ZIBELINE INTERNATIONAL PUBLISHING
ISSN: 2616-4302 (Online)
CODEN: AMMCFL

Acta Mechanica Malaysia (AMM)

DOI: http://doi.org/10.26480/amm.01.2023.25.28

REVIEW ARTICLE

AUTOMATION OF A SMALL-SCALE INDUSTRIAL WATER PURIFICATION PLANT

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ARTICLE DETAILS

Article History:

Received 22 November 2022
Revised 30 December 2022
Accepted 02 February 2023
Available online 05 February 2023

ABSTRACT

Safe potable water for human use has become an emerging concern in this era. A Programmable Logic Controller (PLC) based automatic water treatment plant has been designed to remove unexpected materials from water and to confirm drinking quality of water. The conventional methods used in older times result into problems like empty running, dose and coagulation control, overflow, leakage etc. The operations of the plant such as water intake from raw water tank, water intake for chlorination, mixing of chlorine water with raw water, and water feed into various treatment chambers are done automatically. For automation PLC and microcontroller are used to control the above-mentioned functions. The iron content is reduced to negligible amount and contaminations are removed to ensure safe, odorless, clean water.

KEYWORDS

Safe Water, Automation, PLC, Iron Removal, Filtration

1. INTRODUCTION

Water is a vital element for every living thing, but this water has to be safe. Less than 3% water is fresh of all the existing water in the world among which less than 1 % is accessible (Earth Water, 2022). Major portion of this accessible water is not safe for drinking directly from source without any treatment. Safe water is important not just for drinking but also for other domestic purposes like cooking, washing clothes, cleaning, bathing, etc. Food and beverage industries, dairy industries, pharmaceutical industries need safe potable water. Raw water may contain dissolved and suspended particles, microorganisms, arsenic, lead, mercury, and minerals. Microorganisms like bacteria can cause serious human disease. Arsenic is a toxic element which can cause cancer and cardiovascular diseases. Millions of people in Bangladesh are at risk of arsenic contamination through tube well water (BBS, 2009; Arsenic, 2022). Heavy metals like lead, cadmium, mercury have poisonous effect on human health which can cause cancer (Rahaman et al., 2022).

Minerals naturally present in water, such as calcium, magnesium, sodium, iodine, phosphorus, chloride, copper, zinc, etc. are very important for the human immune system; but excessive presence of these minerals can cause side effects. High iron in water makes the taste metallic. Besides the importance of iron as mineral, it has some adverse effects; excessive iron in water can be harmful for skin, can cause stains in clothes and household appliances, damages pipes, sinks etc. Arsenic can be removed by flocculation and microfiltration process (Ziarati and Albaji, 2013). In Satkhira district, southwestern part of Bangladesh, arsenic content in 49% of tube well water reached up to 167.9 μg/L which exceeds the maximum contamination level from the guideline of World Health Organization (WHO); iron and chloride content was 10.01–13479.6 μg/L and 29.3–9987.01 mg/L respectively (Han et al., 2002). Using iron oxide coated sand filtration, arsenic level reduces to 5μg/L of drinking water (Rahman and Hashem, 2019).

A study in Jashore district reveals that iron concentration in 73% tube well water and manganese concentration in 87% tube well water exceeds the standard limit of Bangladesh (Thirunavukkarasu et al., 2003). There are various technologies to reduce the iron concentration in drinking water. Biological strategies (using microorganisms), membrane technology such as reverse osmosis, ultrafiltration, and microfiltration, nanotechnology (using carbon nanotubes), and other conventional strategies such as oxidation-precipitation-filtration process, zeolite softening/ion exchange, calcium carbonate-based materials, filter media separation, removal through supercritical fluid, by redox technology, solid sorption separation, wetland treatment, electrocoagulation, aeration, sequestration process are recently used technologies to remove the contamination of iron in water (Ghosh et al., 2020). Recently, automation is emerging in the field of water treatment plants. Programmable Logic Controllers (PLCs) and Supervisory Control and Data Acquisition (SCADA) based automation systems make complex system easier to control, cost effective, and reliable (Khatri et al., 2017). The major focus of this study is automation of small-scale water treatment plant in industries.

2. MATERIALS AND METHODS

2.1 Sample Collection and Primary Testing

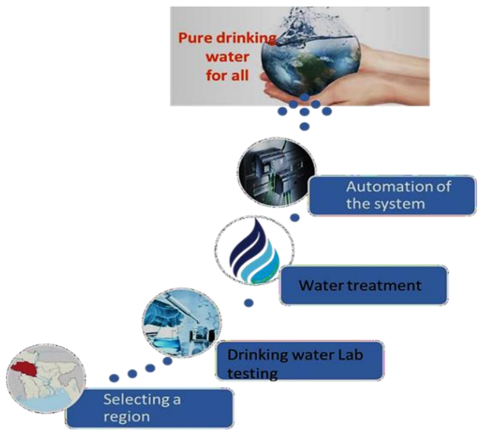

Figure 1: Details of the methodology

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Cite the Article: Md. Khorshed Alam, Shahajada Mahmudul Hasan, Md. Nahid Hossain (2023). Automation of A Small-Scale Industrial Water Purification Plant. *Acta Mechanica Malaysia, 6(1): 25-28.*

The research was carried out in Thakorgaon district, north-western side of Bangladesh. Raw water for treatment was collected from Thakorgaon Polytechnic Institute. The collected sample was tested in Quality Control Laboratory, Dhaka, Bangladesh. Arsenic (As), iron (Fe), manganese (Mn), calcium (Ca), magnesium (Mg), sodium (Na), chlorine (Cl), P^H, total dissolved solids (TDS), salinity were tested in the laboratory. The detail of the methodology is shown in Figure 1.

Table 1: Test Result of Raw Water Sample

Parameter	Raw water Quality	Bangladesh slandered	WHO Standard
As	Nd	0.05	0.01
Fe	3.061 PPM (mg/L)	0.3-1	0.3
Mn	0.0112 PPM (mg/L)	0.1	0.01
Ca	15 mg/L	75	-
Mg	9.115 mg/L	30-35	-
Na	4.603 PPM (mg/L)	200	200
Cl	25 mg/L	150-600	250
PH	6.8	6.5-8.5	6.5-8.5
TDS	53.3mg/L	500	1000
Salinity	0.05%		

Table 1 shows that Fe content is more than ten times greater than the standard limit. So, Fe removal has become the major concern for this sample raw water, as other parameters are within limit.

2.2 Experimental Process

For the purification of this raw water an experimental setup is prepared where a few reservoirs and vessels are used for different processes. Inside the vessels some materials are used for purification purposes.

Figure 2: Materials used in different vessels for the water purification process.

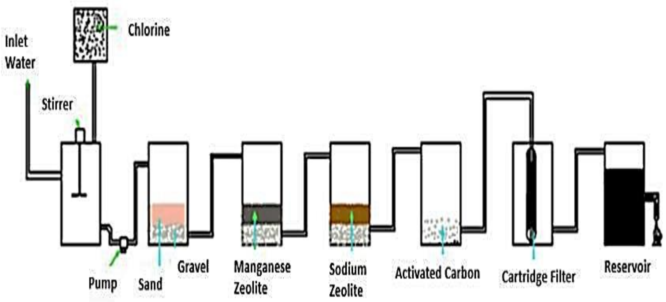


Figure 3: Schematic diagram of PLC based water treatment plant

Figure 2 shows the different materials that are used in different vessels for water purification process. The schematic diagram in Figure 3 shows the stages for treatment of raw water. Chlorine, manganese zeolite, sodium zeolite chemicals are used in three different stages, and sand and gravel, activated carbon, cartridge filter are used for other three stages of filtration process.

(a) (b)

Figure 4: Constructed water treatment plant with PLC

The water treatment plant was constructed for six stages of treatment process as shown in Figure 4. The treatment plant consists of various devices such as vessels, output nipple, pipe, solenoid valve, relay switch, suction pump, IR sensor, DC motor, etc. PLC, microcontroller, and power supply unit are attached with the melamine board shown in the Figure 4.

2.3 Chemical Processes in the Stages

There are six vessels containing chemicals and filters to perform water treatment in six steps, one vessel acts as reservoir of raw water and another vessel works as reservoir of purified water. Impurities present in water react with the chemicals and separated by screening process. Raw water enters the vessel by gravity force and mixes with chlorine mixed water which comes from another vessel. Solenoid valve is used to control the flow of raw water, and chlorine mixed water by predefined signal. Water level sensor is used which sends signal to the solenoid valve to start and stop the flow for predetermined water level. In the first step, chlorine is used as coagulant for disinfection and to remove foreign materials.

Reaction of chlorine with iron and manganese:

$$2Fe^{2+}+Cl_2+6H_2O \longrightarrow 2Fe(OH)_3+6H^++2Cl^-$$

$$Mn^{2+}+Cl_2+2H_2O \longrightarrow MnO_2+4H^++2Cl^-$$

An agitator is used for stirring to mix chlorine with raw water for 5 minutes. Then, the flow will stop for 10 minutes, as the chlorine contact time is considered 15 minutes. Contact time depends on the concentration of chlorine. So, less contact time requires higher concentration of chlorine; minimum 30 minutes contact time is recommended by WHO for residual chlorine concentration ≥0.5 mg/L and P^H level less than 8 (Deb, 2022). After 15 minutes, pump will start to pump chlorinated water into sand filter. This vessel contains sand and gravels. Sand layers are installed above the gravels in the filter to prevent sand from being lost during filtration. Passing flocculated water through sand filter, the floc and the particles trapped within it are strained out which reduces numbers of bacteria and removes most of the solids. After this filtration process, water enters the vessel containing manganese zeolite to remove dissolved and suspended forms of Fe and Mn. Manganese zeolite is used in conjunction with filtration methods to facilitate the removal of iron, manganese, and other substances from water. Iron and manganese are oxidized into insoluble form and filtered out. Manganese zeolite can be regenerated by reacting with potassium permanganate.

Reaction of manganese zeolite with iron and manganese:

$$Z\text{-}Mno_2+Fe^{+2} \longrightarrow Z\text{-}Mno_2+Fe^{+3}$$

$$Z\text{-}Mno_2+Mn^{+2} \longrightarrow Z\text{-}Mno_3+Mn^{+3}$$

Re-generation of manganese zeolite:

$$Z\text{-}Mno_3+KMn\ o_4 \longrightarrow Z\text{-}Mno_2$$

Filtered water enters the sodium zeolite (Na_2Z) softener vessel which is most widely used to exchange hardness ions with sodium. Hard water is percolated at a specified rate through a bed of zeolite; zeolite holds sodium ion loosely (Deb, 2022). Salts of calcium, magnesium in water react with sodium zeolite and ions (Ca^{+2}, Mg^{+2}) causing hardness and are trapped by zeolite.

Chemical reaction taking place in zeolite softener (Deb, 2022):

$$Ca(HCO_3)_2 + Na_2Z \longrightarrow CaZ + 2NaHCO_3\ Mg(HCO_3)_2 + Na_2Z$$
$$MgZ + 2NaHCO_3\ CaSO_4 + Na_2Z \quad CaZ + Na_2SO_4$$

$$CaCl_2 + Na_2Z \longrightarrow CaZ + 2NaCl$$

$MgSO_4 + Na_2Z \longrightarrow MgZ + Na_2SO_4$

$MgCl_2 + Na_2Z \longrightarrow MgZ + 2NaCl$

Sodium zeolites are converted into calcium, magnesium zeolites and zeolite becomes inactive which needs to be regenerated by treating with 10% brine (sodium chloride) solution.

Chemical reaction to regenerate sodium zeolite (Deb, 2022):

$CaZ + 2NaCl \longrightarrow Na_2Z + CaCl_2$ $MgZ + 2NaCl \longrightarrow Na_2Z + MgCl_2$

After softening process, water is passed through an activated carbon filter which removes organic matters and odor causing contaminants to some extent through adsorption process. In the final stage, the water passes through cartridge filter to remove remaining contaminants. Consumer collects treated safe water from the reservoir of purified water.

2.4 Automation Process

For this process, the following components is used: five vessels, three solenoid valves, agitator, three relay modules, three level sensors, one ultrasonic sensor, one IR sensor, inlet and outlet pipes, mechanical sockets, PLC CPU (which has 6 analogue inputs and 6 digital outputs).

Flowchart shown in Figure 5 has the following steps:

Step 1: When power supply is given, the raw water starts entering first vessel. The water flow is controlled by solenoid valve which is operated by a relay module with PLC CPU.

Step 2: When chlorine mixed water is mixed with raw water, an agitator is used for stirring to mix chlorine for 5 minutes. Then the flow will stop for 10 minutes to ensure chlorine contact time (15 minutes). This process is controlled by solenoid valve, where the solenoid valve is energized by a relay module using the PLC output signal.

Step 3: Suction pump is started by PLC output signal for a predefined time and push the chlorinated water inlet into second vessel which was previously filled by gravels and sand and first filtering is done.

Step 4: The water filtered by gravels and sand in previous vessel enters third vessel where the manganese zeolite performs the action to remove iron and manganese from the inlet water.

Step 5: The water flows into the next vessel by gravity force where the sodium zeolite performs ion exchange to remove heavy metal ions from the solution.

Step 6: The water enters next vessel where the activated carbon removes the contaminants, odor, and bad taste from water. A level sensor is used to sense the level of water in vessel; whenever the water level goes down, the PLC generates signal for first solenoid valve and relay module.

Step 7: The odorless and taste free water enters the next vessel with cartridge filter to reduce the remaining dirt and contamination of water.

Step 8: Finally, the water flows into the reservoir of purified water where the water will be ready to drink and safe for health. Here, two sensors are used, one for sensing objects (glass or bottle) where outlet water is collected, and another for sensing water level in glass or bottle which will prevent overflowing of water automatically. In this stage, a P^H meter is used to sense the P^H of water. If P^H value crosses the acceptable range (6.5-8.5), the plant will stop automatically with proper indication.

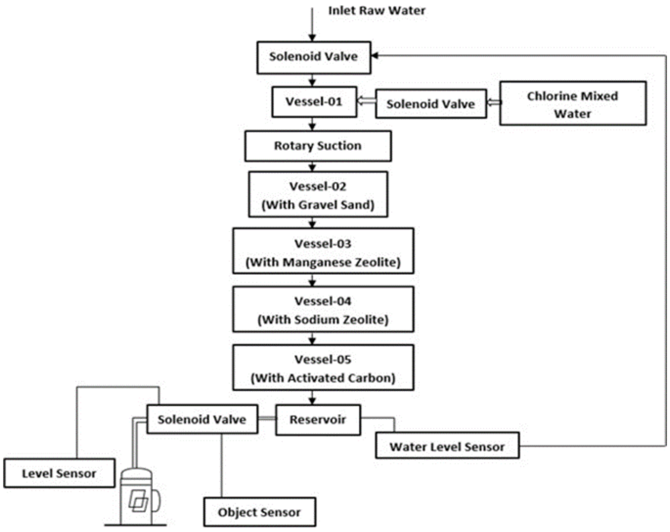
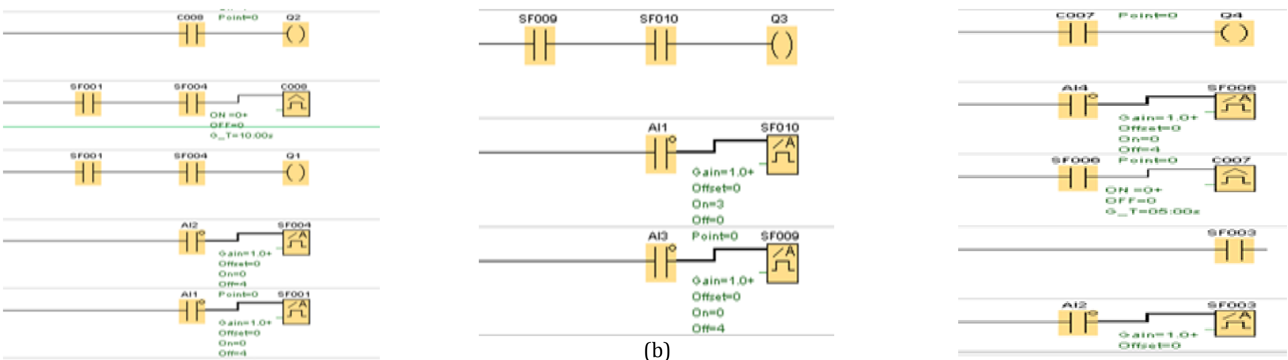


Figure 5: Flowchart for automatic water treatment plant

Ladder Logic Programs:



(a) (b) (c)

Figure 5: Ladder Logic Program for (a) chlorinated water flow control, (b) purified water collection, (c) P^H control.

A P^H Sensor is used to sense the P^H of water. ATMEL 32 Microcontroller Oriented Arduino is used to control PH of water. If P^H value crosses the acceptable range (6.5-8.5), a signal will generate.

3. Results

The purified water was tested, and the test results are shown in Table 2. The iron is reduced to 0.0766 mg/L, and the manganese content is not found. Amount of Calcium, sodium, and chlorine have increased but remains within the limit of Bangladesh standard.

Magnesium has increased greatly from the previous value (raw water) but slightly above the maximum limit of Bangladesh standard. P^H level of water is reduced slightly. TDS has increased to 181.2 mg/L which is below the limit of Bangladesh and WHO standard.

Figure 6 shows the color of water sample before and after the treatment. The color of water was murky before the treatment process due to having a huge amount of iron and contaminants. After treatment in 6 stages, the odorless, clear, purified safe water is achieved.

(a) (b)

Figure 6: Color of water (a) before treatment (Raw water), and (b) after treatment (Purified water)

Table 2: Purified Water Test Results

Parameters (ppm)	Before Treatment	After Treatment	Bangladesh Standards	WHO Standards
As	ND	ND	0.05	0.01
Fe	3.061 PPM (mg/L)	0.0766 PPM (mg/L)	0.3-1	0.3
Mn	0.0112 PPM (mg/L)	ND	0.1	0.01
Ca	15 mg/L	58 mg/L	75	-
Mg	9.115 mg/L	35.2 mg/L	30-35	-
Na	4.603PPM (mg/L)	12.59 PPM (mg/L)	200	200
Cl	25 mg/L	109 mg/L	150-600	250
PH	6.8	6.7	6.5-8.5	6.5-8.5
TDS	53.3mg/L	181.2 mg/L	500	1000
Salinity	0.05%	0.18%	-	-

4. Conclusion

Small scale industries, small enterprises and households can collect safe potable water from automatic control system of water treatment plant with high accuracy, reliability, convenience, and flexible control. This automated process in every stage of purification will eliminate the necessity of manpower for the water treatment process. Automation in the collection of water will reduce the wastage of water. The aim of reducing iron content, which is responsible for unpleasant taste, odor, and murky water, and making the total treatment process automatic using PLC has been achieved. There is huge opportunity of further research in this field to make the automation process more effective to ensure safe potable water.

References

Arsenic. 2022. https://www.who.int/news-room/fact-sheets/detail/arsenic (accessed Sep. 03, 2022).

Bangladesh National Drinking Water Quality Survey. 2009. The Bangladesh Bureau of Statics, ministry of planning, page-159, march-22,2011

Earth's Water. 2022. https://olc.worldbank.org/sites/default/files/sco/E7B1C4DE-C187- 5EDB-3EF2-897802DEA3BF/Nasa/chapter1.html (accessed Sep. 03, 2022).

Ghosh, G.C., Khan, M.J.H., Chakraborty, T.K., Zaman, S., Kabir, A.H.M., and Tanaka, H., 2020. Human health risk assessment of elevated and variable iron and manganese intake with arsenic-safe groundwater in Jashore, Bangladesh. Scientific Reports, 10. doi: 10.1038/s41598-020-62187-5.

Han, B., Runnellsb, T., Zimbronb, J., and Wickramasinghe, R., 2002. Arsenic removal from drinking water microfiltration. Desalination, 145, Pp. 293–298.

Khatri, N., Tyagi, S., and Rawtani, D., 2017. Journal of Water Process Engineering Recent strategies for the removal of iron from water : A review. J. Water Process Eng., 19 (13), Pp. 291–304. doi: 10.1016/j.jwpe.2017.08.015.

Rahaman, M.S., Mise, N., and Ichihara, S., 2022. Arsenic contamination in food chain in Bangladesh: A review on health hazards, socioeconomic impacts and implications. Hyg. Environ. Heal. Adv., 2, Pp. 100004, Jun. 2022, doi: 10.1016/J.HEHA.2022.100004.

Rahman, M.A., and Hashem, M.A., 2019. Arsenic, iron and chloride in drinking water at primary school, Satkhira, Bangladesh. Phys. Chem. Earth, 109, Pp. 49–58. doi: 10.1016/j.pce.2018.09.008.

Thirunavukkarasu, O.S., Viraraghavan, T., and Subramanian, K.S., 2003. Arsenic Removal from Drinking Water using Iron Oxide-Coated Sand. Water. Air. Soil Pollut., 142 (1), Pp. 95–111. doi: 10.1023/A:1022073721853.

Yadav, A.A.B., 2012. PLC & SCADA based automation of Filter House , a section of Water Treatment Plant.

Zeolite Process of Water Softening - Dr. Rajdeep Deb. https://sites.google.com/site/drrajdeepdeb/zeolite?overridemobile=true (accessed Sep. 05, 2022).

Ziarati, P., and Albaji, A., 2013. Mercury and Lead Contamination Study of Drinking Water in Ahvaz. 2, Pp. 751–755.