CHEESA: Chemical Engineering Research Articles
ISSN 2614-8757 (Print), ISSN 2615-2347 (Online)
Copyright © 2025

Research Article

Fluid Flow Rates Regression in Tank Level Control

Regresi Laju Alir Fluida pada Pengendalian Level Tangki

Puji Rahayu[1*)], Khairunisa Betariani[1)], Rachmadi Tutuka[1)], Ari Adrianto[2)], Enny Nurmalasari[3)]

[1)]Politeknik Industri Petrokimia Banten, Teknologi Proses Industri Petrokimia, Jl. Raya Karang Bolong, Cikoneng, Banten, 42166, Indonesia

[2)]Chulalongkorn University, Petrochemical Technology, The Petroleum and Petrochemical College, 254 Phaya Thai Rd, Wang Mai, Pathum Wan, Bangkok, 10330, Thailand

[3)]Politeknik ATI Padang, Teknik Kimia Bahan Nabati, Jl. Simpang Tabing, Bungo Pasang, Sumatera Barat, 25171, Indonesia

Article History
Submitted: 08th December 2024; Revised: 28th July 2025; Accepted: 30th July 2025;
Available online: 21th August 2025; Published Regularly: June 2025

doi: 10.25273/cheesa.v8i1.21400.35-42

*Corresponding Author.
Email:
puji.rahayu@poltek-petrokimia.ac.id

Abstract

The industrial production process is closely related to control systems, including level control. This is often used to ensure that fluid in the tank is available in the appropriate amount at each stage of the process. The process typically uses an automatic control system such as a Proportional Integral Derivative (PID) Controller that can help measure the accuracy of the data obtained. Therefore, this study aims to examine the effect of flow rate on fluid level control in a tank using linear, exponential, and logarithmic regression analyses. In the process, the effect of the automatic control system (PID Controller) on fluid flow rate was evaluated. The materials used were a 4 mm solenoid and a pump speed variation in the range of 30-50%. Data on fluid level increase were obtained at 0 (n = 1), 60.27 (n = 30), and 180 seconds (n = 61) as the lower, middle, and upper limits. The results showed that fluid flow rate significantly affected the process of controlling fluid level in the tank, and is influenced by the speed of the pump used. Based on the regression analysis, the evaluation of the PID Controller was still classified as good, because the deviation observed in the reading flow rate data was very small.

Keywords: exponential; fluid flow rate; regression; tank level control

Abstrak

Proses produksi di industri erat kaitannya dengan sistem kendali salah satunya pengendalian ketinggian (level control). Pengendalian ini sering digunakan untuk memastikan fluida di dalam tangki tersedia dalam jumlah yang sesuai di setiap tahapan proses. Proses pengendalian biasanya menggunakan sistem kendali otomatis seperti Porportional Integral Derivatif (PID) Controller yang dapat membantu mengukur keakuratan data yang diperoleh. Tujuan penelitian ini untuk mempelajari pengaruh laju alir terhadap pengendalian level fluida di dalam tangki dengan analisa regresi linier, eksponensial dan logaritmik. Selain itu, penelitian ini bertujuan untuk evaluasi sistem kendali otomatis (PID Controller) terhadap laju alir fluida. Dalam penelitian ini digunakan solenoid 4 mm dan variasi speed pump pada rentang 30-50%. Pengujian data kenaikan level fluida dilakukan pada waktu 0 detik (n=1), waktu 60,27 detik (n=30), dan waktu 180 detik (n=61) sebagai batas bawah, tengah dan atas. Hasil penelitian ini diketahui bahwa laju alir fluida secara signifikan mempengaruhi proses pengendalian ketinggian fluida di dalam tangki, dimana laju alir fluida juga dipengaruhi oleh speed pump yang digunakan. Selain itu, dari hasil analisis regresi diketahui bahwa evaluasi terhadap PID Controller masih tergolong baik, karena penyimpangan pembacaan data laju alir sangat kecil.

***Kata kunci**: aliran fluida; eksponensial; laju alir; pengendalian level; regresi*

This work is licensed under the CC BY-NC-SA
(http://creativecommons.org/licenses/by-nc-sa/4.0/)

1. Introduction

Industry is an economic activity that processes raw materials into semi-finished or ready-to-use products with high value [1]. The industrial production process is closely related to control systems, including level control [2][3][4]. This is often used to ensure that the fluid in the tank is available in the appropriate amount at each stage of the process [5].

In level control, regulation of flow rate by controlling the pump speed is essential, ensuring a continuous and stable fluid flow. A consistent fluid flow can be influenced by the initial velocity, which impacts the pressure in the pipe or tank [6]. The consistency is also influenced by the pipe diameter, thereby impacting the head loss value [7][8].

The control process typically adopts an automatic control system, such as a Proportional Integral Derivative (PID) Controller. PID can stabilize the system by controlling process variables, including fluid flow rate or valve opening and closing [9][10]. Rahmani et al. [11] stated that the use of this automatic control system offered a fast rise time, minimal overshoot, good settling time, and small steady-state errors. Furthermore, the study was conducted using a single-level tank, and the results were analyzed by adopting the mass conservation equation in the tank and the discharge rate. Puspitarini et al. [12] performed a fluid level control test on a couple of tanks with a series circuit using the model predictive control method. Chen et al. [13] conducted a fluid flow experiment with level control using Computational Fluid Dynamics (CFD) analysis. Gaur et al. [14] initiated a multi-tank level control experiment that integrated intelligent fuzzy logic techniques.

The novelty of this study lies in the use of a multi-level parallel tank configuration and the application of pump speed variations as the main variable. These variations are used to determine the flow rate and the effect on the fluid level in the tank. In addition to simulations, the results were tested experimentally, where flow rate data controlled by a PID Controller were recorded and analyzed to evaluate control performance. This study integrated linear, exponential, and logarithmic regression analyses on the experimental data to obtain the coefficient of determination (R^2), which reflects the level of control accuracy of the system. Scientific studies using this analytical method have not been widely applied in the science of fluid mechanics or fluid flow. This method provides a new contribution in measuring the effectiveness of PID Controllers in parallel tank configurations, a rare primary focus of previous investigations. The results of this study also have the potential to be developed as teaching materials for practical work in the fields of fluid flow, fluid mechanics, as well as instrumentation and process control in vocational education and industry.

2. Research Methods

This study adopted an experimental method using fluid flow equipment as shown in Figure 1. The mechanism included placing distilled water into tank 1, after which the pump was turned on and the speed was increased to initiate fluid flow into tank 2. A solenoid valve with a diameter of 4 mm was installed in tank 2 to serve the purpose of a fixed variable, functioning as a flow control. Furthermore, this experiment utilized variations in pump speed ranging from 30 to 50% to regulate

This work is licensed under the CC BY-NC-SA
(http://creativecommons.org/licenses/by-nc-sa/4.0/)

flow rate, which ranged from 93 to 321 mm³/s. The variations enabled observation of changes in the fluid level in tank 2. Each experimental condition was conducted for 3 minutes, with data recorded at an interval of 3 seconds. The experimental data were processed using linear, exponential, and logarithmic regression analyses to determine the effect of each variable. The resulting equation was validated by performing calculations at time 0 (n = 1), 60.27 (n = 30), and 180 seconds (n = 61), representing the lower, middle, and upper limits.

2.1 Tools and Materials

The tool used in this study was a PCT50 Level Control unit, consisting of a series of parallel tiered tanks. The unit was equipped with a PID Controller, solenoid valve, and pump, while the material used was distilled water.

2.2 Data processing

The experimental data were obtained in the form of fluid flow rate values, process time, and fluid level in tank 2. The results were calculated using a linear regression model in equation (1) [15]. Regression parameters were calcaluated with equation (2) and (3).

Analysis using exponential regression was conducted with equation (4) [15]. Exponential equations are non-linear, hence there is a need for transformation into linear equations using the natural logarithm, as in equation (5) and (6). The value of b was the slope, and A was the intercept using equation (7) and (8). Analysis using logarithmic regression conducted with equation (9) [15]. To obtain the values of b and a, equation (10) and (11) were applied.

Model evaluation was using the coefficient of determination (R^2) equation (12). R^2 value approaching 1 signified that the model had good accuracy.

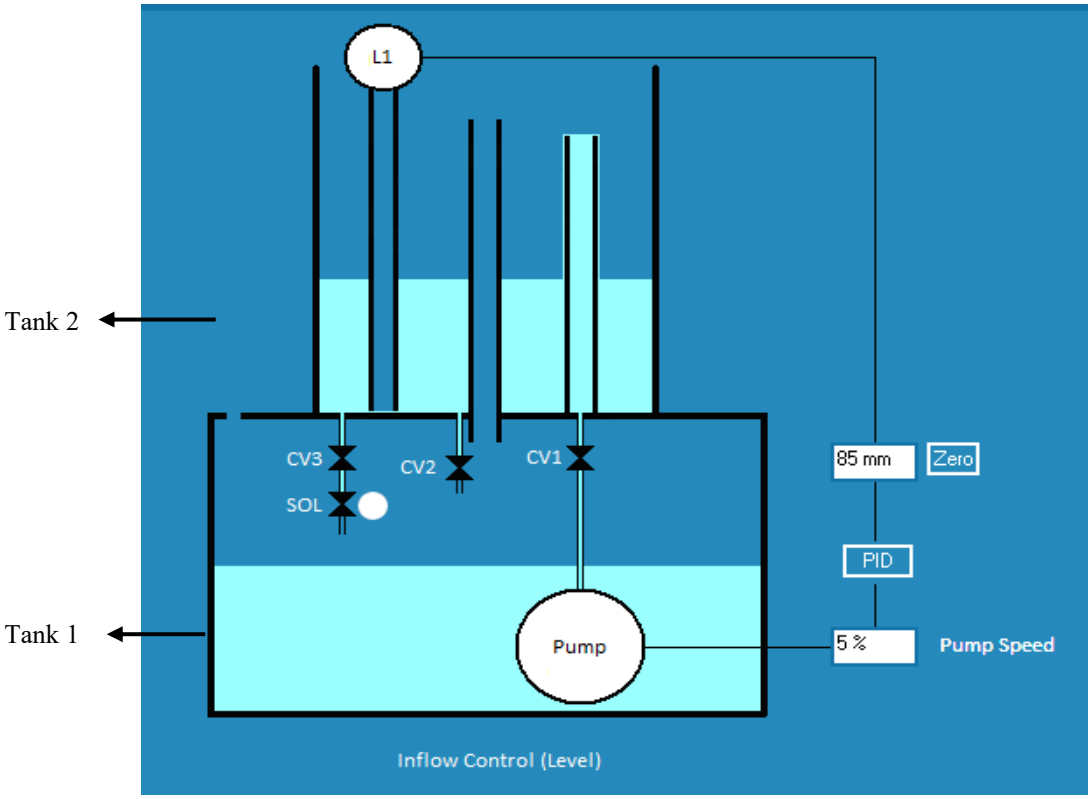

Figure 1. Multi level tank of PCT50 level control unit

This work is licensed under the CC BY-NC-SA
(http://creativecommons.org/licenses/by-nc-sa/4.0/)

$$y = a + bx \quad \text{.....(1)}$$

$$b = \frac{n\sum(xy) - \sum x \sum y}{n\sum(x)^2 - (\sum x)^2} \quad \text{.....(2)}$$

$$a = \frac{\sum y - b\sum x}{n} \quad \text{.....(3)}$$

y : dependent variable
a : constant (intercept)
b : regression coefficient (slope)
x : independent variable
n : number of data
Σ : summation operation

$$y = a \cdot e^{bX} \quad \text{.....(4)}$$

$$ln\ y = ln\ (a \cdot e^{bX}) \quad \text{.....(5)}$$

$$Y' = A + bX \quad \text{.....(6)}$$

Y' = ln y
bX = bX
A = ln a

$$b = \frac{\sum(X_i - \bar{X})\,(Y_i' - \bar{Y}')}{\sum(X_i - \bar{X})^2} \quad \text{.....(7)}$$

$$A = ln\ a = e^A$$

y : dependent variable
a : constant
b : regression coefficient
x : independent variable
e : Euler's number

$$Y = a + b \cdot ln\ (X) \quad \text{.....(9)}$$

$$b = \frac{\sum(X_i' - \bar{X}')\,(Y_i - \bar{Y})}{\sum(X_i' - \bar{X}')^2} \quad \text{.....(10)}$$

(3) $$a = \bar{Y} - b \cdot \bar{X}' \quad \text{.....(11)}$$

Y : dependent variable
X : independent variable
ln X : natural logarithm of X

$$R^2 = 1 - \frac{\sum(y_i - \hat{y}_i)^2}{\sum(y_i - \bar{y}_i)^2} \quad \text{.....(12)}$$

y_i : actual value (i[th] observation)
$\hat{y}_i$: predicted value of the regression model
$\bar{y}_i$: the average of all actual values y_i
Σ : sum of error/residual squares

3. Results and Discussion

3.1 Fluid Level Changes

In fluid mechanics, the function of a pump is to propel fluid from a pipe to a tank. This movement occurs due to mechanical energy being transformed into kinetic energy and pressure [16]. Changes in fluid level in the tank due to the influence of pump speed were observed, as shown in Figure 2.

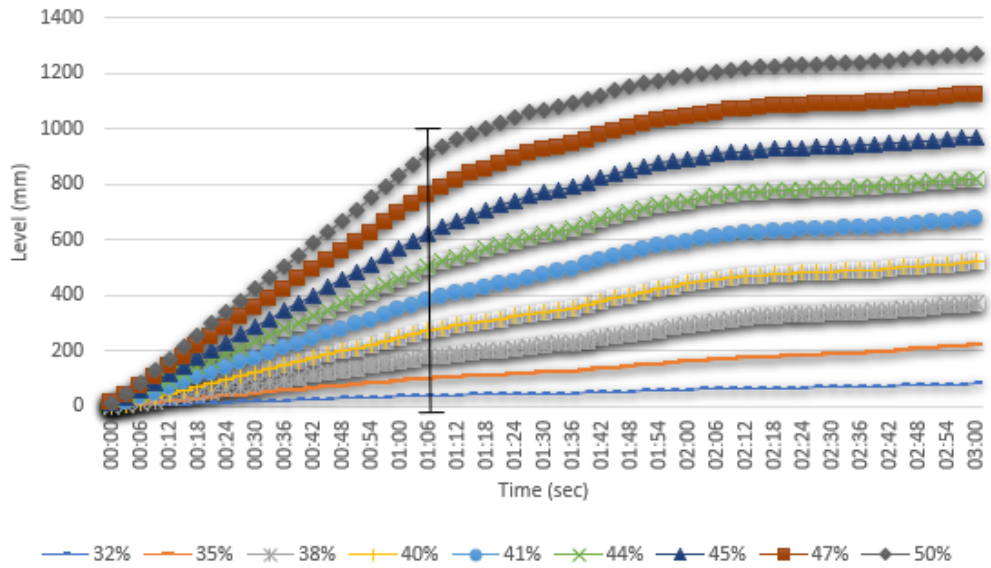

Figure 2. Change in fluid level against pump speed

This work is licensed under the CC BY-NC-SA
(http://creativecommons.org/licenses/by-nc-sa/4.0/)

Pump speed variations ranged from 30% to 50% with flow rates ranging from 93 to 321 mm3/sec. However, the experiments showed that at 30%, no fluid movement occurred in the piping system. This implied that the kinetic energy converted into kinetic energy and pressure was not strong enough to push the fluid towards the tank. Based on observations, fluid began to move up with a flow rate of 95 mm3/sec when the pump speed was increased to 32%. Flow rate data are presented in Table 1.

Table 1. Flow rate value from the pump speed setting

Pump Speed (%)	Flow Rate (mm^3/sec)	Fluid Level (mm)
32	95	45
35	159	75
38	200	96
40	235	105
41	258	110
44	302	119
45	276	117
47	305	121
50	321	125

In Figure 2, the fluid level in the tank, when pumped at a speed of 32%, is at the bottom line, with an average increase of 44.02 mm. At a pump speed of 50%, the average increase in the tank is 122.54 mm. The results showed that fluid level continued to increase significantly from the 0th second to the 60th second, or the first minute. After the first minute of 01:06, the flow towards the tank became faster than at the 0th second. This phenomenon explained that changes in kinetic energy in the pump affected fluid thrust when the pump was first turned on. After some period, the pump begins to adapt to the energy changes, thereby increasing the thrust on fluid [17]. These variations in kinetic energy were also influenced by the pump speed given during the experiment, which increased the fluid flow rate towards the tank [6]. The result is in line with Chen et al. [18], who stated that the impeller rotated based on the pump speed, making it able to influence the movement of fluid particles in the inlet section. The longer the impeller moves, the more the fluid becomes accustomed to the shape of the movement, leading to more stability.

Observations showed that the pump speed applied at the start of the process increased the flow rate, which affected the level in the tank. The energy change also influenced the amount of pressure exerted on the fluid.

3.2 Regression Analysis

Based on the data, calculations were performed to determine the results of a simple derivative analysis of fluid flow rate. This data was used to evaluate changes in fluid level in the tank based on flow rate.

According to the results shown in Figure 3, a linear regression analysis was performed by entering the level value and flow rate as y and x, respectively, leading to the equation $y = a + bx$. In this study, the resulting equation was $y = 2.8257x - 47.65$, where the value of a was determined to be -47.65, and b, the regression coefficient, was 2.8257. A test was conducted to predict the value of y by entering the existing value of x.

This study tested fluid level increase data at 0 (n = 1), 60.27 (n = 30), and 180 seconds (n = 61), representing the lower, middle, and upper limits, which led to values of -47.65, 122.65, and 460.98 mm, respectively. The coefficient of determination (R^2) was obtained at 0.9641. The results showed that pump speed was capable of producing thrust on fluid, thereby increasing the flow rate.

This work is licensed under the CC BY-NC-SA
(http://creativecommons.org/licenses/by-nc-sa/4.0/)

Observations also presented that the fluid level in the tank was influenced by the flow rate. A temporary deviation was observed, as shown in Figure 3. Specifically, when pump speed was increased to 45%, flow rate unexpectedly decreased from 302 mm³/s to 276 mm³/s, leading to a 2 mm drop in fluid level. This anomaly was attributed to the presence of impurities in the impeller, which disrupted discharge flow. The deviation did not last long and returned to normal when the pump speed was increased to 47%. Fil'o et al [19] stated that fluid flow regulation in each industry differed depending on the water withdrawal/pipeline dynamics.

An analysis was performed using an exponential regression model, as detailed in equation (4), with fluid level (y) and flow rate (x) values presented in Figure 4. To derive the exponential equation, Y′ was calculated as ln y. The slope (b) was determined using Equation 8, while the constant A was obtained from Equation 9. After A was known, the coefficient a was derived by e^A. This process produced the exponential equation $y = 49{,}048^{0{,}015x}$. Data was tested at 0 (n = 1), 60.27 (n = 30), and 180 seconds (n = 61), representing the lower, middle, and upper limits, which led to values of 49, 393, and 24,582 mm, respectively. Finally, R^2 evaluation using exponential regression was 0.9937.

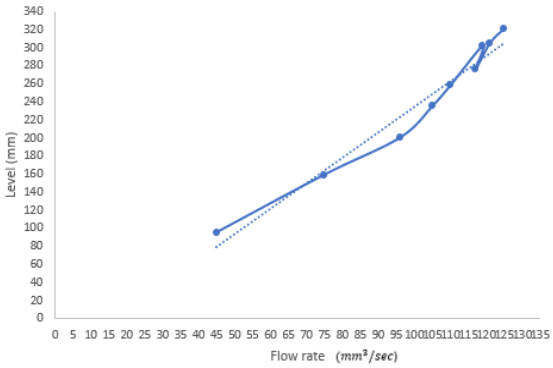

Figure 3. Linear regression curve of flow rate against fluid level

Logarithmic regression analysis was performed using equation (9), as presented graphically in Figure 5. The values of b and a were calculated based on Equations 11 and 12, respectively. Using flow rate and fluid level as the x and y values, the model obtained was $y = 46.595\ln(x) - 47.36$. Testing was performed by computing ln(x) for the same x values at 0 (n = 1), 60.27 (n = 30), and 180 seconds (n = 61), corresponding to the lower, middle, and upper limits. Therefore, the values obtained were approximately 134.61 and 372.59, respectively. The ~ value at 0 seconds was not obtained because ln(0) was undefined for n = 1. Evaluation of R^2 using logarithmic regression resulted in 0.9038.

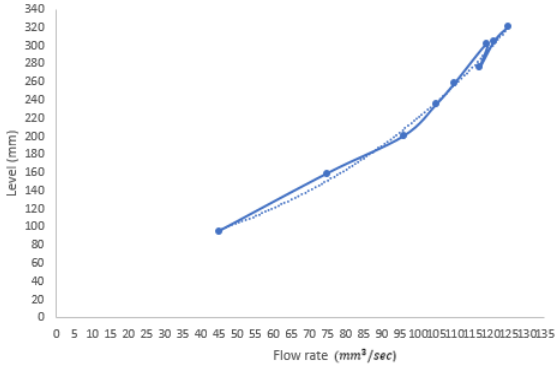

Figure 4. Exponential regression curve of flow rate against fluid level

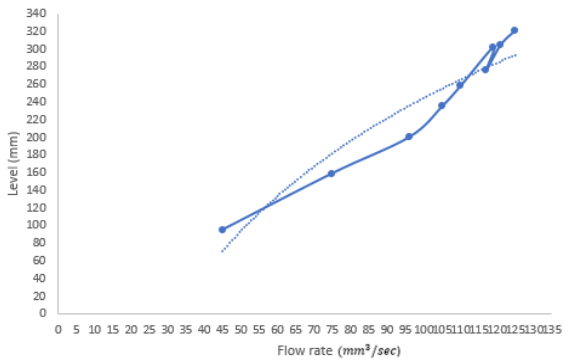

Figure 5. Logarithmic regression curve of flow rate against fluid level

This work is licensed under the CC BY-NC-SA
(http://creativecommons.org/licenses/by-nc-sa/4.0/)

Based on the analyses of linear, exponential, and logarithmic regression equations, R^2 values obtained are 0.9641, 0.9937, and 0.9038, respectively. These values showed that the model falls within the acceptable or recognized category, with the ideal value being 1 [17]. Therefore, based on the 3 analyses, exponential regression produces the optimum value, as it is closest to 1, followed by modeling using linear regression and logarithmic regression. These results showed that the flow rate has a significant effect on changes in the level height in the tank.

4. Conclusion

In conclusion, changes in pump speed affected the flow rate, thereby influencing the height of the fluid level in the tank. The level increases significantly at the start of the process due to the conversion of mechanical energy into kinetic energy and the resulting considerable pressure. Furthermore, the regression analysis served as an evaluation of the PID Controller and remained good, due to the very small deviation in flow rate data. R^2 values from the linear, exponential, and logarithmic regression analyses were 0.9641, 0.9937, and 0.9038, respectively. To analyze the influence of flow rate, a Mean Absolute Percentage Error (MAPE) regression was necessary for development purposes. This analysis was used to measure the size of the prediction error in percentage form relative to the actual value.

References

[1] Soeharto. (1984). *Undang-Undang RI Tentang Perindustrian*. Jakarta.

[2] Yunus, R., Repi, V.V.R., & Hidayanti, F. (2016). Perancangan Sistem Kontrol On/Off Multivariabel Level dan Temperatur Berbasis Microcontroller. *Jurnal Ilmiah GIGA*, 19(1), 9–16. doi: https://doi.org/10.47313/jig.v19i1.559

[3] Koumoutsakos, P., & Mezic, I. (Eds.). (2006). *Control of Fluid Flow* (Vol. 330). Berlin, Heidelberg: Springer Berlin Heidelberg. doi: https://doi.org/10.1007/978-3-540-36085-8

[4] Bhujade, C. P., Bisen, H. D., Hatwar, G. V, Bharati, A. K., & Sawarkar, N. (2022). Flow Rate and Fluid Level Measurement and Automatic Controlling Unit. *International Research Journal of Modernization in Engineering Technology and Science*, 04(05), 3257-3263. Retrieved from https://www.irjmets.com/uploadedfiles/paper//issue_5_may_2022/23883/final/fin_irjmets1653202007.pdf

[5] Petru, L. T., Tivlea, M. V., & Popa, S. E. (2023). Water Level Control and Monitoring System in a Tank Made With Arduino Uno and NodeMCU ESP8266 Development Boards. *Preprints*. doi: https://doi.org/10.20944/preprints202304.0735.v1

[6] Rahayu, P., Ikhsandy, F., Jerry, Utomo, P., & Thariq, A. (2023). Rekayasa Pump Speed Untuk Menghitung dan Menganalisa Initial Velocity (U0) Pada Rangkaian Unit Flow Control Tipe PCT51 Armfield. *Prosiding Seminar Nasional Teknologi Industri (SNTI)*, 10(1), 253–258. Retrieved from https://journal.atim.ac.id/index.php/prosiding/article/view/651

[7] Rahayu, P., Putri, D.K., & Indriyani, N. (2021). Pengaruh Diameter Pipa Pada Aliran Fluida Terhadap Nilai Head Loss. *Jurnal Agitasi*. 2(1), 23-32.

[8] Yahya, A.K., Rahayu, P., Ulia, H., & Maulana, A.Y. (2022). Analisa Head Loss dan Kerja Pompa Dengan Variasi Perubahan Diameter Pada Sistem Pemipaan. *Majalah Ilmiah Teknologi Industri (SAINTI)*, 19(2), 51–57.

[9] Ali, M., Afandi, A. N., Parwati, A., Hidayat, R., & Hasyim, C. (2019). Design of water level control systems using pid and anfis based on firefly algorithm. *JEEMECS (Journal of Electrical Engineering, Mechatronic and Computer Science)*, 2(1), 9–14. doi: https://doi.org/10.26905/jeemecs.v2i1.2804

[10] Djalilov, A., Juraeva, N., Nazarov, O., Chulliyev, Y., Sobirov, E., Begmatov, M., & Urolov, S. (2020). An intellectual system for water flow and water level control in water management. In

This work is licensed under the CC BY-NC-SA
(http://creativecommons.org/licenses/by-nc-sa/4.0/)

IOP Conference Series: Earth and Environmental Science (Vol. 614). IOP Publishing Ltd. doi: https://doi.org/10.1088/1755-1315/614/1/012044

[11] Rahmani, S., Rosana, S. A., & Tian, G. H. (2023). Sistem Kontrol Level Air Dengan Pengontrol PID. *Telekontran : Jurnal Ilmiah Telekomunikasi, Kendali dan Elektronika Terapan*, 10(2), 174–181. doi: https://doi.org/10.34010/telekontran.v10i2.9330

[12] Puspitarini, E. D., Effendie, R., & Pramudijanto, J. (2015). Desain Pengaturan Level pada Coupled Tank Process dengan Menggunakan Metode Model Predictive Control. *Jurnal Teknik ITS*, 6(1). doi : https://doi.org/10.12962/j23373539.v6i1.21345

[13] Chen, C., Song, S., Guo, J., Zhang, Q., Zhang, S., & Shen, T. (2021). CFD analysis on internal flow field of liquid level control valve under steady working state. *Journal of Mines, Metals and Fuels*, 66(2), 57–63.

[14] Gaur, A.S., Chauhan, A.S., Sharma, N.K., Kumar, R., Gautam, P., & Gupta, M. (2024). Advanced Fluid Level Control in Interconnected Tank Systems Using Fuzzy Logic and Neural Networks. *J. Electrical Systems*, 20-3(2024), 3362-3372. Retrieved from https://journal.esrgroups.org/jes/article/view/4971

[15] Azizi, A., & Emira, D. (2023). Perencanaan Reservoir Air Bersih di Wilayah Pelayanan IPA Legong PDAM Tirta Asasta Depok, *Jurnal Serambi engineer*, 8(3), 6226-6235. doi: https://doi.org/10.32672/jse.v8i3.6123

[16] Wibowo, M. (2001). Pemodelan Statistik Hubungan Debit dan Kandungan Sedimen Sungai Contoh Kasus di Das Citarum-Nanjung. *Jurnal Teknologi Lingkungan*, 2 (3), 255-260.

[17] Lakovlev, A. P., Erofeev, A. S., & Gorelkin, P. V. (2022, November 1). Novel Pumping Methods for Microfluidic Devices: A Comprehensive Review. *Biosensors*. MDPI. doi: https://doi.org/10.3390/bios12110956

[18] Chen, J., Chen, X., Li, W., Zheng, Y., & Li, Y. (2024). Research on Two-Phase Flow and Wear of Inlet Pipe Induced by Fluid Prewhirl in a Centrifugal Pump. *Journal of Marine Science and Engineering*, 12(6). doi: https://doi.org/10.3390/jmse12060950

[19] Fil'o, M., Brestovič, T., Lázár, M., Jasminská, N., Dobáková, R., & Kender, Š. (2024). Application of Unsteady Fluid Flow Simulation in the Process of Regulating an Industrial Hydraulic Network. *Applied Sciences (Switzerland)*, 14(6). doi: https://doi.org/10.3390/app14062393

This work is licensed under the CC BY-NC-SA
(http://creativecommons.org/licenses/by-nc-sa/4.0/)