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Article

Water Monitoring and Control System in Krofta System with *Fuzzy* Logic Method

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Abstract: Krofta is a water purification technology widely used in industries, particularly in paper and tissue manufacturing. In this study, a *Fuzzy* logic-based control method is applied to the input and output parameters of the system. The developed system utilizes a Sugeno *Fuzzy* system with three main inputs: TSS (Total Suspended Solids), pH, and temperature, and an output parameter in the form of PWM (Pulse Width Modulation) to control the booster pump for injecting chemicals to maintain water quality. The water purification process involves the injection of a chemical agent, specifically a fennopol solution, which is pumped by a booster pump. The booster pump is controlled by an AC Dimmer module driver based on the PWM output generated by the *Fuzzy* method. During this process, data from each parameter is recorded in real-time using a MySQL database and displayed via a *web interface*, with both components interconnected. Based on the research findings, the accuracy results for the sensors are as follows: the temperature sensor has an average *error* of 2.736%, the pH sensor has an average *error* of 1.742%, and the TSS sensor has an average *error* of 4.10%. For the PWM parameter, the system achieves highly accurate PWM values, effectively optimizing the tested water parameters. In conclusion, the Sugeno *Fuzzy* method demonstrates an average accuracy of 97.1% in monitoring and controlling the system to support decision-making processes.

Keywords: Krofta System, Total Suspended Solid (TSS), Water pH, Water Temperature, *Fuzzy* Logic

1. Introduction

Tissue has become a primary necessity in daily life due to its practicality compared to handkerchiefs, which require washing after use [1]. Made from natural fibers or recycled paper, tissue serves various purposes, such as cleaning hands, faces, and sanitation needs. Its high demand has driven industries to produce diverse tissue types tailored for specific uses. An essential component in tissue production is water, utilized at various stages, including pulp processing, sheet formation, and cleaning production components like felt and wire. Felt and wire are critical elements in tissue-making machines. Felt absorbs water from wet tissue sheets, while wire serves as a platform for forming wet pulp into sheets [2]. Maintaining their cleanliness is crucial to ensure optimal production, which is achieved using high-pressure water sprayed through specialized nozzles. This water often originates from recycled production water, such as white water, processed into clarified water using the Krofta system. The Krofta system, or Dissolved Air Flotation (DAF), is a wastewater treatment technology that separates solid particles from water, enabling its reuse in production processes.

Water plays a vital role in industrial processes, particularly in maintaining quality standards and supporting recycling systems. Monitoring parameters like pH, Total Suspended Solids (TSS), and temperature is essential to ensure water quality.

Recent studies have explored innovative methods to enhance water quality management, integrating Internet of Things (IoT) and *Fuzzy* Logic. [3] developed a system to control pH and temperature for ornamental fish farming using *fuzzy* logic. Their system utilized sensors to detect pH and temperature, processed by a *Fuzzy* Sugeno Method with membership functions for temperature (cold, normal, hot) and pH (highly acidic to highly alkaline). Outputs were managed via actuators like motor pumps, with results displayed on an LCD and web-based monitoring.

Similarly, [4] designed a water quality monitoring system using IoT to control parameters like pH, Total Dissolved Solids (TDS), and TSS. They employed *fuzzy* logic to analyze data and manage water quality effectively. These studies highlight the effectiveness of integrating *fuzzy* logic and IoT for monitoring and controlling water quality in industrial applications. Fuzzy logic is the chosen method because the data is constantly changing or uncertain, as the three parameters fluctuate over time and with water quality. It also offers ease of implementation and operation and can process multiple variables. Given the importance of water recycling in tissue manufacturing, accurate monitoring and control of parameters such as TSS, pH, and temperature in the Krofta system are crucial. This study aims to develop a *fuzzy* logic-based control system to optimize water recycling processes, enhance efficiency, and minimize liquid waste in the tissue manufacturing industry.

2. Materials and Methods

The study described focuses on developing a system for control and monitoring KROFTA system with Lugic *Fuzzy*. The method used is using sugeno *fuzzy* logic. This method will be a system that will get input from three sensors and the system output will regulate the water flow speed of the booster pump and the sensor readings will be displayed on the LCD screen. The results of sensor readings and booster pump settings will be recorded because it uses a realtime database, namely MySQL and the user interface will use a web url., as illustrated in Figure 1, outlines the key components and processes involved in the application's functionality.

The sensors used are to monitor the parameters of temperature, pH, and TSS. The sensor used is waterproof and in accordance with the scale of small projects that can support ESP32 microcontrollers. The sensors used on average already have drivers to accommodate sending analog to digital converting data, the sensors used are DS18B20 temperature sensors, DFRobot Turbidity Sensor V1 sensors, and PH-4520C water pH sensors. This ensures that the input data is of sufficient quality for accurate detection. Using Sugeno *fuzzy* because the system has adventange of how many input and output data. this method also has advantages for the control and supervision process [5]. the advantages include: using linear or constant mathematical functions, easy implementation because the output is constant, and stable performance because it does not require a complex defuzzification process. Finally, the system undergoes testing to evaluate its performance and accuracy in monitorig and controlling Krofta System under various conditions.

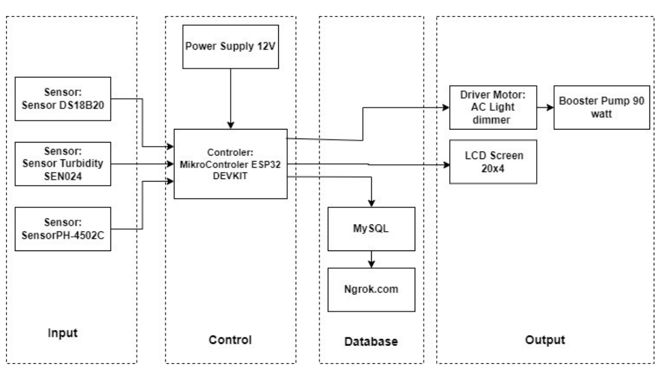

Figure 1. System Framework

In this research process, it begins by observing problems related to water parameters in the krofta system. Afterthat, review the relevant and appropriate literature because it will be used as a reference for the research. This literature review includes an analysis of previous studies on control and monitoring proccess the water parameter that have been developed and tested by other researchers. After reviewing the literature used as a reference, it will be continued by analyzing the needs. This needs analysis includes methods that use the *fuzzy* sugeno method, the form of a device that can detect for monitoring and controlling, and after determining the design, namely determining the program to be created. The factors that are taken into account are the water parameters used, namely temperature, pH, and saturation level of the crofta water as well as the controlling factors for pumping the flocculant solution in the crofta system. The next step in making a mechanical design is to make a control panel that contains the sensor module and ESP 32 and determine the water pump path that will be used. in the process also calibrate the accuracy of each sensor used with the linear regression method so that the presentation of the sensor reading error is small so that the sensor can be said to be accurate and precise. also ensure the testing of the *fuzzy* method used using the *fuzzy* toolbox in the MATLAB application which is useful as a validation tool for the program whether it run properly. testing the output of esp 32, namely the regulator driver, namely AC Dimmer. During testing the data taken will be stored in real time using MySQL data and the data is displayed on the web interface with the HTTP Get Request method. This ensures that the data is recorded so that it can be monitored when the parameters change. After the field tests, the collected data is analyzed to assess the efficiency, reliability, and potential improvements for the system. Based on this analysis, the researchers draw conclusions regarding the viability of the design and its implication for monitoring and controling the water of the Krofta System. Based on this analysis, the researchers draw conclusions about the feasibility of the design and its implications for renewable energy deployment in coastal areas and offer recommendations for future research. These conclusions may include suggestions for refining the turbine design, increasing system durability, and scaling up the technology for larger applications. Figure 2 illustrates a detailed flowchart of the entire research process.

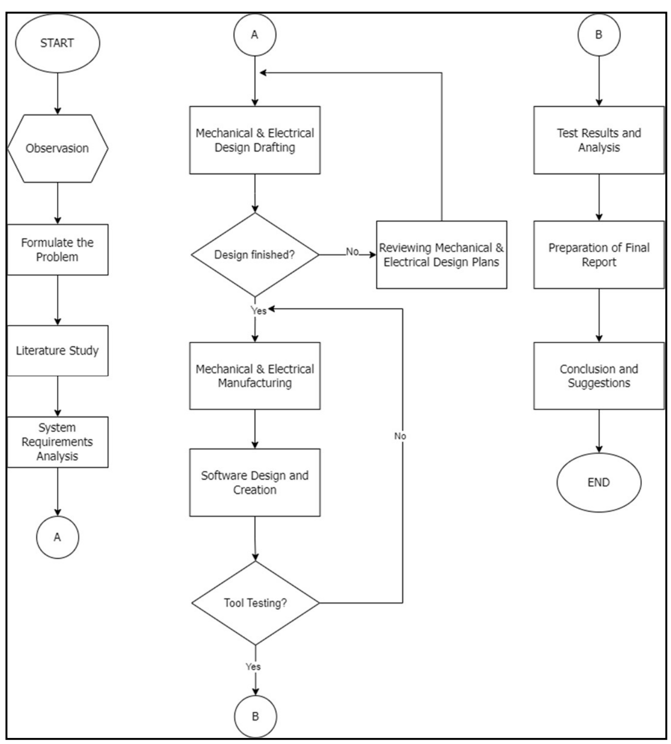

Figure 2. Flowchart Research

3. Results and Discussion

3.1. Fuzzy Methods

Fuzzy is a logic set theory that was created as a solution to the concept of values that lie between true and false [6]. In the controller process using the *Fuzzy* Logic Method, where this intelligent system is a program that can model the human thinking system (numerical variables) which is applied according to machine language (linguistic variables) in order to control the output used. In measuring 3 parameters and 1 actuator using the Sugeno *Fuzzy* logic method, the following are 4 stages of design using the Sugeno *fuzzy* logic method [7]:

- *Fuzzy* Variable & Linguistic Valuedetermine 4 variables, in each variable the linguistic value is determined, namely:
  a. The Temperature variable is divided into 3 inputs, namely Low, Normal, and High.
  b. The pH variable is divided into 3 inputs, namely Acid, Neutral, and Base.
  c. TSS variable is divided into 3 inputs, namely Small, Medium, High.
  d. The PWM variable is divided into 3 outputs, namely Slow, Normal, High.
- *Fuzzy*fication In this process, the input data variables and output variables will be converted into *fuzzy* sets. This determination is taken from the reference value of Stock preparation in the company. In determining each linguistic value, the category of each parameter to be used can be seen in the table 1.

Table 1. Parameters form The Water

Num	Parameter	Unit	Criteria	
1	Water Temperature	°C	<30	Low
			30 - 39	Normal
			>39	High
2	Water pH		<6,3	Acidic
			6,3 - 8,2	Neutral
			>8,2	Alkaline
3	TSS (Total Susupended Solids)	Mg/L	<30	Small
			30 – 65	Optimum
			>65	Large
4	PWM	*% duty cycle*	30	Slow
			60	Medium
			80	Fast

- Rule Base (*Fuzzy* Inference) The next process is to determine *fuzzy* rules. Rules are made to present the relationship between input variables and output variables. The operator used to present the relationship between 3 input variables is the AND operator, and the mapping between output variables is IF-THEN. There are 3 variables and each variable has only 3 *fuzzy* sets, so the rules made as many as 27 rules, as shown in Table 2.

Table 2. Rule Base for *Fuzzy* Logic

Num	Variable			
	Input			Output
	Temperature	pH	TSS	PWM
1	Low	Acidic	Small	Slow
2	Low	Acidic	Optimum	Slow
3	Low	Acidic	Large	Slow
4	Low	Neutral	Small	Slow
5	Low	Neutral	Optimum	Medium
6	Low	Neutral	Large	Fast
7	Low	Alkaline	Small	Medium
8	Low	Alkaline	Optimum	Medium
9	Low	Alkaline	Slow	Slow
10	Normal	Acidic	Small	Medium
11	Normal	Acidic	Optimum	Slow
12	Normal	Acidic	Large	Medium
13	Normal	Neutral	Small	Fast
14	Normal	Neutral	Optimum	Slow
15	Normal	Neutral	Large	Fast
16	Normal	Alkaline	Small	Medium
17	Normal	Alkaline	Optimum	Medium
18	Normal	Alkaline	Large	Pelan
19	High	Acidic	Small	Medium
20	High	Acidic	Optimum	Medium
21	High	Acidic	Large	Slow
22	High	Neutral	Small	Medium
23	High	Neutral	Optimum	Medium
24	High	Neutral	Large	Fast
25	High	Alkaline	Small	Medium
26	High	Alkaline	Optimum	Slow
27	High	Alkaline	Large	Slow

- Defuzzification is a *fuzzy* set of *fuzzy* rule composition results. Also, Defuzzification is the process of converting linguistic output into numerical data [8]. Meanwhile, the output result issued is a numerical number in the domain of the *fuzzy* set itself. using Sugeno *fuzzy* logic, the defuzzification used is the average method (Weight Average).
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$$z = \frac{\sum_{i=1}^{n} W_i Z_i}{\sum_{i=1}^{n} W_i} \tag{1}$$

Explanation:

- Z is the crisp value (firm value) of the defuzzification result.
- W_i is the membership degree or weight of the i-th rule. This weight is usually derived from *fuzzy* inference and indicates how much the rule is satisfied.
- Z_i is the output of the i-th rule. This output can be a constant value or a linear function like $Z_i = a_i X + b_i y + c_i$
- n is the number of *fuzzy* rules.

3.2. Mechanical Design

Mechanical design for the placement of temperature, pH and turbidity (TSS) sensors will be installed through a sample tank that is already available and sourced from the Krofta tank. The actuator used, the booster pump, will pump the chemical agent to the krofta system in the whitewater tank. In addition, the mechanical design for the controller in the work of this tool uses an electric panel box with a size of 12 cm long, 17 wide, and 20 cm high where the box will contain components according to Figure 3 and Figure 4:

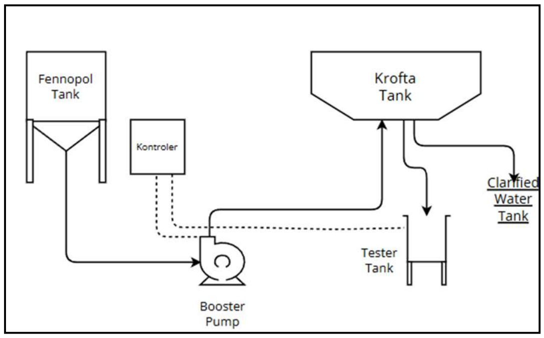


Figure 3. Sample Tank Krofta System

Figure 4. Sample Tank Krofta System

3.3. Software Design

The software design is escorted by programming the ESP32 microntroleer to be able to run the system where to read the sensor value and control the actuator as the output of the system. the program must also be able to transmit and store data in realtime. for the use of data storage systems, the use of MySQL as a data cloud system that can store the results of reading the parameters of temperature, pH, and water turbidity level (TSS). MySQL is a database system system that is widely used for web application development [9]. Using HeidiSQL application to design and manage MySQL database. HeidiSQL was chosen because of its easy interface that supports the process of creating tables, relationships, and organizing data efficiently [10]. Data from the system is sent to the server via the GET method using PHP files specifically designed to accept parameters from client devices. With this approach, integration between the hardware and the database becomes easier.

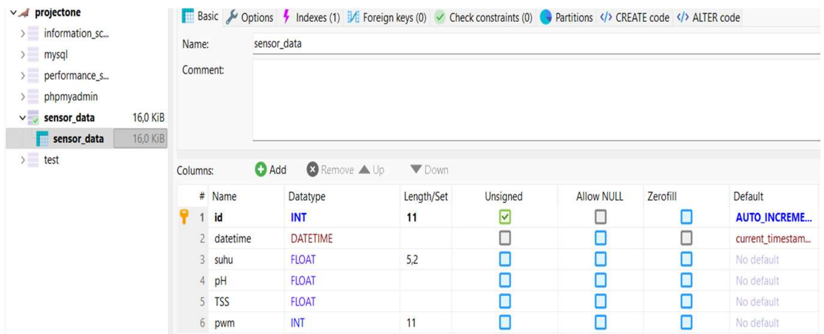


Figure 5. Table from MySQL Database

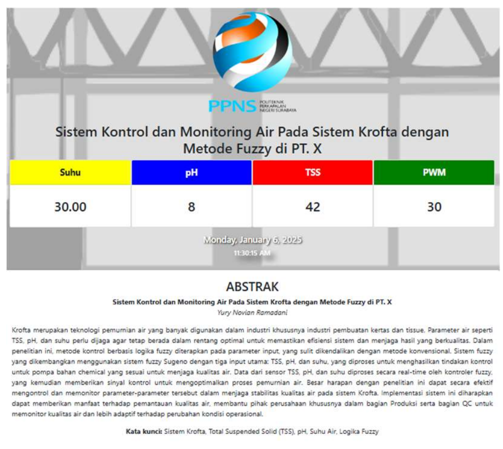


Figure 6. System view on the web

The system interface uses a web that will display the tested parameter data in real time by connecting the Arduino program with a realtime database and using ngrok.com web hosting to be able to publish. Ngrok is a platform that provides a solution that enables applications on private networks to be accessed over the internet [11]. The following is figure 6 which displays the parameters.

3.4. Sensor Testing Results

Sensor testing is essential to ensure the accuracy and reliability of water quality monitoring systems. It involves evaluating sensor performance in detecting parameters such as pH, TSS, and temperature under varying conditions. Proper testing helps optimize the system for real-time monitoring and efficient water management. This aims to evaluate the level of accuracy and determine the percentage of deviation for each component used. The test results will be compared with standard measuring instruments to assess sensor accuracy and validate its performance. The difference between the sensor measurements and the established standard will then be identified. Additionally, the percentage of deviation calculated from this comparison provides a deeper understanding of the sensor's accuracy in measuring the tested parameters.

$$\%\ Percentage\ Eerror = \frac{set\ point\ -\ Sensor\ Value}{Set\ point} \quad (2)$$

Knowing whether the DS18B20 Temperature Sensor Module, 4520c pH sensor module, and SEN024 sensor module can work properly and can display the temperature, pH, and TSS according to the program that has been made on the Arduino IDE by comparing the readings with the calibrator tool. The test uses liquids of different temperatures to prove the reliability of the sensor readings. The liquid has 5 different set points as each reading will have an interval of 2 seconds and 10 data samples are taken. The results of the temperature sensor are shown in Table 3.

Table 3. Results of DS18B20

No	SetPoint (°C)	Measurement No.	Measured Temperature (°C)	Percentage Error (%)
1	3,7	1	3,63	4,54
		2	3,63	
		3	3,63	
		4	3,52	
		5	3,52	
		6	3,52	
		7	3,5	
		8	3,48	
		9	3,48	
		10	3,41	
2	17,2	1	17,52	2,07
		2	17,52	
		3	17,46	
		4	17,52	
		5	17,52	
		6	17,58	
		7	17,58	
		8	17,58	
		9	17,64	
		10	17,64	
3	27,2	1	27,36	0,48
		2	27,36	
		3	27,36	
		4	27,44	
		5	27,44	

No	SetPoint (°C)	Measurement No.	Measured Temperature (°C)	Percentage Error (%)
		6	27,30	
		7	27,30	
		8	27,35	
		9	27,30	
		10	27,30	
4	52,8	1	52,69	0,51
		2	52,75	
		3	52,75	
		4	52,50	
		5	52,50	
		6	52,50	
		7	52,44	
		8	52,44	
		9	52,38	
		10	52,38	
5	80,9	1	82,29	1,11
		2	81,81	
		3	81,06	
		4	81,06	
		5	80,42	
		6	80,42	
		7	79,4	
		8	79,8	
		9	79,8	
		10	79,2	
Percentage Error from 5 Set Points (%)		1,742		

The DS18B20 temperature can display the temperature according to the program that has been made. This shows that the sensor can work well and in accordance with existing specifications. In the test results using the AMTAST WT-1 digital thermometer, an average error of 1.742% was obtained. The voltage required by the sensor is 5V which is taken from ESP 32. The results of the pH sensor are shown in Table 4.

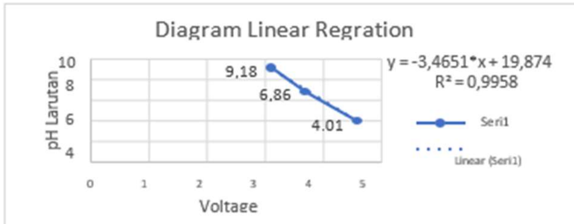
Table 4. Results of sensor 4502 pH Module

No	Setpoint for pH	Measurement No.	pH Measured	Percentage Error (%)
1	2,33	1	2,55	7,04
		2	2,48	
		3	2,55	
		4	2,47	
		5	2,4	
		6	2,45	
		7	2,38	
		8	2,55	
		9	2,56	
		10	2,55	
2	4,01	1	3,79	3,17
		2	3,83	
		3	3,89	
		4	4,0	
		5	4,24	
		6	4,19	
		7	4,09	
		8	4,02	
		9	4,16	
		10	3,92	
3	6,88	1	7,02	2,12
		2	7,01	
		3	7,07	
		4	7,15	

No	Setpoint for pH	Measurement No.	pH Measured	Percentage Error (%)
		5	7,10	
		6	7,07	
		7	6,95	
		8	6,95	
		9	6,97	
		10	6,97	
4	8,76	1	8,7	0,81
		2	8,69	
		3	8,69	
		4	8,75	
		5	8,74	
		6	8,7	
		7	8,66	
		8	8,65	
		9	8,59	
		10	8,72	
5	9,19	1	9,18	0,54
		2	9,19	
		3	9,2	
		4	9,16	
		5	9,05	
		6	9,05	
		7	9,13	
		8	9,2	
		9	9,2	
		10	9,1	
Percentage Error from 5 Set Points (%)		2,736		

Table 5. Results of Voltage from pH sensor

pH	Voltage	ADC Value
4,01	4,6	3.767
6,86	3,7	3.030
9,18	3,12	2.555



The 4520C pH module sensor can display pH in accordance with the program that has been made. This shows that the sensor can work well and in accordance with existing specifications. This is supported by using the linear regression method which gets the equation pH solution = (3.4651 * voltage) + 19.874. In the test results, the calibrator uses a pocket pHMeter PH- W2 and the sensor test results obtained an average error of 2.736%. On 5 different pH solution samples. The results of the Turbidity (TSS) sensor are shown in Table 5, Table 6, and Table 7.

Table 6. Results of sensor SEN024 DFRobot

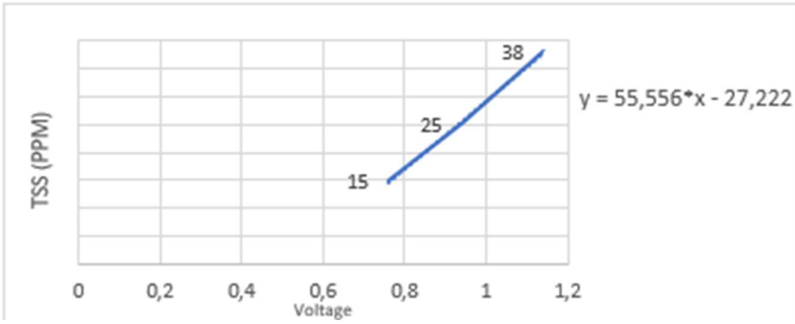
No	Setpoint for TSS (PPM)	Measurement No.	Measured TSS (PPM)	Percentage Error Every Setpoints (%)
1	15	1	15,8	2,12
		2	15,9	
		3	15,4	
		4	16,1	
		5	16,2	
		6	14,9	
		7	14,3	
		8	15,1	
		9	15,4	
		10	14,8	
2	25	1	26	4,36
		2	26,1	
		3	27,4	
		4	24,1	

No	Setpoint for TSS (PPM)	Measurement No.	Measured TSS (PPM)	Percentage Error Every Setpoints (%)
		5	24,7	
		6	25,4	
		7	24,8	
		8	27,5	
		9	25,3	
		10	26,8	
3	52	1	50	4,02
		2	54,4	
		3	51	
		4	54,5	
		5	52,9	
		6	55,7	
		7	53,8	
		8	54,8	
		9	54,1	
		10	50,3	
Percentage Error from 5 Set Points (%)		4,10		

The TSS sensor SEN024 DFRobot can display TSS according to the program that has been made. This shows that the sensor can work well and in accordance with the existing specifications.

Table 7. The result of ADC data readings with sensor voltage

TSS (PPM)	Voltage	ADC Value
15	0,76	622
25	0,99	770
52	1,56	1.188



This is supported by using the linear regression method which obtained the equation TSS solution 55.556*ADCvoltage - 27.222). In the test results, the calibrator uses the DR900 Calorimeter and the sensor test results obtained an average error of 4.10%. In 3 different TSS solution samples.

3.5. Overall System Real-Time Testing

- First Experiment

In this comprehensive testing, the designed tool will be tested to see if all the designs that have been made are working according to their intended purpose. This test proves whether the tool used can control each parameter and whether it can run well to monitor and store data simultaneously, as shown in figure 7.

In this experiment, data was taken on January 12, 2025. In this experiment, the system can change the condition that originally had a High TSS (id number 130) to a TSS that had a small value (id number 139). The following is the data that was successfully saved on January 12, 2025. The image below shows the data stored in MySQL, in figure 8.

Figure 7. Sensor in the Testing Tank

dbmultisensor.tb_sensor: 151 rows total (exact)

#	id	suhu	pH	TSS	PWM	datetime
130	130	28,86	7,8	81,2	80	2025-01-12 10:05:43
131	131	28,87	7,83	81,36	80	2025-01-12 10:12:50
132	132	28,87	7,81	70,77	80	2025-01-12 10:19:57
133	133	28,87	7,74	60,28	60	2025-01-12 10:25:05
134	134	28,9	7,84	63,33	60	2025-01-12 10:31:11
135	135	28,87	7,87	54,84	60	2025-01-12 10:37:16
136	136	28,88	7,85	41,8	60	2025-01-12 10:43:21
137	137	28,87	7,82	38,94	60	2025-01-12 10:50:26
138	138	28,88	7,81	27,82	30	2025-01-12 10:57:36
139	139	28,87	7,9	25,0	30	2025-01-12 11:05:38

Figure 8. The Data from January 12, 2025

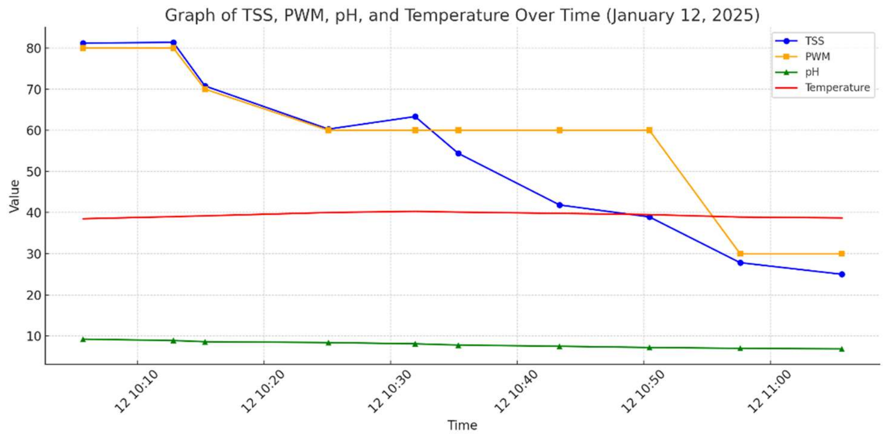


Figure 9. Graph of changes in 3 parameters

This means it takes at least 62 minutes. This depends on how cloudy the initial conditions are and the dosage of the fennopol solution dissolved, which is 1150 mg/50 L and a pressurized air injection of 0.8 bar. The booster pump will be installed after the filter pump which will filter out the dirt clumps contained in the fennopol tank.

- Second Experiment

In the experiment for second experiments, data was taken on January 27, 2025. In this experiment, the system can change conditions that originally had a slightly alkaline pH (id number 211) to an optimal pH (id number 199). This experiment was carried out for approximately 35 minutes. The pH change tends to be stable towards an optimal number, namely between 6.3 - 8.2. The use of fennopol in crofta tends not to affect changes in pH values because it is neutral. From the image below, it can be concluded that the use of fennopol for pH parameters in Krofta water does not significantly change the pH value. The pH value tends to be stable, because the nature of the chemical fennopol is neutral which will aim to lower the pH value if the pH is too high. in this experiment also for temperature parameters. In this experiment the system does not directly affect the temperature. This experiment was carried out for approximately 35 minutes. The use of this solution in krofta does not affect the temperature, because the water temperature depends on the forming process, heating by the yankee dryer, and the drying process. However, the temperature is monitored because if the water temperature is too low it will affect the production process because the water processed in the krofta system will be reused by the production section. The image figure 9 shows the data stored in MySQL. If the pH and temperature tests are displayed in the following graph figure 10.

dbmultisensor.tb_sensor: 151 rows total (exact)

#	id	suhu	pH	TSS	PWM	datetime
	199	31	5,74	52,22	30	2025-01-27 07:55:42
	200	27,8	5,3	55,25	30	2025-01-27 07:57:42
	201	33	5,6	54,17	30	2025-01-27 07:59:41
	202	31	5,96	58,11	30	2025-01-27 08:02:41
	203	28	5,88	60,3	30	2025-01-27 08:05:42
	204	41,2	5,88	60,87	60	2025-01-27 08:08:42
	205	42,57	6,05	44,87	60	2025-01-27 08:12:32
	206	37,56	6,21	55,32	30	2025-01-27 08:16:42
	207	36,89	5,982	48,28	30	2025-01-27 08:19:40
	208	34,74	6,44	36,3	30	2025-01-27 08:22:42
	209	30,5	7,11	40,37	30	2025-01-27 08:25:47
	210	30.9	7.368	40.65	30	2025-01-27 08:28:47

Figure 9. The Data from January 27, 2025

Figure 10. The Graphic of pH and Temperature

4. Conclusions

This research developed an application called " Water Monitoring and Control System in Krofta System with *Fuzzy* Logic Method" system offers use fuzzzy logic methods for to handle data that is uncertain or cannot be stated clearly. The application demonstrated an average accuracy under 6% of error on 10 trials in each different parameter, indicating its potential to facilitate and expedite the counting process for the company. However, despite the relatively high values of precision, there is always a difference in readings with the calibrator tool used in the system, as well as limited motor control by only using a 90 watt booster pump. To achieve a better balance, adjusting the detection threshold or retraining the model with a larger dataset that encompasses diverse environmental conditions could be considered. Integrating this application into actual kofta system operations has the potential to enhance both efficiency and accuracy in the monitoring and controlling of krofta system.

However, it is essential to consider various challenges, including technical, operational, and user adoption aspects. It is crucial to implement technical adjustments such as improving dataset quality, utilizing superior hardware, optimizing models, and providing user training to ensure that the application functions efficiently and effectively in real-world conditions. Future work may focus on enhancing model performance through improvements in types of sensors, the use of interfaces that can accommodate convenience, the use of pumps with greater power and can certainly be applied to the entire production system of the company.

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