

Control of DC Motor in Laundry Liquid Waste Treatment Based on ESP32-S3 and Thingsboard Platform

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ABSTRACT

Untreated laundry wastewater contributes to environmental pollution, with TSS levels reaching 600 mg/L, far above the 100 mg/L limit set by East Java Governor Regulation No. 72 of 2013. This research develops an IoT-enabled automated wastewater treatment system utilizing the ESP32-S3 microcontroller, integrated with pH, TSS, and temperature sensors, and featuring real-time monitoring via the ThingsBoard platform. A DC motor serves as an actuator for chemical dosing and mixing, controlled by sensor feedback. The system serves small-scale laundry businesses with limited access to centralized treatment. Testing showed 100% effectiveness in reducing TSS and 95% in stabilizing pH. Data transmission delays averaged 4 seconds for turbidity and 5 seconds for pH. Processing effectiveness was evaluated based on regulatory compliance, with 71% classified as Feasible, 5% as Very Feasible, and 19% as Less Feasible. While calibration and reliability improvements are necessary, the system demonstrates potential to assist local laundries in meeting environmental standards. Future work will focus on enhancing sensor accuracy and implementing fault-tolerant control.

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1. INTRODUCTION

Laundry liquid waste generated from various washing businesses is a significant source of environmental pollution, but it often receives less serious attention. One of the main parameters indicating the quality of liquid waste is Total Suspended Solids (TSS), which in practice can range from 200 to 500 mg/L [1]-[3]. This figure far exceeds the quality standard limit stipulated in East Java Governor Regulation Number 72 of 2013, which allows a maximum TSS level of only 100 mg/L for laundry activities. Optimal wastewater treatment relies not enough only on chemical processes but also requires technological support that can monitor and control the process automatically, in real-time, and with high precision. The system ensures consistent quality in the treatment results. The system operates by continuously measuring wastewater parameters via sensors. The microcontroller processes the data and adjusts the DC motor speed to optimize chemical mixing and distribution, ensuring consistent treatment quality. Additionally, control logic is implemented using proportional control based on real-time sensor feedback to regulate motor speed and chemical dosing, improving accuracy and process adaptability.

The integration between microcontrollers, Internet of Things (IoT), and DC motor control systems is a relevant and efficient approach in supporting technology-based wastewater treatment processes [4] [5]. This research proposes a system specifically designed for small-scale laundry businesses, which often lack access to cost-effective and automated waste management solutions. ESP32-S3 was chosen as the control center in this research because it is the latest microcontroller series that has advantages in terms of data processing and wireless connectivity [6]-[8]. The system incorporates a PH-4502C pH sensor to measure acidity, a SEN0189

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TSS sensor to measure turbidity, and a DS18B20 temperature sensor to monitor effluent temperature. A microcontroller processes the data from the three sensors and controls the DC motors, which serve as actuators for mixing and adding chemicals during the treatment process. The Things Board platform enables remote, quick, and efficient monitoring and management of the system.

Several previous studies have explored similar themes, albeit with different approaches. For instance, a study by [9] developed a liquid waste monitoring system using an SMS gateway, which, although functional, still required additional costs and is not fully automated. Similarly, [10] [11] developed a hospital wastewater monitoring system using a web server, but have not integrated advanced control or processing features. Another study [12] investigated the processing of tofu liquid waste using the electrocoagulation method to reduce BOD, COD, pH, and TSS levels. Furthermore, the implementation of an Internet of Things (IoT) system for monitoring and managing water quality in wastewater treatment plants using the Raspberry Pi Zero W is also proposed [13].

Based on various weaknesses in previous studies, this research aims to design and implement the system “DC Motor Control in Laundry Liquid Waste Treatment Based on ESP32-S3 and ThingsBoard Platform”. The system aims to provide a more efficient and adaptive solution through IoT-based monitoring, as well as the automatic control of the physical parameters of the waste, to ensure that the treatment results meet the applicable quality standards. Thus, this research aims to contribute to the development of a more integrated and sustainable waste treatment system.

2. METHOD

The chosen research approach shapes the design of the research process. Experimental research is a type of research that aims to test hypotheses or answer research questions by manipulating the independent variable and observing the resulting changes in the dependent variable. Experimental research is a branch of research that aims to demonstrate how specific treatments affect outcomes [14]-[16]. For example, this research aims to implement a DC motor control automation system for treating laundry liquid waste.

2.1. Laundry waste

Laundry waste is a type of liquid waste generated from the clothes washing process, containing suspended solids, surfactants, phosphates, and organic matter that can contribute to water pollution. In Indonesia, East Java Governor Regulation No. 72 of 2013 governs the quality of laundry wastewater, which specifies the maximum permissible limits for several parameters relevant to laundry effluents.

Table 1. Wastewater Quality Standard for Laundry Activities

WASTEWATER QUALITY STANDARD FOR LAUNDRY ACTIVITIES	
Maximum Wastewater Volume per product unit : 16 liters/kg of laundry	
Parameters	Maximum Level (mg/L)
BOD ₅	100
COD	250
TSS	100
Oil and Fats	10
MBAS (Detergent)	10
Fosfat (as P ₂ O ₄)	10
pH	6-9

To complement these regulatory standards, several studies also provide categorical classification for pH [17]-[20] and TSS levels [21] [22] as shown in Table 2 and Table 3.

Table 2. pH Classification

pH Range	Description
6–6.4	Mild acid (lower limit of quality standard)
6.5–7.5	Normal
7.6–9	Mildly alkaline (close to the upper limit of the quality standard)

Table 3. Turbidity Classification

TSS Range (mg/L)	Description
0–25	Crystal Clear
26–50	Clear
51–75	Almost cloudy
76–100	Turbid (upper limit of quality standard)

To reduce TSS levels and lower pH values in the sewage treatment process, the PAC (Poly Aluminum Chloride) coagulant liquid functions to bind and precipitate suspended particles. A pH-lowering liquid (10% Phosphoric Acid) is used to balance pH levels and to approach normal values. This mixing process requires an ideal stirring speed setting of 100-200 rpm, with a recommended stirring duration of 1 minute to ensure even distribution of the chemicals [23]. In addition, the temperature of the effluent should be maintained within the range of 20-29°C, as a stable temperature within this range helps the chemical reactions to take place more optimally, increasing the efficiency of the treatment process [24] [25]. A combination of appropriate stirring speed, duration, and temperature settings is crucial to achieve maximum results in effluent treatment.

2.2. System Workflow

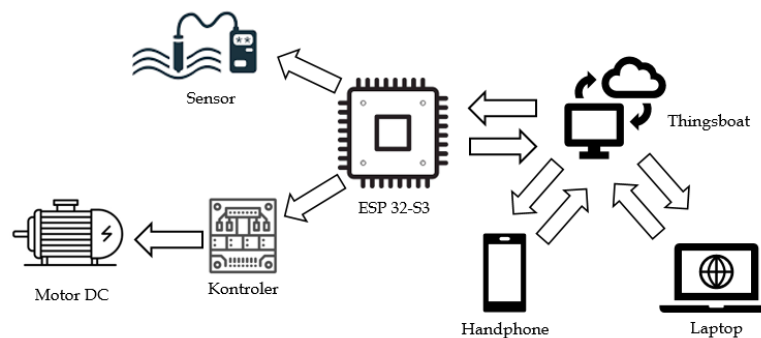


Figure 1. Workflow

Figure 1 illustrates the workflow of the automated laundry wastewater treatment system based on ESP32-S3. The system starts by receiving input from various sensors, including pH, TSS, and temperature sensors. These sensors have sent the collected data to the ESP32-S3 microcontroller, which has processed the data in real-time. Based on pre-defined threshold values, the ESP32-S3 has generated control signals and transmitted them to the motor driver module, which in turn has activated the DC motors responsible for chemical dosing and stirring processes. The system simultaneously sends sensor data to the Things Board platform via the MQTT protocol over an internet connection. This platform offers real-time data visualization in the form of graphs and gauges, accessible through both laptops and mobile phones. Through this workflow, the system enables automatic control based on sensor feedback, while also allowing users to remotely and efficiently monitor the treatment process.

2.3. Microcontroller

A microcontroller is a compact computing unit embedded in a chip (IC) that processes instructions from pre-programmed code. The study utilizes the ESP32-S3 because of its advanced SoC architecture with dual-core Xtensa LX7 processors reaching up to 240 MHz, integrated WiFi and Bluetooth, and low power consumption, making it ideal for continuous IoT applications [26]-[30]. This microcontroller reads sensor inputs (pH, TSS, temperature), processes the data, and sends control signals to DC motors based on threshold logic.

2.4. Internet of Things (IoT)

The Internet of Things (IoT) is a system collects, monitors, and processes data in real-time over the internet. This system enables remote monitoring and control of devices, thereby reducing the potential for human error and enhancing efficiency. The IoT mechanism involves a microcontroller reading sensor data, transmitting it to a server via the internet for processing and analysis, which then serves as the basis for actions such as device activation, report generation, or automatic system control [31]-[33]. In implementing IoT, a

server or platform is needed that functions as a communication medium between devices [34] [35]. One of the widely used platforms is ThingsBoard, which supports the MQTT protocol. The platform offers an Auto Provisioning feature, enabling the automatic and secure integration of devices. Additionally, ThingsBoard offers an interactive dashboard that facilitates detailed data visualization and allows for customization according to user needs [36] [39]. With these features, ThingsBoard is an ideal choice for implementing an IoT system.

2.5. PH-4502C

PH-4502C is a device used to measure the concentration of acidity in water and can be connected to a microcontroller for monitoring or automation control purposes [40] [41]. This sensor contains two electrodes: a working electrode and a reference electrode. These electrodes work together to detect the electrical potential difference that occurs due to the interaction between hydrogen ions in the solution. The system converts this potential difference into a pH value that represents the acidity or basicity of the solution [42]. With this mechanism, pH sensors can provide accurate and precise measurement results, making them very important in various applications that require water quality control or monitoring of environmental conditions.

2.6. SEN0189

The SEN0189 sensor is a device used to measure the turbidity of water by measuring the amount of suspended particles that affect water clarity. This sensor operates by measuring the light intensity to detect particles or solutes in the water [43], [44]. In this sensor, a transmitter sends light rays into the water, and the light is then reflected to the receiver [42]. The system expresses turbidity measurement results in Nephelometric Turbidity Units (NTU), which is the standard for measuring turbidity in water. Therefore, the sensor provides an effective means of monitoring water quality.

2.7. DS18B20

The DS18B20 is a type of digital temperature sensor that communicates using a single data line. This sensor is capable of measuring temperatures ranging from $-55\text{ }^{\circ}\text{C}$ to $+125\text{ }^{\circ}\text{C}$, with an accuracy of $\pm 0.5\text{ }^{\circ}\text{C}$ when operating within the temperature range of $-10\text{ }^{\circ}\text{C}$ to $+85\text{ }^{\circ}\text{C}$ [45] [46]. This sensor utilizes a thermistor element as a temperature gauge, which then converts the signal into digital data that a microcontroller can read to obtain the measured temperature value [47].

2.8. DC motors

Accurate regulation of liquid flow and solution mixing is crucial in sewage treatment to ensure the performance and consistency of results. To support this, a microcontroller-based automation system precisely controls liquid flow and composition parameters. In this system, two DC motors serve as the primary actuators, namely the motor for the stirrer and the dosing pump. The dosing pump functions to add chemical solution precisely based on the threshold value detected by the sensor, thus ensuring mixing accuracy according to the set dose [48]-[50]. Meanwhile, the stirring motor plays a crucial role in maintaining the homogeneity of the solution, especially when the coagulant is added, ensuring thorough mixing of all components, particularly during the addition of the coagulant [51]. The design of the motor enables it to withstand continuous workload in the mixing process. The combined use of DC motors in these two systems enables the effluent treatment to run more efficiently and in accordance with the specified operational standards.

2.9. L298N

The L298N module is a type of DC motor drive module. The module functions to regulate the current supply and control the direction of the DC motor within a circuit. Additionally, the L298N features built-in thermal protection, which helps prevent damage from overheating during intensive use [52]-[55]. These features make the L298N a superior choice for automation applications that require robust and continuous motor control of DC motors.

3. RESULTS AND DISCUSSION

In testing the ESP32-S3-based DC motor control system and the ThingsBoard platform, the data collected includes the state of the sewage, the duration of motor operation in sewage treatment, the use of current and voltage, and RPM when the motor is working, as well as delay in sending data between the LCD and the ThingsBoard dashboard. This study analyzes the results to evaluate the system's response to operational parameter changes and the ThingsBoard platform's real-time data presentation. The purpose of this test is to evaluate the system's performance in the IoT-based control and monitoring process.

3.1. System testing

This study conducts system testing of the entire device to observe changes in liquid waste parameters before and after processing by the ESP32-S3-based DC motor control system

Table 4. Overall System Testing

Initial State of Waste			Motor 1's Duration (s)	Motor 2's Duration (s)	Motor 3's Duration (s)	Motor 4's Duration (s)	Motor 5's Duration (s)	After Processing		
pH	Turbidity (mg/L)	Temperature (°C)						pH	Turbidity (mg/L)	Temperature (°C)
10.23	(1) 341.97	28.25	40	20	200	100	0	8.58	70.51	28.25
	(2) 153.19									
10.33	200.58	28.28	20	20	100	100	0	7.97	61.71	28.28
10.42	82.16	28.13	0	20	0	100	0	8.04	82.16	28.13
9.55	57.55	29.67	0	20	0	100	68	6.94	57.55	28.82
10.57	46.23	27.81	0	20	0	100	0	8.46	46.23	27.81
11.11	63.37	28.06	0	20	0	100	0	7.31	63.37	28.06
9.54	(1) 434.49	28.19	40	20	200	100	0	6.78	99.96	28.19
	(2) 315.78									
10.44	134.89	28.12	20	20	100	100	0	7.36	58.04	28.12
6.85	180.21	28.19	20	0	100	0	0	6.85	82.16	28.19
7.11	214.31	28.06	20	0	100	0	0	7.11	56.4	28.06
8.43	12.64	32.12	0	0	0	0	2383	8.43	12.64	29
11.02	206.82	29.73	20	20	100	100	105	9.75	65.98	29
10.25	179.83	31.44	20	20	100	100	1985	8.43	51.28	29
9.58	172.76	29.37	20	20	100	100	905	7.28	74.93	29
9.88	199.27	30.75	20	20	100	100	1765	7.53	59.05	29
13.79	6.82	30.31	0	20	0	100	1325	8.96	6.82	29
8.43	201.42	29.44	20	0	100	0	159	8.43	-45.75	29
7.24	(1) 286.24	29.88	40	0	200	0	738	7.24	10.64	29
	(2) 206.2									
10.71	167.32	29.38	20	20	100	100	33	8.43	49.73	29
7.89	(1) 135.72	30.62	40	0	200	0	1674	7.89	49.32	29
	(2) 107.86									
8.8	46.74	28.06	0	0	0	0	0	8.08	46.74	28.06

Table 5. Name and Function of Motor

Name of Motor	Function of Motor
Motor 1	Turbidity Dosing Pump
Motor 2	pH Dosing Pump
Motor 3	Turbidity Stirring Motor
Motor 4	pH Stirring Motor
Motor 5	DC Fan

3.1.1 pH motor duration

Figure 1 shows the duration of motor operation during pH adjustment. The system activates two motors when the pH sensor detects a value above 9. The dosing motor (blue) runs for 20 seconds to inject a controlled amount of pH-lowering solution, while the stirring motor (orange) operates for 100 seconds to ensure homogeneous mixing. In contrast, when the pH is within the normal range (6–9), both motors remain inactive, indicated by zero durations.

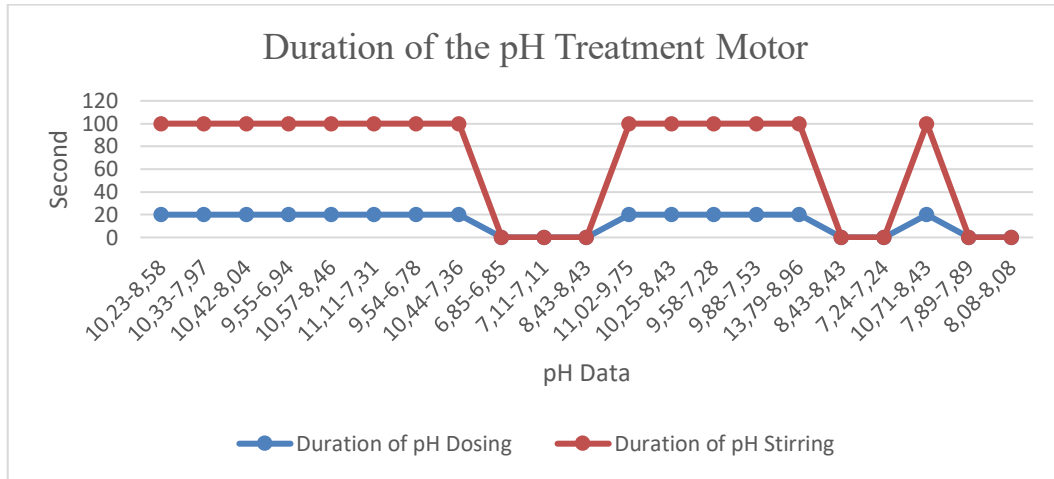


Figure 2. Duration of the pH Treatment Motor

This behavior demonstrates that the system is designed to respond adaptively and only activate the motors when required, enhancing energy and chemical efficiency. From a practical perspective, this finding supports the feasibility of using real-time pH monitoring and motor control to stabilize effluent conditions, particularly in decentralized or small-scale facilities. However, the limitation lies in the fixed dosing duration (20 seconds), which may not be sufficient in cases where the pH deviates drastically.

3.1.2 Turbidity motor duration

Figure 2 illustrates motor activation during turbidity control. When the TSS value exceeds 100 mg/L, the system activates the dosing motor for 20 seconds and the stirring motor for 100 seconds. Notably, at higher turbidity levels (>250 mg/L), the system automatically initiates a second treatment cycle, with the dosing motor running for 40 seconds and the stirring motor for 200 seconds.

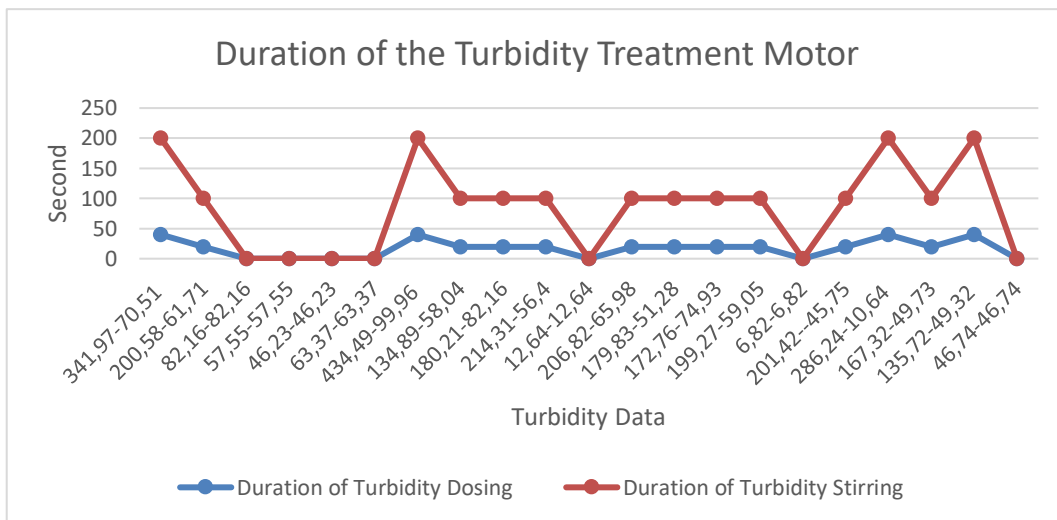


Figure 3. Duration of the Turbidity Treatment Motor

This pattern suggests the presence of a tiered response mechanism, where higher pollutant loads trigger more extensive treatment. In practical terms, such dynamic behavior ensures the treatment remains efficient across a range of pollutant levels. It minimizes unnecessary energy usage under low-load conditions, while still responding adequately to severe contamination. A possible limitation is that the system’s tiered logic currently only supports up to two levels of response. Further refinement could include finer granularity of control or feedback loops that continuously monitor the TSS reduction rate.

3.1.3 Fan duration

Figure 3 illustrates the duration required to cool the effluent to a safe temperature range prior to chemical treatment. For instance, at 29.38°C, the fan requires only 33 seconds to reach the target range. However, when the temperature exceeds 32°C, the cooling process can last up to 2.383 seconds (approximately 40 minutes).

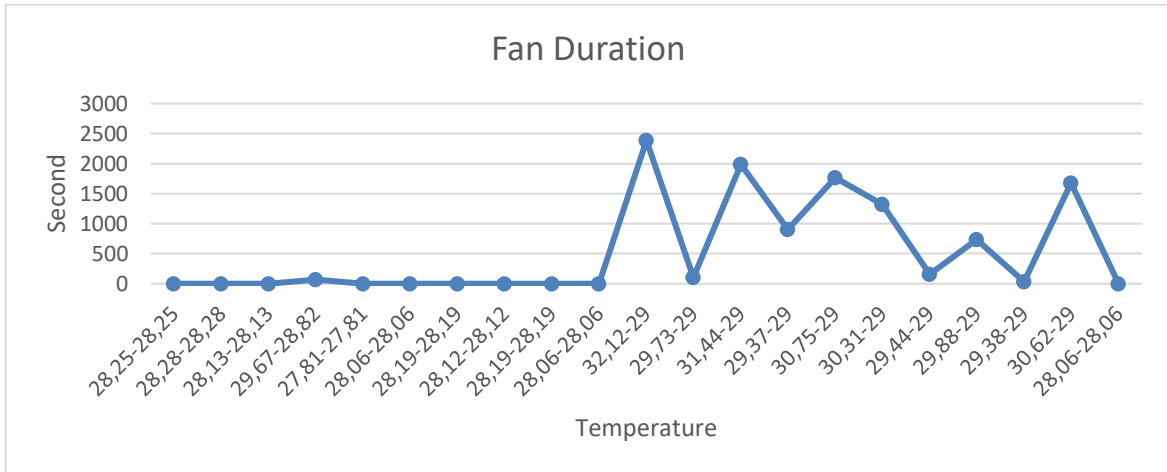


Figure 4. Fan Duration

While this shows that the system is capable of passive cooling, it also reveals a key performance limitation. The fan-based cooling approach, although energy-efficient, becomes significantly time-inefficient at higher initial temperatures. From a practical standpoint, such a prolonged cooling period may be unsuitable for facilities with high wastewater throughput. The study highlights the need for future improvements, including the integration of more active cooling technologies and the implementation of bypass logic when temperature thresholds are slightly exceeded but do not significantly affect chemical reaction rates.

3.2. Motor testing

Motor performance testing aims to determine the relationship between turbidity difference, dosing pump working time, current used, voltage used, and motor speed (RPM). This data is important to evaluate the effectiveness of energy use and motor performance in the ESP32-S3-based wastewater treatment system.

Table 6. pH Dosing Motor Testing

pH	Current Used (A)	Voltage Used (V)	RPM
10.23-8.58	0.1	10.01	3077
10.33-7.97	0.14	10.03	3085
10.42-8.04	0.12	10	3077
9.55-6.94	0.1	10	3072
10.57-8.46	0.1	10	3077
11.11-7.31	0.13	10	3077
9.54-6.78	0.13	10	3085
10.44-7.36	0.13	10	3085
6.85-6.85	0	0	0
7.11-7.11	0	0	0
8.43-8.43	0	0	0
11.02-9.75	0.13	9.9	3088
10.25-8.43	0.12	10	3077
9.58-7.28	0.12	10	3077
9.88-7.53	0.13	9.8	3076
13.79-8.96	0.13	10	3086
8.43-8.43	0	0	0
7.24-7.24	0	0	0
10.71-8.43	0.12	9.9	3076
7.89-7.89	0	0	0
8.08-8.08	0	0	0

Table 7. pH Stirring Motor Testing

pH	Current Used (A)	Voltage Used (V)	RPM
10.23-8.58	0.41	7.3	254.6
10.33-7.97	0.38	7.3	250.1
10.42-8.04	0.42	7.2	253.6
9.55-6.94	0.34	6.6	235.5
10.57-8.46	0.38	7.3	250.8
11.11-7.31	0.42	7.7	277.8
9.54-6.78	0.35	6.6	235.5
10.44-7.36	0.41	7.3	253.2
6.85-6.85	0	0	0
7.11-7.11	0	0	0
8.43-8.43	0	0	0
11.02-9.75	0.44	7.8	280.2
10.25-8.43	0.41	7.3	253.6
9.58-7.28	0.35	6.5	235.4
9.88-7.53	0.35	6.5	232.5
13.79-8.96	0.42	7.8	277.8
8.43-8.43	0	0	0
7.24-7.24	0	0	0
10.71-8.43	0.41	7.3	255
7.89-7.89	0	0	0
8.08-8.08	0	0	0

Table 8. Turbidity Dosing Motor Testing

Turbidity	Current Used (A)	Voltage Used (V)	RPM
341.97-70.51	0.09	10	2952
200.58-61.71	0.13	10	3002
82.16-82.16	0	0	0
57.55-57.55	0	0	0
46.23-46.23	0	0	0
63.37-63.37	0	0	0
434.49-99.96	0.13	10	2997
134.89-58.04	0.13	9.6	2997
180.21-82.16	0.13	10	3002
214.31-56.4	0.12	10	2997
12.64-12.64	0	0	0
206.82-65.98	0.13	9.7	2997
179.83-51.28	0.1	9.7	2976
172.76-74.93	0.13	9.7	2997
199.27-59.05	0.13	9.7	2997
6.82-6.82	0	0	0
201.42-45.75	0.13	9.6	2976
286.24-10.64	0.1	9.7	2997
167.32-49.73	0.1	9.7	2976
135.72-49.32	0.13	9.7	2997
46.74-46.74	0	0	0

Table 9. Turbidity Stirring Motor Testing

Turbidity	Current Used (A)	Voltage Used (V)	RPM
341.97-70.51	0.59	9.6	321.5
200.58-61.71	0.57	9.5	315.8
82.16-82.16	0	0	0
57.55-57.55	0	0	0
46.23-46.23	0	0	0
63.37-63.37	0	0	0
434.49-99.96	0.64	9.6	315.8
134.89-58.04	0.52	8.3	288.1
180.21-82.16	0.55	9.5	305.4
214.31-56.4	0.57	9.6	321.5
12.64-12.64	0	0	0
206.82-65.98	0.58	9.5	315.8
179.83-51.28	0.57	9.5	315.4
172.76-74.93	0.57	9.5	315.4
199.27-59.05	0.59	9.5	315.8
6.82-6.82	0	0	0
201.42-45.75	0.58	9.5	315.8
286.24-10.64	0.58	9.6	315.8
167.32-49.73	0.57	9.5	315.8
135.72-49.32	0.48	8.3	288.1
46.74-46.74	0	0	0

Table 10. Fan Testing

Temperature	Current Used (A)	Voltage Used (V)	RPM
28.25-28.25	0	0	0
28.28-28.28	0	0	0
28.13-28.13	0	0	0
29.67-28.82	0.23	11.8	2618
27.81-27.81	0	0	0
28.06-28.06	0	0	0
28.19-28.19	0	0	0
28.12-28.12	0	0	0
28.19-28.19	0	0	0
28.06-28.06	0	0	0
32.12-29	0.23	11.6	2618
29.73-29	0.23	11.6	2618
31.44-29	0.23	11.6	2618
29.37-29	0.22	11.7	2618
30.75-29	0.23	11.6	2618
30.31-29	0.23	11.6	2618
29.44-29	0.23	11.6	2618
29.88-29	0.23	11.6	2618
29.38-29	0.2	11.8	2618
30.62-29	0.23	11.6	2618
28.06-28.06	0	0	0

3.2.1 pH dosing motor performance

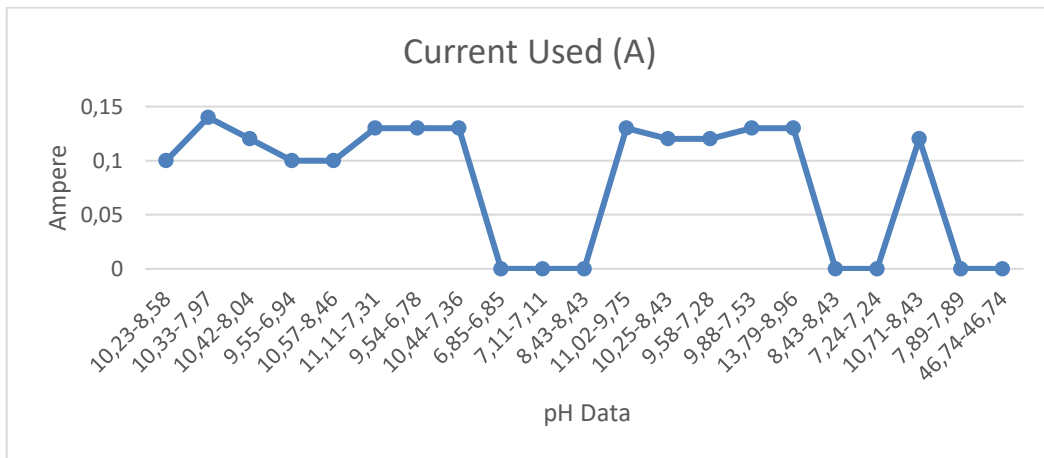


Figure 5. pH Dosing Motor Current

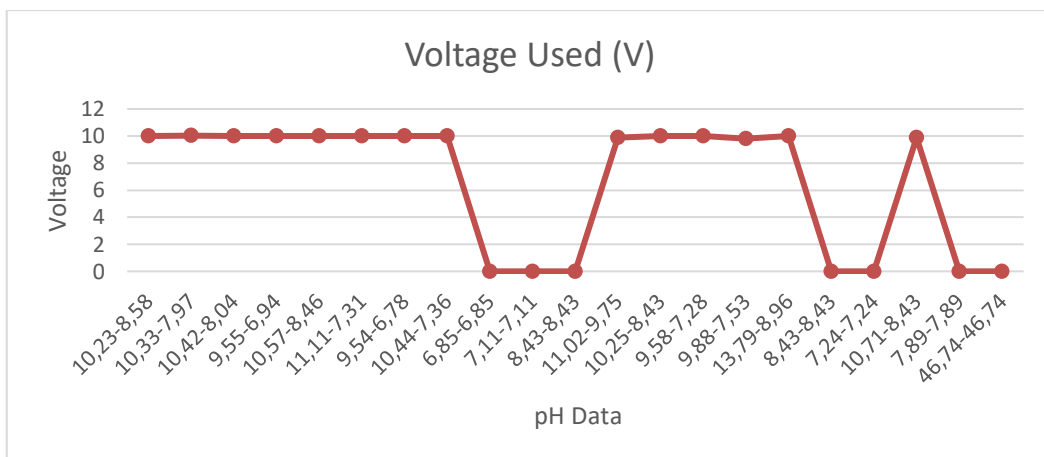


Figure 6. pH Dosing Motor Voltage

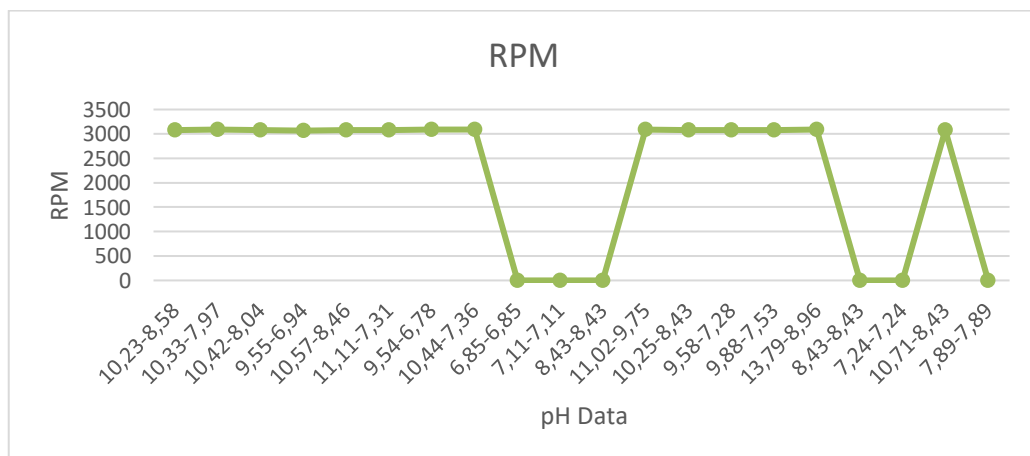


Figure 7. pH Dosing Motor RPM

Figure 5 to Figure 7 illustrate the performance of the pH dosing motor in terms of current, voltage, and rotation speed (RPM), as recorded in Table 6. When the motor is active, it operates within a stable range, characterized by a current of 0.10–0.14 A, a voltage between of 9.8–10.3 V, and a rotational speed of 3076–3085 RPM. The motor is only activated when the pH exceeds the threshold (pH > 9), which aligns with the system’s logic for initiating chemical dosing only when necessary. This data confirms that the system performs adaptively, minimizing unnecessary power usage during periods when effluent pH remains within safe limits. The observed stability in motor parameters during operation reflects good electrical and mechanical reliability.

3.2.2 pH stirring motor performance

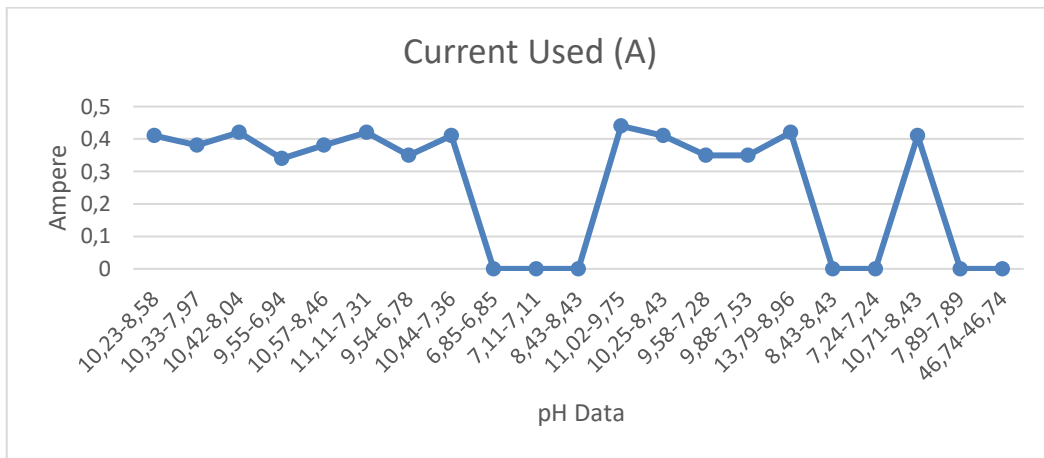


Figure 8. pH Stirring Motor Current

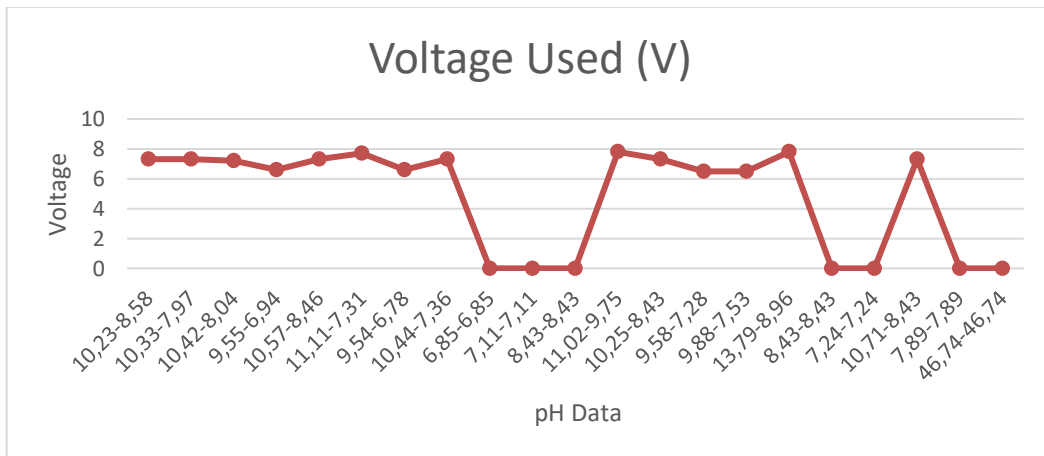


Figure 9. pH Stirring Motor Voltage

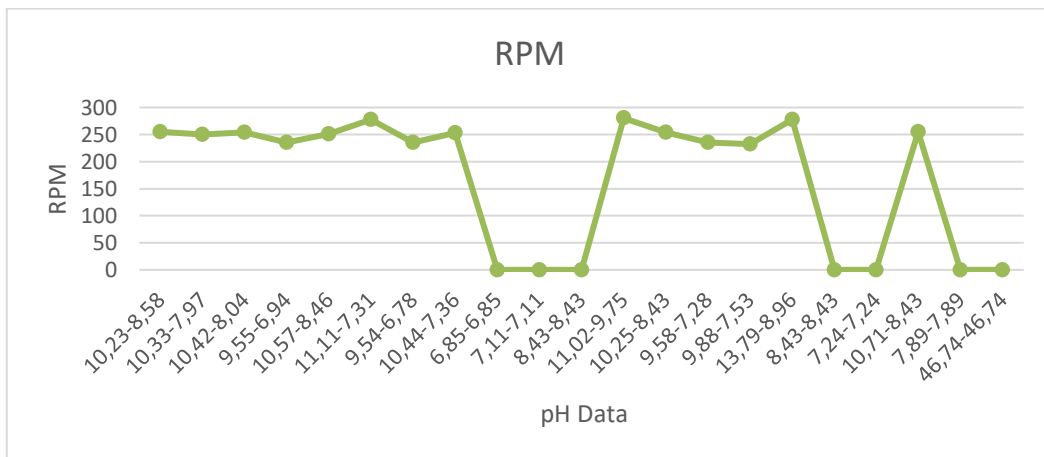


Figure 10. pH Stirring Motor RPM

Figures 8 to Figure 10 present the performance of the pH stirring motor. Based on Table 7, the motor exhibits variable performance depending on the effluent’s pH level. At high pH (13.79), the motor draws 0.42 A at 7.8 V and operates at 277.8 RPM. At a moderate pH (9.54), it consumes 0.35 A at 6.6 V and rotates at 235.5 RPM. The data indicate that motor speed and power usage are controlled in proportion to one another, allowing for efficient stirring tailored to specific treatment needs. Nonetheless, the RPM range was still

relatively low for high viscosity fluids, which might limit mixing effectiveness under certain conditions highlighting a potential area for mechanical optimization in future iterations.

3.2.3 Turbidity dosing motor performance

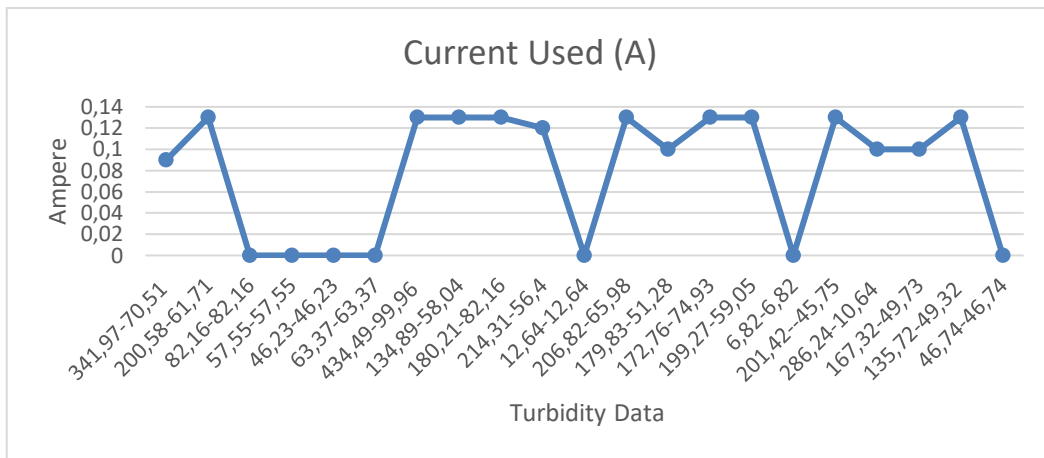


Figure 11. Turbidity Dosing Motor Current

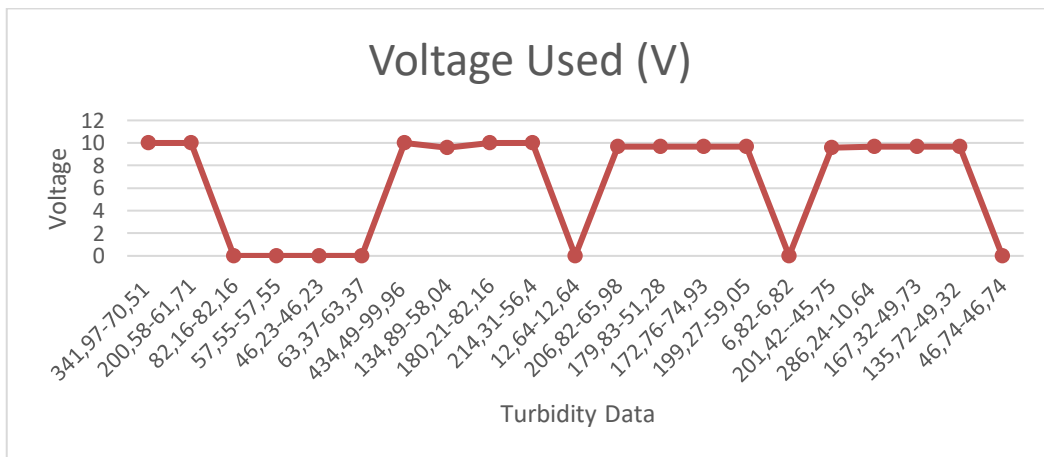


Figure 12. Turbidity Dosing Motor Voltage

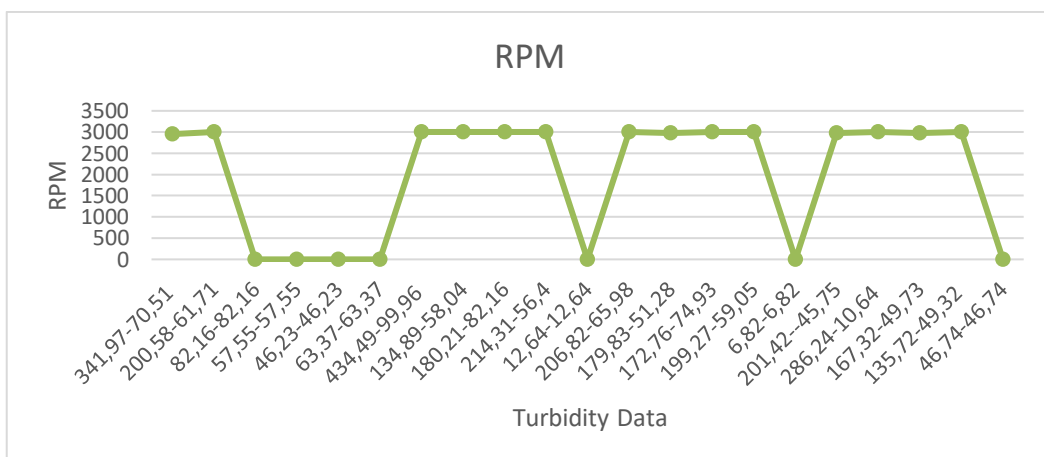


Figure 13. Turbidity Dosing Motor Voltage

Figures 11 to Figure 13 display the current, voltage, and RPM performance of the turbidity dosing motor, as summarized in Table 8. During active operation, the motor runs at 0.09–0.13 A, 9.6–10 V, and 2952–3002 RPM. The motor is only triggered when turbidity exceeds 100 mg/L; it remains completely inactive (0 values) when the turbidity is below the threshold. The data clearly demonstrate the on-demand actuation behavior of the system, which reduces power consumption and mechanical wear during idle states. Compared to

conventional systems with scheduled dosing cycles, this real-time trigger logic offers higher precision and cost efficiency. A noted constraint is the absence of feedback verification of dosing quantity; future versions could include a flow sensor for closed-loop validation.

3.2.4 Turbidity Stirring motor performance

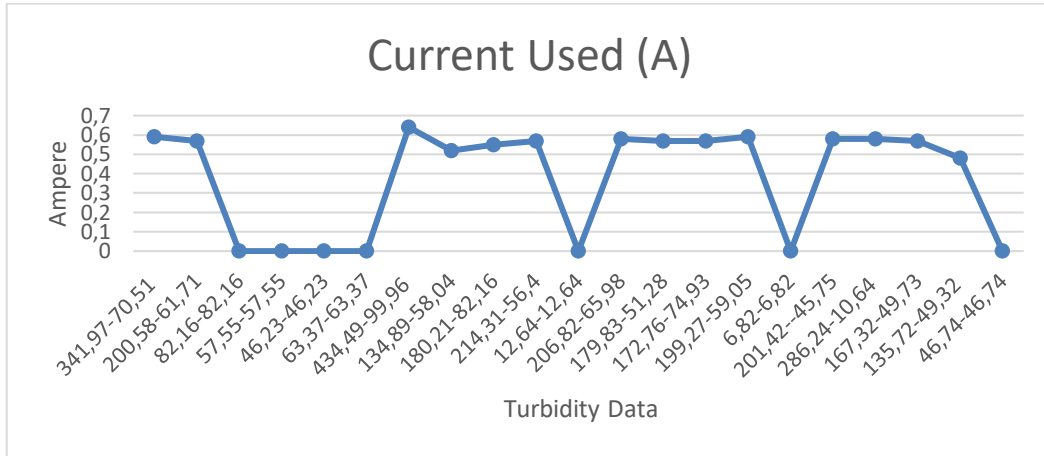


Figure 14. Turbidity Stirring Motor Current

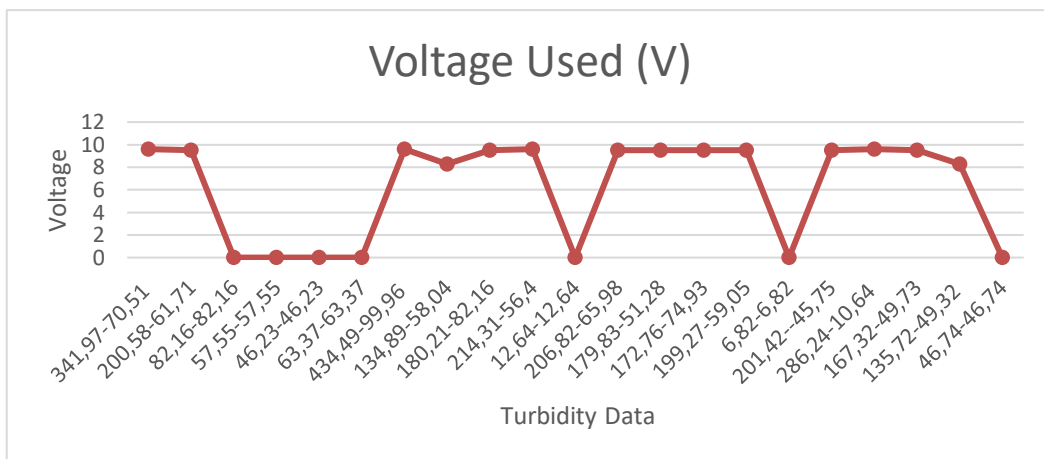


Figure 15. Turbidity Stirring Motor Voltage

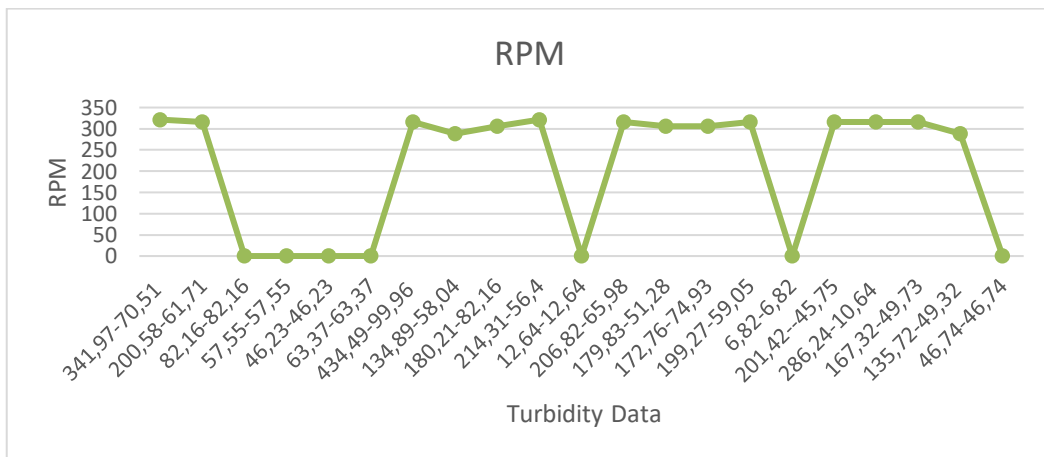


Figure 16. Turbidity Stirring Motor RPM

Figure 14 to Figure 16 illustrate the behavior of the turbidity stirring motor, which adjusts its power and speed in response to the TSS concentration. As shown in Table 9, when TSS is high (434.49 mg/L), the motor

operates at 0.64 A, 9.6 V, and 315.8 RPM. When TSS drops to 135.72 mg/L, the motor decreases to 0.48 A, 8.3 V, and 288.1 RPM. This adaptive mechanism ensures that energy expenditure is appropriate relative to the treatment complexity. However, the RPM drop at lower loads still maintains stirring adequacy, indicating good calibration. In future upgrades, coupling motor speed with fluid viscosity sensors could further improve treatment uniformity.

3.2.5 Fan performance

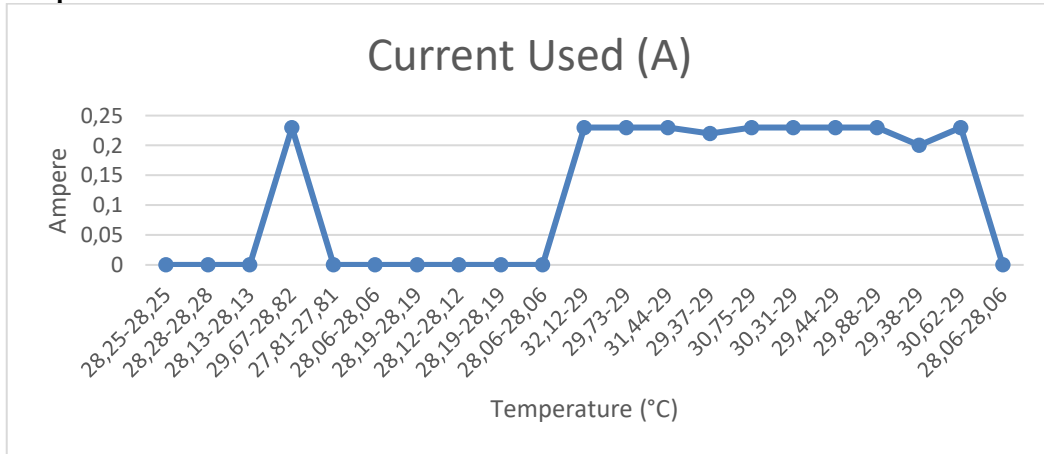


Figure 17. Fan Current

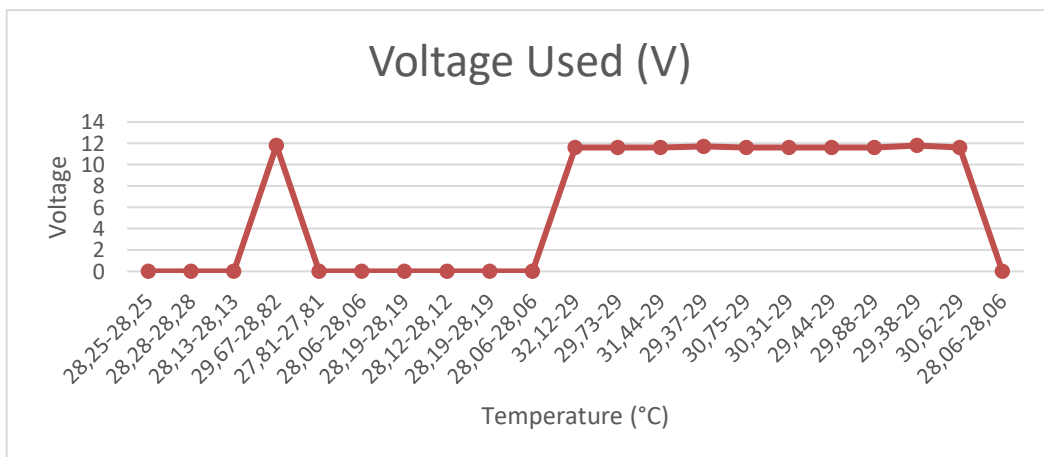


Figure 18. Fan Voltage

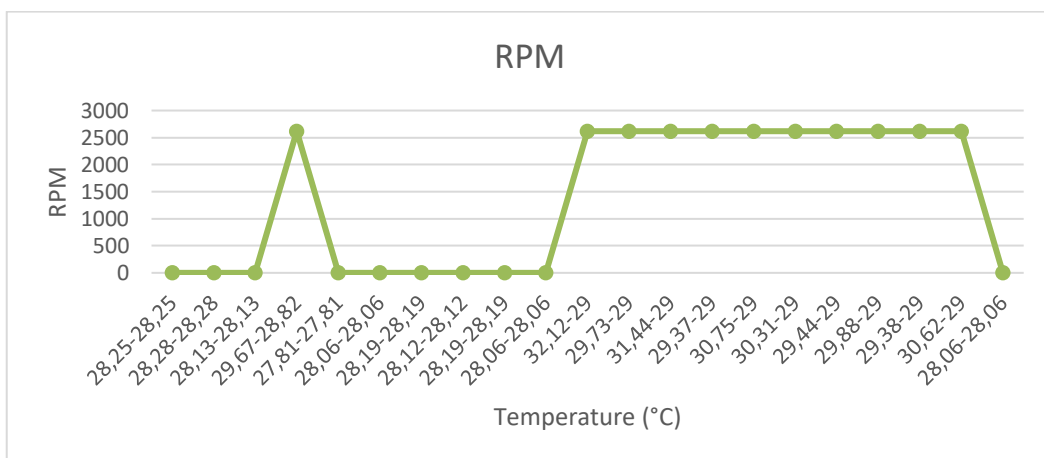


Figure 19. Fan RPM

Figure 17 to Figure 19 evaluate the fan performance responsible for controlling effluent temperature. According to Table 10, when the temperature exceeds 29°C (e.g., 29.67°C), the fan activates at 0.23 A and 11.8 V, and maintains a stable speed of 2618 RPM. Across various temperature readings, the current and voltage ranged from 0.20 to 0.23 A and 11.6 to 11.8 V, respectively, with minimal fluctuation in RPM. This

stability confirms the reliability and low-power nature of the cooling fan system. Nonetheless, as previously discussed in Section 3.1.3, the fan's cooling duration is lengthy, especially at higher initial temperatures (up to 40 minutes). While suitable for small-scale operations, this limitation suggests the need for enhanced thermal management, potentially through integration with heat exchangers or predictive cooling activation.

3.3. Data delivery testing

Data transmission testing aims to evaluate the speed of sending sensor data from the ESP32-S3 to the ThingsBoard platform. Ensuring proper performance is important for the system to operate in real time, especially when monitoring wastewater quality.

Table 11. pH Data Delivery Testing

Testing	Data	Displayed on LCD Display (minutes)	Displayed on ThingsBoard Display (minutes)	delay
1	10.23	12.22	12.28	6 Second
2	8.58	17.24	17.32	8 Second
3	10.33	07.22	07.22	0 Second
4	7.97	12.24	12.29	5 Second
5	10.42	02.20	02.20	0 Second
6	8.04	07.22	07.22	0 Second
7	9.55	03.28	03.28	0 Second
8	6.94	08.30	08.30	0 Second
9	10.57	02.20	02.33	13 Second
10	8.46	07.22	07.22	0 Second
11	11.11	02.20	02.28	8 Second
12	7.31	07.22	07.22	0 Second
13	9.54	12.22	12.22	0 Second
14	6.78	17.24	17.36	12 Second
15	10.44	07.22	07.22	0 Second
16	7.36	12.24	12.34	10 Second
17	6.85	07.22	07.22	0 Second
18	7.11	07.22	07.22	0 Second
19	8.43	42.13	42.24	11 Second
20	11.02	09.09	09.15	6 Second
21	9.75	14.11	14.26	15 Second
22	10.25	40.27	40.27	0 Second
23	8.43	45.28	45.35	7 Second
24	9.58	22.27	22.27	0 Second
25	7.28	27.29	27.38	9 Second
26	9.88	36.47	36.47	0 Second
27	7.5	41.49	41.49	0 Second
28	13.79	24.25	24.30	5 Second
29	8.96	26.25	26.46	21 Second
30	8.43	10.11	10.19	8 Second
31	7.24	24.42	24.42	0 Second
32	10.71	07.54	08.01	7 Second
33	8.43	09.54	10.00	6 Second
34	7,89	39.50	39.50	0 Second
35	8.08	02.20	02.20	0 Second

Table 12. Turbidity Data Delivery Testing

Testing	Data	Displayed on LCD Display (minutes)	Displayed on Thingsboard Display (minutes)	Delay
1	341.97	00.03	00.03	0 Second
2	153.19	05.05	05.15	10 Second
3	70.51	10.05	10.12	7 Second
4	200.58	00.03	00.11	8 Second
5	61.71	05.05	05.05	0 Second
6	82.16	00.03	00.03	0 Second
7	57.55	01.11	01.11	0 Second
8	46.23	00.03	00.11	8 Second
9	63.37	00.03	00.15	12 Second
10	434.49	00.03	00.03	0 Second
11	315.78	05.05	05.18	13 Second
12	99.96	10.05	10.15	10 Second
13	134.89	00.03	00.03	0 Second
14	58.04	05.05	05.17	12 Second
15	180.21	00.03	00.03	0 Second
16	82.16	05.05	05.05	0 Second
17	214.31	00.03	00.03	0 Second
18	56.4	05.05	05.19	14 Second
19	12.64	39.56	39.56	0 Second
20	206.82	01.50	01.55	5 Second
21	65.98	06.52	06.52	0 Second
22	179.83	33.08	33.27	19 Second
23	51.28	38.10	38.20	10 Second
24	172.76	15.08	15.18	10 Second
25	74.93	20.10	20.28	18 Second
26	199.27	29.28	29.28	0 Second
27	59.05	34.30	34.30	0 Second
28	6.82	22.08	22.08	0 Second
29	201.42	02.39	02.39	0 Second
30	-45.75	07.44	07.44	0 Second
31	286.24	12.21	12.21	0 Second
32	206.2	17.23	17.23	0 Second
33	10.64	22.25	22.25	0 Second
34	167.32	00.35	00.35	0 Second
35	49.73	05.37	05.37	0 Second
36	135.72	27.29	27.29	0 Second
37	107.86	32.31	32.31	0 Second
38	49.32	37.33	37.33	0 Second
39	46.74	00.03	00.03	0 Second

3.3.1 pH data delivery

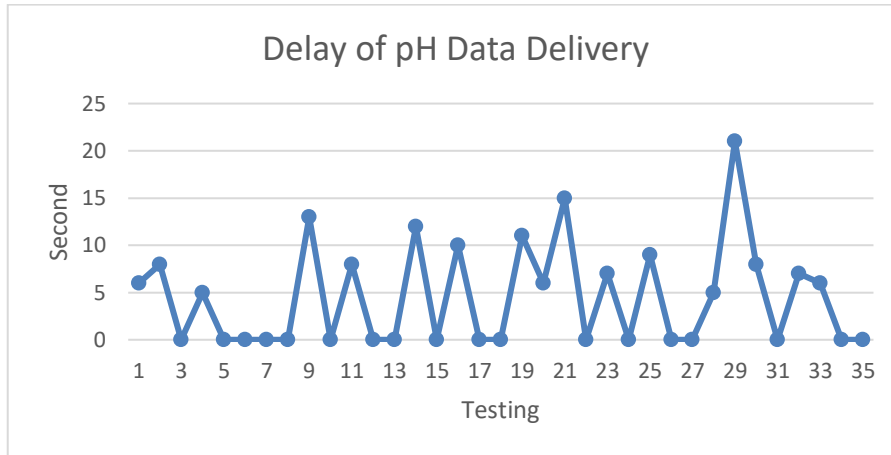


Figure 20. Delay of pH Data Delivery

Figure 20 and Table 11 illustrate the transmission delay of pH data from the ESP32-S3 microcontroller to the ThingsBoard IoT platform. Out of 34 trials, 44% exhibited a delay of 0 seconds, suggesting real-time data transmission under stable internet conditions. However, variations were observed in several instances, most notably a 21-second delay during the 29th test. These delays are not attributed to system design or hardware limitations but are instead caused by fluctuations in internet connectivity, particularly during testing conducted under poor weather conditions (e.g., rain). Despite this, the average delay remained within acceptable thresholds for monitoring applications, with the system proving robust under typical field conditions. It is essential to note that data latency is crucial for control decisions, particularly when scaling the platform for more time-sensitive applications. To enhance system reliability in real-world deployments, future upgrades may consider incorporating local buffering or edge computing to reduce dependency on continuous network stability.

3.3.2 Turbidity data delivery

Figure 21 and Table 12 present the transmission delay of turbidity data from the TSS sensor. Of the 38 tests conducted, approximately 60% resulted in a 0-second delay, confirming the system’s ability to deliver real-time data-under optimal conditions. However, several tests, such as the 22nd trial, showed a notable delay of up to 19 seconds. Interestingly, the study observed longer delays more frequently during the second cycle of wastewater treatment, which suggests that the microcontroller’s task queue or internal processing load may play a role alongside external network latency. Although the system remains functionally reliable for monitoring purposes, minimizing delay remains essential for control accuracy and responsiveness. As such, implementing task prioritization in the firmware or migrating to multi-core task distribution can help ensure smoother performance in multi-sensor environments.

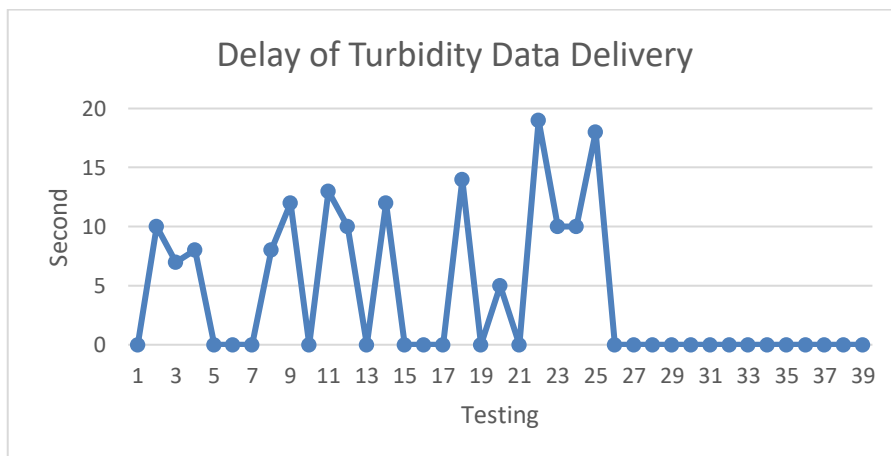


Figure 21. Delay of Turbidity Data Delivery

3.4. Classification of system effectiveness

This study conducts effectiveness testing to evaluate the performance of the developed system in treating laundry liquid waste, based on the final pH values, Total Suspended Solids (TSS) levels, and effluent temperatures. This study uses these three parameters to assess the technical feasibility of the system's output. This study classifies the data according to predefined threshold values derived from environmental standards and existing research, as outlined in Section 2.1, and refined in Table 13 below.

Table 13. System Effectiveness Classification Criteria

Effectiveness Level	pH Criteria	TSS Criteria (mg/L)	Temperature Criterion	Additional Notes
Very Viable	pH between 6.5–7.5	TSS ≤ 50 (Clear/Very Clear)	Temperature < 29°C	All three parameters meet optimal thresholds
Viable	pH 6–6.4 or 7.6–9	TSS 51–75 (Slightly Cloudy)	Temperature = 29°C	Within tolerance range, but not optimal
Less Viable	pH < 6 or > 9	TSS > 75 (Cloudy)	Temperature > 29°C	One or more parameters exceed threshold

Based on the 21 test trials, the researchers classified each result into one of the effectiveness levels above. The classification is shown in the Table 14 below (condensed here for brevity).

Table 14. Classification of System Effectiveness

Testing	pH	Turbidity (mg/L)	Temperature (°C)	Description	Effectiveness Category
1	8.58	70.51	28.25	-	Viable
2	7.97	61.71	28.28	-	Viable
3	8.04	82.16	28.13	-	Less Viable
4	6.94	57.55	28.82	-	Viable
5	8.46	46.23	27.81	-	Viable
6	7.31	63.37	28.06	-	Viable
7	6.78	99.96	28.19	-	Less Viable
8	7.36	58.04	28.12	-	Viable
9	6.85	82.16	28.19	-	Less Viable
10	7.11	56.4	28.06	-	Viable
11	8.43	12.64	29	-	Viable
12	9.75	65.98	29	pH Value Exceeds Threshold	Less Viable
13	8.43	51.28	29	-	Viable
14	7.28	74.93	29	-	Viable
15	7.53	59.05	29	-	Viable
16	8.96	6.82	29	-	Viable
17	8.43	-45.75	29	TSS Invalid	Invalid
18	7.24	10.64	29	-	Very Viable
19	8.43	49.73	29	-	Viable
20	7.89	49.32	29	-	Viable
21	8.08	46.74	28.06	-	Viable

Tools in waste processing refer to the final parameters of the waste, as determined by the data obtained including following data:

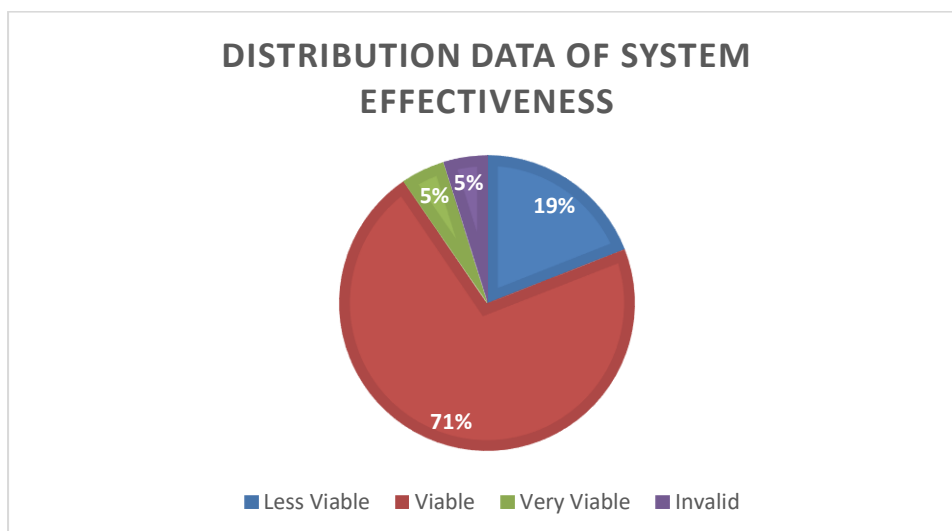


Figure 22. Distribution Data of System Effectiveness

The high proportion of “Viable” outcomes confirms that the system is technically feasible and well-suited for small-scale wastewater treatment applications. However, the low occurrence of “Very Viable” results suggests a need for more precise chemical dosing, improved motor speed control, and more effective thermal regulation. Additionally, the presence of invalid data (e.g., negative TSS values) underscores the importance of robust sensor calibration and input validation mechanisms. This study addresses these issues by implementing error-checking routines and introducing sensor redundancy to enhance data reliability and accuracy. Future improvements should focus on the development of dynamic control logic that adjusts dosing duration based on the severity of pH or turbidity deviations, the integration of real-time feedback loops for adaptive motor actuation, and the adoption of advanced temperature control methods to achieve faster and more stable effluent cooling.

4. CONCLUSION AND LIMITATION

Based on the results of this research, a laundry wastewater treatment system based on the ESP32-S3 microcontroller, DC motors, and the ThingsBoard IoT platform was successfully designed, implemented, and tested. The system integrates real-time monitoring and adaptive motor control, enabling automatic adjustment of chemical dosing and mixing based on sensor feedback for pH, turbidity (TSS), and temperature. Data from the sensors is transmitted wirelessly to the ThingsBoard platform, which displays the readings in real-time and allows for remote observation of system performance. The DC motors performed reliably during the dosing and stirring processes, with measurable and consistent current, voltage, and RPM values. The ESP32-S3 effectively handled adaptive control logic based on sensor inputs, and the ThingsBoard platform demonstrated robust functionality, with average delays of 4 seconds for turbidity data and 5 seconds for pH data transmission.

The final treatment results of pH and TSS serve to evaluate the system’s effectiveness, using a classification framework grounded in environmental standards and scientific references. Specifically, the researchers classified a result as ‘Very Feasible’ if the pH was in the range of 6.5–7.5, TSS was ≤ 50 mg/L, and temperature $< 29^{\circ}\text{C}$. Results were “Feasible” if pH and TSS were within tolerable but suboptimal thresholds, and “Less Feasible” if one or more parameters exceeded regulatory limits. Out of 21 trials, 71% fall into the Feasible category, 5% into Very Feasible, and 19% into Less Feasible. This analysis indicates that the system is technically feasible for field implementation. However, further calibration, particularly of the TSS and pH sensors, is recommended to increase consistency toward the “Very Feasible” category.

This research presents a low-cost, portable, IoT-enabled wastewater treatment system designed for small-scale laundry operations, providing an alternative to conventional treatment methods that often necessitate extensive infrastructure. Unlike previous systems that relied on SMS gateways or static control logic, this system employs sensor-driven automation with dynamic motor control, improving both energy efficiency and treatment precision. To support scalability and broader environmental impact, future developments may focus on integrating predictive control models using machine learning, supporting multi-site monitoring, or improving sensor redundancy and error correction for even higher reliability. Overall, this research provides a concrete foundation for the advancement of innovative real-time, and sustainable wastewater treatment technologies in decentralized settings.

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