A Program in Visual Basic for Simulation and Control of Acidic Wastewater Neutralisation System*

[1]S. Fosu, [1]E. B. Danuba, [1]F. Krampah, [1]T. Joe-Asare
[1]University of Mines and Technology, Tarkwa, Ghana

Abstract

The primary objective of this paper was to investigates the use and benefits of simulation for basic instrumentation and process control education. This simulation approach provides valuable solution by giving clear insights into complex systems. A graphic computer simulation program, for controlling and neutralising acidic wastewater has been developed. The simulator (pH-neutraliser) was developed using Microsoft Visual Basic Programming language and process control principles. The program was designed to provide an intuitive interface by correcting and adjusting the acidic pH of wastewater to 7 (neutral pH) before discharge into the environment. The acidic wastewater can be neutralised by alkali reagents like caustic soda or lime. The simulator was designed to operate in both manual and automatic modes during the neutralisation process. In the manual mode, the pH-neutraliser alerts an operator by sounding an alarm and suggests the percentage by which the alkali reagent valve should be opened to add required amount to bring the pH of the wastewater to 7. This is done when the measured value from the pH sensor and transmitter is not equal to the desired value. In the automatic mode, the neutraliser is expected to automatically open the alkali reagent valve to the required percentage to add the needed amount of alkali to make the pH of wastewater neutral. The pH neutralisation automation of wastewater can be achieved with the aid of pH analytical sensor and transmitter, signals, controller and feedback control mechanism.

Keywords: Computer Simulation, pH-Neutralisation, Visual Basic Programming, Wastewater

1 Introduction

Modern day industrial application of advanced control techniques for most process industries is becoming more stringent due to increasing complexity of the processes as well as the enhanced requirement in terms of product quality and environmental factors (Suchithra *et al.*, 2016). The process industries require more reliable, accurate, robust, efficient and flexible control systems for the operation of process plant (Walsh ,1993; Suchithra *et al.*, 2016). Process such as control of pH has become very important in many industries, especially where the objective is to neutralised or maintain the pH of wastewater within stringent environmental limits before discharge to the environment (Shinskey, 1973; McMillan, 1994). Control of pH is extensively use in wastewater treatment plants, biotechnology, metal-finishing operations, production of pharmaceuticals and many chemical process industries (McMillan, 1994; Henson and Seborg, 1994; Hermansson and Syafiie, 2015; Ławryńczuk, 2016). Wastewater treatment is very herculean task since it is necessary for the effluent stream to remain neutral to avert corrosion, protect aquatic life or provide neutral water for reuse as process water or as boiler feed (Loh, 1998; Regunath and Kadirkamamathan, 2001). The control of pH in bioreactors is of great significance because, it supports cell growth (Regunath and Kadirkamamathan, 2001). In the production of pharmaceuticals, a steady control of pH is critical to maintain the quality of the products (Regunath and Kadirkamamathan, 2001).

Generally, some industrial processes such as the mining and metallurgical processing industry, laboratories, pharmaceutical industries, distilleries and phosphorous industries generate highly acidic effluents (Kaksonen *et al.*, 2003; Mokone and Lewis, 2010; Feng *et al.*, 2017; Goyal and Srivastava, 2017; Lamichhane *et al.*, 2017). This highly acidic wastewater causes serious environmental problems if discharged into the environment (Wang *et al.*, 2015; Wang *et al.*, 2016). The low pH causes the solubility of heavy metals and other contaminants, making chemicals more mobile and increasing the risk of exposure to humans and aquatic organisms in the environment (Adamczuk and Kolodynska, 2015; Goyal and Srivastava, 2017). For regulation requirements, there is the need to neutralise the pH of effluent waste to curb the adverse impact on the environment. Controlling the pH of liquid waste is a challenge and tedious process for some processing industries like the textile dyeing, mining, water and wastewater treatment industries in developing countries like Ghana, especially where manual addition of reagent type is used for the neutralisation process depending on the pH. Manual control of liquid acidic waste can cause over dose of reagent addition leading to other side reactions in the water and may also increase cost of treatment.

In this work, to ensure that acidic liquid waste is neutralised to the set point (pH of about 7), a

software has been developed to simulate, monitor and control the pH of industrial liquid waste before it is finally discharge into the environment. This software application was developed using Visual Basic Programming Algorithm and basic instrumentation and process control principles for simulation and theoretical control of pH neutralisation in industries.

2 Resources and methods Used

2.1 Theory and Principles

The background of this work is based on the process and instrumentation diagram (P & ID) shown in Fig. 1. The P & ID shown in Fig. 1 depicts a typical pH neutralization system where a waste liquid (influent) from a process plant assumed to be low in pH (acidic) flows into a mixing tank. Just at the discharge of the mixing tank is a pH Analytical Transmitter (AT) which measures the pH of the effluent and then transmits it in the form of electrical current signal (as dashed lines) to the Analytical Indicating Controller (AIC) with the pH input set point. The Analytical Indicating Controller (AIC) then evaluate the signal (converts it to pH value) and compare the measured value to the set point. The outlet valve opens for the effluent to be discharge into the environment if measured value equal set point. Deviation from the set point causes the Analytical Indicator Controller (AIC) to executes the control law and sends an appropriate electrical current signal to the alkali reagent valve (control valve) to adjust the alkali reagent input rate based on the magnitude of the error. This allows the require quantity of alkali reagent to enter and neutralise the solution mixture. The mixing agitator's job is to initiate the reaction by mixing the alkali reagent to obtain a uniform mixture in the system.

To consider how this feedback control strategy could be implemented, a block diagram (closed loop) for the pH-neutralisation mixing tank control system is shown in Fig. 2. For the neutralisation mixing tank under feedback control (Fig.1), the exit pH y is controlled and the alkali reagent flow rate r_2 of the alkali type is adjusted using proportional control. The operation of this feedback control system can be summarised as follows:

(i) *Analyser and transmitter*: The mixing tank exit pH is measured by an analyser and then the measurement is converted to a corresponding electrical current signal by a transmitter.

(ii) *Feedback control*: The controller performs three distinct calculations. First, it converts the actual pH set point X_{sp} into an equivalent internal signal i_{sp}. Second, it calculates an error signal $e(s)$ by subtracting the measured value $y_m(s)$ from the set point i_{sp}, that is $e(s) = i_{sp} - y_m(s)$. Third, controller output $c(s)$ is calculated from the proportional control law.

(iii) *Control valve*: The controller output $c(s)$ in this case an electrical current signal is sent to the control valve (alkali reagent valve) to adjust the valve stem position, which affects flow rate $r_2(s)$.
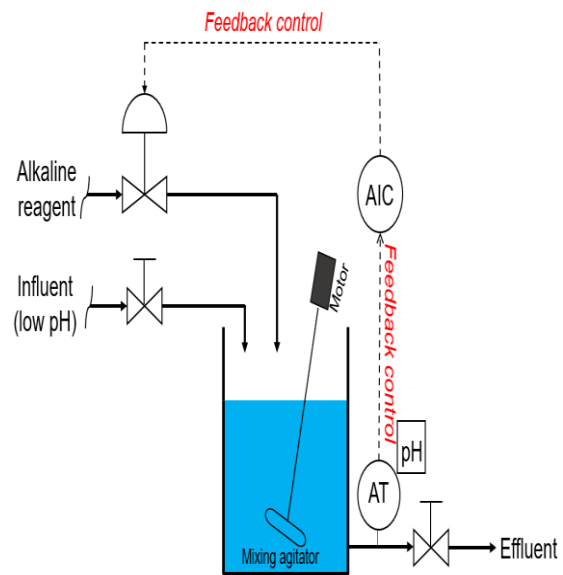

Fig. 1 Process and Instrumentation Diagram (P & ID) for pH Neutralisation System
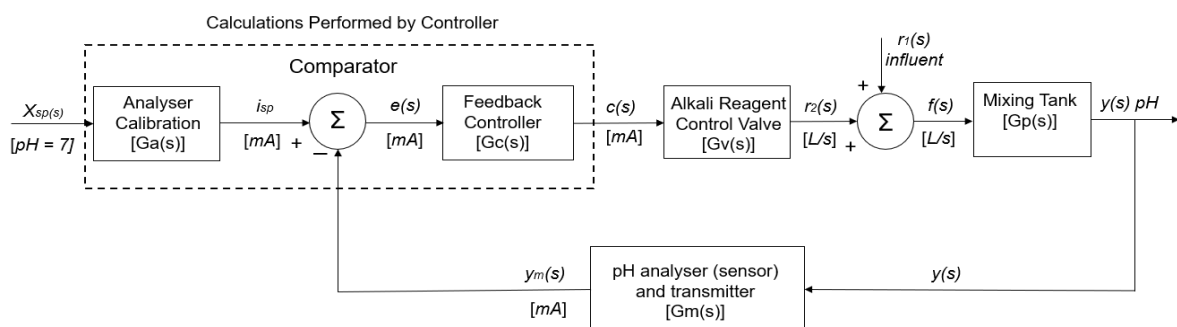

Fig. 2 Block Diagram for the Effluent pH Neutralisation Feedback Control System in Fig. 1

The mathematical expression or the transfer function showing the closed loop response (Fig.2) is given by Eq. 1:

$$y(s) = \frac{Ga(s)Gc(s)Gp(s)Gv(s)}{1+Gm(s)Gc(s)Gp(s)Gv(s)} \cdot Xsp(s) + \frac{r_1(s)Gp(s)}{1+Gm(s)Gc(s)Gp(s)Gv(s)}$$

(1)

where; $Ga(s)$ is the transfer function of analyser calibrator in the controller, $Gc(s)$ is the transfer function of the controller, $Gv(s)$ is the transfer function of the valve or actuator, $Gp(s)$ is the transfer function of the process in the mixing tank, $Gm(s)$ is the transfer function of the senor (feedback) and $f(s)$ is the total flow mixture of acidic liquid waste and alkali in the mixing tank.

2.1.1 Potential (Power) of Hydrogen (pH)

Neutralisation is the process of adjusting the pH of water through the addition of acid or a base, depending on the target pH and process requirement. The pH of a solution is defined as the negative logarithm of hydrogen ion concentration of the solution mixture. It is very convenient to measure the acidity or alkalinity of the solution by using the logarithm of the concentration of hydrogen ions, (log H^+) Eq. 2, rather than the concentration (H^+) itself.

$$pH = -log_{10}[H^+]$$

(2)

Based on this concept and Eq. 2, the scale for measuring the acidity or alkalinity of a solution is between 1 and 14. At 25°C, if the pH value is below 7 the mixed solution has a higher concentration of hydrogen ions and thus the solution is acidic (Christian, 2004). If the pH value is 7, it shows that the mixed solution is neutral and if the pH value is more than 7, it indicates that the solution is alkaline and contains higher concentration of hydroxide ion. The process of neutralisation is not only limited to bringing the pH to 7; it is invariably used in the processes, where pH adjustment to other than 7 is required depending on the chemical process in question (Goel *et al.*, 2005). For example, some processes like biological wastewater treatment require pH to be near neutral, whereas other processes like metal precipitation require pH to be in the alkaline range (Chen and Yu, 2000; Chen and Wang, 2001).

2.2 Design and Testing of pH-Neutraliser

The main purpose of the software is to ensure that the pH of an industrial effluent is neutral before discharge into the environment, to meet regulatory requirement. This is achieved by adjusting an alkaline supply valve to the required percentage to achieve the desired value.

2.2.1 Reagent Supple Rate

The rate at which the alkali reagent required to be added per seconds to the wastewater to obtain the neutral point is shown in Eq. 3. The rate depends on the percentage at which the valve must be opened (Rottier and Inc, 2003; Minkah *et al.*, 2018):

$$R = \frac{F}{V} \times C_s$$

(3)

where; R is the rate at which the alkali reagent must be added to the solution in the system (mL/s), F is the flow rate of the wastewater into the treatment system (L/s), V is the volume of water used in the test (L) and C_s is the amount of alkali reagent needed to neutralised the test influent (mL)

2.2.2 Transmitter Signal- Measured Value Conversion

Eq. 4 was used in the program to convert the transmitter signal (mA) to the measured pH so that it can be compared with the set point (Kuphaldt, 2008; Minkah *et al.*, 2018):

$$MV = \left(\frac{M_s - LRV_s}{S_s} \times S_m\right) + LRV_m$$

(4)

where; MV is the measured pH value, M_s is the measured electric signal, S_s is the span of the transmitter electric signal, S_m is the span of the measured pH, LRV_s is the lower range value of the transmitter signal and LRV_m is the lower range value of the pH measurement.

2.2.3 Error Correction

The error in the system is the difference between the measured value and the desired value (set point = 7). The error correction which account for the valve correction depends on the rate at which alkali must be added to achieve the set point as shown in Eq. 5 (Minkah *et al.*, 2018):

$$Valve\ correction = /(SP - MV) \times R/$$

(5)

where; SP is the set point pH, MV is the measured value pH and R is the rate at which alkali reagent is added to neutralised the acidic wastewater in the system.

2.3 Design of pH-Neutraliser

The interface of pH- Neutraliser was designed using common Visual Basic (VB) properties and controls such as textboxes, labels, track bar and radio buttons in the simulation section of the interface. These were

used to show the flow of industrial influent into pH control process chamber and the percentage by which the reagent valve is opened to release appropriate amount of reagent to obtain neutrality. The interface also has open or close buttons acting as the outlet valve which controls the flow of effluent into the environment. The button opens only when the set point is achieved. The user input section was also designed using VB controls such as:

(i) Textboxes to accept parameters of the system from the user
(ii) Radio buttons to select the mode of operation of the system
(iii) Labels to inform the user about the system parts
(iv) Buttons to start, stop, continue and reset the treatment process

2.4 Coding

The codes were written with Visual Basic (Visual Studio 2013). It is made up of many declaration statements, conditional statements (If-then statements), comparison of parameters and conversion of parameters in order to ensure effective operation of the software. About seven hundred (700) lines and thirty-three (33) columns of programming codes were used to build the application's interface. Fig. 3 below shows the flow chart of pH-Neutraliser.

3 Results and Discussion

The pH neutralisation software was developed to mainly measure the magnitude of an acidic influent and to ensure that the pH of the influent in the treatment tank is made neutral (thus at pH 7) by adjusting an alkaline reagent supply valve. When the setpoint pH is achieved, the neutralised water is discharge as effluent into the environment to avoid pollution. The basis of operation of the pH-neutraliser application is based on the principles of the process and instrumentation diagram (P&ID) shown in Fig. 1 which forms the fundamental framework guiding the operation of the software. pH-neutraliser operates in both manual and automatic mode using feedback control mechanisms. The feedback mechanism (which occurs in the contact chamber after the analytical transmitter measures the solution pH) ensures that the error is corrected in order to achieve the set point value.
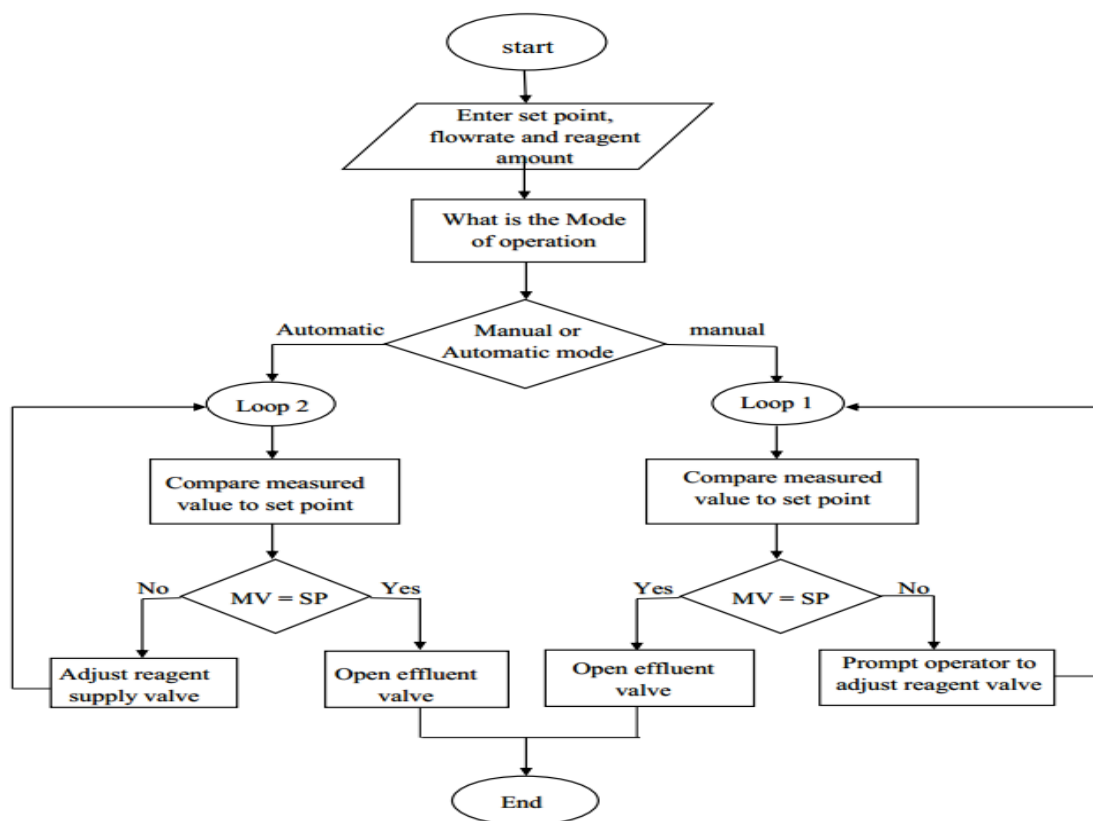

Fig. 3 Flow Chart of pH-Neutraliser

In the manual mode, pH-neutralizer has been designed to measure the pH of the solution in the contact chamber, trigger an alarm to alert an operator and suggesting the percentage by which the alkaline reagent valve has to be adjusted to achieve the set point when there is deviation. In the automatic mode, pH-neutraliser has been designed to measure the solution pH in the contact chamber with aid of Analytical Transmitter (AT) which should send the measured value in the form of electrical signal to a controller. The controller compares the measured value to the set point, if there is deviation and then automatically adjusts the alkaline reagent valve to the required percentage in order to achieve the set point.

3.1 Graphic User Interface (GUI) of the pH-Neutraliser

The pH-neutraliser application has an interactive and simple interface which was designed using Visual Basic control properties as shown in Fig. 4. It also comprises of simulation portion model with assumed numerical values to represent the real-world system. The simulation section mainly consists of controls (such as the progress bar) to show the flow of acidic influent into the system and radio buttons to allow the flow of neutral effluent out of the system into the environment. During the running process of pH-neutraliser, the progress bar depicts the influent and effluent flow with a green colour code. The vertical lime colour mounted on the mixer chamber indicates the flow of alkaline reagent into the system. The interface has controls which accept user inputs or actions to perform certain task. Other controls such as labels and the picture box found on the GUI provides information about the system to the users. Fig. 4 shows the initial Graphic User Interface (GUI) of the pH-neutraliser application after loading (when the flow has not started).

3.2 User Controls

3.2.1 Buttons

The software application employs basic buttons such as the Start, Stop, Continue, Reset and Accept buttons. When the start button is clicked, the feed water starts to flow through the influent pipe, the stop button stops the flow of water in the simulation section, the continue button makes the fluid in the simulation section resume its flow and operation and the reset button clears the pipes in the simulation section. The accept button in the Analytical Indicating Controller also serves as the input option for the sensor's output.

3.2.2 Radio buttons

Radio buttons in the software are used to select the mode of operation, thus whether the operation is manual or automatic. Visual basic has no valve object in the control properties, hence radio button is used to represent the state of the outlet valve (opened or closed).

3.2.3 Textbox

The software also has textboxes to take the inputs of the user such as the Set point and measured value. These textboxes were programmed to reject alphabets and other non-numeric characters to ensure efficient operation and also notify the user when the set limits for the parameters are exceeded.

3.3 Conditional Interface of pH-Neutraliser

The pH – Neutraliser application was tested with constant values to simulate how the application operates in the automatic and manual modes and the various conditions for which measured value (MV) deviation from the set point (SP) could be corrected to obtain the desired value. The assumed values chosen within the limit are as follows: Set point = 7 pH, Flowrate = 10 L/s, Test volume = 20 L, Alkali amount = 15 mL.

These constant parameters would initially cause the alkali valve to open by 38%, which basically means that the 38% open allows some alkali reagent to enter the solution mixture.

3.3.1 Demonstration of pH-Neutraliser

When the various input and conditions are selected and the start button is clicked, acidic influent (colour code green) flows into mixing chamber where alkaline reagent (lime colour code) is added and mixed to obtain uniform water mixture. The addition of the alkaline reagent is confirmed by the initial opening of the alkaline supply valve of 38% (based on the simulation conditions discussed in section 4.3). The water treated with alkaline then flows into the contact chamber where there is a pH transmitter to measure and record the pH of the treated water as shown in Fig. 5. How the simulator application responds to changes to the lime supply rate valve to achieve the set point (neutral pH) depends on the mode of operation.
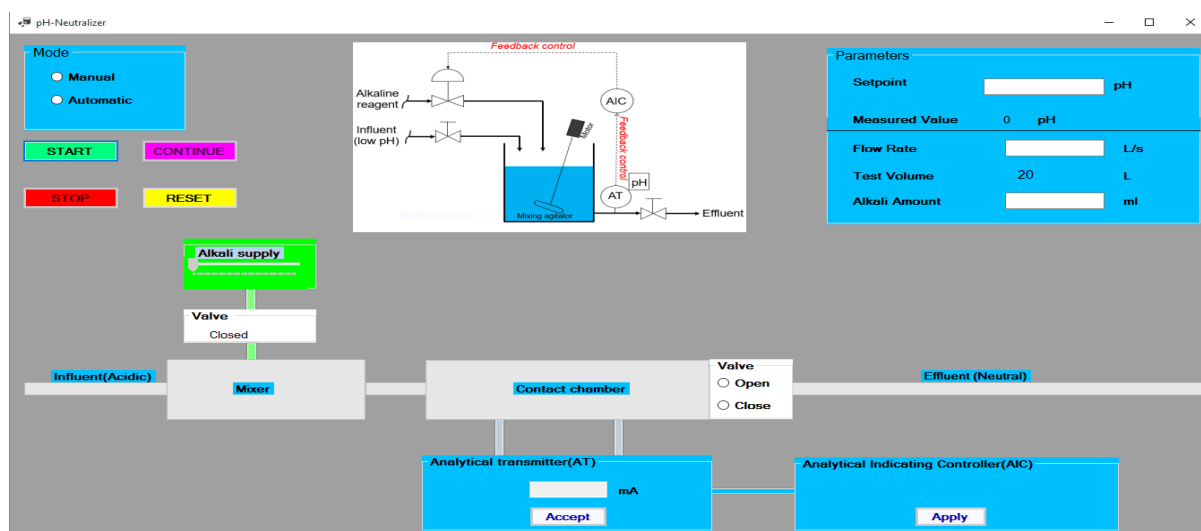
Fig. 4 Initial Interface of pH-Neutralizer Application

Automatic mode

Assuming after the addition of lime at 38% lime supply rate for the parameters entered in Fig. 5, the transmitter measured a signal of 9 mA (which represents 4.38 pH), meaning the water is still acidic after clicking on the accept button. The application automatically adjusts the alkali valve from 38% to 45% to increase the alkaline amount per second in order to achieve the set point by clicking on the continue button as shown in Fig. 6. When the measured value becomes equal to the set point value, the outlet valve then opens for the treated water at pH 7 to be discharged into the environment.

Manual mode

In the manual mode, the analytical indicator controller's (AIC) role is played by human operator. The system alerts an operator to open the outlet valve to discharge the effluent when the set point is equal to the measured value. It also notifies the operator when the measured value is less than the set point by sounding an alarm and reading out the percentage by which the operator should adjust the alkaline valve in order to achieve the set point. It gives the user the option of accepting that suggestion by clicking on the *apply* button. Clicking on the *apply* button adjust the reagent valve to the suggested percentage for which the set point could be achieved. Fig. 7 shows the interface when the system suggests the percentage for which the reagent valve should be adjusted so as to achieve the set point (pH of 7). For the same measured value signal and pH as in the automatic mode, the operator clicks on the *apply* button and the reagent valve percentage changes to the suggested percentage (7% approximation). Double click on the *continue* button gives the total percentage the alkaline valve opens (45%) for which the set point could be achieved. The outlet valve then opens to discharge the solution as shown in Fig. 8.
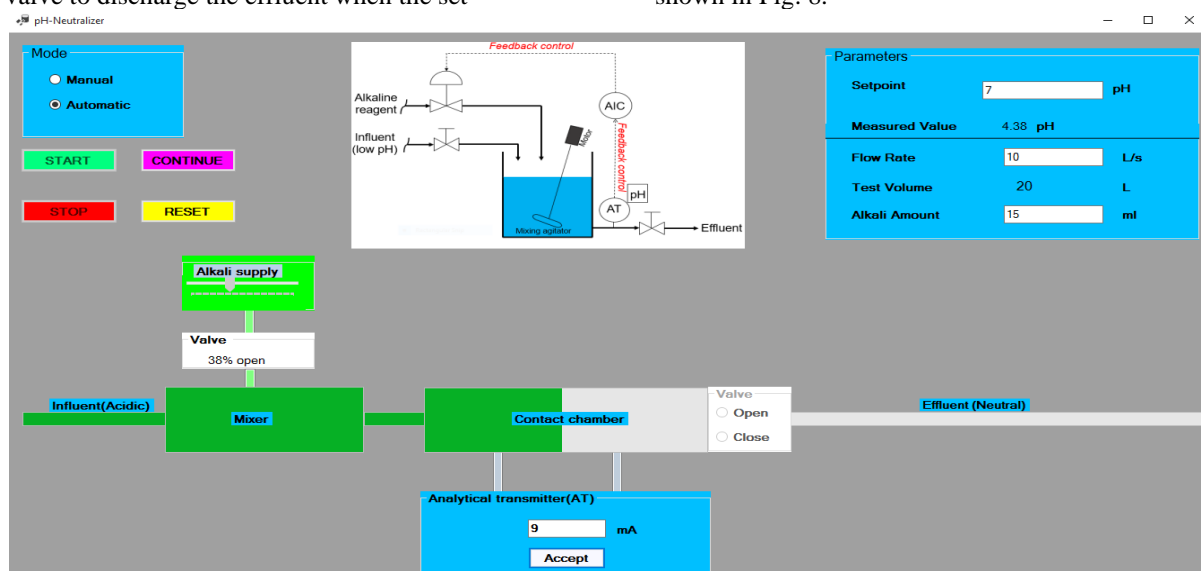

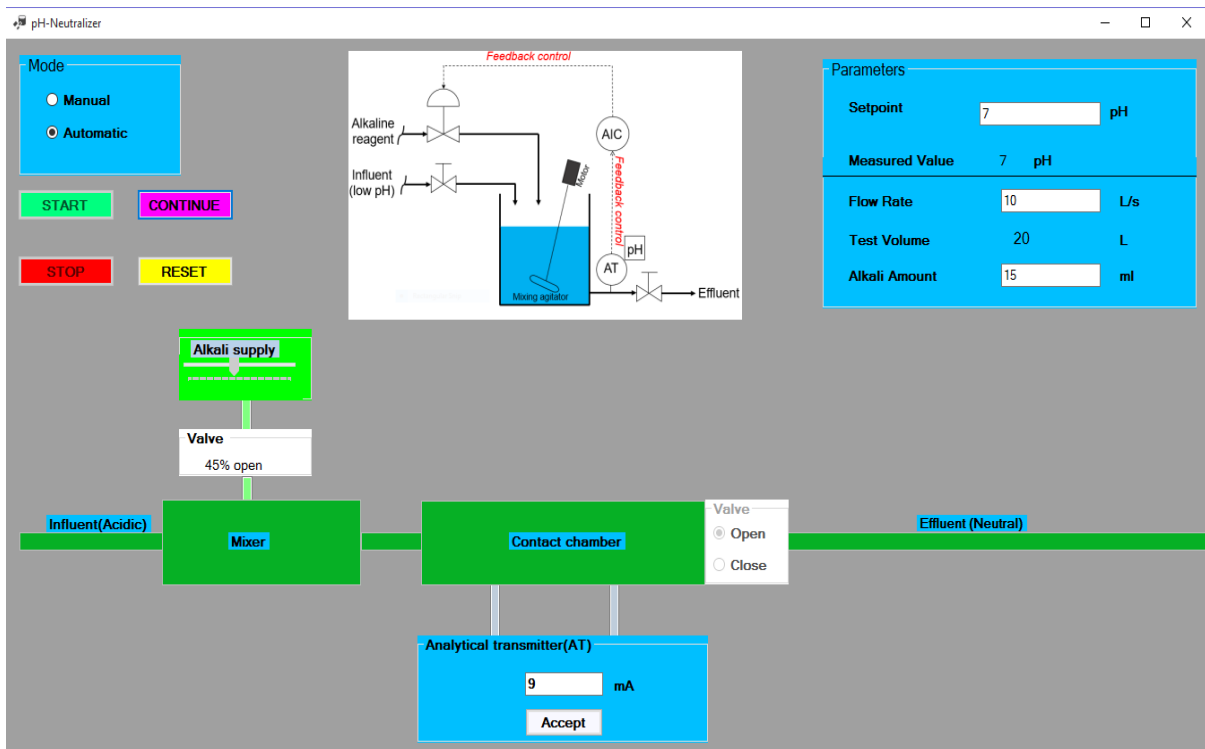**Fig. 5 pH Neutraliser Measuring 4.38 pH of the Effluent (Automatic Mode)**

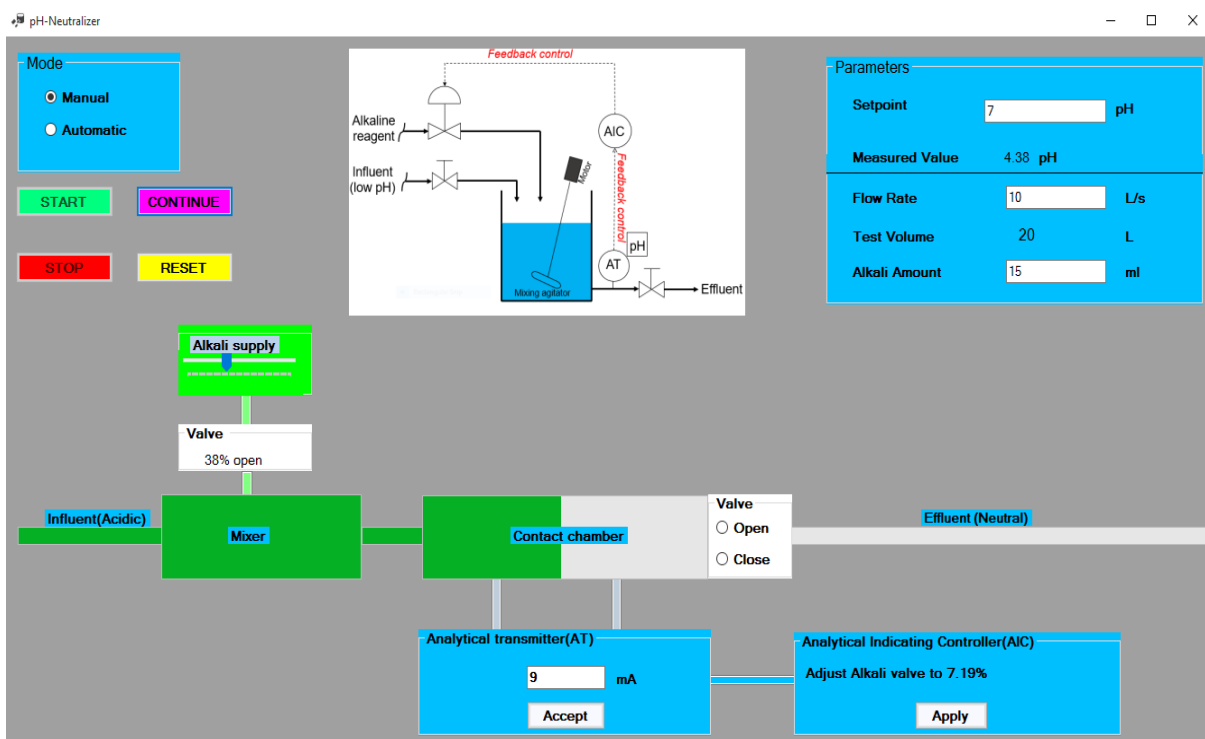**Fig. 6 pH Neutraliser Adjusting 4.38 pH Of the Effluent with Alkaline (Automatic Mode)**

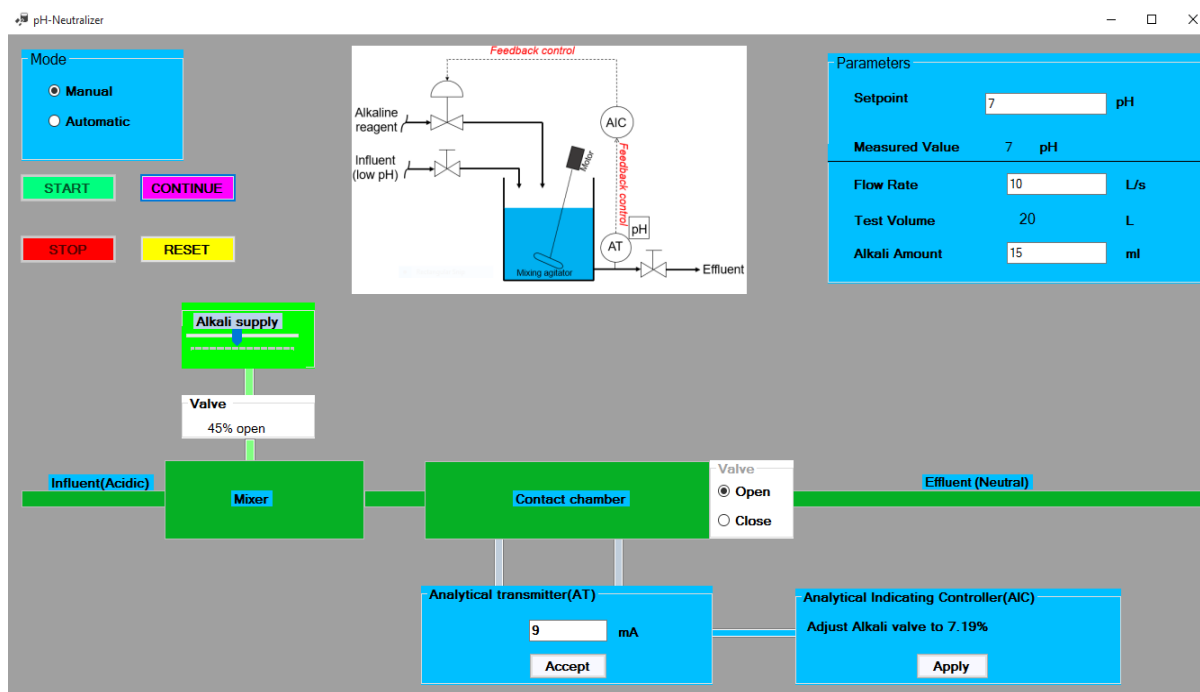**Fig. 7 pH Neutraliser Measuring 4.38 pH of the Effluent (Manual Mode)**

Fig. 8 pH Neutraliser Adjusting 4.38 pH Of the Effluent with Alkaline (Manual Mode)

3.4 Limitations of pH-Neutraliser

The track bar property in visual basic is discrete, hence the application works by rounding the valve percentage (%) output to whole integers. The parameters of the application also work in the following range,

    (i)   Set point: 6.5 – 8.5 pH

    (ii) Measured value: 0 – 14 pH (pH scale)

    (iii) Flowrate: 0.5 – 15 L/s

    (iv) Volume of liquid waste used in the test: 20 Liters

    (v) Amount of alkali reagent needed to achieve set point: 0 – 20 mL

4 Conclusion

A pH neutraliser control simulator application has been developed using Visual Basic programming language (VB) for the purpose of neutralising industrial acidic wastewater to pH 7 before discharge into the environment. It is an interactive control application that measures, alerts and/or controls the pH of an industrial wastewater to the desired value using the basic principles of instrumentation and control. The control simulator application with a user-friendly graphical interface can simulate both manual and automatic pH neutralisation control of industrial wastewater using the feedback control mechanism. The application was developed to enhance instrumentation and process control education with the aid of simulation. This was done to motivate, help students with visualisation and hands on practice with a broad range of meaningful experience in a safe and efficient process in the field of environmental science and engineering.

Acknowledgements

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Authors

S. Fosu is currently a Lecturer at the University of Mines and Technology, Tarkwa, Ghana. He holds a PhD in Minerals and Materials Engineering from University of South Australia and a BSc in Minerals Engineering from University of Mines and Technology, Tarkwa, Ghana. He is a member of Institute of Chemical Engineers (IChemE), Australia. His current research interests include Mineral Flotation Process, Ore Process Mineralogy and Characterisation, Aqueous Metallurgy and Interfacial Chemistry, Environmental Chemistry, Environmental Management, Instrumentation and Computer-Aided Process.

E. Danuba is a graduate of the University of Mines and Technology (UMaT)- Tarkwa. He holds a BSc (Hons) in Environmental and Safety Engineering. His research interests include pH-Neutralizer modelling, and liquid waste management. He is a member of the Ghana Institution of Safety and Environmental Professionals, Ghana Institute of Engineers, and Australian Institution of Mining and Metallurgy.

F. Krampah is currently a Lecturer and a PhD candidate at the University of Mines and Technology, Tarkwa, Ghana. He holds an MSc. In Safety, Health and Environmental Management from the University of South Wales, UK, A certificate in Loss Prevention and Safety Promotion from the University of Wuppertal, Germany and a BSc in Environmental Science, from the University of Cape Coast,

Ghana. He is a member of Occupational Safety and Health Africa Foundation (OSHAfrica) and the Ghana Institute of Safety and Environmental Professionals. His research interests are in the areas of Risk Assessment and Management, Safety Promotion and Loss Control, Environmental and Social Impact assessment, Industrial Toxicology, Safety Management Systems and Audit and Environmental Monitoring.

T. Joe-Asare is a Teaching and Research Assistant and PhD candidate at the University of Mine and Technology (UMaT), Tarkwa, Ghana. He holds a BSc in Environmental and Safety Engineering from (UMaT), Tarkwa, Ghana. He is a member of Ghana Institute of Safety and Environmental Professionals, Red Cross Society and Society of Petroleum Engineers. His research interest is in the areas of Fire Risk Assessment, Occupational Hygiene, Accident Investigation and Control and Environmental Sampling and Monitoring.