk of erosion and corrosion of the pipe wall was reduced. Also, the level of noise and vibrations at the impact of the fluid between the two pipes was reduced.

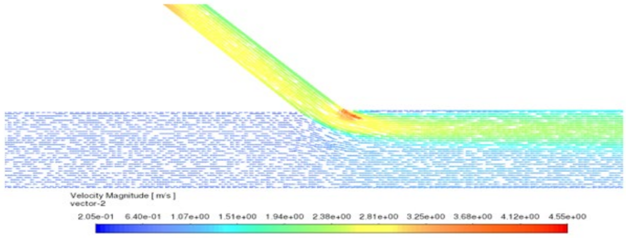

Figure 6. Velocity magnitude for Y-junction pipe

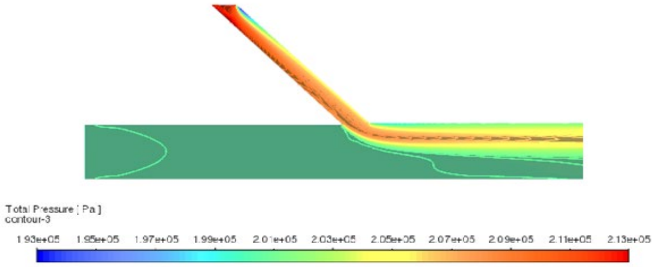

Figure 7. Total Pressure for Y-junction pipe, pressure inlet 2.12 bar

The pressure results show that if the pressure inlet was the same as in the case of the T-junction, p = 2.12 bar, the minor pressure loss was 0.03 bar and the pressure outlet 2.09 bar, with 0.04 bar higher than the network requirement (Fig 7). According to theoretical calculations, the modelling for the Y-junction was repeated for the pressure inlet 2.07 [bar]. The results showed that the pressure outlet was 2.05 bar (Fig 8).

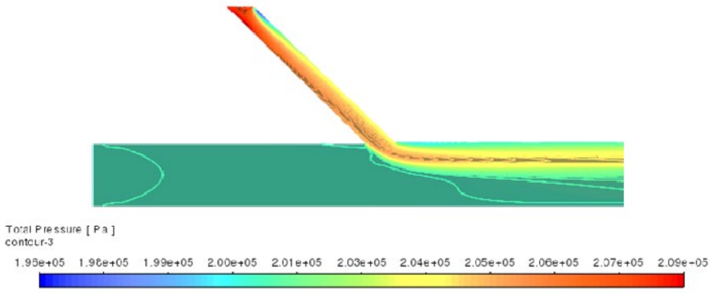

Figure 8. Total Pressure for Y-junction pipe, pressure inlet 2.07 bar

Just like the theoretical calculations, in the mathematical modelling, it was observed that the minor pressure loss is lower in the case of the Y-junction.

4. Conclusions

The research showed that the way of connecting the pipes in a water supply network has a significant impact on the energy consumption of pumping systems. Changing the T-junctions into Y-junction led to a 71% decrease in minor pressure loss. The experimental research presented that a pumping system connected to the network through the T-junction of the pipes determines an additional pressure of 0.07 [bar] which implies an additional energy consumption of 19.02 MWh/year. In this case, changing the T-junction with the Y-junction can reduce the energy consumption and implicitly the operating costs by up to 1141.2 euros/year. Mathematical modelling also shows that the minor pressure loss in the T-junction was higher than in the Y-junction.

The research will continue with mathematical modelling and simulations to identify the impact of several additions to the minor loss (pressure loss) and energy consumption, respectively. In the current context of rising energy costs, designing pumping stations while adhering to optimal hydrodynamic criteria is a goal of efficient energy management. In order, to reduce energy consumption, this paper can be considered a guide for pumping station designers.

R E F E R E N C E S

[1] *M. Munsamya, A. Telukdariea, P. Matjutaa,* Water systems modeling and optimization, Procedia Computer Science, **vol.217**, 2023, pp. 699–708.

[2] *K.B. Welter, Q. Wu, Y. You, K. Abel, D. McCreary, S.M. Bajorek, J.N. Reyes Jr*, Experimental investigation and theoretical modeling of liquid entrainment in a horizontal tee with a vertical-up branch, Int. J. Multiphas. Flow, **vol. 30**, no. 12, 2004, pp. 1451.

[3] *Ho.Tse*, Challenges for pumping station design in water industries: An overview of impacts from climate change and energy crisis, Water Research, **vol. 253**, 2024, 121250.

[4]*V. Wachem, A.E. Almstedt*, Methods for multiphase Computational Fluid Dynamics, Chemical Engineering Journal, **vol. 96**, no. 1-3, 2003, pp. 81-98.

[5] *H. Oh, I. Guk, S. Chung, Y.S. Lee*, Energy saving through modifications of the parallel pump schedule at a pumping station: A case study, Journal of Water Process Engineering, **vol 54**, 2023, 104035.

[6] *L. Kong, Y. Li, H. Tang, S. Yuan, Q. Yang, Q. Ji, Z. Li, R. Che*, Predictive control for the operation of cascade pumping stations in water supply canal systems considering energy consumption and costs, Applied Energy, **vol. 341**, 2023, 121103.

[7] *B. Brentan, F. Mota, A. Menapace, A. Zanfei, G. Meirelles*, Optimizing pump operations in water distribution networks: Balancing energy efficiency, water quality and operational constraint, Journal of Water Process Engineering, **vol. 63**, 2024, 105374.

[8] *B. Jafarzadeh, A. Hajari, M.M. Alishahi, M.H. Akbari*, The flow simulation of a low-specific-speed high-speed centrifugal pump, Appl Math Model, **vol. 35**, no. 1, January 2011, pp 242-249.

[9] *C.M Chini, A.S. Stillwell*, The state of U.S. urban water: Data and the energy-water nexus, Water Resour Res, **vol 54**, no 3, 2017, pp. 1796-1811.

[10 *M.S María, S.G. Ramón*, Energy intensity of treating drinking water: Understanding the influence of factors, Appl Eng, **vol. 202**, 2017, pp. 275- 281.

[11] Z.M. Meng, L.S. Wang, W.X. Tian, S.Z. Qiu, G.H. Su, Entrainment at T-junction: a review work, Prog. Nucl. Energy, **vol. 70**, 2014, pp. 221-241.
[12] *C. Boncescu, L.D. Robescu*, Air fractions impact over pressure drop in air-water mixture flow, Scientific Bulletin UPB, Series D, **vol. 79**, no. 4, 2017, pp 295-304.
[13] *C. Jara-Arriagada, I. Stoianov,* Pipe breaks and estimating the impact of pressure control in water supply networks, Reliability Engineering and System Safety, **vol. 210**, 2021, 107525.
[14] *C. Zhi, Y. Zhang, C. Zhu, Y. Liu*, Numerical analysis and artificial neural network-based prediction of two-phase flow pressure drop of refrigerants in T-junction, International Journal of Refrigeration, **vol. 137**, 2022, pp. 34-42.
[15] *D. Robescu, M. Grigoriu*, Pompe, ventilatoare şi compresoare (Pumps, fans and compressors), Lito. UPB, Bucuresti, 2001.
[16] *D. Bertolotto, A. Manera, S. Frey, H.M. Prasser, R. Chawla*, Single-phase mixing studies by means of a directly coupled CFD/system-code tool, Ann Nucl Energy, **vol. 36**, no. 3, 2009, pp. 310-316.
[17] *T. Frank, C. Lifante, H.M. Prasser, F. Menter*, Simulation of turbulent and thermal mixing in T-junctions using URANS and scale-resolving turbulence models in ANSYS CFX, Nucl Eng Des, **vol. 240**, no. 9, 2010, pp. 2313-2328.
[18] *Th. Frank, C. Lifante, H.M. Prasser, F. Menter*, Simulation of turbulent and thermal mixing in T-junctions using URANS and scale-resolving turbulence models in ANSYS CFX, Nuclear Engineering and Design, **vol. 240**, no. 9, September 2010, pp 2313-2328.
[19] *Y. Yina, K. Chena, X. Qiaoa, M. Lina, Z. Linb, Q. Wanga*, Mean pressure distributions on the vanes and flow loss in the branch in a T pipe junction with different angles, Energy Procedia, **vol. 105**, 2017, pp. 3239 – 3244.
[20] *Li Xin, W. Shaoping*, Flow field and pressure loss analysis of junction and its structure optimization of aircraft hydraulic pipe system, Chinese Journal of Aeronautics, **vol. 26**, no. 4, 2013, pp. 1080–109.
[21] *J. Baker, A. Armaou, P. Christofides,* Nonlinear control of incompressible fluid flow: application to Burgers equation and 2D channel flow, J. Math. Anal. Appl. **vol. 252**, no.1 2000, pp. 230-255.
[22] *P.G. Kiselev*, Îndrumar pentru calcule hidraulice (Guide for hydraulic calculation), Ed. Tehnică, Bucharest, 1988.