Design and Evaluation of a Control Water Treatment Quality System Based on Chemical Addition Process

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Abstract: Most of countries have been suffering from the problem of water quality requirements. Automation control plays an essential role in water treatment plant that secures the necessary qualities and quantities of water with high level of efficiency. This paper presents the real-time control systems that measure the water parameters, then accordingly adjusting the addition of chemical materials used in water treatment. Sensors devices readings are used as inputs to the microcontrollers and PLC. An algorithm was designed to calculate the required doses from purification and disinfection chemical materials. The control system has been successfully simulated; therefore the obtained results prove the reliability and applicability of the system with more advantages at similar areas. .

Keywords: Water treatment, Real-time application, Chemicals addition, Sensors, PLCs.

Introduction

Nowadays there is a growth in population, and in the requirements to provide adequate drinkable water supplies with the hygiene conditions (Osman, 2015). In order to attain these requirements, the need emerged to apply automation control system in the water treatment plants to assure a higher possible quality of treated water.

Most modern factories have adopted automation in order to provide better quality control and to meet manufacturing standards of today (Dotoli, 2017). However, automation control is being now a crucial part of any development system (Cecílio, 2013). In this era, the recent revolution brought the market with one of the most practical, cheap and simple to configure a computerized device which is Programmable Logic Controllers (PLC) (Chakraborty, 2016). As shown (See Figure 1), the system has ability to be connected with input instruments which are widely used for measuring any parameter or via outputs controlling the mechanism of any system that is under operation. The inputs such as sensors respond to the physical input applied and give the electrical output that carries information (McGrath, 2013). The outputs represented by an actuator, which is a component of a machine that is responsible for moving or controlling the mechanism or the system, according to the tasks issued by PLC (Vanderborght, 2013).

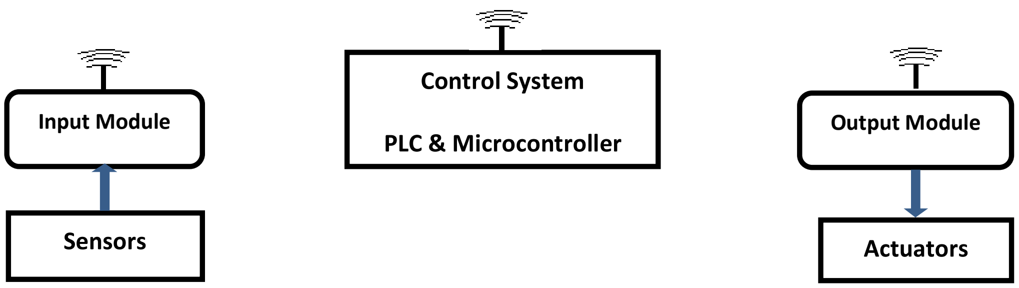

Figure 1: Control System Demonstration

To communicate with peripherals, the PLC started using wired cables. Later, the wireless technology was invented and being used as one of communication mediums. XBee module is the most common in use as a data transmitter and a receiver wireless device. It is resilient, easy configurable with other XBees in a network, and compatible interfacing with computers and microcontrollers (Sparkfun, 2016). In such systems, in order to reduce the overload on the PLC, the microcontrollers as programmable input/output electronic circuits can be used to carry out a vast range of tasks (Simpkins, 2013). Therefore, it is used as an interface device to communicate data with sensors and communication module.

The water treatment

The standards of water quality and quantity are necessary for survival and reduce the risk of disease. The main health problems associated with drinking water contamination are caused by insufficient water for hygiene purposes and consumption of that contaminated water (WHO, 2004). There are two standards defined for water supply standards. The first standard involves the quantity of water, while the second standard regulates water quality (Ray, 2014). The minimum amount of water for safe and healthy consumption is summarized by around 7.5 to 15 Liters of water per person per day. Water quality is a secondary standard, according to the (Ray, 2014). Once water quantity has been assured, water quality should be improved to reduce the risk of dysentery and other diseases. The quality parameters include Coliforms, Turbidity, and Chlorine residual are specified as the minimum standards that must be met by water treatment technologies.

Therefore, this work intends to enhance the quality of water treatment plant by controlling its affecting parameters using measuring instruments that adjust the clarification and disinfection chemical materials addition. Besides, the instrument's readings are used to determine the time needed for water to stay in sedimentation basin so as to regulate the production.

P**roposed Control System Design**

To implement this system, a control system using a PLC has been suggested to accomplish this process in order to raise quality to the best possible level without misuse of chemical materials. Mainly, the modification focuses on improving the quality of treated water in plant using measuring instruments to measure parameters that affect this quality. Depending on the readings, the accurate doses from chemical materials which are used for water sedimentation e.g. Poly Aluminum Chloride (PAC) and disinfection e.g. Chlorine gas ($Cl2$) will be determined (Okuda, 2014). Accordingly, pumps are used to inject the corresponding doses to the water. Therefore, it is important that automated system must efficiently work to guarantee the healthiness of the produced water, prevent possible fatal error or even disasters that might affect people, as well as, to reach the maximum level of production (Haight, 2005). Figure 2 illustrates the water plant structure and the samples of control instruments that should be installed (Ali, 2007).

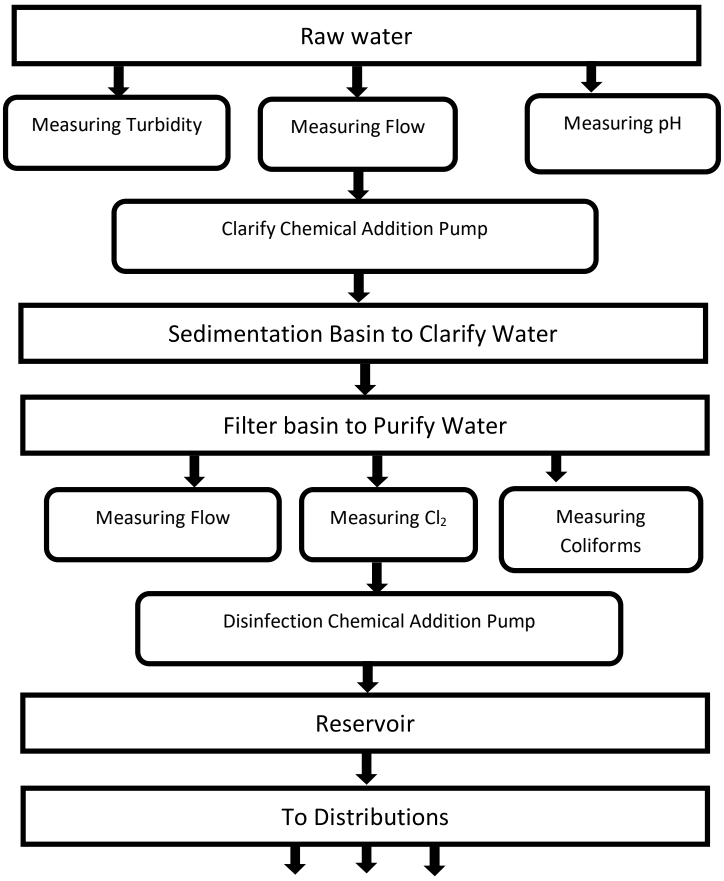

Figure 2: Water Treatment Proposed Control Instruments

Control System Implementation

This section gives the general description of the developed water treatment system. The system contains the proposed control to be implemented as demonstrated in Figure 3.

In the control system the sensors, with different functions has been used. Sensors used to read water turbidity, flow rate, pH, and resident chlorine are connected directly to microcontroller. The microcontroller used a designed algorithm to calculate the required doses from clarification and disinfection chemical materials to be added to water in real-time application mode, and sends appropriate signals to the central PLC via a wireless communication module. The PLC generates the corresponding output pulses and communicates with actuators that govern the working dosing pumps. These dosing pumps have broad range of flow rate in litters per hour (l/h) (Milton, 2017).

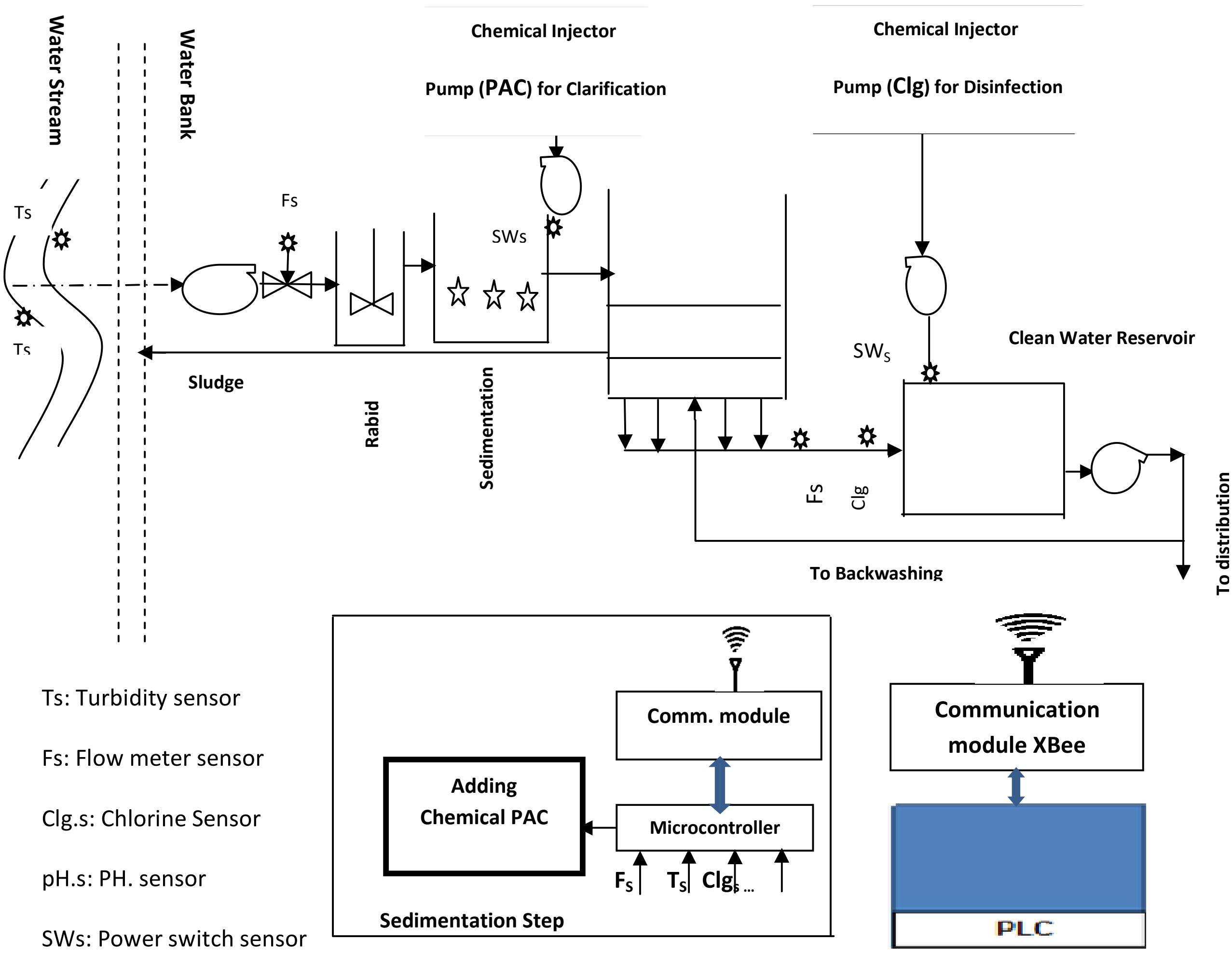

Figure 3. The Proposed Control System for Water Treatment

The following is a designed algorithm works to calculate the required doses from purification and disinfection chemical material used in water treatment plants.

Algorithms: Water clarification and disinfection materials calculation

For $i = 0$ ***to*** ∞ ***do***

Input: *read* (T_{S1}, T_{S2}) , *read* (F_{m1}, F_{m2}) , *read* ($Ref._{Cl2}$) , *read* (F_{m3}) , *read* ($Ref._{Dose}$)

Calculate:

T_S *Average* (T_{S1}, T_{S2})

F_m *Average* (F_{m1}, F_{m2})

Convert water rate (W_{rate}) *to water volume* (W_{volume})

$$W_{volume1} = W_{rate1} \cdot t$$

$W_{volume2} = W_{rate2} . t$

Clarification (e.g. Ploy Aluminum Chloride) injection)

Calculate the dosing $Clar_{dose}$

$$Clar_{dose} = Ref_{\cdot Dose} \times T_S \times W_{volume1}$$

Set injector control pulse P_{C1}

Calculate injection time T_{i1}***:***

$$T_{i1} = \frac{Clar_{dose}}{Injector_{rate}}$$

Output: *pulse control* P_{C1} *(To drive injector)*

P_{C1} = *pulse modulation* (P_{i1} , T_{i1})

Disinfection (Residual chlorine injection)

Calculate the dosing (Di_{dose})

$$Di_{dose} = Ref_{\cdot Cl2} \times W_{volume2}$$

Set injector control pulse P_{C2}

Calculate injection time T_{i2}***:***

$$T_{i2} = \frac{Di_{dose}}{Injector_{rate}}$$

Output: *pulse control* P_{C2} *(To drive injector)*

P_{C2} = *pulse modulation* (P_{i2} , T_{i2})

End

Results and Discussions

In this section the results obtained from the simulations of the model developed using MATLAB will be presented. The modeled system was successfully executed. The simulation program fed with measured data of water quality values, and then generated the required doses in four modes of injection methods at differ in times.

Figure 4 shows the time relation between the flow rate and the injected doses of materials in mg/L. The system collects the values of turbidity and flow rate intervals of 10, 20, 30, and 40 Seconds. These obtained reading values are feed the modes from one to four consequently. According to the equation used in the model mode 1, the injected purification material was due to the optimal dose, this is presented (See Figure 4) with black graph. The system injected doses in the other modes (2, 3, 4) varied from the required value in respect to the time differences specially in mode 4 (green graph). For example, in case of 45 Litter/Sec flow rate, mode 4 injects excess material by around 30 mg, mode3 injects less material by around 20 mg, while at 80 litter/sec flow rate, mode 4 injects less material by around 60 mg from the reference mode (mode1). Therefore, according to the frequent changes in water turbidity and flow rate, the injection at higher rate (mode 1) is likely to be accurate and close to optimal dose.

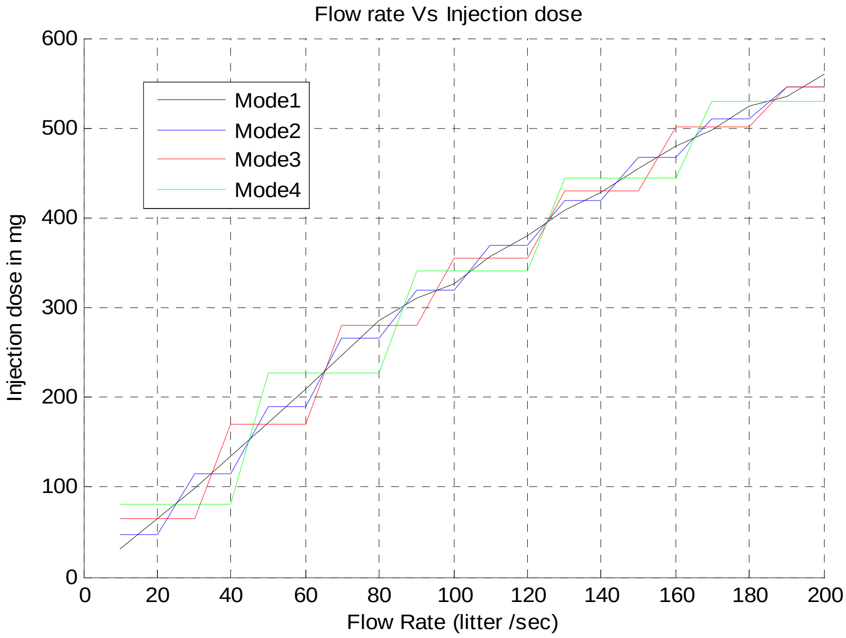

Figure 4: The Relation in Time Between The Flow Rate and The Injected Doses

Figure 5 illustrates the efficiency of the four modes according to the change in flow rate and random values of turbidity. In mode1 as nominated to be the optimal reference mode, the efficiency represented (See Figure 5) by (black graph) bounded between 83 to 87 % , so that the system in mode 1 is likely to be stable. In mode 2 which is represented by blue graph, the efficiency is bounded between 80 to 90 % but there are large fluctuations. The remaining higher modes gave unstable and poor efficiency fluctuated between 0 and 95 % .

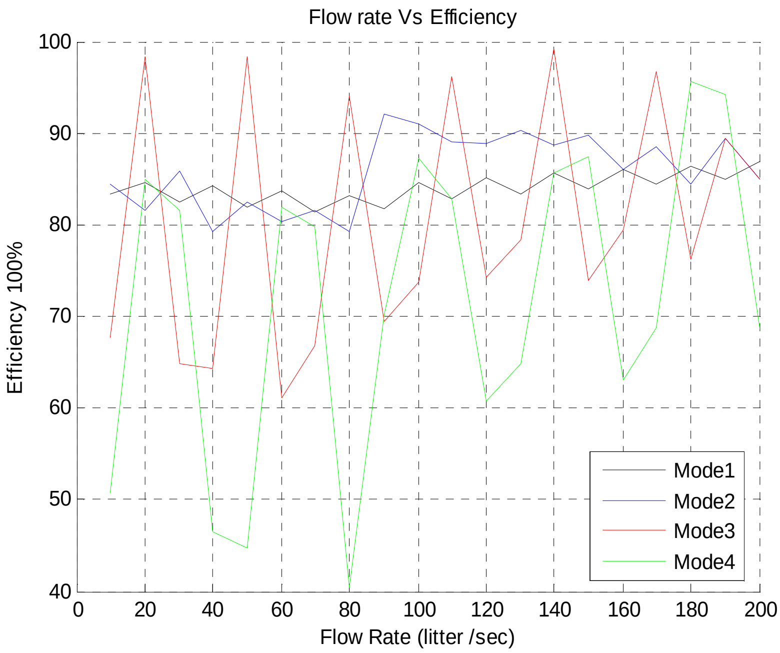

Figure 4: The Relation Between Injection Efficiency and The Flow rate

Conclusion

The paper addressed the problem of misuse of chemical materials in water treatment plants caused by frequent water quality changing. The readings of turbidity, flow rate, pH, and resident chlorine sensors are used as inputs to the microcontroller and PLC. Then a designed algorithm used to calculate the required doses from purification and disinfection chemical materials and added to water in a real-time application mode. The developed control system has been successfully evaluated, where the obtained simulation results prove the applicability of the system to replace the traditional Jar Test which conducts every two hours in water plants. It can be concluded that when the system reads and injects in high rate (mode 1), it will be more accurate and come close to optimal.

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