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Pilot study of in-line continuous flocculation water treatment plant

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ABSTRACT

Human consumption of groundwater without treatment is not safe and can cause water-borne diseases and other kinds of illnesses. Usually, groundwater extracted through boreholes may be acidic and contains impurities such as organic and inorganic contaminants, microbes, and heavy metals. Hence, it becomes imperative to treat groundwater to make it potable for human consumption. This pilot study was conceptualized based on a simple and the most economical technological approach in groundwater treatment. It employed the basic concepts and working principles of essential unit operations such as coagulation, sedimentation, filtration, and adsorption to ensure potable water for human consumption based on WHO standard specifications. The plant specifically treats groundwater of pH 6.30-6.50. The average flow rate of the plant is 12,570 cm^3/min (0.7542 m^3/hr) and a centrifugal pump of 0.5 HP and a pipe size of 20 mm diameter were selected for this design. Equipment used were determined, sized and selected as required and the treated water quality is ensured through laboratory routine tests carried out in the course of the continuous operation of the pilot plant. Sand filter and carbon purifier are inevitable and a turbidity sensor is proposed for the filters to optimize the backwash operation. Capital cost evaluation was carried out using the percentage of delivered equipment cost method and the total capital cost for this pilot plant was estimated as One Thousand, Seven Hundred and Eighty-Two-Ringgit (RM 1,782.00 ≈ USD445.50). Thus, with this successful pilot study for a continuous treatment operation, a plant scale-up is feasible for groundwater purification to ensure potable water security in both rural and urban communities.

1. Introduction

Abundant in nature, water is an essential commodity for humans and makes up about 75% of the total body weight [1–3]. The recommended daily water consumption per capita stands at 64 ounces (about 1.8 kg) [4]. There are several sources of water which include wells, lakes, springs or rivers. Groundwater has been a common source of water for most rural communities in under-developed and developing countries. There are contaminants associated with groundwater which come about through various reactions of rainfall water with other minerals in the soil and rocks as it percolates through the rock making its way down to the aquifers. More so, groundwater gets contaminated with microbes such as algae, bacteria, virus and other foreign materials including salts of various forms. Hence, groundwater contains all types of insoluble and soluble impurities. These impurities are capable of infecting humans with various forms of diseases associated with groundwater. Therefore, the consumption of groundwater without adequate treatment poses some serious health challenge to humans. Groundwater consumption has been seen as an alternative to surface water especially for communities that depend on surface water. Shortage of water can lead to people drinking surface water laced with serious health issues such as hypertension, heart disease, and high cholesterol. Many research studies have linked insufficient water in the human body to arthritis, headache, and heartburn [5,6]. To a great

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extent, the medical treatment for these illnesses has socio-economic undertones of which the impact is much more negative.

This water treatment pilot plant study was done taking cognizance of the proper design stages which include inception, a preliminary evaluation of economics, costing, detailed engineering design, procurement and construction [7,8]. This design chiefly addresses the problem of water-borne diseases (e.g. cholera and diarrhea) mostly caused by groundwater and which are common in the rural communities where people rely solely on groundwater as their source of drinking water. When surface water becomes an option as a result of insufficient water, diseases such as sleeping sickness, river blindness, bilharzia, and guinea worm attack are rife [9,10]. Water purification is the removal of contaminants from raw water to produce drinking water that is pure and safe for human consumption. Substances that are removed during this process include bacteria, algae, viruses, fungi, minerals, and man-made chemical pollutants.

Water purity is a crucial issue in addressing water shortage [11]. In areas where water catchments are inadequate, treated water (from wastewater sources) using membrane technology is thoroughly disinfected and reused for discharges into groundwater [12]. To ensure adequate groundwater purification, the essential treatment processes incorporated in this design include filtration, disinfection, coagulation, and adsorption. As a requirement, some chemicals are injected into the raw water to enhance purification which includes sodium hypochlorite (NaOCl) dosed for disinfection, caustic soda (NaOH) dosed for pH balance, and ferric chloride ($FeCl_3$) dosed to achieve the formation of floc of impurities. The flocs formed are removed through filtration. The pipes and pump selection suitable for the design were critically and carefully considered. Some factors determine the approach to the design and were taken into consideration such as the total cost of the design and construction, availability of materials of construction, plant size requirements, past experience of such plants, environmental considerations and the regulatory body requirements. The sand filter and carbon purifier are the most compact and complex equipment in the pilot plant as they involve packed beds of sand and activated carbon respectively. Carbon purifier incorporated as the final treatment step aids in the complete removal of contaminants and other undesirable water tastes, and odours. Carbon purifier removes the residual chlorine through the adsorption process. Apart from the primary aim of setting up a typical water treatment plant, this design looks at the science of optimizing the backwash operation of the filters using a turbidity sensor in order to reduce cost and ensure sustainability of the treatment process.

Thus, this pilot study specifically addresses issues of drinking water quality by providing a very cheap treatment method for groundwater in the rural areas of under-developed and developing nations. Typically, this pilot plant employs an affordable treatment technology for groundwater (pH of 6.30–6.50) to ensure safe and potable water for human consumption. Consequently, water-borne diseases which bring about economic hardship to rural community dwellers are avoided.

2. Materials and method

Three principal stages are involved in this water purification plant viz; primary, secondary, and tertiary treatments. The primary treatment involves collecting, pre-conditioning, screening, and initial storage of raw water. The secondary treatment takes care of the pH adjustment and the removal of fine solids and the majority of contaminants using coagulation, flocculation, and filtration while the tertiary treatment involves disinfection, pH adjustment, polishing with carbon treatments to remove tastes and odour. The two most important operating conditions for this water treatment system are the *flow rate of the water stream and concentration of the contaminants relative to its solubility in water*. The sample was collected from a functional borehole at Irete district of Imo State, Nigeria (Table 3). The water purification pilot plant is therefore intended to treat acidic groundwater having a pH of 6.30. The key physicochemical water characteristics for this study were TSS, NH_3, Acidity, Alkalinity, Colour, and pH levels. This pilot study incorporated equipment such as raw water reservoir, reaction tank, hydraulic mixer, sand filter, semi-treated water tank, carbon purifier, water polisher and Potable/treated water storage tank. From the design inception, comparison of the water quality with WHO specifications were made to emphasize areas that required adequate attention in addressing the issues of impurities. The water sample was far from the threshold set for the heavy metals. Based on the water quality, the issues of pH balance and disinfection of the raw water becomes a clear case of what the study should tackle. Iron (III) chloride was used as a coagulant in this study owing to its advantage of allowing a wide range of pH than aluminum sulfate. Iron (III) is cheaper and most effective in the removal of organic contaminants from water. Laboratory routine tests carried out for water quality assurance are listed below.

Table 1
Jar test.

Beaker A	Beaker B	Beaker C
NaOH- 2.2 $FeCl_3$- 2.0 Cl_2-1.0	NaOH- 2.5 $FeCl_3$- 2.0 Cl_2- 0.8	NaOH- 2.8 $FeCl_3$-2.2 Cl_2- 0.6

The actual amount of reagents based on percentage purity; NaOH = (10 × 100)/98.5 = 10.15 g (98.5% purity); Cl_2 = (10 × 100)/65 = 15.38 g (65% purity); $FeCl_3$ = (10 × 100)/46 = 21.74 g (46% purity).

A jar test was done to determine the percentage by weight of the chemicals used in the treatment process (Table 1). NaOCl, NaOH, and $FeCl_3$ come with the percentage purities of 65%, 98.5%, and 46% respectively, and then the actual weight of each of them is calculated to get the required weight of 100% purity. This was done by measuring out 10 g each of these chemicals and introduce to 1000 mL of distilled water each in 3 separate beakers (A, B and C) and thoroughly mixed to give 10,000 mg/L (ppm) as shown in Table 1. From the contents of the three beakers, the best result after a reaction time of 20–30 min is taken and used as the standard for injection into the water. The typical parameters for the best result are pH, Cl_2 content, size of floc, clarity, time of settlement, nature of settlement (rapid) and flocculation. WHO specifications for potable water was used as a yardstick to measure the performance of the pilot plant [13]. Some of the specifications are tabulated in Table 4.

2.1. pH adjustment, disinfection and adsorption

Caustic soda or lime was added to balance the pH since making the water slightly alkaline ensures that coagulation and flocculation processes work effectively and minimizes the risk of lead being dissolved from lead pipes. The equations for neutralization reaction of lime in the water purification are shown below:

$$3Ca(HCO_3)_2 + 2NaOH \rightarrow 3CaCO_3 + Na_2CO_3 + 4H_2O + 2CO_2$$
$$3Mg(HCO_3)_2 + 2NaOH \rightarrow 3MgCO_3 + Na_2CO_3 + 4H_2O + 2CO_2$$
$$CaSO_4 + Na_2CO_3 \rightarrow Na_2SO_4 + CaCO_3$$
$$MgSO_4 + Na_2CO_3 \rightarrow Na_2SO_4 + MgCO_3$$
$$CO_2 + 2NaOH \rightarrow Na_2CO_3 + H_2O$$

Chlorine was used in the form of NaOCl to achieve disinfection of the groundwater. The drawback of using sodium hypochlorite is that they react with organic compounds in the water to form a potentially harmful level of chemical by-products such as trihalomethanes (THMs) and halo-acetic acid, of which both are known to be carcinogenic. The formation of these by-products is minimized by the effective removal of as many organics as possible from water before disinfection. Adsorption process ensures that impurities such as chlorine, organics, colour, objectionable taste, and odour are removed from the water when water is passed vertically downwards through a bed of packed activated carbon.

Chlorine aids in the oxidation of soluble ions to insoluble ions. The oxidation effect of chlorine can be illustrated as shown below:

$$Cl_2 + 2Fe^{2+} \rightarrow 2Fe^{3+} + 2Cl^{-1}$$

2.2. Sand filtration and carbon purification

A sand filter tank was used to filter the groundwater to remove suspended solids. It contains a bed of packed sand materials, which is charged on a support. The sand filter is recharged from time to time to ensure efficiency. The bed retains the sediments, thereby allowing for their removal. As a maintenance procedure, it is backwashed from time to time [14]. The effective size of the sand used in this study varies between 0.15 mm and 0.35 mm.

Carbon purifier was used to ensure adsorption of unwanted contaminants and effective removal of chlorine used in the disinfection process. Carbon purifier is a vessel packed with activated carbon materials, which is used to remove or reduce the undesired quality of water such as chlorine, organics, colour and objectionable taste and odour in water. Here, utmost care was taken to avoid the chemical reaction that occurs on the carbon surface as a result of the chlorine. Operating conditions that affect the performance of a carbon purifier include particle size, temperature, pH, and concentration of the contaminants relative to its stability. Backwashing was routinely carried out in both sand filter and carbon purifier tank to remove trapped contaminants within the filter bed and washes them down the drain.

3. Results and discussion

The groundwater quality at Irete District of Imo State, Nigeria was determined before and after the pilot study. The water analysis/test methods adopted for this study are represented in Table 2 as recommended by the American Public Health Association (APHA). Basically, to achieve this, water analysis was carried out using the Membrane test, M-value test, pH test, and Chlorine test. The removal of microbes was done by using NaOCl for disinfection purposes before sand filtration. The flocs generated in the course of the treatment (using $FeCl_3$) were removed in the sand filtration process and water polishing. Odours, objectionable tests, and residual chlorine were removed through the carbon adsorption mechanism. Table 3 represents the water quality before and after water purification. Our analysis showed that the turbidity of the groundwater was drastically reduced from 35.00 NTU to 4.5 NTU and this result is within the standard limits of 5.00 NTU set by WHO. The pH range for the treated water was from 7.5 to 7.8. Even though the iron and chlorine contents increased after treatment due to the dosing of treatment chemicals such as NaOCl and $FeCl_3$, their contents in the water after treatment are within the recommended acceptable limits for potable water. The total conductivity of the treated water was reduced from 665 Ω/cm to 240 Ω/cm and this value was within the recommend acceptable limits as enshrined in the guidelines for the establishment of packaged water in Nigeria [22,23]. The values for the total hardness, total alkalinity, and total salinity were slightly increased as a result of the oxidation of organic compounds by the chemicals during the treatment process. However, these values are within the specified WHO limits for safe drinking water (Table 4). Overall, the results achieved with this pilot study indicate that groundwater (acidic borehole water) can be treated and made safe for human consumption at an affordable cost. Therefore, this prototype can be scaled up for commercial purpose to solve the problem of safe water scarcity for developing communities while also addressing the issues of water-borne related illnesses associated with untreated groundwater.

4. Choice of process route and process flowsheets

The selection of the process route that will meet the process objective is based on the analysis of the merits and the purpose for which they will be used [15]. Also, each chemical used will offer different advantages over the other. Based on the analysis of the process route, the selected process made use of slow sand filtration. Iron (III) chloride was used as the coagulant because it works over a large pH range than others, has a lower cost and offer better removal of organics. Lime was used for pH adjustment because it was cheaper and enhanced water hardness removal. Sodium hypochlorite was used as a disinfectant for safety reasons since chlorine in its uncombined state is a very toxic gas and sodium hypochlorite releases chlorine on dissolution in water. Other equipment used were carbon filter, water polisher, hydraulic mixer, reaction tank, semi-treated water tank, reaction tank, and water reservoir. Fig. 1 shows the block diagram of the groundwater purification process. The pictorial flow diagram of the groundwater purification process is shown in Fig. 2.

5. Material balances

The material balance is an expression from computation based on the law of conservation of mass. It gives an exact account of all the materials entering and leaving during the course of operation of the process. The chemical reaction in the plant is hardly noticed and only leads to the formation of floc. Thus, the overall material balances for this particular plant is given as the below equation: [16]

Input - output = accumulation.

Time basis for this balance: 1 h, Feed volumetric flow rate: 754.2 m^3 ≡ 754.2 kg

Fig. 3 shows the quantitative material flow diagram for the purification of groundwater. Detailed material balances for the different units are shown in Table 5.

6. Equipment design and specifications

The best material of construction for all the tanks including raw water reservoir would be stainless steel owing to the corrosive nature of groundwater. However, due to some cost constraints, galvanized iron sheet was used in this pilot study as it is relatively cheap, easy to weld and fabricate and has a relatively low rate of corrosion. All the equipment were designed cylindrically and the different tank heights and volumes are a function of their diameter. The specification sheets for the various equipment, pump and pipe selection are presented in Tables 6 and 7 as calculated.

Table 2
Water test methods.

TEST NAME	BRIEF DESCRIPTION
MEMBRANE TEST	Conducted to ensure that backwashing was efficient. A membrane paper of pore size 0.45 μm was used with the filtration unit (a device for filtering). No observed deposits on the membrane would mean that the backwashing is efficient.
M-VALUE TEST	Conducted to determine the maximum alkalinity value of the treated water after dosing the water with caustic soda (NaOH). Samples were collected from the carbon and sand filter tanks.
PH TEST	Conducted using pH meter to determine the pH of the treated water.
CHLORINE TEST	Carried out to determine the amount of chlorine in the treated water and verify if it was within the WHO standards. Tablets of DPD (N, N-diphenyl propyl diamines) were used for this purpose.

Table 3
Water quality at Irete district (before and after water purification).

WATER QUALITY BEFORE WATER PURIFICATION			
Parameter	Composition	Parameter	Composition
Turbidity (NTU)	35.00	Ammonia (mg/L)	0.18
Conductivity (Ω/cm)	665.00	Hardness (mg/L)	45.00
Temperature (°C)	26.50	Sulphate (mg/L)	2.70
pH	6.30	Manganese (mg/L)	0.01
TDS (ppm)	376.00	Copper (mg/L)	0.01
Nitrates (mg/L)	0.91	Magnesium (mg/L)	0.02
Fluoride (mg/L)	1.29	Calcium (mg/L)	4.60
Chlorine (mg/L)	2.40	Total Alkalinity (mg/L)	41.00
Iron (mg/L)	0.2	Total Salinity (mg/L)	40.00
CRITICAL PARAMETERS AFTER WATER PURIFICATION			
Parameter	Composition	Parameter	Composition
pH	7.5-8.2	Chlorine (mg/L)	150.00
Turbidity (NTU)	4.50	Iron (mg/L)	0.25
Conductivity (Ω/cm)	240.00	Hardness (mg/L)	60.00
Temperature	25 °C	Total Alkalinity (mg/L)	58.00
TDS (mg/L)	320.00	Total Salinity (mg/L)	55.00

Table 4
WHO specification for potable water.

Parameter	WHO Specification	Parameter	WHO Specification
Appearance	Clear	Odour	Odourless
Taste	Tasteless	pH	7.0-8.5
Conductivity	250 MS/cm	Turbidity	5 NTU
Residual Chlorine	0.3 mg/l	Total solid	500 mg/l
Total hardness	100 mg $CaCO_3$/l	Free CO_2	10 mg/l
Total Alkalinity	< 85 mg/l	Sulphate	200 mg/l
Chlorine	200 mg/l	Nitrate	20 mg/l
Silica	40 mg/l	Calcium	75 mg/l
Magnesium	30 mg/l	Iron, total	0.3 mg/l
Lead	0.01 mg/l	Arsenic	0.01 mg/l
Chromium	0.05 mg/l	Zinc	5 mg/l
Copper	1 mg/l	Manganese	0.1 mg/l
Cadmium	0.05 mg/ml	Coliforms	0 CFU/ml
Feccal Streptococci	0 CFU/ml	Staphylococcus aureus	0 CFU/ml
Salmonella	0 CFU/25 ml	Shigella	0 CFU/25 ml
Vibrio	0 CFU/25 ml	Total plate count	100 CFU/ml

6.1. Pump, pipe and valve selection

Fluid will always flow by gravity but when the flow is against gravity, a pump is required to boost the pressure required by the fluid to flow. Pump selection was done based on the volume of water to be handled, the head against which the liquid was to be pumped, the nature of the power supply and the cost and mechanical efficiency of the pump. A centrifugal pump was selected among other types for this design. Piping which gives information on the interconnection between the major pieces of equipment is shown on the process flowsheet in Fig. 3. Although pipes are made of many special materials for special purposes, PVC pipe was employed for the purpose of this study. PVC pipes of 0.269 - 0.826 inch were used for the piping and a centrifugal pump of 4.091 Psi was used. Valves were used to slow down the flow of liquids where necessary. Manual PVC pipes valves were used to reduce pressure buildups in the plant instead of automatic control systems and sensors along with release valves.

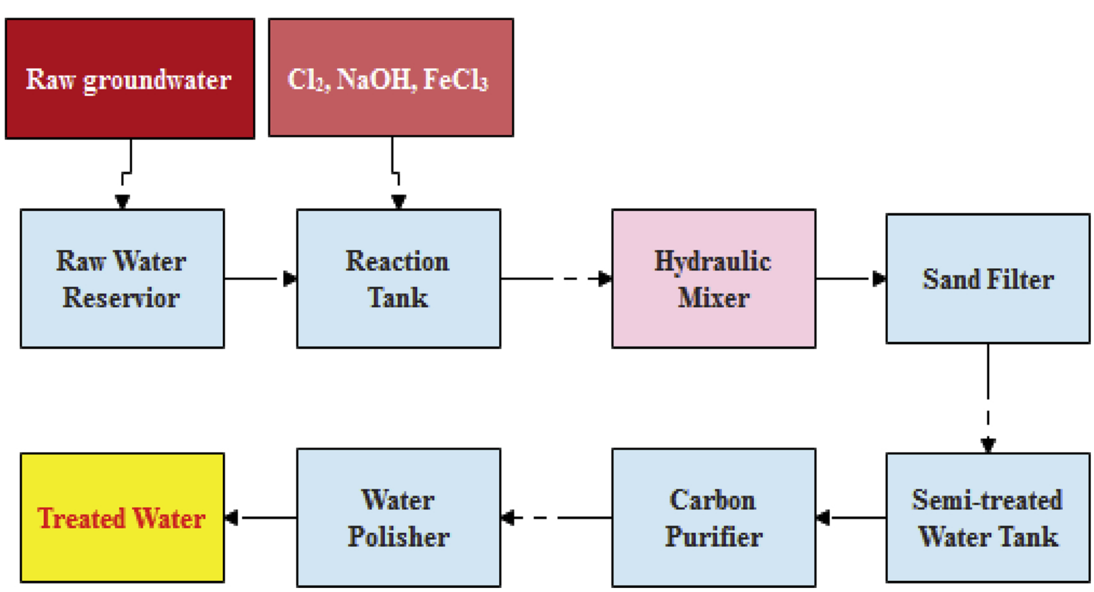

Fig. 1. Block diagram of groundwater purification plant.

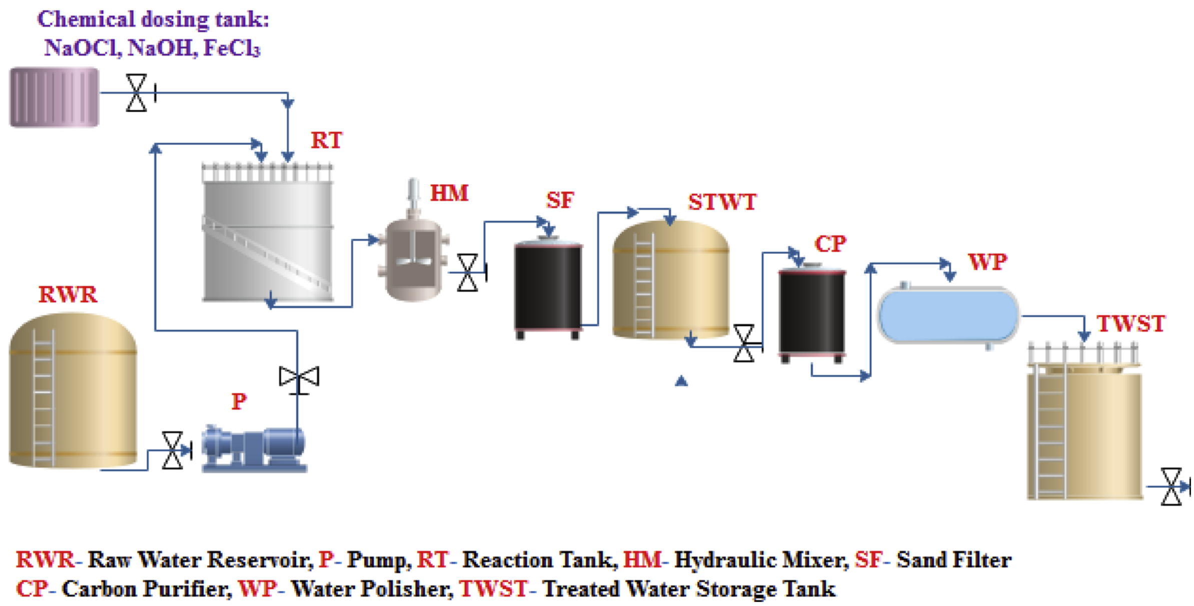

Fig. 2. Pictorial flow diagram of the groundwater purification process.

6.2. Cost estimation

The aim of setting up a pilot plant is primarily to maximize profit at reduced costs within the limits of the optimal conditions of the plant and as such, every plant design must definitely present a process that is capable of operating under conditions which yield or maximize profit [17]. The estimated cost of establishing this pilot plant was carefully and systematically determined to ensure economic viability. The percentage of delivered equipment cost method was used to analyze the process economics. Costing of all the equipment including raw water reservoir was based on the quality of materials required to construct the plant and the current market price of the materials. The most accurate method to determine process equipment cost is to obtain firm bids from the fabricators or suppliers. The cost of establishing the pilot plant was calculated as a sum of the direct cost and indirect cost. The sum of these two costs gives the fixed cost i.e. Fixed Cost = D.C + I.C. Working capital is the capital required to keep the plant running. It involves the cost of raw materials, labour etc. Total Investment Cost = Fixed Cost + Working Capital i.e. T.I.C = F.C + W.C. Using the percentage of delivered equipment cost method, the total investment cost was estimated as shown in Table 8. The purchased cost of equipment (PCE) = RM 1,000.00

6.3. Plant safety and equipment layout

In every pilot plant designed and constructed, safety is of paramount importance. In this pilot study, chemicals such as NaOCl, NaOH, and $FeCl_3$ have specific hazards, which could cause injury or death in extreme cases. Chlorine is an asphyxiant and irritates respiratory systems in its gaseous form and when it is not carefully handled in its liquid form causes burnt skin when in contact. Therefore, exposure to this chlorine gas should not exceed 0.5 ppm. Gloves and eye protection goggles are worn when handling NaOH because contacts cause chemical burns, permanent injury or scanning, and blindness. A PVC apron

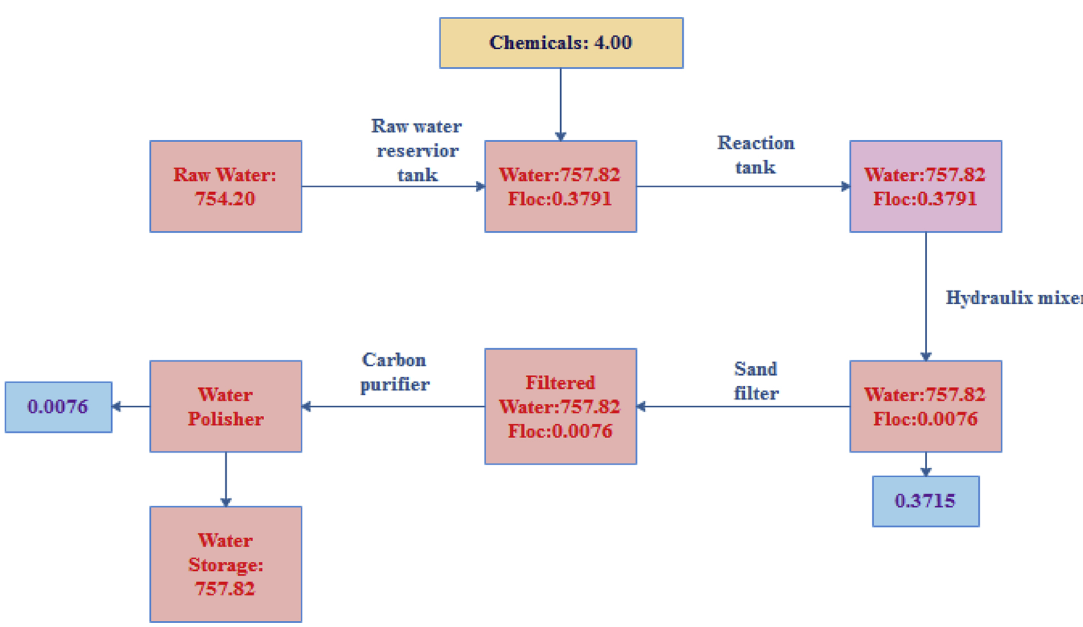

Fig. 3. Quantitative flowsheet of the groundwater purification (All flows in kg/hr).

Table 5
Mass balances around treatment tanks.

Equipment	Component	Mass (Kg)
Raw water reservoir	Raw water in	754.2
	Raw water out	754.2
Reaction tank	Raw water in	754.2
	Raw water out	757.82
	Chemical in	4.00
	Floc out	0.3791
Hydraulic mixer	Raw water in	754.2
	Raw water out	754.2
Sand filter	Raw water in	758.2
	Filtrate	757.83
	Residue	757.83
Semi-treated water tank	Filtered water in	757.83
	Filtered water out	757.83
Carbon purifier	Filtered water in	758.2
	Filtered water out	757.83
	Residue	–
Water polisher	Water in	757.83
	Water out	757.82
	Floc	0.0076

Table 6
Equipment specification sheet.

Equipment	Volume	Diameter	Height	Breadth	Length	No of units
Raw water reservoir	12750 CM^3	22 CM	33 CM			1
Reaction tank	6188 CM^3	17.4 CM	21.6 CM			1
Semi-treated water tank	6188 CM^3	17.5 CM	26 CM			1
Hydraulic mixer	1571 CM^3	11 CM	16.5 CM			1
Water polisher	905 CM^3	9.2 CM	13.8 CM			1
Storage tank	7875 CM^3		15 CM	15 CM	35 CM	1

Table 7
Specification sheet for pump and pipe selection.

PUMP SELECTION		
CAPACITY [cm^3/min]	DP/100 ft [psi]	Type
12570	4.091	Centrifugal
PIPE SELECTION		
Nominal Size	8-Jan	4-Mar
d (inch)	0.269	0.826
Re	624.5	203.4
Flow regime	Laminar	Laminar
F	0.0173	0.0242
DP/100 ft	2.9 Psi	4.091 Psi

is being recommended when concentrated solutions or the solid form is used. Ferric chloride is toxic and highly corrosive. Therefore, hand gloves, boots should be worn while working with $FeCl_3$ and MSDS instructions should be strictly followed. In the case of an electrical fire, CO_2 extinguisher is used. Proper equipment grounding was done to prevent electrical shock hazards. Shocks is avoided by adopting the proper electrical connection measures. Lastly, food, beverage, tobacco or cosmetic products are restricted in the chemical storage areas. Fig. 4 shows the equipment layout of the pilot plant.

7. Optimization of the backwash process

Both the sand filter and carbon purifier backwashing is a crucial and very essential process in the drinking water treatment system. The filters are needed to remove solids, odours, trace metals, and undesirable tastes in water. Backwashing is a process of reversing water flow through the bed of sand (in the case of sand filter) and through the activated carbon (in the case of carbon purifier) [18]. Usually, the filter bed is expanded to enhance the efficiency of solids removal and other unwanted impurities deposited within the interstices of the filter media [19]. Factors such as the filter run time, turbidity break-through, head loss development, or a combination of these factors determine the schedule of backwash [20]. The backwash turbidity profiles are used to determine the turbidity levels of the water and in turn, gives information on the performance of the process. Turbidity in the range of 10–20 NTU is recommended by the American Water Works Association (AWWA) as a baseline for terminating backwash so as to leave adequate particulate matter within the filter media to ensure effective performance at the start of the next filter run. A turbidity sensor installed in the tanks and digitally interfaced with the plant control system will give an optimal backwash duration. It is noted that both under washing and over washing of the filter can reduce the performance of the filter and decrease its life over a period of time. Also, this drastically reduces the plant operating capacity. Even though this is a grave concern and is being tackled currently using a sensor (turbidity sensor), the duration of backwash for water treatment plants is wholly based on the quantitative judgment of the technician or operator who determines and assumes backwash requirements. The technician uses mostly the time, flow and visual inspection of turbidity development based on his experience.

Table 8
Direct cost (DC) and Indirect cost (IC) using PCE.

Process type: Fluid-Solid processing	
Item DC USING PCE	Cost (RM)
Equipment Erection	0.45 x PCE
Piping	0.45 x PCE
Instrumentation	0.12 x PCE
Electrical	0.10 x PCE
Storage	0.10 x PCE
TOTAL	1,320.**00**
Process type: Fluid-Solid processing	
Item IC USING PCE	Cost (RM)
Design	0.25 x DC
Contingency	0.1 x DC
TOTAL	**462.00**

7.1. Turbidity sensor

Turbidity trends appear to be a good means by which the water treatment plant can optimize the backwash duration. The filter operation and backwash cycles can be modified to establish an optimal duration of backwash through turbidity trends using a turbidity sensor. This sensor can be installed about 10–12 inches within the filter media in the backwash trough downstream of a bed of sand or activated carbon and monitors water turbidity. The area where the sensor is stationed above the filter media should have minimum entrained air and flow turbulence. Colour interference to the sensor is minimized as the sensor utilizes an infrared light source and gives a highly accurate and linear measurement over a wide range up to 4000 NTU. The sensor can display results in the units of mg/L solids. The sensor is paired with a digital controller to interface with the plant control system. The idea is to use the sensor to terminate backwash based on a set point turbidity level and store data for future reference. The use of a turbidity sensor can reduce the high backwash flow by 50% in water treatment plant and consequently reduce the amount of wasted water per backwash per filter (water conservation). Therefore, the cost of water treatment is reduced especially in terms of energy and labour savings. The cost of installing a permanent turbidity sensor has been justified in a study

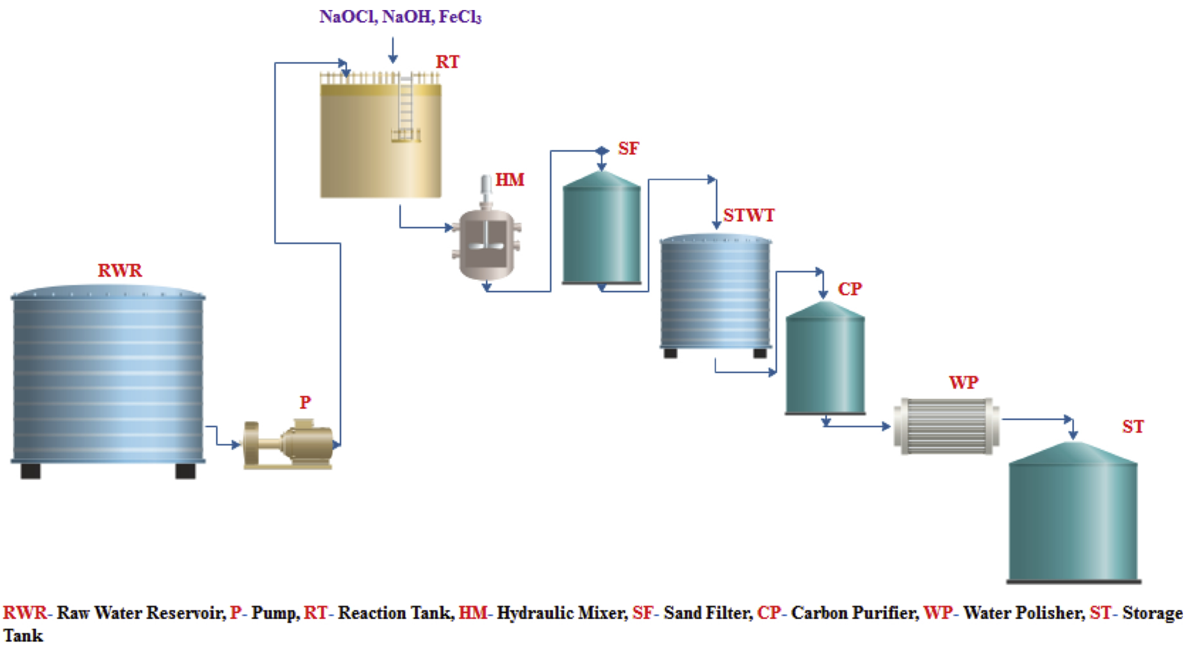

Fig. 4. Equipment layout of the pilot plant.

using a Solitax sensor to optimize the backwash duration of a sand filter tank [21].

8. Conclusion

This pilot plant is a continuous-flocculation process plant and employed a sustainable water treatment technology to purify groundwater for human consumption. The continuity in operation of this plant makes it more convenient, economical, and sustainable when compared with other technologies in water treatment. This treatment technology can be widely adopted in groundwater purification process in both rural and urban areas of under-developed and developing nations. This will fulfill the need to overcome water-borne diseases and make groundwater safe for human consumption. This pilot plant operates continuously with a constant flowrate of 12570 cm^3/min. Finally, a turbidity sensor is proposed for optimal backwash duration of the filters. The recommended routine test results so obtained are in conformity with the standards set by WHO for potable water.

Conflicts of interest

The authors declare no conflicts of interest.

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