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Automation of the Addition of Aluminum Sulfate Doses in the Pdam Water Treatment Process Using the Fuzzy Logic Controller Method

By

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Abstract

Water is a very important element of human life because water can be used for various purposes, one of which is in the household sector. There are several processes in water treatment, one of which is the coagulation process which is where the addition of Aluminum Sulfate dosage is made, but at PDAM Karang Pilang this process is still carried out manually or the jar test method. Therefore, in this study, a prototype system for the Automation of Addition of Aluminum Sulfate Doses has been designed using the fuzzy logic controller method. The type of fuzzy method used is the Mamdani type. This prototype is equipped with 2 sensors, namely the E-201-C pH Sensor and the SEN0189 Turbidity Sensor. The actuator used is a 12-volt peristaltic dosing pump and the microcontroller used is Arduino Uno. From the results of the design of the static characteristics of the pH sensor E-201-C and Turbidity SEN-0189, it has the highest accuracy rates of 99.8% and 99.5% in pre-sedimentation water samples. In testing the dynamic response of pH and Turbidity, it was found that the rise time values were 15.32 seconds and 25.49 seconds, the max overshoot was 4.76 % and 9.88 %, Steady State Error was 0.36 and 0.51 and the Settling time was 54.15 seconds and 83.27 seconds.

Keywords— Automation, pH, Turbidity, Fuzzy Logic Controller, Aluminum Sulfate.

Introduction

Population growth is increasing every year. As the population increases, it will cause an increase in the need for water to meet the needs of the community. However, this population growth also causes a decrease in water quality in raw water sources due to human activities and land use around the source [1]. In Indonesia, the adequacy of clean water is partially supplied by PDAM or Regional Drinking Water Company. Based on the Government Regulation of the Republic of Indonesia Number 82 of 2001 concerning water quality management and water control, it is explained that water as a very important component of natural resources must be used as much as possible for the prosperity of the people. Therefore, water needs to be managed properly so that its availability is sufficient both in terms of quantity and quality, and is beneficial for human life [2]. The clean water treatment carried out by PDAM uses several processing methods, namely physical, chemical and biological treatment. In physical processing, several methods are used, namely filtration and sedimentation. Biological processing is usually carried out to kill pathogenic microorganisms by adding a disinfectant. In chemical processing, the processing is done by adding a chemical compound which is usually called a coagulant and flocculant in which this compound functions as a water purifier [3]. In general, the most frequently used coagulant is Aluminum Sulfate or commonly known as alum. The addition of Aluminum Sulfate in the water treatment process at PDAM Karang Pilang is still done manually or by the jar test method. This is less effective in terms of time and labor. Therefore, in this final project, research will be conducted on the automation system for adding aluminum sulfate doses to PDAM water treatment using the fuzzy logic controller method as an output regulator for the aluminum sulfate dose. and improve the efficiency of time as well as PDAM workers.

Research Description

Water Treatment and Production System in PDAM

Water treatment is defined as a technical operation carried out on raw water so that it becomes clean water that meets the quality requirements of clean water/drinking water by combining several processing processes. Water treatment aims to reduce the concentration of each pollutant in the water so that it is safe to use. Water treatment carried out by PDAM consists of several processes, such as water treatment in general. Each processing is carried out in a different reservoir. In general, there are six tanks in a clean water treatment system, namely raw water tanks, coagulation tanks, flocculation tanks, sedimentation tanks, filtration tanks, and clean water tanks/reservoirs. Each treatment tank has a different capacity and length of processing time. Each of these interrelated components must be designed in such a way that it can treat raw water and produce clean water according to consumer needs.

Table 1. Quality Standards of Water Quality

Mandatory Parameters	Unit	Quality Standards (Maximum Rate)
Turbidity	NTU	25
Color	TCU	50
Dissolved solid (Total Dissolved Solid)	mg/l	1000
Temperature	°C	Air temperature ± 3
Flavor		No taste
Smell		No smell

Quality Standards

Based on the provisions of the Regulation of the Minister of Health of the Republic of Indonesia Number 32 of 2017 concerning the requirements and supervision of water quality a good standard of clean water quality is to have a maximum turbidity level of 25 NTU. This statutory regulation regulates that water for Sanitary Hygiene Needs is used for maintaining personal hygiene such as bathing and brushing teeth, as well as for washing food, eating utensils, and clothes. Based on these provisions are described in the table below.

Uses of Aluminum Sulfate in Water Treatment Process

Aluminum Sulfate or Alum has many uses, one of which is as a flocculator, which functions to collect dirt in the water purification process. One way to speed up the deposition process is to add chemicals that can trigger the deposition process. Aluminum Sulfate is very effective in depositing suspended particles in water in the form of keloids or suspensions, so it is widely used by PDAMs in the process of treating clean water which will later be distributed to the public [4].

Arduino Uno

Arduino Uno is an ATmega328-based microcontroller board. It has 14 input pins from digital output where 6 input pins can be used as PWM outputs and 6 analog input pins, a 16 MHz crystal oscillator, USB connection, power jack, ICSP header, and reset button. This Arduino performance requires microcontroller support by connecting to a computer with a USB cable to turn it on using AC or DC and it can also use batteries. Each of the 14 digital pins on the Arduino Uno can be used as input and output, using the pin Mode(), digital write(), and digitalRead() functions. These functions operate at a voltage of 5 volts, each pin can provide or receive a maximum current of 40 mA [5].

pH Sensor E-201-C

pH is the degree of acidity used to express the level of acidity or alkalinity possessed by a solution. An acidity meter (pH meter) is an electronic device used to measure the pH of a liquid. The basic principle of measuring pH using a pH meter is the electrochemical potential that occurs between the known solution inside the glass electrode and the unknown solution outside the glass electrode [6].

Turbidity Sensor SEN-0189

A turbidity Sensor is a sensor that functions to measure water quality by detecting the level of turbidity. This sensor detects suspended particles in water by measuring the transmittance and scattering of light which is directly proportional to the level of Total Suspended Solids. The higher the TTS level, the higher the turbidity of the water [7].

Motor Driver L298N

The L298N motor driver is a DC motor driver module that is used to control the speed and direction of rotation of the DC motor. IC L298 is an IC-type H-bridge capable of controlling inductive loads such as relays, pumps, stepper motors, and DC motors. The L298 IC consists of logical transistors (TTL) with NAND gates that function to make it easier to determine the direction of rotation of a dc motor or stepper motor [8].

Peristaltic Dosing Pump

A peristaltic dosing pump is a type of positive displacement pump used for pumping various liquids. A flexible tube mounted in a loop inside the pump casing contains the fluid and a vane with a number of coils, swabs, or grooves attached to the outer ring of the vane. When the vane moves, the bottom of the tube will be compressed and squeezed so that it becomes closed, and will eventually force the liquid to be pumped to move through the tube. After that, the tube will open as before. after leaving the wheel, fluid flow will be induced to the pump. The peristaltic pump can be continuously running to deliver smaller amounts of fluid.

Fuzzy Control Method

Fuzzy logic was first developed by Lotfi A. Zadeh in 1965. This theory is widely applied in various fields, including representing the human mind into a system. "Fuzzy logic is an appropriate way to map an input space into an output space" [9]. Fuzzy logic also has fuzzy sets which basically, fuzzy set theory is an extension of classical set theory. Whereas with fuzzy logic, the results that come out will not always be constant with the existing input. The workings of fuzzy logic broadly consist of input, process, and output. Fuzzy logic is a logical set theory that was developed to overcome the concept of value that exists between true and false. By using fuzzy logic the resulting value is not only "yes" (1) or "no" (0) but all possibilities between 0 and 1.

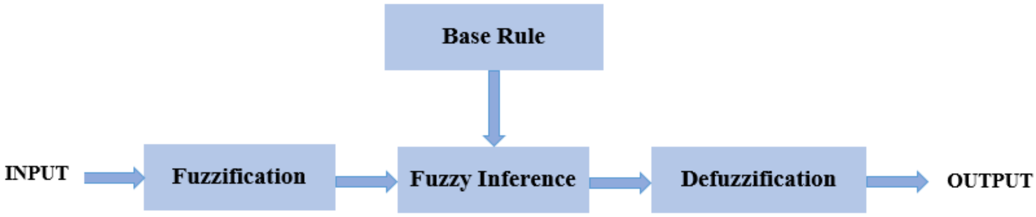


Figure 1 *Fuzzy Logic System*

A fuzzy system is a system based on fuzzy set rules. Some of the features of the fuzzy logic system have several operational stages including:

Fuzzification

Fuzzification is defined as a mapping from a firm set to a fuzzy set [10]. The criteria that must be met in the fuzzification process are that all members of the firm set must be included in the fuzzy set, there is no interference with the input fuzzy system used, and it must be able to simplify calculations on the fuzzy system.

Ground rules

The basic rule (rule-based) in fuzzy logic is a form of "If-Then" or "if-then" relation rules as follows: if x is A then y is B where A and B are linguistic values defined in the range of X variables and Y. The statement "x is A" is called the antecedent or premise. The statement "y is B" is called the consequent or conclusion.

Fuzzy inference

Fuzzy inference is an evaluation stage on fuzzy rules. The evaluation stage is carried out based on reasoning using fuzzy input and fuzzy rules so that the output is a fuzzy set.

Defuzzification

Defuzzification is the opposite process to the process of fuzzification. Defuzzification as a mapping from fuzzy sets to firm sets. The fuzzy set referred to here is the output obtained from the inference results. In the defuzzification process, three criteria must be met, namely reasonable, simple and continuous calculations.

Method

System planning

In implementing the Automation System for Adding Aluminum Sulfate Doses in PDAM water treatment, the prototype design is carried out first. The design of the Automation System for Adding Aluminum Sulfate Doses in PDAM water treatment consists of hardware design, monitoring, and control design, and Fuzzy Logic Controller design as follows. The prototype design of the Automation System for Adding Aluminum Sulfate Doses in PDAM Water Treatment is as follows.

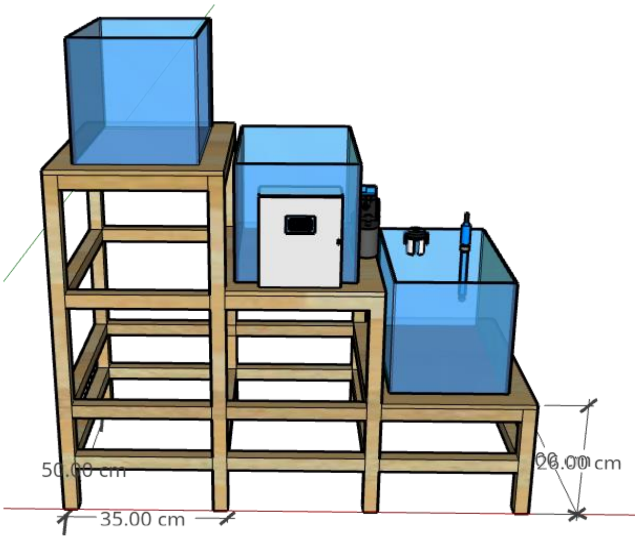


Figure 2 *Prototype Design*

In the picture above is a prototype design of the Automation System for Adding Aluminum Sulfate Doses in PDAM Water Treatment. This prototype consists of three tanks. Tank 1 serves to accommodate water as the initial place of deposition, in this place the pH of the water and turbidity of the incoming water is checked. The sensors used are pH and Turbidity. The pH sensor and Turbidity sensor will read the level of acidity and turbidity which will then be sent to Arduino as input. This input is then processed into data which is then sent to the actuator, namely the dosing pump as a command to run the pump to inject Aluminum Sulfate into tank 2. After the Aluminum Sulfate is injected, the water will enter tank 3. The water in tank 3 is water that has been Addition of Aluminum Sulfate is carried out in accordance with the set point and it is feasible for further water treatment processes to be carried out.

The specifications for the prototype of the Aluminum Sulfate Dosing Automation System are listed in the table below.

Table 2. Prototype Specification

Specification	Size
Material	Glass
Long	40 cm
Wide	25 cm
Tall	25 cm
Thick	1 cm
Volume	25000 liter

The block diagram of the Automation System for Adding Aluminum Sulfate Doses in PDAM Water Treatment is shown in the following figure.

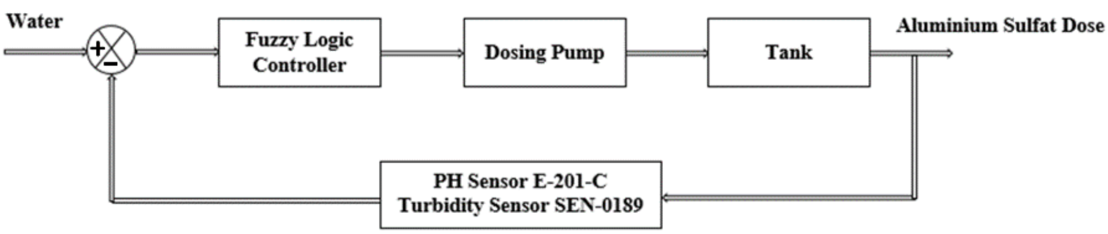


Figure 3 *Block Diagram of Automation System*

Fuzzy Logic Controller Design

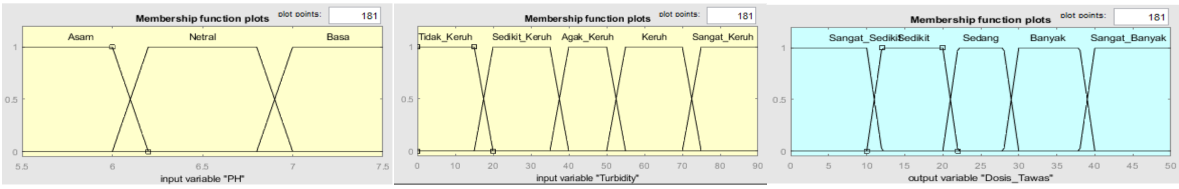
Table 3. *Rule Base*

Turbidity \ PH	**A**	**N**	**B**
NT	TL	TL	TL
ST	S	S	S
RT	Md	Md	Md
T	M	M	M
SM	SM	SM	SM

The design of the Automation System for Adding Aluminum Sulfate Doses in PDAM Water Treatment using the Fuzzy Logic Controller method. The type of method used is the Mamdani method. The advantage of the Mamdani Fuzzy Method in the process is that it pays more attention to the conditions that will occur for each fuzzy area, resulting in more accurate decision results [11]. From the observation with PDAM Surya Sembada Karangpilang in Surabaya, in this study, it is assumed that pH and Turbidity determine the dose ratio of Aluminum Sulfate. Therefore, these two parameters will be used as input for the system to be designed. Fuzzy rules in more detail can be described as follows:

where,

A = Acid	SaK = Very Turbid
N = Neutral	TL = The Least
B = Base	S = Slight
TK = No Turbid	Md = Medium
SeK = Slightly Turbid	M = Many
RT = Rather Turbid	SM = So Many
T = Turbid	



(a) (b) (c)

Figure 4 *Membership Function of (a) Input pH, (b) Input Turbidity, and (c) Output Dose*

Result and discussion

System Design Results

The results of the design of the Automation System Prototype and Addition of Aluminum Sulfate Dosage and electrical wiring contained in the Prototype Panel in PDAM Water Treatment Using the Fuzzy Logic Controller Method are as follows:

(a) (b)

Figure 5 *Design Results of (a) Hardware and (b) Electric Wiring*

The results of the fuzzy logic control design of the Automation System Prototype of Adding Aluminum Sulfate Doses in PDAM Water Treatment Using the Fuzzy Logic Controller Method are as follows.

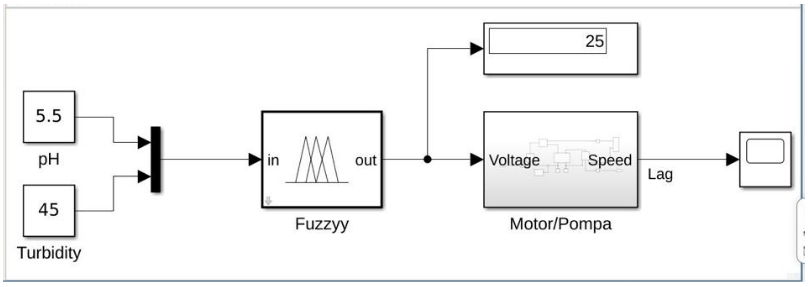


Figure 6 *Simulink Prototype Design*

The picture above is a simulation result of the designed system, for example, if the pH value is known to be 5.5 and the Turbidity is 45 NTU then the Fuzzy logic controller will process the data according to the parameters and fuzzy rules that have been previously created and get the aluminum sulfate dose given at 25 mg/l with Moderate status.

Sensor Validation

Table 4. *Comparison of pH Sensor Values- E-201C and Buffer Solution*

pH Buffer Solution	Value Measuring Instrument	Status
4.01	3.92	Acid
6.86	6.86	Neutral
9.18	9.12	Base

The validation of the E-201-C pH sensor and SEN-0189 Turbidity Sensor used in the final project of the Automation System for Adding Aluminum Sulfate Doses in PDAM Water Treatment Using the Fuzzy Logic Controller Method are as follows.

Validation of pH sensor E-201-C

In the process of validating the pH sensor, the analog value conversion formula is read to get the pH voltage value using a pH solution of 4.01 as an acid solution, 6.86 as a neutral solution, and 9.18 as a base solution. The range of analog values produced by the E-201C pH sensor is 0 – 1024 and the range of voltage values sought is between 0 – 5 volts. The pH sensor calibration circuit is shown in the following figure:

Figure 7 *pH sensor Calibration Circuit*

Description:

a. Orange wire: Sensor Po Pin to Arduino A0 Pin
b. Red wire: Pin G sensor to Pin Gnd Arduino
c. Brown wire: Sensor V+ Pin to Arduino 5V Pin

In the test results for the accuracy of the pH-E-201C sensor, there is a difference in the pH 4.01 buffer solution with the pH value read by the sensor, which is 3.92 with a difference of 0.09 and the pH buffer solution is 9.18 with the pH value read by the sensor, which is 9.12 with a difference of 0.06.

Validation of Turbidity Sensor SEN-0189

In the process of validating the Turbidity sensor SEN 0189 using the formula for converting the readable analog value to get the Turbidity voltage value from the sensor and using a Turbidity meter calibrator to compare the correction values. The range of measurement values produced by the SEN 0189 Turbidity sensor is ±600 NTU. The first thing to do is find the ADC sensor value used by trying on 3 samples, namely PDAM water, lake water, and coffee. Then take data on 3 samples and experiment 10 times to get the average NTU value. The Turbidity sensor calibration circuit SEN 0189 is shown in the following figure:

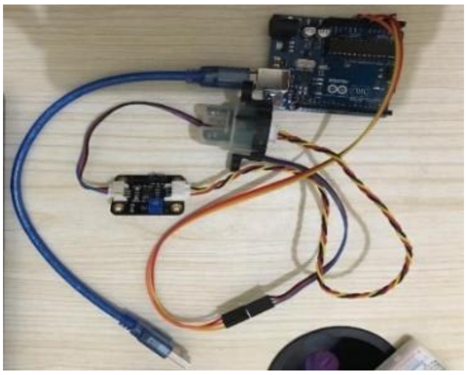


Figure 8 *Turbidity Sensor Calibration Circuit*

Description:

a. Sensor blue wire to Arduino Pin A1
b. Sensor red wire to Arduino 5V Pin
c. Sensor black wire to Arduino Gnd Pin

In the test results of the Turbidity sensor accuracy level SEN 0189, there is a difference in the PDAM Water sample with the turbidity value read by the sensor, which is 0.49 with a difference of 0.18, and the lake water solution sample with the turbidity value read by the sensor is 25.08 with a difference of 0.92 and the sample is Coffee with turbidity values read by the sensor is 53 with a difference of 0.9.

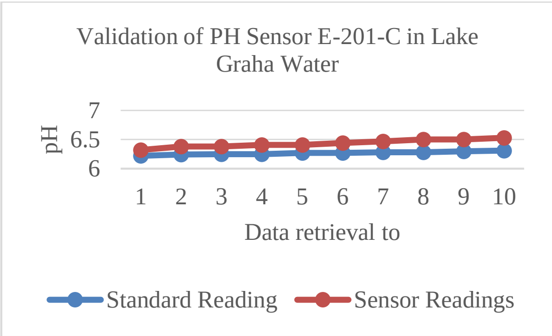
Component Test

Component testing is carried out to determine the work performance of each component according to the design. The test consists of testing the pH sensor E-201-C which is used to measure the degree of acidity and the Turbidity sensor SEN-0189 which is used to measure the turbidity of the water. The following is a graph of the results of the tests carried out.

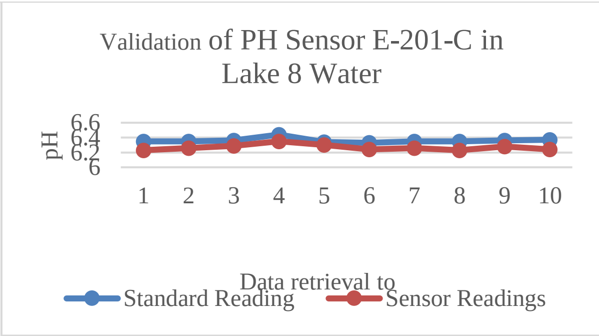
pH Sensor E-201-C Testing

Table 5. *Comparison of SEN 0189 Turbidity Sensor Values and Standard Measuring Instruments*

Water sample	Measuring Instrument Turbidity Value (NTU)	Standard Turbidity Value (NTU)
PDAM Water	0.49	0.31
Lake Water	25.08	26
Coffee Solution	53	52.1



(a)



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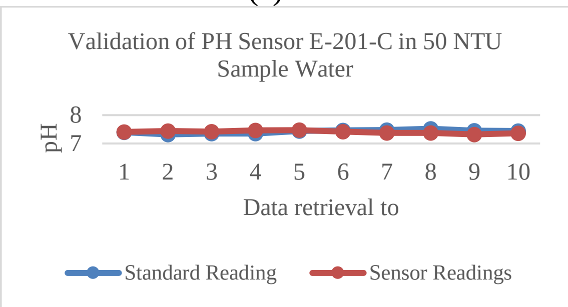

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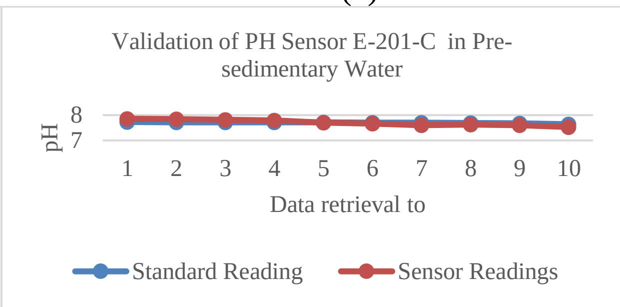
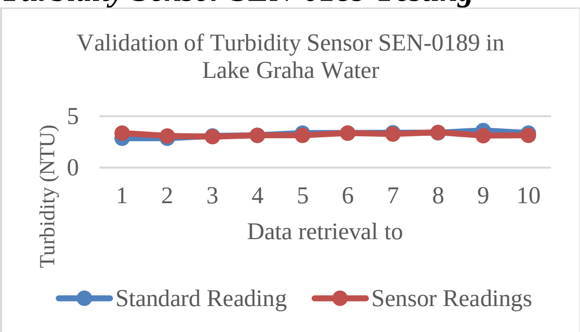


(d)

Figure 9 *Graph of pH Sensor Testing in (a) Graha Lake Water, (b) 8 Lake Water, (c) Artificial Samples, and (d) Pre-sedimented Water*

Turbidity Sensor SEN-0189 Testing



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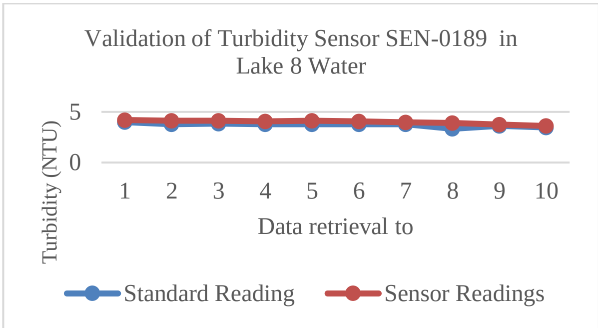

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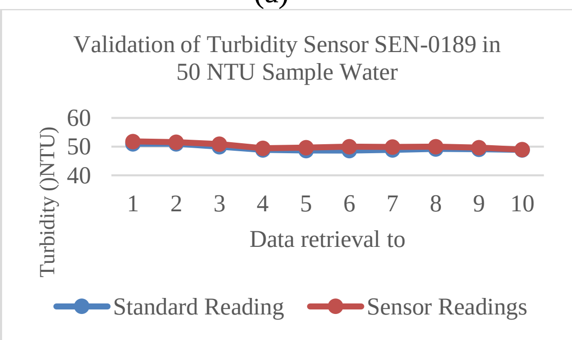

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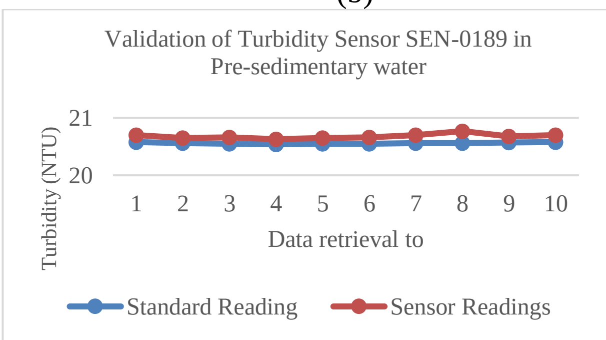


(d)

Figure 10 *Graph of Turbidity Sensor Testing in (a) Graha Lake Water, (b) 8 Lake Water, (c) Artificial Samples, and (d) Pre-sedimented Water*

Actuator Testing

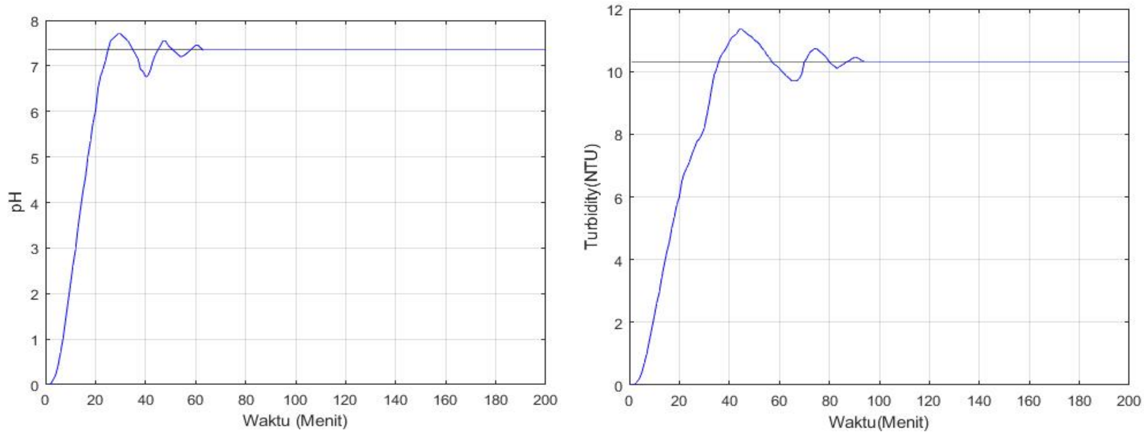
The peristaltic pump testing is carried out to determine the response of the automatic control by fuzzy to the given setpoint input in the form of pH and Turbidity values. Tables and graphs of the response of the control system are given below.

Table 6. *pH Control System Response*

System Response	Value
Rise time (tr)	15.32 s
Maximum overshoot (mp)	4.76 %
Error Steady State (Ess)	0.36
Settling time (ts)	54.15 s

Table 7. *Turbidity Control System Response*

System Response	Value
Rise time (tr)	25.49 s
Maximum overshoot (mp)	9.88 %
Error Steady State (Ess)	0.51
Settling time (ts)	83.27 s



(a) (b)

Figure 11 *System Response Graph of (a) pH Control and (b) Turbidity Control*

Data Retrieval

The data retrieval carried out on the Automation System for Adding Aluminum Sulfate Doses in PDAM Water Treatment Using the Fuzzy Logic Controller Method are as follows:

Table 8. *Data Retrieval*

No	Sample Water	Before addition of Aluminum Sulfate		Dosage amount of Aluminum Sulfate (ml/l)	After addition of Aluminum Sulfate	
		pH Value	Turbidity Value		pH Value	Turbidity Value
1	Graha lake water	6.77	10.29 NTU	5.39 ml/l	6.35	6.36 NTU
2	8 lake water	6.89	10.79 NTU	5.61 ml/l	6.05	10.49 NTU
3	Pre-sedimentation Water	7.19	20.49 NTU	16 ml/l	6.46	10.32 NTU
4	Artificial sample water 1	5.26	8.20 NTU	5.39 ml/l	5.04	8.12 NTU
5	Artificial sample water 2	5.59	34.79 NTU	16 ml/l	5.44	25.82 NTU
6	Artificial sample water 3	6.99	12.52 NTU	5.42 ml/l	6.77	10.79 NTU
7	Artificial sample water 4	7.87	34.64 NTU	25 ml/l	7.26	12.33 NTU

Data analysis

In the data collection stage, 4 samples of water were tested for pH and turbidity values before adding a dose of aluminum sulfate. The place where the pH and turbidity values are taken before adding the dose is in tank 1, the pH and Turbidity value data and the number of doses are displayed on the LCD screen. In the process of increasing the dose in tank 2, after adding a dose of water, the pH and Turbidity values were taken again to determine the change in the value of pH and Turbidity in tank 3. The results of the experiment showed that after adding the dose using the Fuzzy Logic Controller method, the pH value decreased from 0.15 to 0.84, and turbidity values decreased by 0.50 NTU to 10.17 NTU. The largest difference in the pH value occurred in the lake water sample 8 which was 0.84 and the largest difference in the turbidity value occurred in the pre-sedimentation water sample of 10.17.

The comparison of input and output values using the Fuzzy Logic Controller Method and using the manual method. The manual method is carried out using the jar test method, namely by adding doses with different amounts every 30 seconds and obtaining values that are close to when using the fuzzy method. The results of the trial show that using the Fuzzy Logic Controller method works better with a smaller turbidity value than the turbidity value when using the manual method. The largest difference in the pH value occurred in the artificial sample water of 0.28 and the turbidity value occurred in the lake water sample 8 of 1.45.

Conclusion

Based on the results of the research that has been done, the tool can be implemented properly using the pH sensor E-201-C and the Turbidity sensor SEN-0189 tested with 4 different water media, namely Graha Lake water, Lake 8 water, artificial sample water, and pre-sedimentation water. On the pH sensor E-201-C, the average error value of the sensor is 0.04, 0.01, 0.20, and 0.01. While on the Turbidity sensor SEN-0189, the average error values obtained are 0.09, 0.07, 0.01, and 0.01. The Mamdani type fuzzy method can be implemented in the Automation system for adding aluminum sulfate doses to PDAM water treatment. The dynamic response to the pH and Turbidity tests carried out showed that the rise time values were 15.32 seconds and 25.49 seconds, the max overshoot was 4.76 % and 9.88 %, the Steady State Error was 0.36 and 0.51 and the Settling time was 54.15 seconds and 83.27 seconds.

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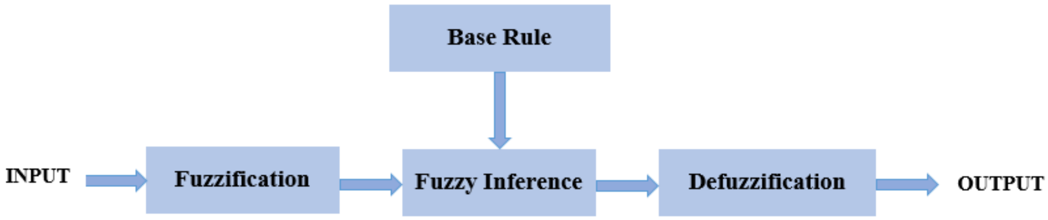

Figure. 1. *Fuzzy Logic System.*