Research Article

# The utilization of bentonite enhanced termite mound soil mixture as filter for the treatment of paint industrial effluent

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**Abstract**

This research investigates the applicability of bentonite enhanced termite mound soil mixture as an alternative filter medium for paint industrial wastewater (PIWW) management in a constructed pilot-scale filtration tank with four different sections. The mixture of bentonite (BC) and termite mound soil (MS) used as the filter was proportioned by percentage weight as (100% MS), (5% BC + 95% MS), (10% BC + 90% MS), (15% BC + 85% MS) and placed into four sections, respectively. The filter materials were compacted, cured and subjected to wastewater loading for 30 weeks. The results obtained from the analysis of the filtrate samples revealed that filter with 15% BC content generally exhibited high and effective pollutant removal efficiencies of 51.3%, 98.9%, and 72.7% for total dissolved solids, total suspended solids, and copper, respectively, while a maximum removal efficiency of 100% was recorded for lead, chromium and cadmium. The pollutants (TDS, TSS, Pb, Cr, Cu and Cd) concentrations of the treated PIWW were below the National Environmental Standards and Regulations Enforcement Agency permissible limits for discharge. Hence, the 15% bentonite and 85% termite mound soil mixtures are recommended for the small-scale paint industries as a point of use measure for effective pollutant removal. Its application would mitigate the degradation of environmental resources caused by indiscriminate disposal of untreated effluent.

**Keywords** Bentonite · Filter · Paint effluent · Termite mound

## 1 Introduction

Waste may be referred to as an unwanted material in liquid, solid or gaseous form which is discarded in accordance with standard regulations after it has served its primary purpose. The rise in human population growth across the globe without sustainable control measures had resulted in a vast volume of waste generated per day. The effective management of these generated wastes is a perpetual challenge in both developed and developing countries [1, 2]. The significant growth of manufacturing industries in Nigeria has contributed to the high volume of generated effluents which has impacted the environmental resources due to the indiscriminate and unsanctioned discharge of untreated effluents into surface water bodies. Depending on the category of industry, wastewater pollutants may include high levels of biological oxygen demand ($BOD_5$), chemical oxygen demand (COD), total dissolved solids (TDS), total suspended solids (TSS), and toxic heavy metals. Filtration is considered an essential wastewater

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treatment technique due to its efficiency in the removal of suspended particles and reduction of organic and inorganic pollutants. Ripperger et al. [3] classified filtration processes based on four different criteria, namely location of particle retention, generation of the pressure difference, operation mode, and application. In recent studies, different filter media have been used in the removal pollutants from wastewater. For instance, Shafiquzzaman et al. [4] employed low-cost ceramic filter for urban stormwater treatment, whereas Ajibade et al. [5] and Akosile et al. [6] utilized ceramic filter to enhance the microbial quality of household drinking water. Also, Liu et al. [7] used oyster shell for biological aerated filter medium for municipal wastewater. Lawal et al. [8] studied the treatment of agro-processing wastewater using ceramic wastewater and Gasemloo et al. [9] used sulphated carboxymethyl cellulose nano-filter for tannery wastewater. Composite clayey soils have been applied as an efficient chemical filter and pollutants removal in recent times [10–13]. Mounds otherwise known as termitaries are structures built by dissimilar termite species from surrounding soils through the redistribution of soil organic matter and elements in their biomass and organo-mineral constructions. They possess low thermal conductivity, resistance to moisture penetration, comparative compressive strength and mostly found in tropical and subtropical geographical environments [14–17]. Termitaries have been classified as nuisance to agricultural farm lands and wooden infrastructure because of the space occupied and their destructive nature [18]. They are usually destroyed and turned into wastes. This conventional waste has been utilized as construction materials [19–21] and an adsorption material in the decontamination of metal polluted effluent [22]. However, the potentials of mound soil as a filter material in the removal of wastewater pollutants are yet to be analysed and ascertained. There is no literature available on the application of enhanced mound material as an alternative filter system for wastewater management. The presence of high pollutant concentrations in the generated industrial wastewater makes adequate treatment sacrosanct prior to their usual disposal into receiving water bodies. There is a need to comprehensively study the applicability of alternative low-cost materials for wastewater management as the on-site biophysiochemical treatment of these generated effluents could be capital-intensive. Thus, this study investigates the applicability of bentonite enhanced termite mound soil mixture as a filter medium for the treatment of paint wastewater and evaluates its pollutants removal efficiency.

## 2 Materials and methods

### 2.1 Materials

The major materials used for the research are termite mound soil (MS), bentonite (BC) and paint industrial wastewater (PIWW).

(a) *Termite mound soil* A reddish brown mound soil was sourced from Ifo, Ogun State within the geographical coordinates of latitude 6° 48′ 39.82″ N and longitude 3° 5′ 58.76″ E (Fig. 1). It possesses a specific gravity of 2.53 and classified as a poorly graded soil with silty clay (Table 1). The X-ray diffraction analysis revealed quartz (93.76 wt%) as the dominant mineral. The unconfined compressive strength and

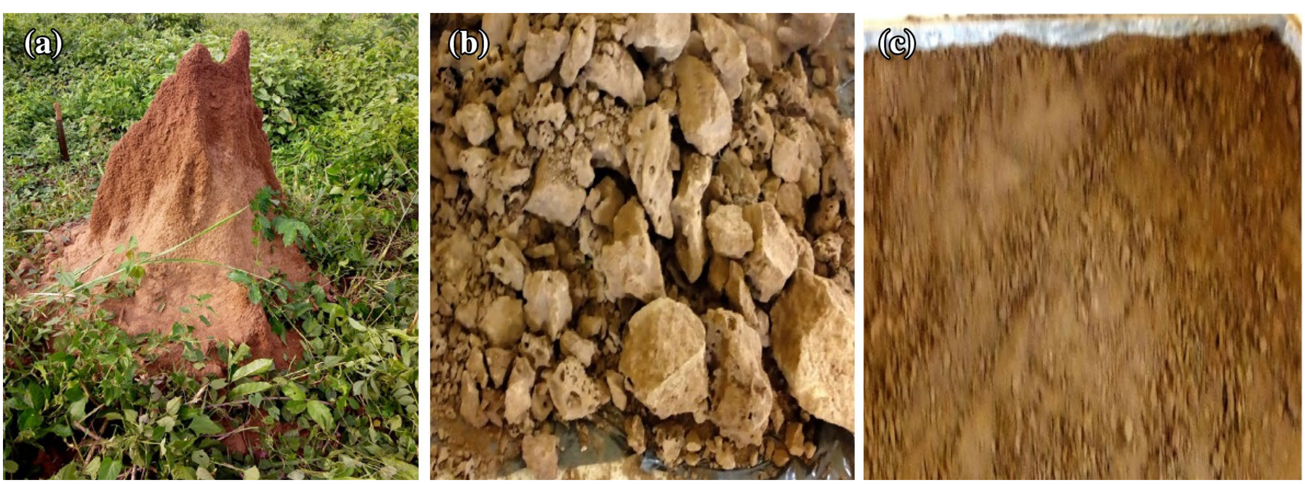



**Fig. 1** **a** Termite mound prior to sampling, **b** broken mound, and **c** pulverized mound sample

**Table 1** Physical characteristics of bentonite and termite mound soil [1]

| Properties | Bentonite | Termite mound |
|---|---|---|
| Colour | Yellowish–brown | Reddish–brown |
| Specific gravity | 2.37 | 2.53 |
| Dominant mineral | Montmorillonite | Quartz |
| Sand (%) | 20.1 | 87.5 |
| Silt (%) | 20.4 | 2.3 |
| Clay (%) | 59.5 | 10.2 |
| Liquid limit (%) | 189 | 49 |
| Plastic limit (%) | 61 | 27 |
| Plasticity index (%) | 128 | 22 |
| USCS classification | – | Poorly graded soil with silty clay |

*USCS* Unified soil classification system

hydraulic conductivity of MS are 298.42 kN/m$^2$ and $783.4 \times 10^{-9}$ m/s, respectively.

(b) *Bentonite* A yellowish–brown bentonite was obtained from a major supplier within Lagos, Nigeria (Fig. 2). It is characterized with a specific gravity of 2.37 (Table 1). The X-Ray diffraction analysis revealed montmorillonite (73.73 wt%) as the dominant mineral.

(c) *Wastewater* PIWW used as a contaminant was a composite sample acquired from a major paint manufacturing company's plant situated in Lagos State (Fig. 3). The characterization of the acquired wastewater is shown in Table 3.

**Fig. 2** Bentonite clay

**Fig. 3** PIWW

## 2.2 Methods

### 2.2.1 Elemental and mineralogy analysis of the filter materials

The major and trace elements present in the bentonite and termite mound soil were identified through the use of X-ray Fluorescence Spectrometer (EDX 3600B Skyray Instrument, USA). The soil samples were air-dried and sifted (fraction below 2 mm). The X-ray diffraction (XRD) technique was employed to determine the mineralogical phase composition and quantification of the materials.

### 2.2.2 Performance evaluation framework

The applicability of bentonite enhanced termite mound soil mixture as an alternate filter medium for paint effluent management was assessed with the aid of a well-designed and constructed pilot-scale filtration tank (800 × 800 × 800 mm) with four different sections (400 × 400 × 400 mm) designated as AX, AY, BX and BY, respectively, as shown in Fig. 4.

The soil mixtures placed in each section were prepared and proportioned by percentage weight as (100% MS), (5% BC + 95% MS), (10% BC + 90% MS) and (15% BC + 85% MS) for sections AX, AY, BX and BY, respectively. The soil mixtures were compacted with optimum water content in three layers to attain 100 mm thickness with the aid of a hand compactor of 7 kg self-weight and cured for 28 days as described by Tucan et al. [11]. The mixture in each section was subjected to paint wastewater loading for 30 weeks. The content schematic of the tank is illustrated in Fig. 5. Filtrate samples were collected from the leakage outlets of each section in triplicate (Fig. 6) and placed in an ice-cooled insulated cooler and transported to the laboratory. The samples were refrigerated at 4 °C upon arrival at the

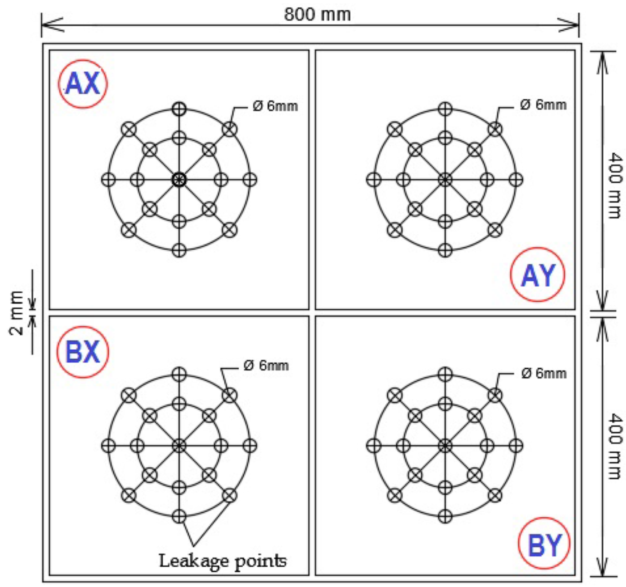



**Fig. 4** Plan view of the pilot scale filtration tank

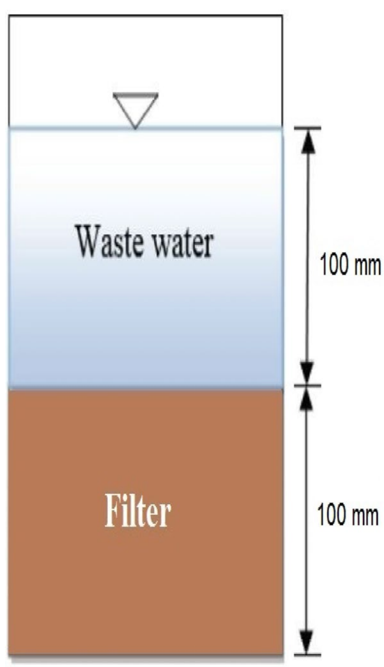



**Fig. 5** Content schematic

laboratory preserve their physicochemical qualities prior to analysis in accordance with APHA, [23] and USEPA, [24]. The quantification and analysis of filtrate samples were obtained after the experimental framework. The performance of the filter was evaluated through the relationship between the characterization of raw PIWW and filtrate samples. The

**Fig. 6** Experimental setup

removal efficiencies of the filter were determined by using Eq. (1);

$$R_e(\%) = \frac{C_i - C_f}{C_i} \times 100 \tag{1}$$

where $R_e$ is the removal efficiency, $C_i$ is the initial concentration of contaminant, and $C_f$ is the final concentration of contaminant.

## 3 Results and discussion

### 3.1 Elemental composition of the filter materials

XRF results for the collected soil samples attest to the existence of the following major (Al, Si, P, S, K, Ca, Ti, V, Fe, W, Nb, Mo, Sn, Sb) and trace (Co, Cr, Cu, Mn, Ni, Pb, Zn) elements. The composition is major and trace elements in the bentonite and termite mound are summarized in Table 2. The principal occurring elements in both bentonite and mound soils are aluminium 8.91 and 14.11 wt%, silicon 25.19 and 25.82 wt%, iron 17.92 and 10.50 wt%, respectively.

### 3.2 Mineralogical composition of the filter materials

The XRD diffractograms and mineralogical analysis of the termite mound disclosed quartz (93.76%) as the primary and dominant mineral which exhibits a strong reflection

**Table 2** Composition of major and trace elements in the soil samples

| S/N | Element | Concentration (wt%) | |
|---|---|---|---|
| | | Bentonite | Termite mound |
| 1 | Al | 8.91 | 14.11 |
| 2 | Si | 25.19 | 25.82 |
| 3 | P | 0.12 | 0.13 |
| 4 | S | 0.44 | 0.34 |
| 5 | K | 0.97 | 0.20 |
| 6 | Ca | 0.32 | 0.15 |
| 7 | Ti | 0.32 | 1.25 |
| 8 | V | 0.02 | 0.02 |
| 9 | Cr | 0.03 | 0.01 |
| 10 | Mn | 0.22 | 0.12 |
| 11 | Co | 0.34 | 0.20 |
| 12 | Fe | 17.92 | 10.50 |
| 13 | Ni | 0.06 | 0.08 |
| 14 | Cu | 0.03 | 0.05 |
| 15 | Zn | 0.11 | 0.11 |
| 16 | Pb | 0.01 | 0.02 |
| 17 | W | 0.11 | 0.02 |
| 18 | Nb | 0.01 | 0.03 |
| 19 | Mo | 0.23 | 0.16 |
| 20 | Sn | 1.25 | 1.43 |
| 21 | Sb | 1.13 | 1.29 |

at 60.2° 2$\theta$ with peak intensity of 8500 counts. However, the crystalline phase of secondary minerals contained in bentonite displays reflections of anhydrite (3.20%), gypsum (1.57 wt%), bassanite (0.56 wt%), ferrite (0.47 wt%) and lime (0.44 wt%) at 62.3° 2$\theta$, 62.1° 2$\theta$, 57.4° 2$\theta$, 59.8° 2$\theta$ and 54.1° 2$\theta$ with peak intensities of 1500, 1100, 1300, 700 and 1000 counts, respectively (Fig. 7). Analysis of the mineralogical phase composition revealed montmorillonite (73.73 wt%) as the primary and dominant mineral in bentonite which exhibits a strong reflection at 28° 2$\theta$ with peak intensity of 6400 counts. Moreover, the crystalline phase of secondary minerals contained in bentonite display reflections of gypsum (8.43 wt%), periclase (7.07 wt%), lime (6.06 wt%) and calcite (3.14 wt%) at 21° 2$\theta$, 43° 2$\theta$, 37.3° 2$\theta$ and 33° 2$\theta$ with peak intensities of 2400, 2100, 2500, and 2300 counts, respectively (Fig. 8). However, a weak reflection found at 60.2° 2$\theta$ with maximum intensity of 1900 counts affirm the presence of portlandite (1.57 wt%).

### 3.3 Filtrate quantification and flow rate

The filtrate quantification, flow rate and period of debut droplet from respective filters are presented in Table 3. Filter AX with 100% termite mound soil (control) has the highest filtrate discharge of 1.1 L with a corresponding flow rate of $11 \times 10^{-4}$ LPH while filter BY with bentonite and termite mound ratio of 15:85 has the lowest filtrate discharge and flow rate of 0.2 L and $0.43 \times 10^{-4}$ LPH, respectively. The particles of cohesive soils have the tendency to stick to each other due to intermolecular interactions and greater quantity of clay particles produces high liquid limit, as a result, they usually have low permeability [25, 26]. The liquid limit of bentonite is more than thrice compared to that of termite mound soil. The low filtrate discharge recorded for filter BY could be attributed to more fines present in bentonite compared to termite mound soil.

### 3.4 Characterization of raw and treated paint industry wastewater.

The characteristics of the raw paint wastewater are presented in Table 4. The total dissolved solids (TDS), biochemical oxygen demand (BOD) and chemical oxygen demand (COD) are 585, 254 and 569 mg/L, respectively. The heavy metals analysis revealed elements such as lead (0.35 mg/L), chromium (0.76 mg/L), copper (1.43 mg/L), cadmium (0.43 mg/L) and nickel (9.45 mg/L). The concentrations of TDS, BOD, COD, copper and nickel were above the permissible limits of NESREA [27]. Similar results were reported by Oladele et al. [28] and Onuegbu et al. [29]. Hence, it's imperative to treat the wastewater prior to its discharge into the environment to forestall the pollution of surface and groundwater. The trends of bentonite content on colour, TSS, Pb, Cr, Cu, Ni, TDS, BOD and COD of the treated samples are shown in Figs. 9 and 10. The strength of pollutants in the filtrate samples generally reduced with the stepped introduction of bentonite. However, the $BOD_5$ and COD of the treated samples (Fig. 10) failed to comply with NESREA ($BOD_5 \leq 30$ mg/L and COD $\leq 60$ mg/L) permissible values for discharge into inland waters. The availability of organic compounds (nitrocellulose, alkyd resins and acrylic/styrene co-polymer) and oxidizable inorganic compounds (pigments and additives) is responsible for the impact on $BOD_5$ and COD [29].

### 3.5 Filter removal efficiency

The performance of the filters was assessed based on their removal efficiency (RE). Table 4 presents the RE of the filters with respect to their bentonite contents. The RE of colour for filter AX, AY, BX and BY is 7.3%, 12.7%, 16.4% and 20%, respectively. Hu et al. [30] stated that application of bentonite as an adsorbent of basic red dye is largely based on its ability to exchange cations. The best colour RE recorded for filter BY is largely based on the high cation exchange capacity of the bentonite used. The RE of TDS ranged from

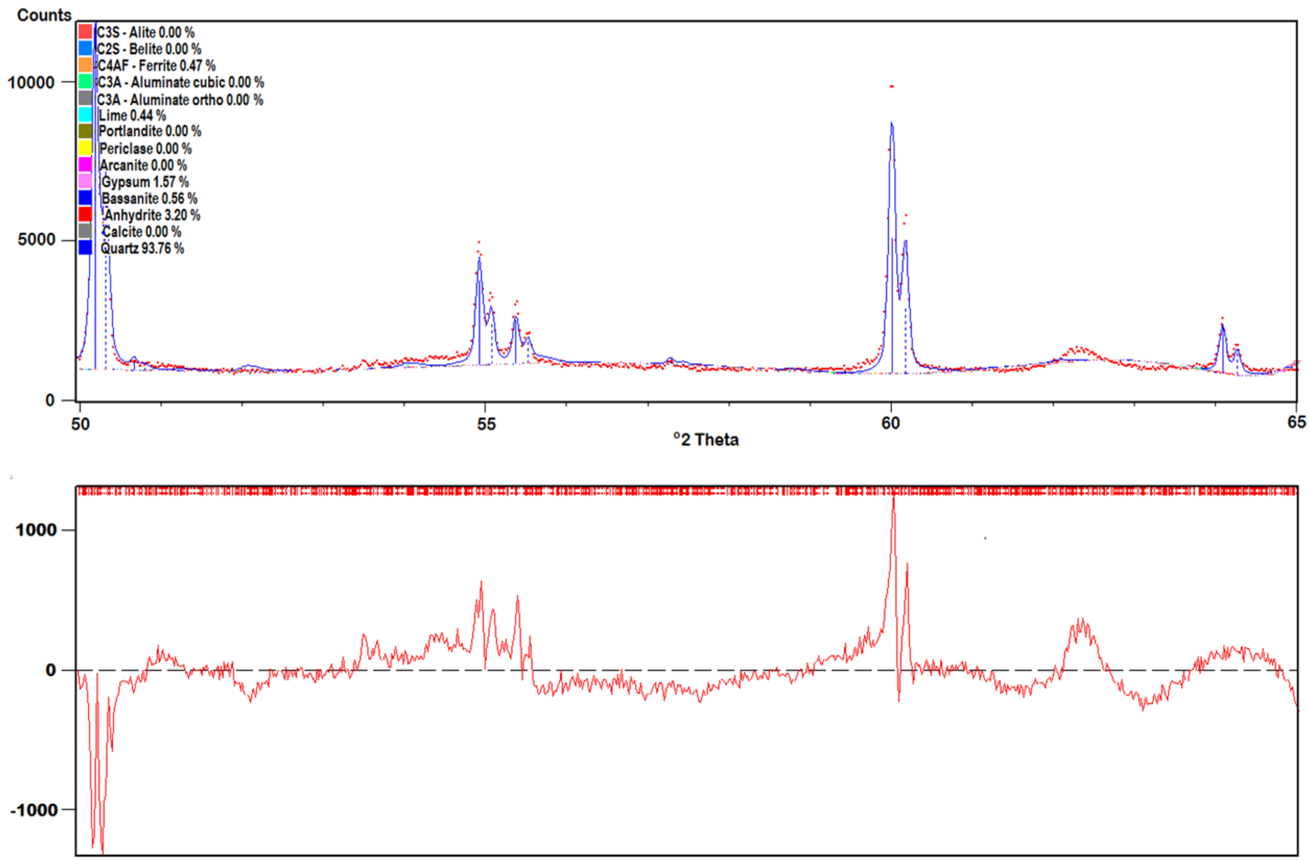



**Fig. 7** X-Ray diffraction spectrum of termite mound soil

19.7 to 51.3% reduction while that of TSS ranged from 97.8 to 98.9% reduction (Fig. 11). Healy [31] reported that bentonite-based hydrophobic media has the capacity to absorb up to 60% of its weigh in organic contaminants. The high reduction in TSS and TDS of the treated samples may be attributed to the capacity of bentonite to adsorb particulate matter on its surface. The RE of copper significantly increased from 5.6% for filter AY to 72.7% reduction for filter BY with the stepped introduction bentonite. The finding is in tandem to that of Cao et al. [32] that reported efficiency removal of 73.63% for copper ion on adsorption study using bentonite-zeolite. Filters AX and BX gave the minimum RE values of 42.9% and 85.7%, respectively, for lead while filters AY and BY with bentonite content of 5% and 15% recorded the maximum removal efficiency of 100%. The treatment efficiency of nickel gradually increased with the stepped introduction of bentonite. Filter AX gave the minimum RE value of 63% while maximum RE value of 78.8% was recorded for filter BY. Chromium removal efficiency values for filter AX, AY and BX are 35.5%, 55.3% and 67.1%, respectively, while filter BY with 15% bentonite content gave a maximum RE value of 100%. An exceptional maximum treatment efficiency of 100% was recorded for cadmium in all the filtrate samples obtained from the filters (Fig. 11). Bentonite is characterized with a high specific surface area, tendency to absorb water in the interlayer sites and affinity to adsorb ions from solutions [33, 34]. The excellent removal efficiencies of metal ions generally recorded for filter BY could be attributed to its high adsorption capacity and vast specific area.

## 4 Conclusion

The investigation on the applicability of bentonite (BC) enhanced termite mound soil (MS) mixture as an alternate filter medium for the treatment of paint industry wastewater revealed the following conclusions.

a. Filter BY with 15% bentonite content is the best filter compared to other filters with lower percentage of bentonite.

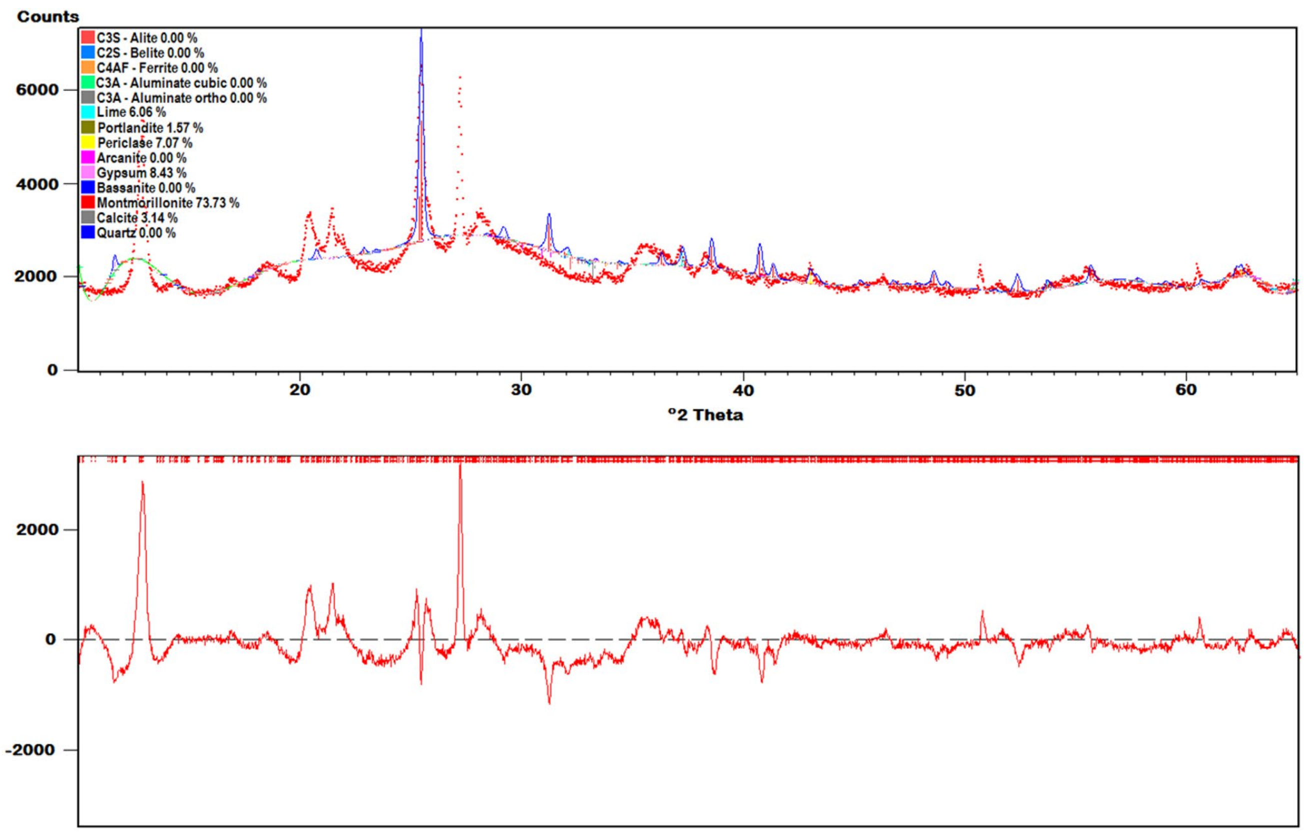



**Fig. 8** X-Ray diffraction spectrum of bentonite

**Table 3** Quantification and flow rate of the filtrate samples

| Filter | Composition | Filtrate discharge (Litre) | Period of debut droplet (weeks) | Flow rate $\times10^{-4}$ (LPH) |
|---|---|---|---|---|
| AX | 0%BC + 100%MS | 1.1 | 6 | 11 |
| AY | 5%BC + 95%MS | 0.5 | 11 | 2.7 |
| BX | 10%BC + 90%MS | 0.4 | 17 | 1.4 |
| BY | 15%BC + 85%MS | 0.2 | 28 | 0.43 |

*BC* Bentonite clay; *MS* Mound soil; *LPH* Litre per hour

b. Filter BY is effective and efficient for the treatment of paint wastewater pollutants such as TDS, TSS, Pb, Cr, and Cu.
c. The blend of 15%BC + 85% MS can be applied effectively as an alternate filter medium for the treatment of paint industry wastewater.
d. The filtration technique can be applied in small paint industry to remove pollutant from their effluent due to its design simplicity, availability of filter materials, cost and treatment efficiencies.

**Table 4** Characteristics of paint wastewater and filter removal efficiency

| Parameter | Initial concentration (mg/L) | *NESREA standards | Removal efficiency (%) | | | |
|---|---|---|---|---|---|---|
| | | | AX | AY | BX | BY |
| Colour | 5.5 | 7 | 7.3 | 12.7 | 16.4 | 20.0 |
| TDS | 585 | 500.0 | 44.4 | 19.7 | 39.3 | 51.3 |
| TSS | 11.28 | 25.0 | 97.8 | 98.7 | 98.2 | 98.9 |
| BOD5 | 254 | 30.0 | 8.7 | 4.3 | 6.7 | 13.0 |
| COD | 569 | 60.0 | 10.2 | 8.3 | 9.3 | 11.6 |
| Lead | 0.35 | < 1.0 | 42.9 | 100.0 | 85.7 | 100.0 |
| Chromium | 0.76 | < 1.0 | 35.5 | 55.3 | 67.1 | 100.0 |
| Copper | 1.43 | < 1.0 | 5.6 | 56.6 | 46.9 | 72.7 |
| Nickel | 9.45 | < 1. 0 | 63.0 | 65.1 | 68.8 | 78.8 |
| Cadmium | 0.43 | < 1.0 | 100.0 | 100.0 | 100.0 | 100.0 |

*TDS* Total dissolved solids; *TSS* Total suspended solids; *BOD* Biochemical oxygen demand; *COD* Chemical oxygen demand; **NESREA* National environmental standards and regulations enforcement agency [27]

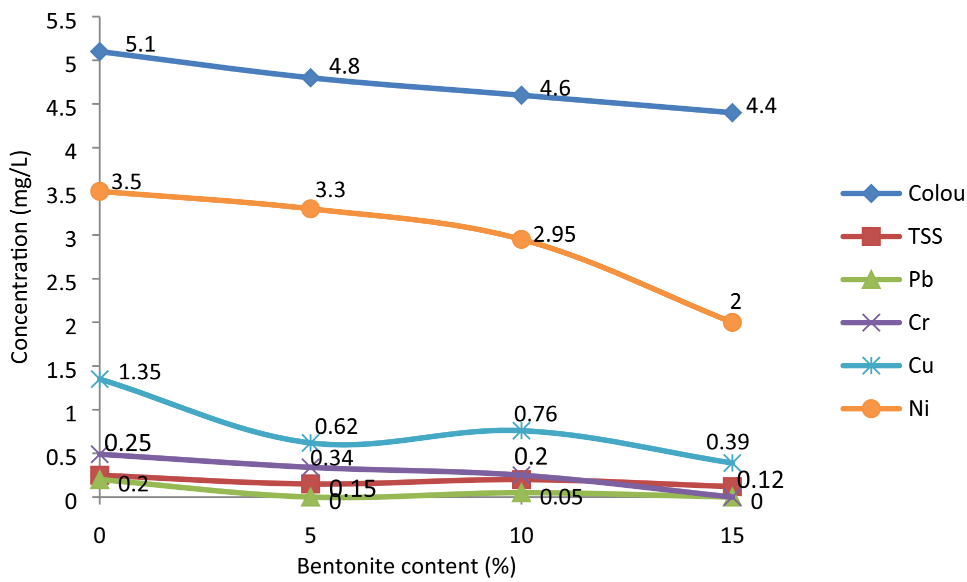



**Fig. 9** Effect of bentonite content on colour, TSS, Pb, Cr, Cu, Ni

**Fig. 10** Effect of bentonite content on TDS, BOD and COD

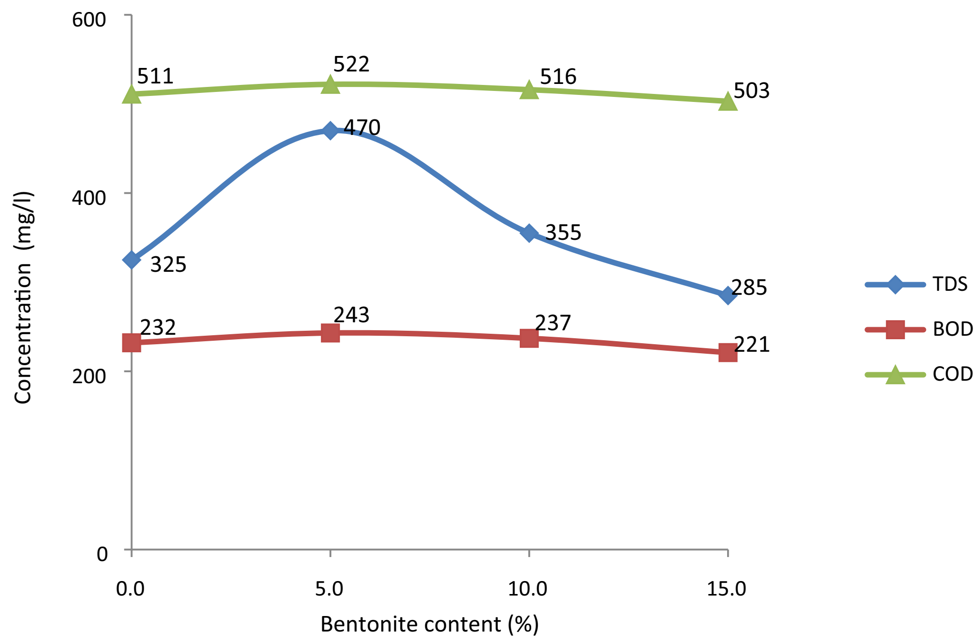
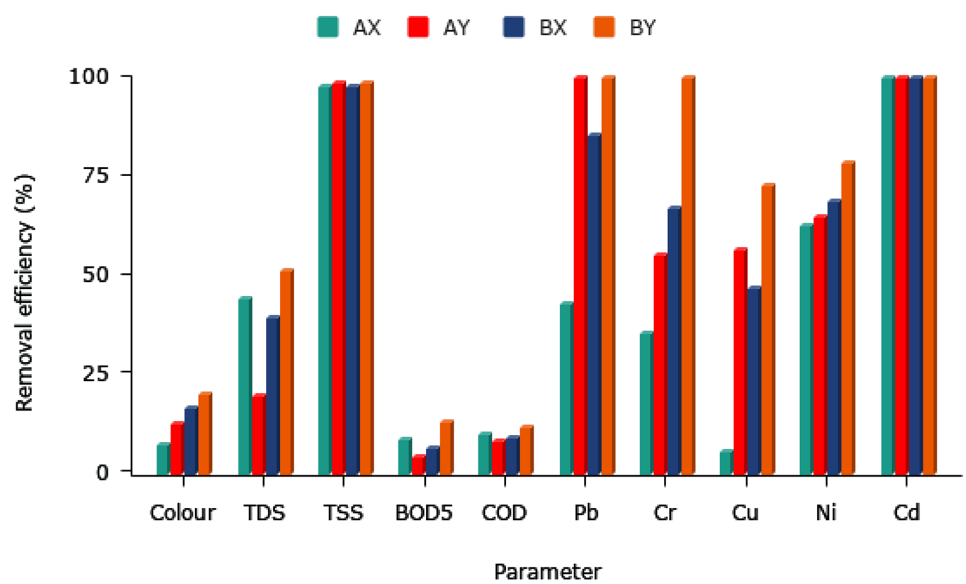



**Fig. 11** Removal efficiencies trend of the filters



## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.



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