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Conference Paper

Author(s):
Nascimento, Bruno O.; Ortiz, Jayme Pinto

Publication date:
2024

Permanent link:
https://doi.org/10.3929/ethz-b-000675989

10th International Symposium on Hydraulic Structures Zurich, Switzerland 17-19 June 2024
ISSN 0374-0056 DOI: 10.3929/ethz-b-000675989

Energy Efficiency Analysis of the Final Lift Station of an Activated Sludge Wastewater Treatment Plant in Brazil Based on the Hydraulic Design and Pumps Operation – Case Study

B.O. Nascimento[1], J.P. Ortiz[1]
[1]*Universidade de São Paulo - Escola Politécnica, São Paulo, Brazil*
E-mail: bruno.on@usp.br, jportiz@usp.br

Abstract: *As the demand for wastewater treatment increases, treatment plant energy efficiency becomes an essential topic of study, since modern treatment processes requires a significant amount of energy. Whereas optimal energy consumption is desired, laws and guidelines have been established to encourage plant operation improvements. This work shows the importance of energy efficiency in wastewater treatment plants and its main energy consumption processes. The literature shows that aeration and sewage pumping are the two most energy demanding systems, therefore, this work focuses exclusively on the pumping system. A methodology to analyze a wet well lifting system operation is presented and applied to a case study of a large, activated sludge wastewater treatment plant. Three conditions that can compromise the performance of the pumping system were studied: the suction system inlet screen, siltation of the suction duct, and pump wear. Only the suction system inlet screen proved to be significantly prejudicial to pump performance. For this condition, it is shown that, when obstructions occur, the water level in the wet well increases, as does the energy consumption of the pumping system. In the case study, variable speed pumps proved to be more susceptible to power variations due to obstructions in the inlet screen, while constant speed pumps are less susceptible. Although the energy consumption variation in the case study may look small, when considering the total volume of treated wastewater over a month's period, the difference in power consumption is significant. The methodology presented here can be adapted to emulate the final lifting systems of similar wastewater treatment plants.*

Keywords: *Sewage lift station, energy efficiency, pump efficiency, hydraulic project, wastewater treatment plant.*

1. Introduction

When the urbanization occurred in the 20th century, large cities needed to control the issue of urban waste, as it generated negative impacts on the population's quality of life, like the transmission of diseases and environmental contamination due to inadequate disposal of wastewater. To reduce these impacts, sewage treatment technology was improved, and new wastewater treatment plants (WWTP) were implemented (Vaz 2015; Vorosmarty et al. 2010).

In Brazil, the law 14026, recently created, defines new regulations for basic sanitation, aiming for 90% universal access to sewage collection and treatment until December 31, 2033. This law defines new regulations, incentives for energy rationalization, promotion of energy efficiency, and improvements in waste treatment processes (BRASIL, 2020).

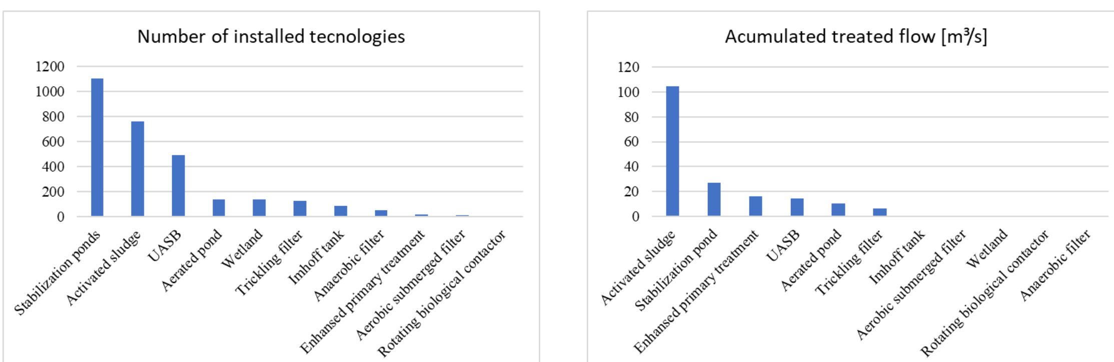
In 2015, the United Nations (UN) established an action plan called the Sustainable Development Goals, shown in Figure 1, with an agenda until 2030, to achieve the stipulated goals (UNITED NATIONS, 2023). The objective 6 of this plan is to ensure the availability and sustainable management of water and sanitation for all. Within this topic, goal 6.2 is defined, which aims to achieve global access to adequate and equitable sanitation and hygiene.

Source: United Nations.

Figure 1. Sustainable Development Goals.

Activated sludge wastewater treatment plants have a good benefit - cost ratio in terms of treatment efficiency alternative, reaching 95% to 98% treatment efficiency (Ferreira 2008). A study by Noyola et al. (2012) show that in Latin America and Caribbean the most used types of WWTP are stabilization ponds, followed by activated sludge, representing 38% and 26%, respectively, of the total WWTPs accounted for, as represented in Figure 2 (a). In the same study, it is shown that the accumulated treated flow of activated sludge treatment is the highest among the types of WWTPs listed, followed by stabilization ponds, as shown in Figure 2 (b), representing 58% and 15%, respectively, of the total accumulated treated flow. This information shows that, even with fewer units installed, the activated sludge system has a greater sewage treatment capacity when compared to stabilization ponds. Activated sludge treatment is a globally popular biological treatment method for treating a wide variety of sewage types, both residential and industrial. Its operation is based on the principle of developing an artificial ecosystem with great biodiversity and large concentrations of biomass. Bacteria contained in the sludge degrade the organic matter and proliferate, forming dense flakes that settle throughout the process (Ju and Zhang 2015).

(a) (b)



Source: Adapted from Noyola et .al (2012).

Figure 2. (a) Installed technologies and its (b) accumulated treated flow in Latin America and Caribbean.

Cardoso et al. (2021) present in their work a list of processes that consume the most energy in wastewater treatment plants, shown in Table 1. Panepinto et al. (2016) mention that sanitation experts focus on modeling and characterization of the effluent, but energy issues end up receiving little or no attention. Cardoso et al. (2021) mention that the aeration system is the first energy demanding structure in WWTPs, followed by pumping systems and sludge treatment. Since pumping is one of the main energy consumption structures in WWTPs, particularly in sewage stations with different levels between the arrival wastewater channel and the entrance of the treatment system, this work focuses on the study of energy consumption by the wet well pumping system, defining a methodology to analyze total head loss, to find the pumps efficiency and energy consumption.

Table 1. Percentage of energy consumption in treatment stages for some countries.

Country	Aeration	Sludge treatment	Pumping	Other
Spain	42%	14%	20%	34%
Japan	48%	29%	15%	8%
Italy	50%	29%	-	21%
China	52%	9%	18%	21%
Portugal	60%	12%	12%	16%
Poland	53%	-	30%	17%
Greece	66%	8%	-	26%
Germany	67%	11%	5%	17%

Source: Adapted from Cardoso et. al (2021)

2. Methodology

In activated sludge WWTP, the raw sewage usually arrives in a wet well, where it is pumped to the beginning of the process (Zhang et al. 2015).

In the work here presented it is analyzed a case study of a large, activated sludge WWTP in the metropolitan area of São Paulo, Brazil. It is tested under different head loss conditions on the wet well pumping system. The WWTP in question has four pumps: one constant speed (CS) pump and three variable speed (VS) pumps. One of the VS pumps is used as a redundancy, then, only three pumps will be considered in this study. The two VS pumps used will be called pumps 1 and 2, and the single CS pump will be called pump 3.

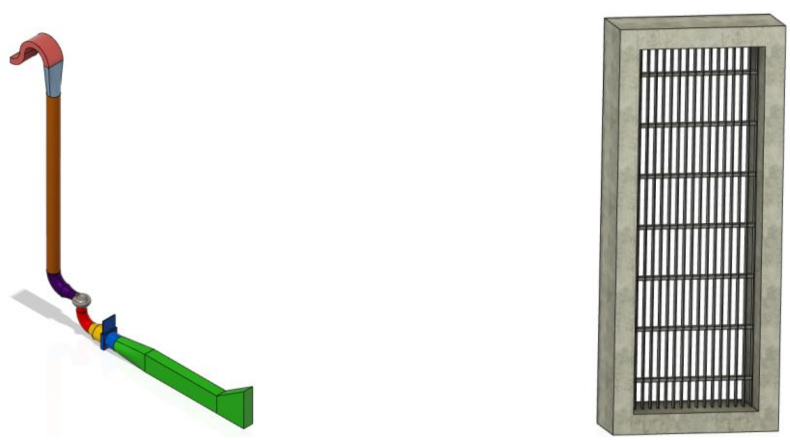
For the case study, the head loss of the pumps' suction and discharge pipes was analyzed, considering changes in the hydraulic operation of the following conditions: suction system inlet screen obstruction, siltation of the suction duct, and pump wear.

Wet well level was calculated using a mass balance equation. Pumped volume, efficiency, and power consumption were estimated using the head loss conditions and characteristics curves of the pumps.

2.1. Hydraulic Considerations

The characteristics of the pumps' suction and discharge piping were taken from the executive project and were used to calculate the head loss for each pump. Figure 3 (a) illustrate the suction and discharge piping of a pump. In the suction piping inlet, there is a coarse screen, as schematized in Figure 3 (b).

(a) (b)



Source: Adapted from the WWTP executive project.

Figure 3. Sketch of the pumps piping (a) and inlet grid (b).

Distributed head losses were calculated using Darcy-Weisbach equation, represented in Eq. (1):

$$\Delta H_d = f \cdot \frac{L}{D_h}\frac{v^2}{2g} \tag{1}$$

Where ΔH_d is the head loss, f is the friction factor, L is the piping length, D_h is the piping hydraulic diameter, v is the section mean flow velocity, and g is the acceleration of gravity.

Singularities head losses were calculated using the local head loss equation, represented in Eq. (2):

$$\Delta H_s = K_s \frac{v^2}{2g} \tag{2}$$

Where ΔH_s is the head loss, K_s is the singularity head loss coefficient, v is the section mean flow velocity, and g is the acceleration of gravity.

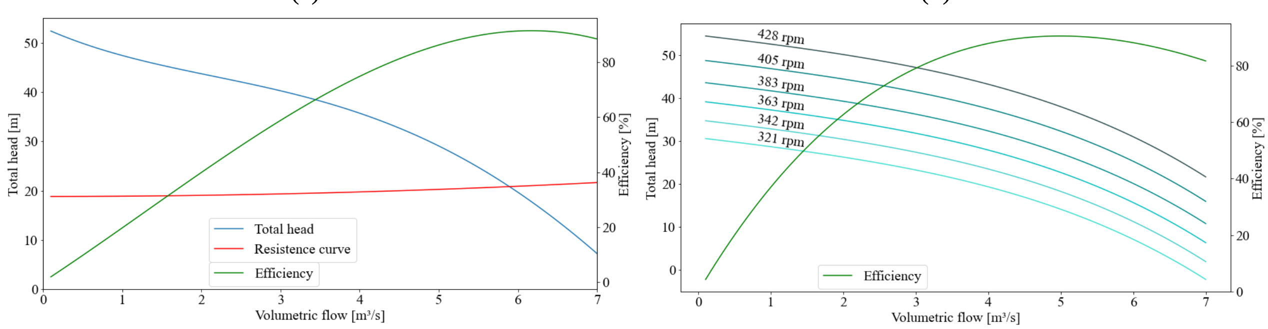
Head loss on the coarse screen was calculated using Eq. (3):

$$H_S = \frac{1}{C}\left(\frac{v_S^2 - v^2}{2g}\right) \tag{3}$$

Where $H_s$is the coarse screen head loss, C is the empirical discharge coefficient, v_s is the flow velocity through the screen, v is the sewage approaching velocity, and g is the acceleration of gravity. In cases of clogging, a reduction in the screen area is considered, increasing flow velocity through the grid.

The pump performance curves were taken from the WWTP executive project and were adapted as shown in Figure 4.

(a) (b)



Source: Adapted from the WWTP executive project.

Figure 4. Characteristic curves for (a) CS pump and (b) VS pumps.

The next sections will explain the influence of head loss in each of the hydraulic structures condition mentioned above.

2.1.1. Suction System Inlet Screen

The head loss on the screen was related to the flow obstruction area. It was observed in historical data that the average pumped flow was 6.27m³/s for the CS pump. The relationship between head loss and obstruction of the screen is shown in Figure 5.

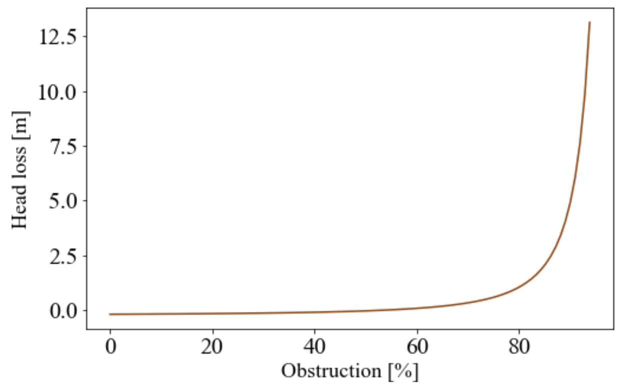


Figure 5. Relationship between head loss and screen obstruction.

Due to the large dimensions and location of the studied WWTP, solid materials are carried by the raw sewage, such as silt, rags, trash, other miscellaneous solids, and even tires, causing obstruction of the pumps' screens. This study considers the critical condition of 80% of the screen area being obstructed.

2.1.2. Siltation of the Suction Duct

The head loss due to siltation on the suction duct was associated with the height of solids deposited at the duct base. Using the historical data mean flow of $6.27 m^3/s$, this relationship is illustrated in Figure 6.

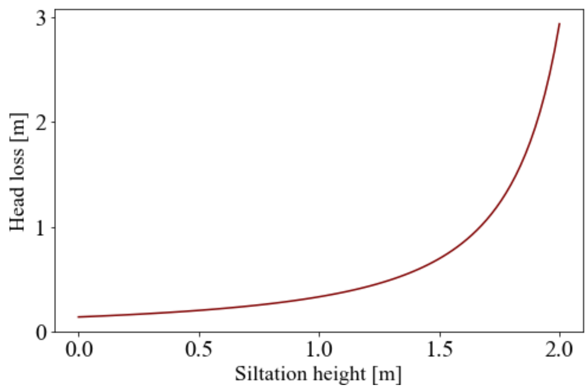


Figure 6. Relationship between head loss and duct siltation.

Since the flow velocities in this section are relatively high, characterizing a rough and turbulent flow, the possibility of siltation in the duct was ruled out.

2.1.3. Pump Wear

Pump wear is represented by a reduction in the pump's total head. Figure 7 illustrates the total head reduction for different levels of wear.

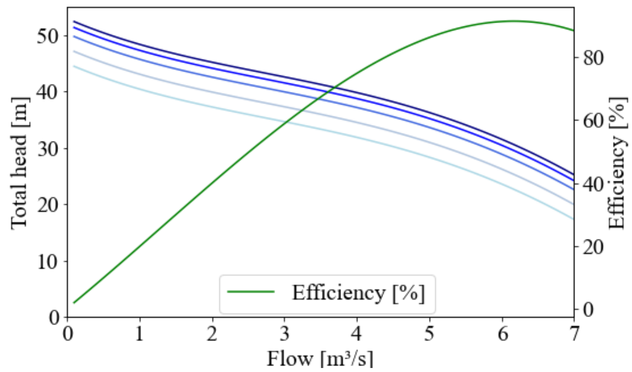
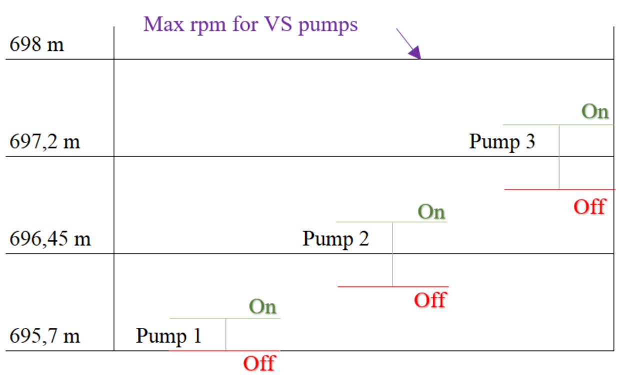


Figure 7. Total head reduction for different levels of wear.

Since the pumps undergo periodic maintenance, it was considered that wear has little to none influence on the system head loss.

2.2. Iterative Analysis

In this work, the analysis was conducted using a mass balance in the wet well to define the volume variation at each instant of time. The pumps' operation is defined in Figure 8 (a) and the daily wastewater inflow used, acquired from historical data, is represented in Figure 8 (b). The mass balance, exemplified in Figure 9, was developed iteratively, second by second, to define: the wet well height in relation to sea level, the pumped flows, the head losses, the power, and the energy consumption of the pumping system throughout the studied period.



Source: Adapted from the WWTP executive project.

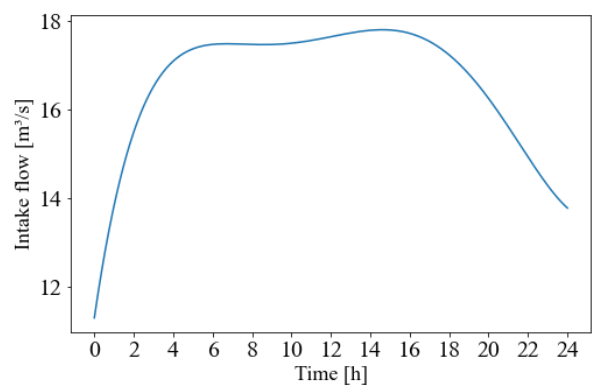


Figure 8. (a) pump operation points and (b) inlet flow used for analysis.

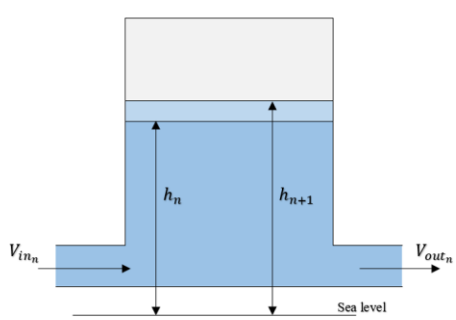


Figure 9. Example of the mass balance in the wet well.

The pumps’ power was calculated using Eq. 4 as follows:

$$P = \frac{\gamma \cdot Q \cdot H_P}{\eta_P} \tag{4}$$

Where P is the pump power, γ is the sewage specific weight, Q is the volumetric flow, H_P is the total head and, η_P is the pump efficiency.

Since the pumped flow is related to the total head of the pump and the resistance curve, their interception was calculated using the Newton-Raphson method, resulting in the pumped flow.

2.3. Tested Conditions

For the case study presented, the following grid conditions were tested:

- All grids with no obstruction.
- Only pump 1 grid 80% obstructed.
- Only pump 2 grid 80% obstructed.
- Only pump 3 grid 80% obstructed.
- All three pumps’ grids 80% obstructed.

The pump operating levels shown in Figure 8 (a) and the inlet flow defined in Figure 8 (b) were used to test these conditions. The starting wet well elevation considered was 698 meters.

3. Results

Analyzing the defined operations, it is possible to obtain the power consumption for each pump and the total, as shown in Table 2. The power of each pump was added together to obtain the total power of the pumping system over the studied period, resulting in the graph shown in Figure 10, where the consumption of the pumping system in each situation are compared.

Table 2. Power consumption of the pumps for each operation.

Condition	Power consumption [MWh]			
	Pump 1	Pump 2	Pump 3	Total
Without obstruction	49.39	44.51	49.01	142.91
Pump 1 screen 80% obstructed	49.85	45.23	49.01	144.09
Pump 2 screen 80% obstructed	49.96	45.25	49.01	144.22
Pump 3 screen 80% obstructed	50.07	45.56	49.16	144.79
All screens 80% obstructed	51.18	47.14	49.15	147.47

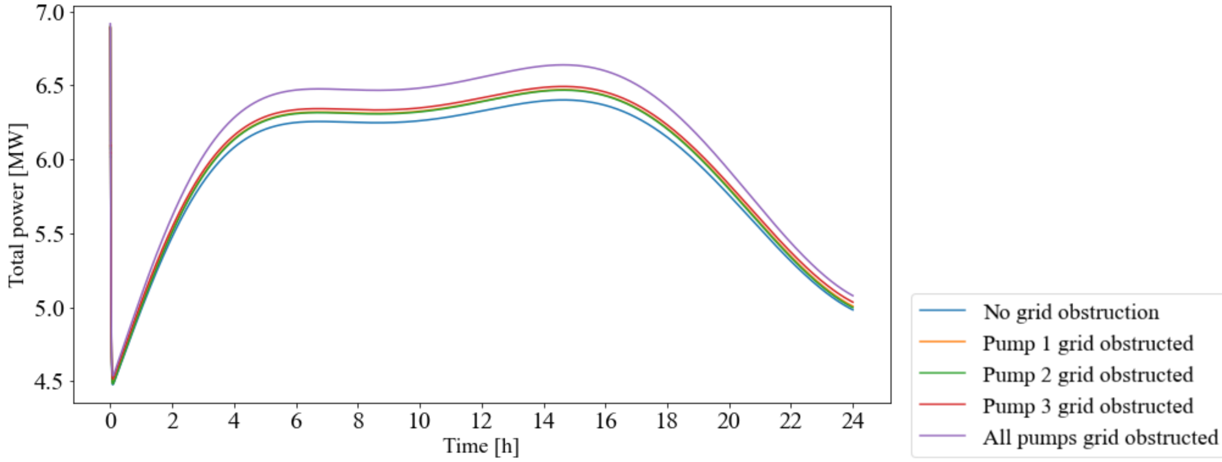


Figure 10. Comparison of the total power of the pumping system.

Observing the behavior of the water level in the wet well, the graph in Figure 11 shows the variation in elevation of the water level for each situation studied. Also, the energy consumption per cubic meter of pumped sewage can be determined since the total pumped volume for each pump was found. Table 3 shows the estimated total pumped volume of the system for all tested conditions.

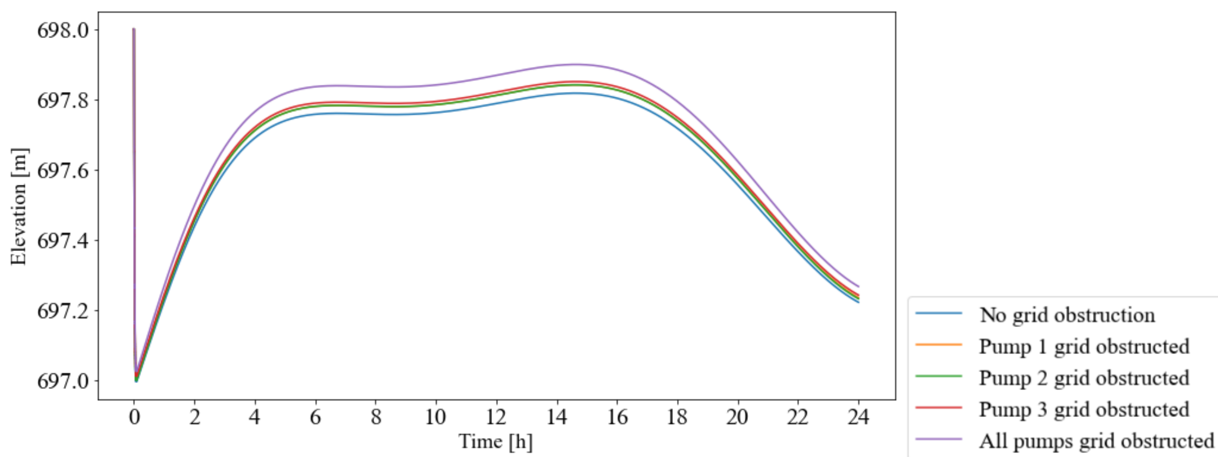


Figure 11. Water level in the wet well for the conditions studied.

Table 3. Pumped volume in the analyzed period.

Condition	Pumped volume [m³]			
	Pump 1	Pump 2	Pump 3	Total
Without obstruction	492,401	447,018	498,832	1,438,251
Pump 1 screen 80% obstructed	485,479	453,625	499,140	1,438,244
Pump 2 screen 80% obstructed	495.987	443,133	499,125	1,438,246
Pump 3 screen 80% obstructed	497,775	456,401	484,064	1,438,240
All screen 80% obstructed	494,516	459,031	484,680	1,438,227

Monthly consumption was extrapolated by multiplying the daily consumption by 30. The difference between the conditions is shown in Table 4.

Table 4. Estimated monthly consumption.

Condition	Energy consumption [MWh]	Monthly consumption [MWh]	Monthly Difference [MWh]
Without obstruction	142.91	4,287.42	-
Pump 1 grid 80% obstructed	144.09	4,322.70	35.28
Pump 2 grid 80% obstructed	144.22	4,326.66	39.24
Pump 3 grid 80% obstructed	144.79	4,343.73	56.31
All grids 80% obstructed	147.47	4,424.19	136.77

To estimate pumping costs, a value of 75.98 USD per megawatt hour consumed was adopted. This value was estimated based on the values charged by the local energy supply company. The costs obtained for the studied day were extrapolated to a 30-day period, resulting in an approximate monthly expense. Table 5 shows energy costs for each operation in the analyzed period, the percentage difference between the condition without obstruction and the other conditions, the extrapolated monthly cost, and the monthly financial difference between operations.

Table 5. Energy costs for each condition.

Condition	Daily cost [USD]	Daily Cost Difference [%]	Monthly cost [USD]	Monthly cost difference [USD]
Without obstruction	10,859.09	-	325,772.80	-
Pump 1 grid 80% obstructed	10,948.45	0.8%	328,453.40	2,680.60
Pump 2 grid 80% obstructed	10,958.48	0.9%	328,754.30	2,981.50
Pump 3 grid 80% obstructed	11,001.71	1.3%	330,051.40	4,278.60
All grids 80% obstructed	11,205.50	3.2%	336,165.00	10,392.20

4. Discussion

Obstructions in the pumping system, in particular obstructions in the inlet screen, can cause an increase in the energy consumption of the pumps, associated with slightly higher water levels in the wet well.

It was observed that when obstruction occurs exclusively on the CS pump, the energy consumption is higher. When comparing the conditions with no obstruction and obstruction of all grids, there is an increase in energy consumption of 4.56 MWh in a day, representing a total of 136.77 MWh over a month. Comparing the cost difference between these operations, an increase of 10,392.20 USD is observed, representing a 3.2% increase in energy expenditure.

Although the level in the wet well increases with obstruction conditions, the total pumped wastewater remains similar in all situations studied.

5. Conclusion

It can be concluded that obstruction of the inlet grid is the main factor in increasing the energy consumption of the pumping system. It was observed that in the condition with grid obstruction of all pumps, there was a 3.2% increase in energy consumption when compared to the condition without grid obstruction. This percentage would represent an increase of 136 MWh in the station's monthly consumption, consequently causing a monthly expense of approximately 10,392.20 USD.

Variable speed pumps are more susceptible to energy consumption variation due to head loss increases, at least when using pump operation based on the wet well level, as shown in this work. Constant speed pumps are less susceptible to power variations caused by obstructions in the system.

Hydraulic analysis of the pumping system pipes proved to be an important tool for detecting possible head loss increasing in the system, and as a result, it is possible to monitor the energy efficiency of the WWTP.

The methodology presented in this work proved to be an essential tool for analyzing the operation of the wet well lifting system, allowing the study of the operation behavior, according to defined conditions, such as obstructions and different wet well inlet flows. Similar studies can be applied to any WWTP wet well pumping system if the project characteristics are known.

6. ACKNOWLEDGMENTS

This work was developed under a partnership project between SABESP/FDTE-EPUSP. For this partnership, the authors gratefully acknowledge SABESP – Companhia de Saneamento Básico de São Paulo for the support in this project by providing operational data and project design information about the WWTP studied in this work.

7. REFERENCES

BRASIL. Law number 14.026, (2020). Diário Oficial da União, Brasília, DF.

Cardoso, B. J., Rodrigues, E., Gaspar, A. R., Gomes, A. (2021) “Energy performance factors in wastewater treatment plants: A review”. *Journal of Cleaner Production,* 322, article 129107.

Ferreira, F.D. (2008). “Eficiência do Lodo Ativado em Fluxo Contínuo para Tratamento de Esgoto”. *Acad., Ciênc. Agrár. Ambient*. 6(2), 259-279.

Ju, F. and Zhang T. (2015). “Bacterial Assembly and Temporal Dynamics in Activated Sludge of a Full-scale Municipal Wastewater Treatment Plant”. *The ISME Journal*. 9, 683-695.

Noyola, A., Padilla-Rivera, A., Morgan-Sagastume, J. M., Guareca, L. P. and Hernández-Padillha, F. (2012). “Typology of Municipal Wastewater Treatment Tecnologies in Latin America”. *Water*, 9(40), 926-932.

United Nations (2023). “Sustainable Development Goals” <https://sdgs.un.org> (Dec. 15, 2023).

Panepinto, D. Fiore, S., Zappone, M., Genon, G. and Meucci, L. (2016). “Evaluation of the energy efficiency of a large wastewater treatment plant in Italy”. *Applied Energy*. 161, 404-411.

Vaz, A. J. (2015). *A importância da Rede coletora de esgoto na promoção da qualidade Sócio-Ambiental*. Universidade do Estado do Rio de Janeiro, Rio de Janeiro.

Vörösmarty, C. J., Mcintyre, P. B., Gessener, M. O., Dungeon, D.; Prusevich, A., Green, P., Glidden, S.; Bunn, S. E., Sullivan C.A., Liermann, C. R. and Davies, P. M. (2010). “Global threats to human water security and river biodiversity”. *Nature.* 467(7315), 555-561.

Zhang, Z., Kusiak, A., Zeng, Y. and Wei, X. “Modeling and optimization of a wastewater pumping system with data-mining methods”. (2015). *Applied Energy*.164, 303-311.