Development of Bench Scale Water Treatment Unit for the Treatment of Medium Turbid Water: The Use of Natural Coagulant

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Abstract. Water purification is a process used to enhance water quality and make it more acceptable for specific end-use. The rising increase for portable drinking water has made natural coagulant application for water purification a welcome development. Most reported researches were on the use of natural coagulants in a laboratory batch scale. Because of those above, a bench-scale laboratory study was carried out on the application of *Balanites Aegyptiaca* seed as a natural coagulant. The outcome showed its usefulness toward water purification. This paper reported the developed bench-scale water treatment plant's performance utilising *Balanites Aegyptiaca* seed stock solution and the powdered kennel as bio-coagulant. Some design equations were adopted. The treatment units considered include coagulation/flocculation, sedimentation, and filtration. The total tank design capacity was 20 litres with the overflow area's actual size for sedimentation of 7.46 litres. 0.5 Hp electric motor with a speed of 600 rpm and a speed gear drop of 120 rpm were selected. 0.0127 m pipe flow line diameter connecting the tanks with a corresponding pipe flow velocity of 0.108 m/s was obtained from the design. However, in both the coagulation, sedimentation and filtration units, the material balance obtained showed a steadiness in the material flow across sedimentation and filtration units. However, among the parameters tested in the raw turbid water, the turbid water revealed turbidity of 514 NTU, the colour of 5600 CTU, the conductivity of 276 µs/cm, pH of 7.10 and total coliform bacteria count of 85 CFU/100 mL which were above the recommended set standard of WHO and NIS. The result of the treated water using the stock solution and the powdered kennel (bio-coagulant) on the developed water treatment unit showed a remarkable reduction in the tested parameters in the raw turbid water used for the treatment process. Total coliform count reduces from 85 CFU/100 ml to 10 CFU/ml in both cases. It was observed that conductivity increases after the treatment, but other inorganic constituents reduce significantly though not to WHO and NIS's recommended set standard. The 0-dosage treatment conducted also showed a reduction in all the tested parameters.

Keywords: pollutant; microbes; bench-scale; water purification; turbidity; bio-coagulant.

INTRODUCTION

Currently, the water crisis is a severe issue of global concern; it has been reported by [12] that in the developing countries more than 1.6 million people are using unhygienic water and among them, most of the people suffer from diarrhoea and water-related diseases. Such reasons also necessitate a sustainable, cost-friendly alternative treatment process to overcome the current water challenges. Surface water/well water can contain suspended solids, colloidal matter, organics, silica, iron, manganese and many other pollutants. That is why it is so necessary to treat it before consumption. Carrying out studies using developed bench-scale water treatment plant have the advantage of requiring a small volume of sample testing, allowing a fast screening of various alternative and testing of many performance variables at a relatively minimum cost. Other studies reported aluminium, which is the significant alum component and poly aluminium chloride, causes Alzheimer's disease [20]. Authors [3] also noted that the natural organic matter combines with Chlorine during water treatment when applied for disinfection hence, generate disinfection by-products (DBPs) and in particular forms halogenated DBPs, this enhances the production of free radicals in the body.

The removal of turbidity and pathogens is an essential step in the water treatment process, and generally, this is achieved using coagulation and chlorination processes. In conventional water treatment processes, aluminium sulphate (alum) and poly aluminium chloride (PAC) is widely used for turbidity removal, while Chlorine is used to disinfect pathogens.

Balanites aegyptiaca is a tree species, classified either as a member of the Zygophyllaceae or the Balanitaceae. This tree is native to much of Africa and parts of the Middle East. There are many common names for this plant. In English, the fruit has been called desert date, soapberry tree or bush, Thorn tree, Egyptian myrobalan, Egyptian balsam or Zachum oil tree; in Arabic, it is known as lalob, hidjihi, inteishit, and healing (hijlij). In Hausa, it is called aduwa, in Swahili mchunju [21]. Authors [4] reported that desert date' has a long history of traditional uses for wide disease ranges. It has been experimentally proved that *Balanites aegyptiaca* Del possess antioxidant, antimicrobial, anticancer, diuretic, hypocholesterolemia, wound healing, antiviral, antidiabetic, hepatoprotective, mosquito larvicidal, anti-inflammatory and analgesic, antivenin, anthelmintic, cardioprotective cum antioxidant activity, and antinociceptive properties [4].

Bark, fruits, seeds, seed oil, and leaves of this plant are widely used in folk medicine, all parts of the desert date tree plant have medicinal uses including fruits, seeds, barks and roots [8], and it was also observed and reported by [14] that *Balanites aegyptiaca* seed could be a potential natural coagulant in raw wastewater treatment. On the other hand, authors [10] said that PAC and alum continuous usage in large amounts are a potential threat for processed water consumers' health because coagulant may remain, although in a small amount. Ecologically, synthetic coagulant use produces a certain amount of sludge sediment that is a pollutant for the environment. The sludge is relatively tricky to degrade and can change soil and water minerals' composition from the normal condition. Thus, in recent years there has been considerable interest in the development of natural coagulants. Some studies on natural coagulants have been carried out. Various natural coagulants were produced or extracted from plants such as *Moringa oleifera* (MO), *Prosopis juliflora*, *Tamarindus indica* and *Cactus latifaria* [20]. Natural organic polymers have been used for more than 2000 years in India, Africa, and China as effective coagulants and coagulant aids in turbidity treatment. Natural coagulants have bright future and are concerned by several researchers due to their abundant source, low price, environment friendliness, multifunction, unlikely to produce treated water with extreme pH and biodegradable nature in water purification, highly biodegradable. Also, naturally occurring coagulants are usually presumed safe for human health [16].

MATERIALS AND METHODS

The materials used for this study include among other raw turbid water, *Balanites aegyptiaca* seed, sterile containers, petri dishes, distilled water and plastic containers. The equipment used in this study includes turbidity meter, pH meter, electronic balance, drying oven, blender, soxhlet extractor, jar test machine, centrifuge, photometer and desiccator.

Botanical Name and Description of *Balanites aegyptiaca* (Desert Date). *Balanites aegyptiaca* is a multi-branched, spiny shrub or tree up to l0 m tall. Crown spherical, in one or several distinct masses. Trunk short and often branching from near the base. Bark dark brown to grey, deeply fissured. Branches armed with stout yellow or green thorns up to 8 cm long. Leaves with two separate leaflets; asymmetric, 2.5 to 6 cm long, bright green, leathery, with fine hairs when young. Flowers in fascicles in the leaf axils are fragrant, yellowish-green [9]. Plate 1 presents the image of the desert date.

Figure 1 – Image of Desert Date [2]

Design of Tanks. For this work's purpose, some storage vessels/ containers were designed and fabricated; the plates manufactured are assumed to be cylindrical. The formula for the volume of the cylinder is shown in Equation 1.

$$V_c = \pi r^2 h_c \qquad (1)$$

where VC = volume of the cylinder; r = radius of the cylinder; h_c = height of the cylinder.

The design flow rate was calculated according to Equation 2.

$$Design\ flow\ rate = \frac{Tank\ capacity\ (Litre)}{Retension\ time\ (minute)} \qquad (2)$$

The impeller diameter was calculated by applying the rule of thumb, as shown in Equation 3.

$$\frac{D_i}{DT} = 0.33 \qquad (3)$$

where D_i = impeller diameter; DT = tank diameter.

The impeller distance from the base of the tank was calculated according to Equation 4.

$$\frac{H_b}{D_i} = 1 \text{ (for flat blade turbine)} \qquad (4)$$

$H_b = D_i$ = 8cm

The impeller width (wi) was calculated according to Equation 5.

$$\frac{W_i}{D_i} = 0.2 \qquad (5)$$

$W_i = 0.2 \times D_i$

Table 1 results from Parameters Considered's calculated values in the Design of Coagulation / Flocculation Unit. For this design work, sedimentation occurred at the space of overflow.

Table 1 – Parameters Considered for the Design of Coagulation/ Flocculation Units

Parameter	Value	Unit
Design flow rate	0.82	L/min
The total diameter of coagulation tank	22.00	Cm
Impeller diameter	8.00	Cm
Impeller width	2.00	Cm
The total diameter of the coagulation and sedimentation tank	30.00	Cm
Height of the sedimentation tank (Hs)	28.00	Cm
Height of the coagulation tank (Hc)	32.00	Cm
Total volume of coagulation+ sedimentation tank	20.00	Litre
The actual size of overflow (Sedimentation)	7.46	Litre
The capacity of electric motor	0.50	Hp
Speed of the electric motor	600.00	Rpm
Speed gear drop	120.00	Rpm

Figure 2 is the schematic diagram of the bench-scale water treatment plant. Figure 3 is the design layout of the coagulation and sedimentation tank with its dimensions in centimetre.

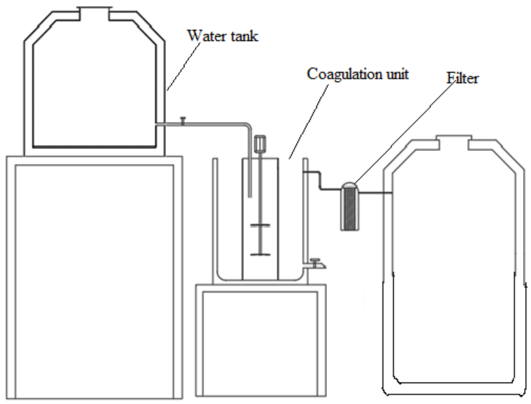

Figure 2 – Schematic diagram of the bench-scale water treatment plant

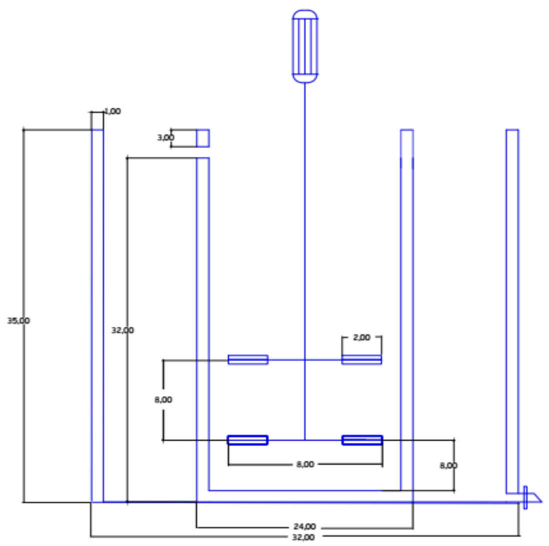

Figure 3 – Design layout of coagulation and sedimentation tank (1)

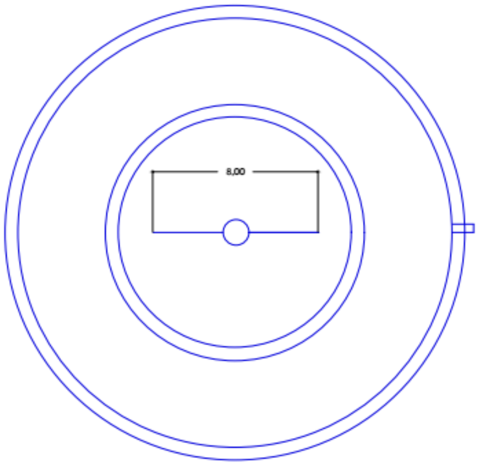

Figure 3 – Design layout of coagulation and sedimentation tank (2)

Design of Piping, Valves and Treatment Unit Supporting Stand. Materials were used to fabricate the bench-scale water treatment unit, such as pipes and valves. A 0.0127 m flow line diameter connecting the unit was considered with a corresponding flow velocity of 0.108 m/s. Details on some of these materials are presented in Table 2.

Table 2 – Materials, Sizes and Their Description

Materials used	Size (inch)	Description
Galvanised steel pipe	¾	Pipe used in constructing the supporting unit stand.
Gate valve	½	Full flow coated aluminium handle and threaded ends.
PVC gate valves	½	Two-ends threaded PVC gate valve
Socket gate valve	½	Threaded PVC socket gate valve
Double union gate valve	½	Low-pressure double union threaded gate valve
Discharge treated water valve	½	Valve for the outflow of treated water.

Development of Bench Scale Water Treatment Unit. Before the fabrication's commencement, the emphasis was given to selecting the vision materials, including pipe fittings, valves unions and gates valve, types of metals, electric motor capacity, and mixing blade type for suitability. The coagulation unit was designed to be 12.33 l capacity with a flow rate of 0.82 L/min; the coagulation/flocculation unit was also designed with a total volume of 20.00 l having a full size of overflow area of 7.46 l. The impeller used has a width of 2.00 cm. Its diameter from the tank's base is 8.00 cm, fabrication work was carried out using stainless steel for the primary treatment unit and cylindrical plastic containers for the storage tanks. Galvanised steel was used for the construction of the companies supporting stand. The gravitational force was considered during the design to overcome the challenges of pumping. Also, corrosion challenges were considered in selecting the materials during the fabrication stage.

Sample Collection / Preparation. *Balanites aegyptiaca* seed, also known as desert date obtained from the local market was weighed and soaked in water for 5 hours, washed thoroughly to remove the pulp, sundried, weighed again. The shell was cracked to obtain the seed kernel using a metal hammer. The seed kernel was weighed and then ground to increase the surface area using mortar and pestle. The ground sample was dried in an oven at 80 °C till constant weight then sieved. One hundred and fifty grams (150 g) ground kernel was charged into a Soxhlet extractor to extract the dried sample oil. The residue/cake from the extraction process was washed severally with distilled water, and then oven-dried. The soaked/dried residue was weighed and then kept in an airtight container for bio-coagulant use.

Method of Seed Oil Extraction. One hundred and fifty grams (150 g) of the prepared sample of *Balanites aegyptiaca* seed was taken inside a thimble made from thick filter paper, which was loaded into the main chamber of the Soxhlet extractor. The Soxhlet extractor was placed on to a flask containing the extraction solvent. The Soxhlet was then equipped with a condenser, and 250 ml of the solvent was heated to reflux. The solvent vapour travelled up a distillation arm and flooded into the chamber housing the thimble of solid. The chamber containing the solid material was slowly filled with warm solvent. When the Soxhlet chamber was almost full, the chamber was automatically emptied by a siphon sidearm, with the solvent running back down to the distillation flask. After many cycles, the desired compound was concentrated in the distillation flask. In this study normal-hexane (N-hexane) was used as a solvent. The micellar, a mixture of oil and solvent, from the distillation flask, which was concentrated, was then taken off for distillation to evaporate the solvent used and retain the oil [11]. Besides, the Soxhlet extraction process was carried out eight times until a total of one thousand two hundred grams (1200 g) of the ground sieved seed kernel was successfully extracted.

Microbiological Properties of the Sample. The following steps were followed to determine coliform bacteria's presence [6]. Membrane lauryl sulphate broth was dissolved in 100 ml of distilled water. Membrane filter was inserted into filter vacuum, one hundred millilitres (100 ml) of the sample was measured and put into the vacuum filter and filtered. Adsorption path was put into Petri dish, and membrane lauryl solution was added, the membrane was removed and inserted into the Petri dish and covered. Petri dish was put into the oven and incubated at 35 °C for 18 h. Hand lens was used in counting the coliform bacteria present.

Description of Experimental Setup and Water Treatment. The raw water was characterised for water quality parameters, and the *Balanites aegyptiaca* seed was processed, during the processing, oil extraction was performed, and dried powdered of the processed *Balanites aegyptiaca* seed was then used as a coagulant, based on the jar test result in the seed powder was then applied for the coagulation and flocculation experiment. Also, 10 g was dissolved in 100 ml of distilled water and then filtered to prepare the coagulant's saturated solution, and the extract was then used for the water purification. The treated water was then allowed to sediment and finally passed through the filter for removal of solutes. The treated water was then re-tested as earlier done on the sample before treatment for water quality parameters and the result compared with the standard. The whole water treatment process was performed within the design and developed water treatment units.

RESULTS AND DISCUSSIONS

Extraction of Oil from Balanites aegyptiaca Seed Powder and Sample Characterization. Balanites aegyptiaca seed used in this study could be a creamy oil source for domestic and industrial applications if correctly processed. It was also observed from the result in Table 3, which contained values for the factors used for the extraction of oil from *Balanites aegyptiaca* seed kernel. The results showed that temperature, extraction time, and particle size were among the factors that affected the extract's yields during oil extraction from the seeds. This is because the increase in temperature, particle size, and extraction time significantly influence the result during the extraction process. It was also observed that the percentage yield of the oil (extract) during the extraction process was 38.42 %. The oil density was found to be 0.84 g/cm3, and this result obtained complies with the literature as written by [18, 22]. The finding further revealed that the more the surface area, the lower the extraction time and the more the yield of the extract, this finding complies with the literature as reported by [14], seed sample for the oil extraction process was sieved through 0.6mm sieve size before experimentation. Detail of the result obtained is as shown in Table 3.

Table 3 – Factors Used and the Responses Obtained for the Oil Extraction

Particle size (mm)	Temperature °C	Extraction Time (hr)	Oil yield (%)	Oil Density g/cm^3
0.60	50.00	4.00	38.42	0.83

However, the sample characterisation result was adopted from the previous research conducted [14], X-ray fluorescence (XRF) analysis revealed that the sample contains Fe_2O3, SiO_2, CaO, which stabilises the pH. At the same time, Ag_2O, and ZnO gives the disinfection properties, scanning electron microscope (SEM) shows back detector Images of the crushed *Balanites aegyptiaca* seed hence, the finely ground powder of the root is in particle structure, Brunauer Emmett and Teller (BET) result revealed total pore volume of 0.003008 cm^3/g.

BET surface area of 11.224953 m^2/g and adequate surface area increases the chemical reaction, FTIR result showed functional groups such as OH (1° alcohol), amine (-NH_2), C=O (Carboxyl) and –C=C– symmetric stretching of alkenes by adsorption at different frequency band among others and at the functional group site the reaction takes place [14]. The proximate analysis results revealed moisture content of 3.65%, oil yield of 41.00%, protein content of 36.60%, ash content of 3.76%, nitrogen content of 5.58% and carbon content of 9.70% [14].

Physico-Chemical and Microbiological Properties of Turbid Water before and after treatment Using the Fabricated Water Treatment Units. The outcome of the physicochemical and microbiological characteristic of the turbid water before treatment revealed that all the tested parameters were above the recommended value set by [15] for safe quality drinking water except pH and conductivity which were within the acceptable range hence, the need for the treatment and this finding is in line with the literature as reported by [13].

Authors [10] also, this same finding complies with the set standard by [15]. It was also observed that the turbidity had exceeded the range of 50–150 NTU classified as medium turbid water as reported by [7, 13], detailing the findings obtained as presented in table 7. Furthermore, Table 4, 5 and 6 show the results of material balances for the coagulation tank, sedimentation tank and the filtration unit. It was observed from the material balances that steady-state operation was considered during the treatment process.

Table 4 – Material Balance for the Coagulation Tank

Component (g)	In(S1)	In(S2)	Out(S3)
Water	12100	100	12200
Nitrate (NO_3)	0.2302263	0	0.18804368
Iron (Fe)	0.10406	0	0.10043
Fluoride (F-)	0.0000	0	0.001573
Chloride (Cl^-)	0.06655	0	0.05445
Sulphate (SO_4)	0.8833	0	0.8833
Phosphate (PO_4)	0.0242	0	0.020449
Potassium (K)	0.3872	0	0.10891111
Copper (Cu^{2+})	0.121	0	0.115918
Bio-coagulant	0.000	10	10.343509
	12101.82	110	12211.8166

Table 5 – Material Balance for the Sedimentation Tank

Component (g)	In(S3)	Sludge(S4)	Out(S5)
Water	12200	1220	10980.0000
Nitrate (NO_3)	0.1880	0.018804368	0.1693
Iron (Fe)	0.1004	0.010043	0.0904
Fluoride (F^-)	0.0016	0.0001573	0.0014
Chloride (Cl^-)	0.0545	0.005445	0.0490
Sulphate (SO_4)	0.8833	0.088333	0.7950
Phosphate (PO_4)	0.0204	0.0020449	0.1884
Potassium (K)	0.1089	0.01089	0.0980
Copper (CU^{2+})	0.1159	0.0115918	0.1043
Bio-coagulant	10.3435	6.2061054	4.1374
	12211.8166	1226.353412	10985.4632

Table 6 – Material Balance for the Filtration Unit

Component (g)	In(S5)	Out filter(S6)	Out(S7)
Water	10980.0000	549.0000	10431.00000
Nitrate (NO_3)	0.1693	0.0000	0.1692
Iron (Fe)	0.0904	0.0000	0.0904
Fluoride (F^-)	0.0014	0.00000	0.0014
Chloride (Cl^-)	0.0490	0.0000	0.0490
Sulphate (SO_4)	0.7950	0.0000	0.7950
Phosphate (PO_4)	0.1884	0.00000	0.0184
Potassium (K)	0.0980	0.0000	0.0980
Copper (CU^{2+})	0.1043	0.0000	0.1043
Bio-coagulant	4.1374	4.0133	0.1241
	10985.4632	553.0133	10432.4499

From Table 4, In(S1) stands for the total components in the first input stream, In(S2) stands for the full details in the second input stream and Out(S3) stands for the total components in the first output stream.

Also, it was observed that the sum of In(S1) and In(S2) less Out(S3) equals 3.2E-07 which is almost zero indicating steady-state condition. From Table 4 In(S3) is the total components in the first input stream and sludge(S4) and Out(S5) are the two output streams full features, it was observed that In(S3) less the sum of sludge(S4) and Out(S5) gives zero which have revealed steadiness in the operation of the treatment process.

From Table 6 In(S5) is the total components in the first input stream while out the filter (S6) and Out(S7) are the two output streams full details, respectively. In(S5) less the sum of Outfitter (S6) and Out(S7) equals zero, which also showed steadiness in the operation of the treatment process.

However, the performance results of a prepared extract of *Balanites aegyptiaca* seed powder and the processed powdered coagulant on the turbid water after treatment showed decreased pH, colour, and total coliform count other inorganic constituents. Also, pH drops from 7.1 to 6.91, turbidity from 514 NTU to 26.5 NTU, colour from 5600.00 PCU to 290.00 PCU and total coliform count from 85 CFU/100 ml to 10 CFU/100 ml.

Other constituents present significantly decreases after treatment; detail on the result is as shown in Table 7.

Table 7 – Results of Turbid Water before Treatment and Performance Results of Stock Solution of *Balanites Aegyptiaca* Seed and Powdered coagulant on the Turbid Water after Treatment

Parameters / Units	Coagulant extract	Powdered Coagulant	0 – dosage Turbid Water before	Treatment	NIS/WHO
Temperature °C	27.400	27.30	27.200	27.900	Ambient
pH	6.91	7.22	7.17	7.100	6.5-8.5
Conductivity ($\mu s/cm$)	441.00	474.00	424.00	276.00	1000.00
Total dissolve solid (mg/l)	220.00	237.00	212.00	139.00	500.00
Turbidity (NTU)	26.500	90.74	234.68	514.00	5.00
Colour (PCU)	290.00	900.00	2300.00	5600.00	15.00
Total suspended solid (mg/l)	20.00	47.00	130.00	115.00	-
Nitrate(NO_3) (mg/L)	3.49	4.81	11.18	19.03	-
Iron(Fe) (mg/L)	0.300	2.300	5.70	8.60	0.30
Fluoride(F^-) (mg/L)	0.13	0.00	0.00	0.00	1.50
Chloride (Cl^-) (mg/L)	1.00	1.60	2.30	5.50	250.00
Sulphate(SO_4) (mg/L)	0.00	0.00	52.00	73.00	100.00
Phosphate(PO_4) (mg/L)	0.31	0.95	1.80	2.00	-
Potassium(K) (mg/L)	23.00	9.50	29.00	32.00	-
Copper(Cu^{2+}) (mg/L)	0.42	1.30	2.65	10.00	1.00
Total-alkalinity (mg/L)	155.00	240.00	400.00	950.00	-
Total Coliform Bacteria (cfu/100mL)	10.00	10.00	55.00	85.00	10.00

When such an outcome is compared with the turbid water's impact before treatment as presented in Table 7, the product agrees with similar work conducted as reported by [14]. Furthermore, when the powdered coagulant was used for the treatment on the developed treatment units, there was also improvement in the treatment process as a decrease in potassium content was observed compared with the result obtained when a stock solution of *Balanites aegyptiaca* Seed Powder was used as bio-coagulant. This is presented in Table 7. After treatment, the turbid water's microbiological property showed that Balanites Aegyptiaca seed powder and extract have good disinfecting stuff in water treatment than the set standard of 10 CFU/100 mL as set by [15]. When subjected to treatment, this study's turbid water also showed a remarkable reduction in its constituents, as presented in Table 7.

The findings are in agreement with the literature, as reported by [13]. It was also observed that coagulation-flocculation occurs within a specific pH range; different pH provides different colour [17].

Detail of the result is as presented in Table 7. Also, *Balanites aegyptiaca* seed and extract solution used as coagulant and disinfectant in comparison with the synthetic coagulants and disinfectants have a more comparative advantage over the synthetic ones used in water purification as showed in the results obtained in Table 6, the statement above complies with the literature [1, 5].

CONCLUSION

This paper reported developing a bench-scale water treatment unit for the treatment of medium turbid water. The total tank design capacity was 20.00 Liters with the overflow area's actual size for sedimentation of 7.46 Liters. The result of the treatment process using the stock solution and the powdered bio-coagulant on developed water treatment unit revealed remarkable reduction in the tested parameters in the raw turbid water used for the treatment process including total coliform count which reduces from 85 CFU/100 mL to 10 CFU/mL in both cases. It was observed that conductivity increases after the treatment, but other inorganic constituents reduce significantly though not to WHO and NIS's recommended set standard. The bio-coagulant application can be a sustainable and more cost-friendly alternative to non-bio-coagulant to purify medium to highly turbid water. However, the optimisation of the entire treatment process in this study is required to achieve optimum performance.

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