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Treatment of Harvested Rainwater in a Pilot Scale Fixed – Bed Filled with Bone Char

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Abstract: The adsorption of a fixed-bed filled with bone char in terms of removal efficiency of pollutants in raw harvested rainwater was investigated. Parameters as pH, temperature, turbidity, TDS, TSS, BOD, COD and nitrate were analyzed in all samples tested. A pre-treatment analysis of the feed stream showed mean values of pH (6.4); temperature (27.7^{0}C); turbidity (19.6NTU); TDS (906mg/l); TSS (28mg/l); BOD (37mg/l); COD (41mg/l) and nitrate (21.17mg/l). The removal efficiency of the treatment column was monitored continuously for a period of five (5) days. The treatment process achieved an overall efficiency of 86.60% turbidity, 69.34% TSS, 62.70%TDS, 84.38% BOD, 41.88%COD and 51.20% nitrate reduction. On the fifth day of operation the removal efficiency of the treatment system became reduced and appropriate back washing of the fixed-bed was required to regenerate it. Effluent characteristics obtained for the treatment process are consistent with WHO standard for drinking water. Kinetic study of the treatment process reveal that adsorption of contaminants was by physiosorption (physical adsorption) with low values of activation energies of E_{COD} (359.84J/mol and E_{TSS} (215.91J/mol).

Key words: Influent, effluent, rainwater, bone char, physiosorption.

INTRODUCTION

Rainwater harvesting is a method for collecting, storing and conserving rainwater from roof tops, land surfaces or rock catchments using simple techniques such as jars and pots as well as more complex technique such as underground check dams for future use[4]. It is a traditional water management technique[12]. This old technology is gaining new popularity these days especially in areas of prolonged periods of little or no rainfall or areas where public water works and distributing systems has completely broken down or areas where hydrogeological conditions does not favour the drilling of bore-hole.

Harvested rainwater is a valuable source of water for domestic use. However, water for human consumption and domestic use must be free from significant concentration of pollutants[14]. Pre-treatment analysis of raw harvested rainwater collected in the study area showed that concentration levels of parameters such as; turbidity, total dissolved solids (TDS), total suspended solids (TSS), biochemical oxygen demand (BOD), chemical oxygen demand (COD) and nitrate are above acceptable / permissible limits for drinking water[14] (See Table 1). Major constituents of the raw harvested rainwater are biodegradable organics. The biodegradable organics can lead to the depletion of natural oxygen resources and are potential sources for water-borne disease vectors[11]. A treatment process aiming to enhance the removal of colloidal particles, suspended matters and organic constituents from waste water or contaminated water is a basic step and starting point in wastewater treatment. This paper presents a study on a treatment method using a fixed-bed filled with bone char aimed at improving the quality of raw harvested rainwater with a good economic advantage and an ease-to-operate technology.

MATERIALS AND METHODS

Study Area: The study area is Agbor. It is enclosed between latitude 5^{0}43^{1}N and 5^{0}30^{1}N and longitude 6^{0}20^{1}E and 6^{0}12^{1}E. It is the administrative headquarter of Ika South local government council area of Delta State, Nigeria. Previous study of the meteorology of the area[6] reveals the atmospheric temperature to be 25.5^{0}C in the rainy season and 30^{0}C in the dry season. The daily relative humidity range from 55.5% to 70%. Rainfall in the area averages 1500-2000mm annually. Rainfall pattern shows two identifiable seasons, the rainy season (April to October) and the relatively short dry season (November to March).

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Table 1: Quality characteristics of raw harvested rainwater (n = 5)

Parameters / units	Mean (+ SD)	WHO (1984)
pH	6.4 (+ 0.11)	6.5-8.0
Temperature (^{0}C)	27.7 (+ 0.06)	25-30
Turbidity (MTU)	19.6 (+ 1.12)	5
TDS (mg/L)	906 (+ 1.18)	500
TSS (mg/L)	28 (+ 1.13)	25
BOD (mg/L)	37 (+ 0.79)	10
COD (mg/L)	41 (+ 1.21)	40
Nitrate (mg/L)	21.17(+ 1.35)	10

Table 2: Chemical and Physical Characteristics of Bone Char.

Components / Characteristics	Content (%)
$CO_3(PO_4)_2$	82.0 – 84.0
$CaCo_3$	7.0 – 8.0
$CaSo_4$	0.1– 0.2
Ca S	0.01– 0.02
C	9.0 – 10.0
Apparent specific gravity	0.65 – 0.75
Effective diameter (mm)	0.4 – 1.0
Void ratio	52.0 – 58.0

The people of Agbor community practice extensive rainwater harvesting technology as they depend on it for consumption and domestic use all year round. Ground water hydrogeology of the area does not favour easy drilling of water borehole. In addition, the only public water works located at Prof. Ebie Street is non-functional coupled with the poor water quality of Orogodo River (the only natural resource in the area)[9] . In Agbor, the roof-catchments technology is the common practice employed in rainwater harvesting. Collection of rainwater from the rooftop is done by means of gutters made from galvanized iron or polyvinyl chloride (PVC) pipes. Collected rainwater is channeled into a storage facility (wells) that is usually made of concrete.

Although, Agbor may not be described as an industrialised community, there exist pockets of industries such as paint and foam manufacturing companies.

Bone Char: Bone Char is a kind of cheap material and the ability of bone char to adsorb a considerable amount of contaminants from contaminated water has been demonstrated recently[3].

Bone char used for the study were prepared by burning animal (cow) bones collected from an abattoir in Agbor. The bones were subjected to an elevated temperature of about 180^{0}C for 10 hours in an oven. The charred bones were cooled to room temperature. They were then grinded to fine particles using a laboratory grinder and sieved through a 5mm mesh. Chemical and physical characteristics of animal (cow) bone char have been reported[15] (Table II).

Harvested rainwater: Harvested rainwater used for the study was collected from ten (10) randomly selected harvested rainwater storage facilities within the month of January 2006. This is a period of little or no rainfall when there is increased utilization of harvested rainwater.

Samples were collected in labeled 2.5L plastic sample container initially pre-treated by washing in dilute hydrochloric acid and rinsed with distilled water. The containers were later sun dried. At the samples collection points, the storage facilities were manually agitated for the purpose of homogeneity in its composition. At each sample collection point the sample containers were rinsed twice with the relevant sample and 2.5L of the sample collected. Samples were taken to the laboratory for analyses. At the laboratory, all samples from the ten randomly selected storage facilities were bulked to form a representative sample, which served as the influent feed for the study.

Treatment Systems and Process Flow: Figure 1 show the schematic diagram of the treatment system and process flow used in the study. The system is made of a column of glass tube (50cm high and 9cm in diameter) packed with the bone char material to a level of 30cm. The column was packed by blocking both ends of the tube with cotton wool. Influent feed (raw harvested rainwater) was fed from the top down flow. Effluent outlet was at the bottom of the column.

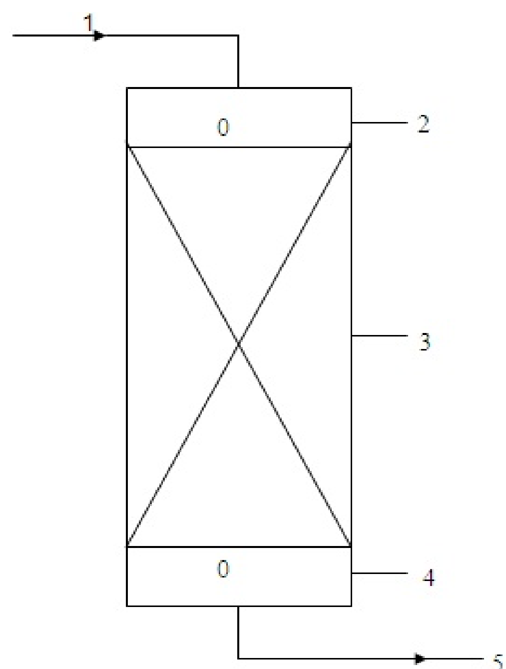

Fig. 1: Schematic diagram of the system
Parts of the treatment system are: (1) Influent feed stream (2) Upper cotton wool layer (3) Bone char packed layer (4) Lower cotton wool layer
(5) Effluent stream.

Methodology: Bulked raw harvested rainwater was fed from the top of the column and allowed to flow down the column under the influence of capillary and gravitational force at room temperature (28^{0}C) and atmospheric pressure (1 atm). At each run, analysis was carried out for both influent and effluent stream daily for 5 days and removal efficiency of the treatment process for each run determined. The analyzed parameters were: pH, temperature, total dissolved solids (TDS), total suspended solids (TSS) turbidity, biochemical oxygen demand (BOD), chemical oxygen demand (COD) and nitrate.

Temperature, pH, turbidity and TDS were determined using a multiparameter water quality monitor (Hydrolab 6000 UPG). At the determination of any of these parameters, the instrument was properly checked and calibrated before and other use. COD and BOD were determined using iodometeric method nitrate and TSS were determined using Brucine colourimeter and weight loss technique respectively. All methods of analyses were consistent with APHA,[2], DPR[5] and WHO[14].

RESULTS AND DISCUSSIONS

Physico-chemical characteristics of the pre-treated (raw) harvested rainwater are presented in Table 1.

Table 3: Quality of effluent obtained from the treatment process after 1 day of operation.

Parameters / units	Influent	Effluent	Removal efficiency (%)
pH	6.4	6.6	3.125
Temperature (^{O}C)	27.8	27.3	1.80
Turbidity (Ntu)	19.4	2.6	86.60
TDS (mg/l)	914	341	62.70
TSS (mg/l)	27.4	8.4	69.34
BOD (mg/l)	36.5	5.7	84.38
COD (mg/l)	41.3	24.0	41.88
Nitrate (mg/l)	20.9	10.2	51.20

Table 4: Quality of effluent obtained from the treatment process after 2 days of operation.

Parameters / units	Influent	Effluent	Removal efficiency (%)
pH	6.4	6.7	4.69
Temperature (^{O}C)	27.4	27.1	1.09
Turbidity (Ntu)	19.2	2.4	87.5
TDS (mg/l)	908	293	62.76
TSS (mg/l)	25.2	8.0	68.25
BOD (mg/l)	36.1	5.2	85.60
COD (mg/l)	39.8	21	47.24
Nitrate (mg/l)	20.8	9.4	54.80

Table 5: Quality of effluent obtained from the treatment process after 3 days of operation

Parameter / units	Influent	Effluent	Removal efficiency (%)
pH	6.5	6.6	1.52
Temperature (^{O}C)	27.8	27.2	2.16
Turbidity (Ntu)	19.1	2.5	86.91
TDS (mg/l)	907	331	63.51
TSS (mg/l)	24.9	7.7	69.08
BOD (mg/l)	36.1	4.9	86.43
COD (mg/l)	39.6	19	52.20
Nitrate (mg/l)	20.7	9.3	55.07

Table 6: Quality of effluent obtained from the treatment process after 4 days of operation.

Parameter / units	Influent	Effluent	Removal efficiency (%)
pH	6.4	6.5	1.56
Temperature (^{O}C)	27.6	27.4	0.72
Turbidity (Ntu)	19	7.6	60
TDS (mg/l)	904	496	45.13
TSS (mg/l)	24.7	13.8	44.13
BOD (mg/l)	35.9	10.2	71.59
COD (mg/l)	39.2	28.6	27.04
Nitrate (mg/l)	20.4	12.4	39.22

Table7: Quality of effluent obtained from the treatment process after 5 days of operation

Parameter / units	Influent	Effluent	Removal efficiency (%)
pH	6.3	6.4	1.59
Temperature (^{O}C)	27.5	27.4	0.36
36Turbidity (Ntu)	18.9	13.4	19.10
TDS (mg/l)	903	568	37.09
TSS (mg/l)	24.2	18.4	23.97
BOD (mg/l)	34.2	24.2	29.03
COD (mg/l)	39.1	31.5	19.44
Nitrate (mg/l)	20.7	18.6	8.37

Table 8: Quality of effluent obtained from treatment process after back washing.

Parameter / units	Influent	Effluent	Removal efficiency (%)
pH	6.5	6.4	1.54
Temperature (^{O}C)	27.6	27.4	0.72
Turbidity (Ntu)	19.3	2.5	87.05
TDS (mg/l)	913	337	63.09
TSS (mg/l)	27.3	8.6	68.50
BOD (mg/l)	36.4	5.8	84.07
COD (mg/l)	40.9	23.6	42.30
Nitrate (mg/l)	20.7	9.3	55.07

From the results (Table 1), the concentrations of the studied parameters in the samples analyzed were above acceptable / permissible limits for drinking water[14]. Similar results have been obtained for harvested rainwater quality in the study area[8]. High levels of nitrate could be attributed to the natural process of photochemical oxidation of atmospheric nitrogen to give oxides of nitrogen (NO_x) during lightening and thunderstorms that becomes soluble during rainfall. High levels of TDS, turbidity, BOD and COD values may have been influenced by heavy dusty atmosphere which is prevalent in the area during dry season. In addition, birds and insects dropping on roofs may be a source since rainwater harvesting in the area does not make provision for purification/treatment process. Similar observations have been made[7].

Results of the treatment efficiency of the bone char column monitored on a daily basis for 5 days are presented in Tables III –VII. From Table III, analyses of the effluent showed a good reduction of turbidity from 19.4 NTU to 2.6 NTU. This shows 86.60% of turbidity removal while TDS was reduced from 914mg/l to 341mg/l giving a 62.70% reduction. TSS was reduced from 27.4mg/l to 8.4mg/l (69.34%). BOD and COD were reduced from 36.5mg/l to 57mg/l (84.38%) and from 41.5mg/l to 24mg/l (41.88%) respectively. Nitrate reduction was by 51.20% (20.9mg/l to 10.2mg/l). pH of the effluent was 6.6 while temperature was reduced by 0.5^{0}C (27.8 to 27.3^{0}C). Comparison of the effluent quality showed a good compliance with WHO requirement for drinking water quality. However, by fourth day of continuous operation of the treatment process using bone char, removal efficiency dropped and by the fifth day, the effluent quality became very poor with values such as; turbidity (13.4) NTU; TDS (568mg/l); TSS (18.4mg/l); BOD (24.2mg/l); COD (31.5mg/l) and nitrate (18.6mg/l) (see Table VII). Major problem of the process was due to deposition of trapped solids, which required back washing of the process column to regenerate it[1,10].

Regeneration of the bone char column was done by back washing directly with tap water. After back washing, turbidity removal increased by 87.05% (19.3 NTU to 2.5 NTU), while TDS was reduced from 913mg/l to 337mg/l (63.09%). TSS was reduced from 27.3mg/l to 8.6mg/l, which represents 68.50%, BOD and COD were reduced from 36.4mg/l to 5.8mg/l (84.07%) and from 40.9mg/l to 23.6mg/l (42.30%) respectively. Nitrate was reduced from 20.7mg/l to 9.3mg/l representing 55.07% reduction. pH of the effluent was 6.6 while temperature of the effluent was 27.4^{0}C as against 27.6^{0}C for influent. The obtained effluent quality from the regenerated column compared positively with that required for drinking water[14].

Using the integrated form of Arrhenius equation (equation 1.1) the activation energies (Ea) for the adsorption of COD and TSS was calculated as 359.84J/mol and 215.91J/mol respectively. The low activation energies values of the adsorped parameters indicate that the process of adsorption was physiosorption (physical adsorption)[13].

$$\text{Log K} = \frac{Ea}{2.303} \quad \frac{T_2 - T_1}{T_1 T_2 -} \quad \text{---------------------1.1}$$

Conclusion: From the study, bone char is an effective adsorbent whose application in the purification of harvested rainwater can be popularize. The fixed bed filled with bone char has demonstrated its ability to adsorb a considerable amount of biodegrable pollutants. Raw harvested rainwater subjected to such treatment has good quality comparatively to WHO standard for drinking water. The use of bone char in the full-scale water purification is therefore suggested.

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