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Tesis

Development of PID control parameters in proportional valves for a wastewater treatment plant filtration process

Jhon Eloy Quispe Quispe
Yadhira Samhira Valenzuela Lino
Jhon Rodrigo Ortiz Zacarias

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Jhon Eloy Quispe-Quispe
Department of Mechatronics Engineering
Universidad Continental
Huancayo, Perú
73378400@continental.edu.pe

Yadhira S. Valenzuela-Lino
Department of Mechatronics Engineering
Universidad Continental
Huancayo, Perú
73105932@continental.edu.pe

Jhon Rodrigo Ortiz-Zacarias
Department of Mechatronics Engineering
Universidad Continental
Huancayo, Perú
71689110@continental.edu.pe

Cleo Alex Alarcón-Vasquez
Department of Mechatronics Engineering
Universidad Continental
Huancayo, Perú
calarcon@continental.edu.pe

Nabilt Moggiano
Engineering Research Unit
Faculty of Engineering
Universidad Continental
Huancayo, Perú
nmoggiano@continental.edu.pe

Carlos Coaquira-Rojo
Department of Mechatronics Engineering
Universidad Continental
Huancayo, Perú
ccoaquira@continental.edu.pe

***Abstract*—Wastewater treatment has remained a topic of interest over the years, since this method allows the water to be reused in other activities, since it establishes a process of conversion to "clean water"; however, this water must comply with quality standards that support the healthiness of the water. On the other hand, the treatment systems are still managed through manual processes, in which the variables and parameters of the plant are measured, however, these do not tend to be accurate, which leads to overflows within the system and consequently contaminate the quality of the water. Therefore, the present study aims to analyze the PID control parameters in proportional valves for a wastewater treatment plant filtration process. Also, it was essential to establish a flow chart of plant processes, and then implement sensors and actuators in the filtration process, in turn, equations were established to find the gain, where a ki=0.5359 and kd=5.1042 were achieved. Therefore, constant oscillations were obtained as a result within the level control, by means of the SCADA system. Finally, it was concluded that the implementation of a PID control system minimized the oscillations (disturbances) of the system, which generated greater precision of the variables that established the filtering of the process and reduced the water overflow, thus maintaining the healthiness of the process.**

Keywords— Sewage, PID, seepage, valves, disturbance.

I. Introduction

As time goes by, there has been increasing interest in the problems of operation and control of wastewater treatment plants (WWTP) [1], since these treatment processes serve to convert wastewater into "clean water", which must comply with various parameters and quality standards to be discharged into natural receptors [2], such as rivers, lakes, etc.

On the other hand, the control system and optimization of the operation of wastewater treatment plants are challenging due to the complexity of biological processes and variable influent patterns [3]. Additionally, such optimization is usually focused on economic objectives. However, in processes oriented to public benefit, priority must be given to healthy water conditions, since the most harmful pollutants in the process, e.g., CO2 from sludge, must be removed [4].

Biological wastewater treatment systems are very complex nonlinear systems, which are usually affected by disturbances, such as process noise and hidden dynamics, which make the modeling and control of these treatment plants difficult [5]. Likewise, in most cases the maintenance and control of these plants is performed by technical experts, who, based on measurements of the plant variables, correct and readjust the system parameters for optimal operation. However, the inherent load disturbances are not detected in time, which reflects a problem of accuracy in the estimation of variables in the control process [6]-[7].

Given this context, it is evident that water quality regulations are becoming more and more demanding, since the treated water is intended to be used for other activities. For this reason, it is essential to optimize various processes in wastewater treatment plants in order to meet environmental constraints and minimize costs [8]. Therefore, the present research aims to develop PID control parameters in proportional valves for the filtration process in treatment plants, in order to reduce the oscillations or disturbances that occur in the system, since they slow down the filtration process and therefore impair the water quality [9].

Previous studies [10] proposed a sensor system for environmental monitoring based on neural networks, where they identify environmental pollutants through a neural network; in addition, they use the neural network to identify the composition of the pollutant censored, also its computation system propagates the data with which the neural network is trained; therefore, as a result, a vector-matrix multiplication and a table lookup that performs the activation function is obtained.

From another perspective, the research [11] focuses on designing a control for a wastewater treatment plant with mechatronic systems, in which they established a control for each level of treatment in order to optimize the time and resources for its construction. In addition, they implemented a heater in the activated sludge treatment, in order to increase the temperature and control the system effectively. Consequently, by implementing PID control in all processes, tank overflow was minimized.

The priority of this research is to analyze the PID control parameters in valves, since this mechanism usually presents the highest number of disturbances, which generates overflows within the system and impairs water quality, thus increasing the costs and time of the process. Similarly, it threatens the environment and affects the sustainability of the industry [12].

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II. MATERIALS AND METHODS

Wastewater treatment is developed through several stages which are: pretreatment, primary treatment, secondary treatment and tertiary treatment. Each stage consists of various processes to treat different materials or organisms present in the wastewater in order to make use of the treated water.

For the purposes of this research, the process begins with pretreatment and primary treatment where the grit separates the larger solid matter through grids, then through the sand trap and a pumping chamber it passes to secondary treatment (biological treatment), a process that consists of a combination of aeration-reactor-clarification in bioreactor tanks and settling tanks as shown in Fig. 2; finally, it passes to tertiary treatment, where filtration and chlorination processes are used. This process is important and is carried out by water treatment plants, which eliminate more than 95% of wastewater waste, in order to make it suitable for human consumption as shown in Fig. 1 [13].

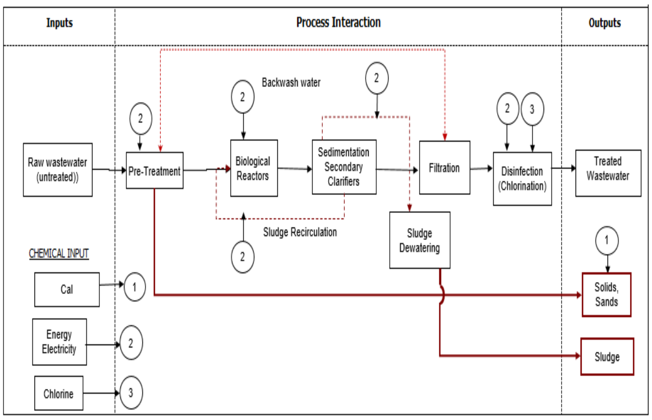


Fig. 1. Wastewater Treatment Plant Process Flowchart.

A. *Description of the sand filtration process*

In the filtration process we find the components that come to make the standardized gravel; in addition, the grit (quantity) is placed on top, after this process we have a treated water that through pipes is directed to the coil, to finish each distribution A, B, C, D, E, and F, which have to be constantly cleaned, also it is exchanged to the other distributions for a better cleaning of these as shown in Fig. 2.

Fig. 2. Bioreactor and settling tanks.

B. *Sensor and actuator implementation*

In the filtration process we find the components that come to make the standardized gravel and on top of it we put the grit (quantity), passing this process we have a treated water which through pipes is directed to the coil to then finish each distribution. A, B, C, D, E, and F have to be constantly cleaned, that is why it is exchanged to the other distributions, in order to have an optimal cleaning of these as shown in Fig. 3.

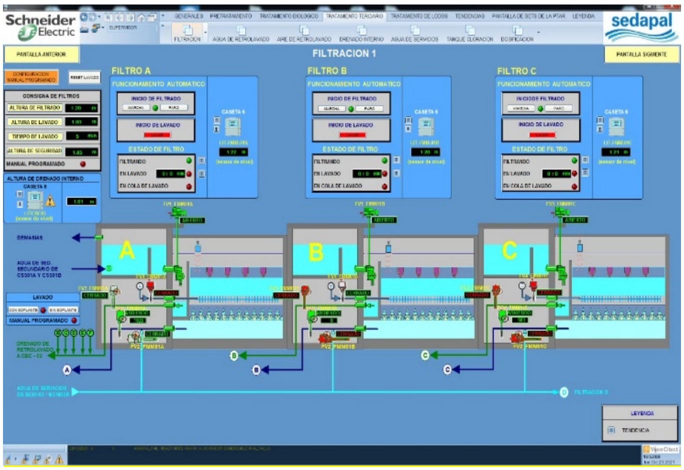


Fig. 3. Wastewater filtration process.

The hydraulic study was carried out at inlet A where a proportional valve is located, the filtering process works from the smaller tank that is directed to an inlet valve where it starts to fill the tank where the level sensor detects up to a maximum level of 1.2m from the base height.

C. *Calculation process for the controller*

For the PID controller process, three factors are summed which in turn are multiplied by a value in error signal; furthermore, the outputs of each function are valued by a proportional, integral and derivative equation as shown in Table 1; while the error signal determined e(t), derived from the variables set point (SP) and measurement variable (PV) thus forming equation 1 [14].

TABLE I. FORMULA OF THE ZIEGLER -NICHOL METHOD

Controller	K_P	τ_i	τ_d
PID	$1{,}2\dfrac{\tau}{K*L}$	$2L$	$0{,}5L$

$$e(t) = SP - PV(t) \quad (1)$$

Likewise, it is necessary that the control variable changes in order to minimize the error in relation to time, thus determining equation 2 [15], as shown below.

$$C(t) = K_p * e(t) + K_i \int e(t)dt + K_d * \frac{de(t)}{dt} \quad (2)$$

However, to optimize the process the Ziegler-Nichols method is used, this is applied from zero in the integral-derivative function leading to the proportional one. When the proportional value reaches a maximum value it generates a point of instability causing the system in process to oscillate. Therefore, 122 data were obtained from the level sensor to find a time-proportional graph as shown in Fig. 4.

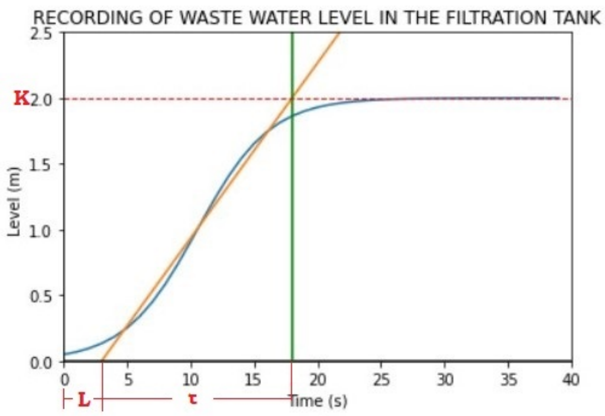


Fig. 4. Recording of waste water level in the filtration tank.

Data obtained to establish the gain values:

$$K = 2{,}1034 \tag{3}$$

$$L = 3{,}0861 \tag{4}$$

$$\tau = 17{,}8935 \tag{5}$$

Transfer function:

$$G_C(s) = K_p\left(1 + \frac{1}{\tau_i s} + \tau_d s\right) \tag{6}$$

Expressed in profit:

$$G_C(s) = K_p + \frac{K_i}{s} + K_d s \tag{7}$$

For the purposes of this study, the following profit values were obtained:

$$K_p = 3{,}3078$$

$$K_i = 0{,}5359$$

$$K_d = 5{,}1042$$

In addition, the integration and derivation times were obtained, respectively:

$$\tau_i = 6{,}1722$$

$$\tau_d = 1{,}543$$

III. Results

New actuators were installed as proportional valves in the tertiary treatment filtration process, due to the high wear of the actuators; on the other hand, an open-loop test was carried out with the Ziegler-Nichols method, in order to find the values and gains required by the process for the PID controller and subsequently include them in the new control logic.

Initially, the first test was performed on a single filter line (Filter F), since it gave positive results; therefore, in coordination with the Operations area, on January 12, 2022, all the filter lines were modified with a new control logic that surpassed the results of the first test and, consequently, the following results were obtained:

- Valve lifetimes exceeded by 2064%, i.e. 21 times more than usual.
- It was possible to eliminate the constant oscillations, since the fatigue of the materials was reduced, for example, gravel and sand, so that in the sedimentation process, compounds such as organic and inorganic matter were deposited, which slow down the filtration process that works with less fatigue.

Fig. 5 shows the recurrent oscillations in the level control graph, due to the fact that the behavior of the valves does not have a stable control; consequently, the level control of the filters is unstable.

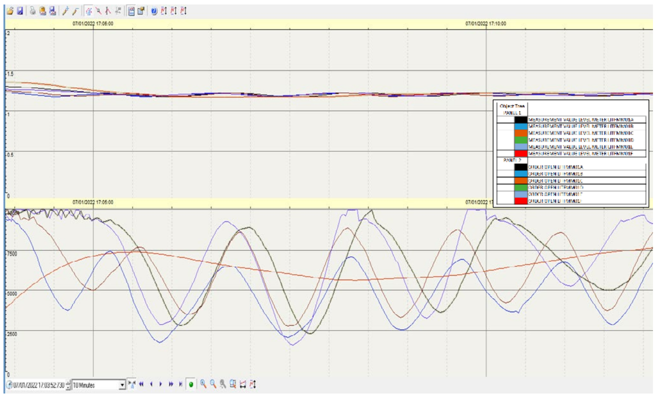


Fig. 5. Valve behavior and level control with ON/OFF control system.

Fig. 6 shows the graph of the level control behavior as a straight line, which can be interpreted as the stability of the process, since there is a lower rate of disturbances due to the PID control system.

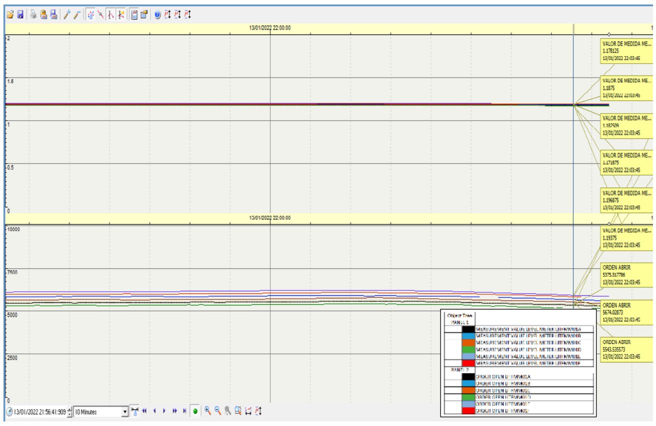


Fig. 6. Valve behavior and level control with a PID control system.

Fig. 7 shows the simultaneous behavior of all the filters at the beginning of the process, and one of the filters tends to reach the overflow limit due to the inadequate control system.

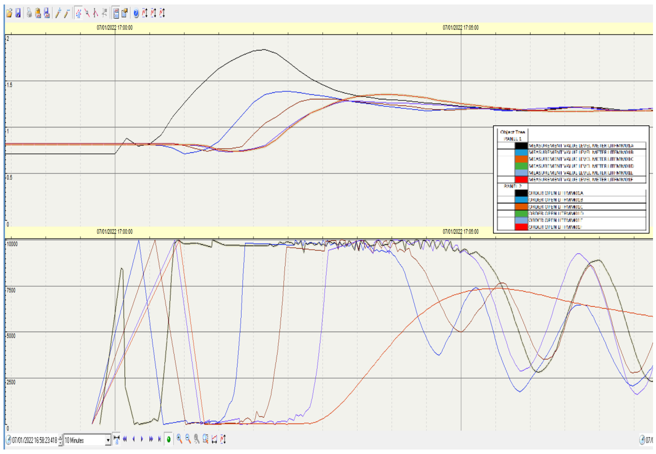


Fig. 7. Simultaneous behavior of all filters.

Fig. 8 shows the simultaneous behavior of all filters with the new PID control, which still has a 5 cm offset. However, it is intended that in an ideal environment the filter works at 1.20 m; however, due to this offset it works at 1.25 m.

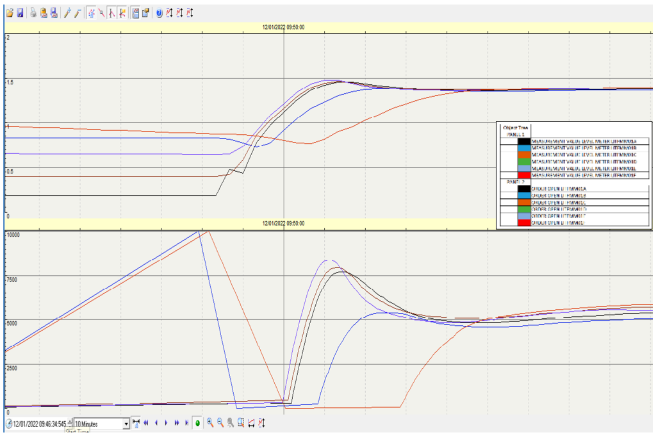


Fig. 8. Simultaneous behavior of all filters with the PID control system.

Fig. 9 shows the simultaneous behavior of the level controls with a deviation correction performed by the PID control system, so that the process has no disturbances when it is in operation.

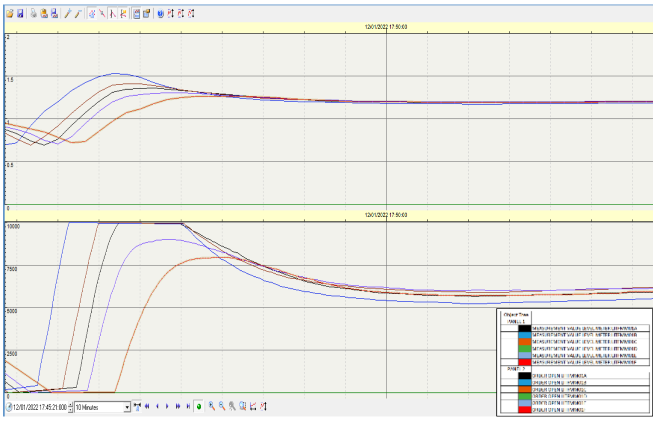


Fig. 9. Simultaneous behavior of all filters in the system without deviation.

Finally, Fig. 10 shows through the SCADA system the simultaneous behavior of the level controls without deviation as the execution time passes, where constant signals are maintained with no oscillations, therefore, the process with the PID control system showed a process with greater efficiency.

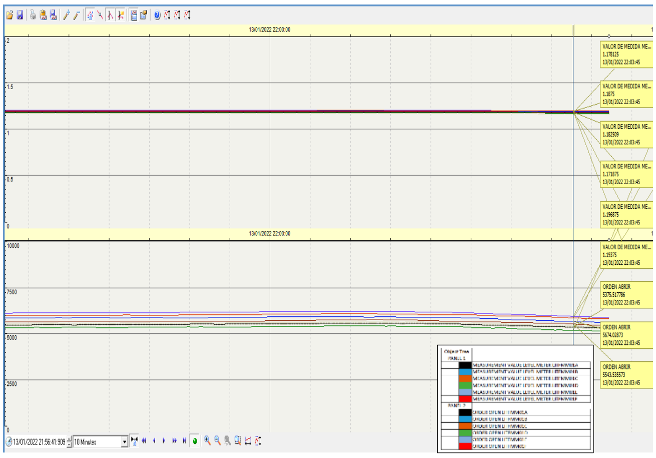
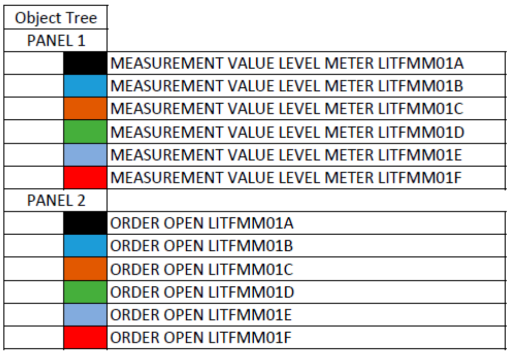


Fig. 10. Behavior of the level controls through the SCADA system.

From the trends shown in Figures 5 - 10, the behavior of the levels and the opening of the valves can be observed as shown in the following legend.



Object Tree		
PANEL 1		
		MEASUREMENT VALUE LEVEL METER LITFMM01A
		MEASUREMENT VALUE LEVEL METER LITFMM01B
		MEASUREMENT VALUE LEVEL METER LITFMM01C
		MEASUREMENT VALUE LEVEL METER LITFMM01D
		MEASUREMENT VALUE LEVEL METER LITFMM01E
		MEASUREMENT VALUE LEVEL METER LITFMM01F
PANEL 2		
		ORDER OPEN LITFMM01A
		ORDER OPEN LITFMM01B
		ORDER OPEN LITFMM01C
		ORDER OPEN LITFMM01D
		ORDER OPEN LITFMM01E
		ORDER OPEN LITFMM01F

Fig. 11. Legend for graphs 5-10.

IV. Discussions

According to the study [16] a PID control was performed to control the dissolved oxygen level, which allowed improving the overall performance of the WWTP; however, the calculations of the control loop and the proportional and integral gain values are limited only to the DO control. On the other hand, in the research [1] shows us a compilation study of control types used in wastewater treatment plants and WWTPs among them the following are shown: classical control (ON/OFF, PI, PID), heuristic control (rule-based control, fuzzy control, artificial intelligence techniques, etc.), model-based control (predictive control, robust, optimal, adaptive, non-linear, adaptive) and supervisory control; in addition, the total plant is presented in the different processes that are intended to control such as: DO control, nitrates, sludge recirculation, external carbon addition, nitrogen removal, ammonium and chemical addition for precipitation; however, due to the different treatment technologies in the WWTP and WWTP some processes were not considered, such as filtration control of treated water post clarification.

Finally, to complement the studies mentioned above, this research shows the analysis of PDI control parameters in proportional valves for a wastewater treatment plant filtration process. For this purpose, a test run was performed in one of the six filters of the filtration system, in order not to affect the regular process, in addition, favorable results were obtained, since it was implemented in all six lines of filters PID control by modifying the gains of the programmable logic controller. For this reason, the objective was achieved in the filtration process, which is planned to be implemented in the remaining 23 WWTP of the company SEDAPAL.

V. Conclusions

The results obtained showed that the tuning of the PID control loop in the proportional valves stabilized the process control in two important aspects, one of them being the elimination of oscillations in the filtration process level control and on the other hand the adequate actuation time of the proportional valves gaining 2064% (20.6 times the previous amount) more life time of the actuators. That is why we sought to linearize the inlet flow through the information obtained from the SCADA, so that a constant flow was stipulated at the inlet of the filtration process.

Additionally, the PID model and control implemented in the automated system helps to optimize energy resources due to the reduction of actuator drives; furthermore, due to the gain in life time of the actuators, their acquisition will be less constant due to mechanical wear. On the other hand, the quality of treated water improved due to the stabilization of the treatment flow, which generated less fatigue in the gravel and sand filters. Consequently, this benefits the end users of the treated water, most of which is used in agriculture and the remainder is reused for water treatment and purification.

From another perspective, as part of the improvements applicable to the integral control of the wastewater treatment plant, it is possible to consider unifying the PID profit calculations of each process in order to establish a control based on predictive models, with the aim of optimizing resources and guaranteeing compliance with the parameters and indicators audited by the environmental and water health authorities.

Finally, it is expected that future research will contemplate other tuning methods such as fuzzy or AI (for integration with other processes of the wastewater treatment plant), where a comparison will be made, in order to obtain a more precise control of this proposal and to implement and optimize the filtration process in the wastewater treatment plant of SEDAPAL in Peru.

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Appendixes

https://drive.google.com/drive/folders/1oSIyw_GYiczdwEQot_1lewgRSN8LKFy0?usp=sharing

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