Advanced Fuzzy Control in Industrial Wastewater Treatment (pH and Temperature Control)

Tawanda Mushiri, Karen Manjengwa, Charles Mbohwa

***Abstract*-Wastewater reuse is being increasingly promoted as a strategy for conservation of limited resources of freshwater and as a mean of safeguarding the aquatic environment from contaminants present in wastewater. Waste water disposed of in the ground reduces the quality of ground water and surface waters. Untreated waste-water generally contains high levels of organic material, numerous pathogenic microorganisms which entails environmental and health hazards. In this project, a design of an automated control for industrial waste water treatment using fuzzy logic control is presented. Fuzzy control concepts have been adopted and control algorithms based on pH and temperature variations provided accurate and reliable treatment of waste water. Two inputs, pH and temperature, and four outputs, hot and cold water valve and acid and base valve were given to the system. The behavior of the system was observed whenever an input came in. the pH was to be kept at a neutral status of between 6.5 and 7.5 and the temperature had to be kept within a range of between 25^0C and 35^0C. The fuzzy rules managed to keep the system stable as was seen from the graphs.**

***Index terms*: Fuzzy Controller, MATLAB, pH, Temperature**

I. INTRODUCTION

Industrial waste water is the aqueous discard that results from the use of water in an industrial manufacturing process or the cleaning activities that take place along that process. Industrial waste water is the result of substances other than water having been dissolved or suspended in water[1]. Wastes from industries are customarily classified as liquid wastes, solid wastes or air pollutants. Solid wastes disposed of in the ground can influence the quality of ground water and surface waters by way of leachate entering the ground water and travelling with it through the ground, then entering a surface water body with ground water recharge. Volatile organics in that recharge water can contaminate the air. Air pollutants can fall out to become surface water or ground water pollutants, and water pollutants can infiltrate into the ground or volatilize into the air[10].

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A: BACKGROUND

The objective of industrial waste water treatment is to remove those dissolved or suspended substances. The degree of wastewater treatment desired will ultimately depend on the cost that can be afforded by the community or government. Wastewater treatment processes are typically classified according to the degree of pollutant removal that has to be realized into.

B: PROBLEM STATEMENT

Untreated waste-water generally contains high levels of organic material, numerous pathogenic microorganisms which entails environmental and health hazards, hence the need to effectively treat it with a more intelligent control system.

C: AIM

To maintain low acceptable levels of hazardous chemicals or substances in waste water

D: OBJECTIVES

The objectives of this project are to

- Design a system that uses advanced fuzzy logic controller for industrial waste water treatment
- To maintain a neutral pH for the wastewater treatment plant and
- To maintain a temperature that is favourable for biological activity to take place

E: WHY FUZZY LOGIC

TABLE 1 MATRIX TO SELECT AI

Intelligence tool	Response time	Scalability	Flexibility	Ease of use	Embeddability	Processing	Expert Dependence	Tolerance for dirty data	Implementation speed	Tolerance for complexity	Accuracy
Genetic algorithm	H	L	L	L	H	H	L	-	H	H	H
Neural networks	H	M	L	L	M	L	L	H	M	H	H
Fuzzy logic systems	H	L	M	H	M	H	H	H	H	M	M
Rule-based systems	X	L	M	H	H	M	H	L	H	M	H
Case based reasoning	L	H	L	M	M	H	L	H	M	H	H

Legend: H = High; L =Low; M = Medium; X = Deteriorates as the number of active rules grows

E: SOURCES OF WASTE WATER

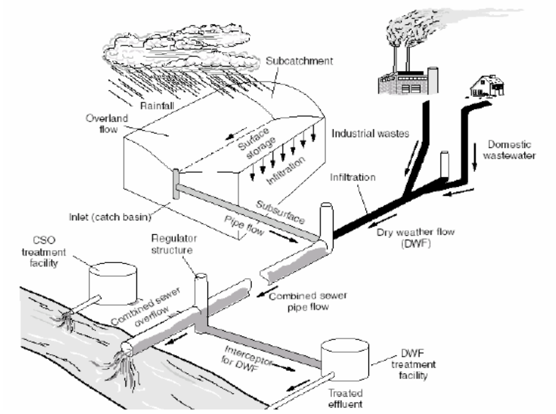

Fig. 1 Qasim WWTP Instrumentation

F: PRODUCTION OF PHOSPHATE FERTILIZERS

The production of phosphate fertilizers also involves a number of processes. The first is the production of sulphuric acid through the contact process. Sulphuric acid is then used in a reaction that produces phosphoric acid. Phosphoric acid can then be reacted with phosphate rock to produce triple superphosphates.

1. The production of sulfuric acid

Sulfuric acid is produced from sulphur, oxygen and water through the contact process. In the first step, sulphur is burned to produce sulphur dioxide.

$$S_{(s)} + O_{2(g)} = SO_{2(g)}$$

(equation 1)

This is then oxidised to sulphur trioxide using oxygen in the presence of a vanadium (V) oxide catalyst.

$$2SO_{2(g)} + O_{2(g)} = 2SO_{3(g)}$$

(equation2)

Finally the sulphur trioxide is treated with water to produce 98-99% sulfuric acid.

$$SO_{3(g)} + H_2O_{(l)} = H_2SO_{4(l)}$$

(equation3)

2. The production of phosphoric acid

The next step in the production of phosphate fertilizer is the reaction of sulfuric acid with phosphate rock to produce phosphoric acid. In this example, the phosphate rock is fluoropatite

$$Ca_5F(PO_4)_{3(s)} + 5H_2SO4_{(g)} + 8H_2O_{(l)} = 5CaSO_{4(s)} + HF_{(g)} + 3H_3PO_{4(g)}$$ (equation 4)

3. The production of phosphates and superphosphates

When concentrated phosphoric acid reacts with ground phosphate rock, triple superphosphate is produced.

$$3Ca_3(PO_4)_2.CaF_2 + 12H_3PO_4 = 9Ca(H_2PO_4)_3 + 3CaF_2$$

(equation 5)

II. WASTE WATER TREATMENT

The first recognition of the need for wastewater treatment occurred in 1854, with the link between improper waste treatment and a cholera epidemic which was recognized. The 1972 Clean Water Act was the first official federal regulation that set specific standards for the treatment of water waste in the United States [5].

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A: PH CONTROL

The control of pH arises in a wide range of industries including wastewater treatment, biotechnology, pharmaceuticals and chemical processing. The general aim in this form of control is to maintain the pH value within a liquid at a specific level. This can be important in order to comply with and satisfy certain environmental requirements or quality standards. The requirement in terms of the pH value for effluent from a wastewater treatment plant is usually in the range 6 to 8. This is mainly to protect life (both aquatic and human) and also to avoid or prevent damage due to corrosion [8].

B: TEMPERATURE

Temperature affects a number of important water quality parameters such as gas solubility (decreases with T), solids solubility (generally increase with T), and chemical or biological reaction rates. Most organisms have distinct temperature range within which they perform best. For example mesophillic anaerobic bacteria perform best at temperature between 30 to 35^{o}C [6]. The best temperatures for wastewater treatment probably range from 77 to 95 degrees Fahrenheit. In general, biological treatment activity accelerates in warm temperatures and slows in cool temperatures, but extreme hot or cold can stop treatment processes altogether. Therefore, some systems are less effective during cold weather and some may not be appropriate for very cold climates [5].

III. PRINCIPLE OF OPERATION

When the pH is measured by the pH sensor, it sends a signal to the controller to calculate the exact amount of acid or base to be added to the wastewater. The volume of the wastewater is needed in order to calculate the concentration, so a level sensor is used in calculating the volume of the waste water. After the right neutralization has taken place, we now measure the temp of the solution to see whether the temperature is not too high or too low for biological activity to take place. If the temperature is too low, hot water from a hot well is added and if its low, cold water is added. The difference of this fuzzy model from the others lies in the defuzzification process. Mamdani does not use the concept of weighted average. Mamdani-type inference expects the output membership functions to be fuzzy sets.

TABLE 2: WWT STANDARDS IN ZIMBABWE

Parameter	Zone 1	Zone 2	Parameter	Zone 1	Zone 2
PH	6 - 7.5	6 - 9	Copper, mg/l	0.02	0.5
Temperature	30^{o}C	35^{o}C	Zinc, mg/l	0.3	1.0
Dissolved Oxygen	75% sat. (min)	60% sat. (min)	Cadmium, mg/l	0.01	0.01
COD, mg/l	30	60	Nickel, mg/l	0.3	0.3
SS, mg/l		25	Mercury, mg/l	0.5	0.5
TDS, mg/l	100	500	Boron, mg/l	0.5	0.5
NH_3 (free), mg/l		0.2	Lead, mg/l	0.05	0.05
Chlorine, mg/l	nil	0.1	Cyanide, mg/l	0.2	0.2
Ammonia nitrogen, mg/l	0.5	0.5	Arsenic, mg/l	0.05	0.05
Phosphate, mg/l	1.0	1.0	Nitrate-nitrogen, mg/l	10	10
BOD, mg/l	5	10	Iron, mg/l	0.3	0.3
Sulphate, mg/l	50	200	Chromium, mg/l	0.05	0.05

TABLE 3: TEMPERATURE-PH RELATIONSHIP

T (°C)	Kw (mol2 dm-6)	pH
0	0.114 x 10-14	7.47
10	0.293 x 10-14	7.27
20	0.681 x 10-14	7.08
25	1.008 x 10-14	7.00
30	1.471 x 10-14	6.92
40	2.916 x 10-14	6.77
50	5.476 x 10-14	6.63
100	51.3 x 10-14	6.14

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pH CONTROL FLOW CHART

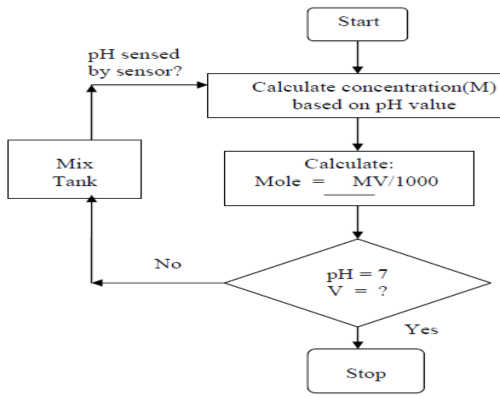

Fig. 5 pH Measurement

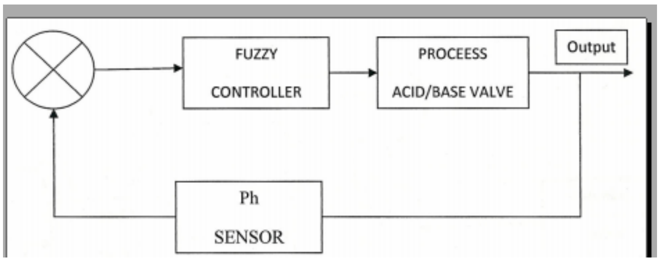

Fig. 6 Process flow chart

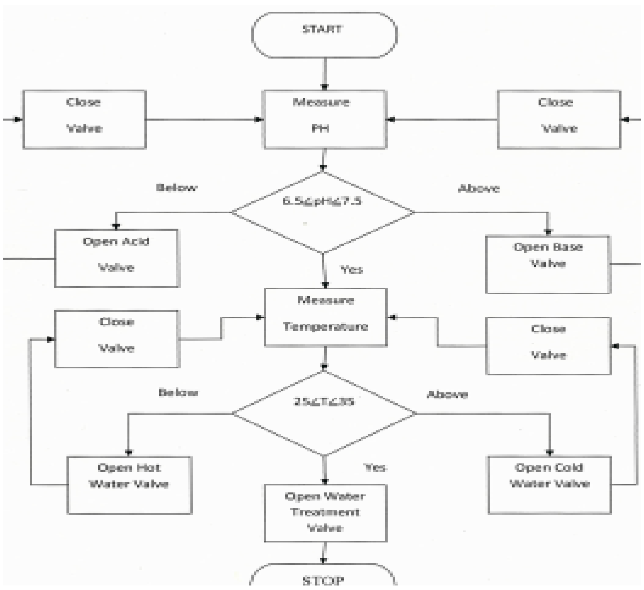

Fig. 7 Process of pH Control

IV. TEMPERATURE MEASUREMENT

Principle operation of a thermocouple

When you have two dissimilar wires twisted together and if temperature T1 is different from T2 then current will flow through the wires.

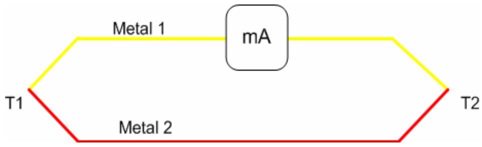

Fig. 8 Thermocouple

Type J – Type J thermocouples have an iron positive leg and a constantan negative leg.

Type J thermocouples have a useful temperature range of 32 to 1400°F (0 to 750°C) and can be used in vacuum, oxidizing, reducing and inert atmospheres. Due to the oxidation (rusting) problems associated with the iron leg, care must be used when choosing this type for use in oxidizing environments above 1000°F. The color code for type J is white for positive and red for negative.

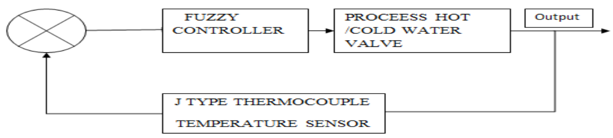

Fig. 9 Temperature measurement

A: RESULTS

The fuzzy logic controller is a Mamdani type 2 fuzzy controller. It has 2 inputs that is pH and temperature. The desired range for ph is 6.5-7.5 and for temperature its 35˚-60˚. The controller also has 4 outputs which are all valve that is the cold and hot water vave and the pH acid and base valve. The openings of these valves all range from 0-1.

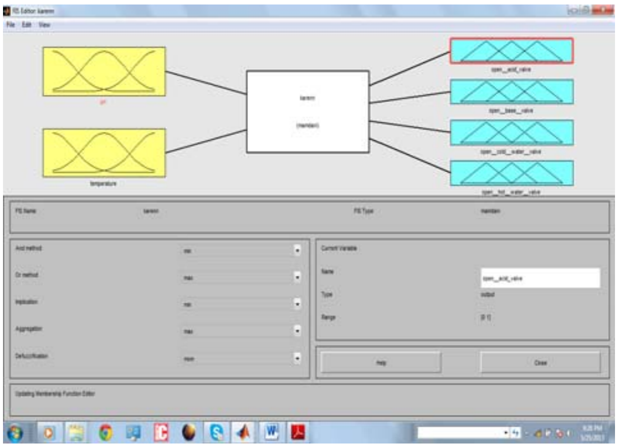

Fig. 10 pH membership functions using MATLAB

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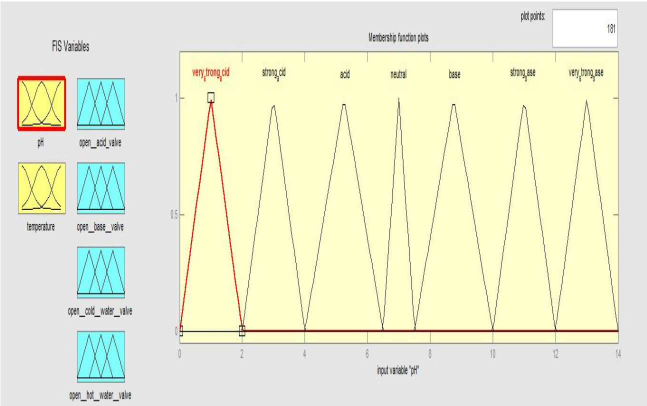

Fig. 11 pH membership Function

The pH membership function is a triangular membership function type with 7 membership functions.

TABLE 4: PH MEMBERSHIP FUNCTION

Very Strong Acid	0-2
Strong Acid	2-4
Acid	4-6.5
Neutral	6.5-7.5
Very Strong Base	12-14
Strong Base	10-12
Base	7.5-10

B: TEMPERATURE MEMBERSHIP FUNCTIONS

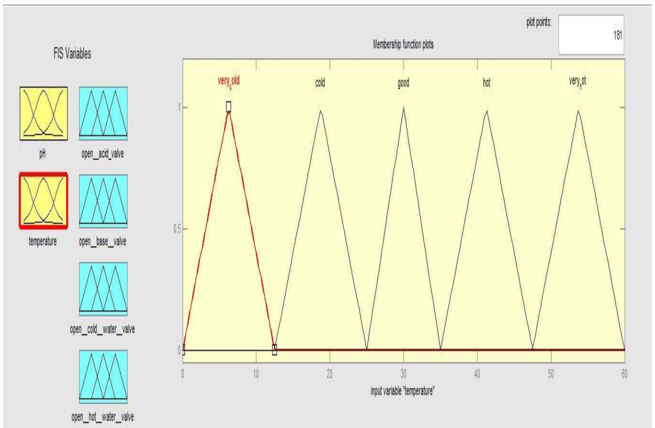

Fig. 2 Temperature Membership Function

Temperature is also of the triangular type with 5 membership functions

TABLE 5: TEMPERATURE MEMBERSHIP FUNCTION

Very cold	0-12.5
Cold	12.5-25
Good	25-35
Hot	35-47.5
Very hot	47.5-60

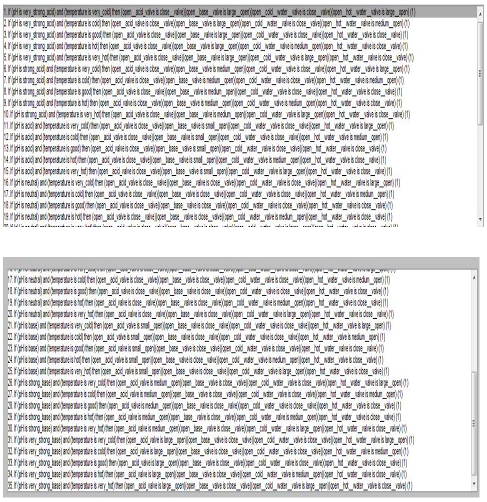

Fig. 13 Fuzzy rules

Fig. 14 Rule viewer

The Rule Viewer displays, in one screen, all parts of the fuzzy inference process from inputs to outputs. Each row of plots corresponds to one rule, and each column of plots corresponds to either an input variable or an output variable. The Rule viewer gives a full representation of the behavior of the controller at different inputs. By default it gives the desired set points of the two inputs and the resultant output. You can enter different inputs and see the behavior of the valves.

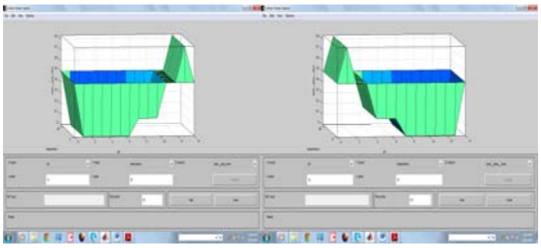

Fig. 15 SURFACE VIEWS FOR ACID VALVE SURFACE VIEW FOR BASE VALVE

The surface views above show acid or base opening against Ph. For the acid valve, as pH increases, i.e. as it becomes more acidic the valve opening is increased to allow more base to neutralise the solution. For the base valve as pH approache minimum it is becoming more basic, so the valve opening becomes larger to allow more acid to neutralise the solution

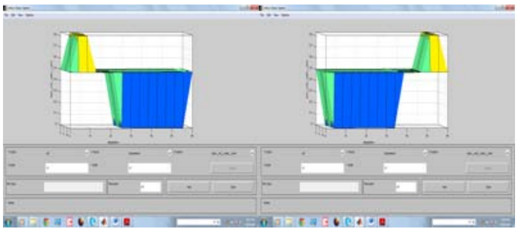

Fig. 16 HOT WATER VALVE COLD WATER VALVE SURFACE VIEW

The graphs show hot and cold water valve openings against temperature. As the temperature increases the valve opening for cold water increases and when temperature decreases, the hot water valve opening is increased in order to maintain the temperature at a range between 25 and 35 degrees.

V. CONCLUSION

A simulation study of pH neutralization process control was carried out successfully using Matlab. It was demonstrated that fuzzy logic control performed well to control the highly nonlinear pH neutralization process within the defined range. In conclusion, by discussing a real online example where it is required to bring the pH from 3 to 7 the researcher can show that the study was effective. This example was chosen to show how the fuzzy controller has successfully solved the control objectives. Using all the expertise to set the membership functions as well as the rules, the membership functions and the pH response show clearly that the pH was brought from 3 to 7 in a very smooth manner, referring to our diagrams.

As a general conclusion, the study presented here has shown that using fuzzy logic control is probably best suited to control the pH for industrial waste water, despite the expertise required to fine tune the controller. Finally, the project has also shown that implementing the fuzzy control technique, by careful selection of memberships and setting the right rules, it is possible to bring any waste water pH to neutrality smoothly in an acceptable time, regardless if the waste is strong base nature or strong acidic or not.

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