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Cost-Effective Utilisation of Industrial Fly Ash Waste in Treatment of Domestic Wastewater

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Abstract: In the present research an economically effective porous fly ash-based filter candle (FFC) was developed for the treatment of domestic wastewater using fly ash, sodium silicate, wood dust, silica fume and water. The four testing specimens of FFC having different sizes (10, 20, 30, and 40 mm) were prepared. The parameters such as turbidity, total suspended solids (TSS), dissolved oxygen (DO), total dissolved solids (TDS), and pH of domestic wastewater were studied before and after treatment. The test results showed that there is a decrease in values of turbidity from 7 to 5.9 NTU, TSS from 300 to 218 mg/L, TDS from 400 to 302 mg/L, pH from 10.6 to 7.9, and BOD from 9.5 to 7.9 while DO values decreased in the range of 8.9 to 7.7. The observed porosity, compressive strength, and flow rate of FFC fall in the range of 24.55-27.26 %, 1.5-2.3 MPa, and 180-290 ml/h, respectively. The filtration tests using FFC exhibited good performance with >92 % filtration efficiency. Overall results have shown that FFC having a 30 mm bed thickness is recommendable for effective wastewater treatment. Thus, an attempt has been made to introduce a novel technology for domestic wastewater treatment using industrial fly ash waste.

Key words: Industrial fly ash waste, fly ash based filter candle, cost effective, domestic wastewater treatment.

Introduction

Water pollution is one of the most critical problems worldwide. All environmental biotic components need water to grow and develop. Maintaining water quality is extremely important since clean water is necessary for a healthy life. Growing population, rapid industrialization and urbanisation are the main reasons for water pollution in India. The effluents laden with contaminants are directly or indirectly discharged into aquatic bodies without any satisfactory analysis leading to water pollution. For treating wastewater, different physical methods such as membrane-filtration processes (electrodialysis, reverse osmosis, nanofiltration, etc.) and adsorption techniques have been used (Koshy and Singh, 2016; Mushtaq et al., 2019; Visa, 2016; Visa and Chelaru, 2014). Abdel-Raouf et al. (2012) reported that microalgae cultures offer an elegant solution for the removal of heavy metals and toxic organic compounds. Sukla et al. (2019) described wastewaters afford essential nutrients in an aqueous medium for the cultivation of microalgae and simultaneous elimination of pollutants like heavy and toxic metals, TSS, TDS, FOG, BOD, and COD from the wastewater. Fly ash is a pulverised fuel ash, rich in carbon content and having 2000-6800 cm^2 surface area. It has been established that fly ash has a significant role in wastewater treatment. Shah et al. (2015) performed experimentations using

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coal fly ash beds coupled with ferrous sulphate and lime for treating wastewater from dyes and pigment industries. They observed a remarkable decrease in colour, COD, turbidity and TSS by 48%, 32%, 50%, and 51%, respectively, in coagulation using ferrous sulphate and lime. But when the coal fly ash beds (CFAB) was embedded with a coagulants mix, it showed an enhanced removal of colour, COD, TSS, and turbidity by 88%, 67%, 92%, and 89%. Gupta et al. (2015) found that the cultivation of algae in aquaculture wastewater helps the nutrient removal efficiency and the production of biomass and various metabolites (proteins, lipids, and carbohydrates) have strain-specific and adaptability towards aquaculture wastewater (Gupta et al., 2015). Zeolite-carbon composites using fly ash were produced for studying the removal of petroleum substances. The adoption of fly ash singly and in distinct combinations with wood ash was evaluated for treating domestic laundry wastewaters. The outcomes of different parameters like combination ratios of fly ash and wood ash, adsorbent dosage, contact time, and adsorbent particle size were analysed. It was found that TSS dropped from 350 ppm to 15-20 ppm, and pH dropped from the highly alkaline range to 8.5-9.5 (Bandura et al., 2021). An effective adsorbent A-type zeolite for nickel cations was produced using coal ash which was generated as waste in power plants. A-type zeolite was used to remove nickel cations (Ni^{2+}) from wastewater and its efficacy was observed up to 94 % (He et al., 2020). A novel zeolite material ZSM-22 was prepared with alkali fusion via the hydrothermal treatment of coal fly ash and it was used in the adsorption of dyes from an aqueous environment (Supelano et al., 2020). A porous SiC candle filter was developed using SiC powder, and clay as a binder in the presence and absence of alumina by ramming process, which was followed by heating treatment in air at 1400°C. The dust filtration efficiency and air permeability of the porous SiC candle filter were evaluated at a laboratory scale. SiC candle filter showed good performance with a filtration efficiency of >97% employing airborne fly ash particle filtration tests (Das and Kayal, 2021). Dewatered sludge, clay, and fly ash (1:1:1) were utilised to prepare filter media sludge-flyash ceramic particles (SFCP). Thus, SFCP paved a sustainable path for utilising wastes, for instance, sludge and fly ash in the treatment of wastewaters (Han et al., 2009). A fly ash particle media filter was designed in this investigation and used for decentralised wastewater treatment systems (Ahmedi and Pelivanoski, 2013). An experimental study was carried out employing fly ash waste as an adsorbent in treatment of domestic sewage water. One filter media was constructed and characterised for removing impurities utilising sand, fly ash, and pebbles, with different thicknesses (Saravanakumar et al., 2019). An economical fly ash filter bed was used to analyse BOD and COD in domestic wastewater (Sanas and Gawande, 2016). This research work highlights the preparation method of FFC and its applications in domestic wastewater treatment.

Experimental Section (Materials and Methods)

Raw Materials

Raw materials practiced in preparation for FFC were fly ash, binder, wood dust, silica fume, and water. Fly ash (conforming to ASTM C 618) obtained from the captive power plant of National Aluminium Company (NALCO), Anugul was utilised for the manufacturing of FFC. The binder plays an important role during the mixing process. It assists in the binding of fly ash particles to form a mould. Sodium Silicate was used as a binder. Chemicals were purchased from Finar Chemicals Supplier Ltd, India. Sawdust or wood shavings, a by-product of woodwork operations were procured from local shops. Water plays a vital role in mix design influencing the workability and setting time of the mixture.

Preparation of Fly Ash Filter Candle (FFC)

FFC was prepared by mixing fly ash, a binding agent (sodium silicate), wood dust, silica fume and water. The mix compositions of different fly ash filter specimens are given in Table 1.

At first, the raw fly ash was possessed from the thermal power plant. The fly ash was conditioned via washing with distilled water to remove the unstable or water-soluble particles present in it. After washing, the fly ash was subjected to sun drying for removing moisture. Then the dried fly ash was sieved. Afterwards, it was allowed for raw mixing with sodium silicate, wood dust, silica fume and water. The mixture was then poured into the mould and allowed for sintering at a temperature of 1200°C. After that, the sample was cooled and subsequently demoulded. During the sintering process wood dust and coal were added to develop the porosity in the candle. For the time being, the sintering process of FFC the wood particles are burnt and fly ash particles are sintered around the sand particles leaving elliptical/circular large size pores in between. The pores are separated by thin fly ash walls (membranes), which are semi-permeable and contain

Table 1: The percentage composition of fly ash, wood dust and binder

Filter code	*Fly ash*	*Wood dust*	*Binder*	*Thickness (mm)*
1	70	25	5	10
2	75	20	5	20
3	80	15	5	30
4	85	10	5	40

ultra-fine capillary openings and thus pores are not connected to each other. The capillary openings of the clay walls (membrane) bridge the large pores. The water travels from one pore to another pore through capillary openings in the fly ash candle walls (membranes). The preparation of FFC is illustrated in Figure 1.

Characterisation Methods

The particle size distribution of fly ash was determined employing a MALVERN particle size analyser instrument. The chemical composition of the fly ash sample was analysed using EDXRF (Model no. EDX7000, Rigaku, Tokyo, Japan). The mineral phase was determined with the help of an X-ray diffractometer (Model no. XRD, Axios-mAX, PANalytical B.V., Almelo, The Netherlands). The morphology was observed by using a scanning electron microscope, SEM (Model no. S-3400N, HITACHI, Tokyo, Japan). The FTIR analysis of fly ash sample was also conducted. The porosity measurements of FFC were carried out using mercury intrusion porosimetry (MIP: MicroMetrics Autopore III 9400 analyser, MicroMetrics, Norcross, GA). The compressive strength of the filter candle was measured by the compressive strength machine. Water quality parameters such as turbidity, TSS, TDS, pH, DO, and flow rate was examined in water samples before and after treatment as per standard methods.

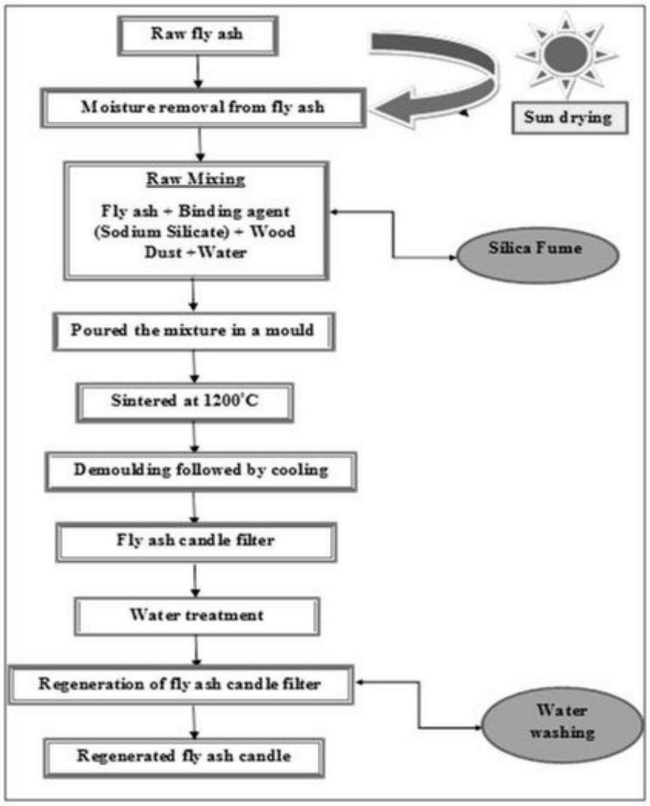


Figure 1: Process flow sheet of fly ash candle for water treatment.

Results and Discussion

Particle Size Distribution Analysis of Fly Ash

The particle size distribution (PSD) of fly ash was analysed using a MALVERN particle size analyser instrument with isopropyl alcohol as dispersing agent. PSD of fly ash varies from sample to sample ranging from 0.01 to 200 µm based on coal combustion parameters, the energy efficiency of boilers, and type of coal burnt in the power plant. The particle distribution diagram of class F fly ash is shown in Figure 2.

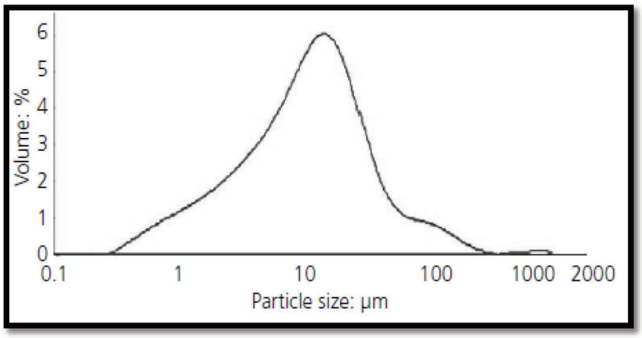


Figure 2: Particle size distribution of class F fly ash.

EDXRF Analysis of Fly Ash

EDXRF analysis was performed for analysing the chemical composition of fly ash and the results are given in Table 2. Fly ash is mainly composed of silica, alumina, iron with oxides calcium, and magnesium. It is observed that the major element Si content in fly ash is 59.512 %. Similarly, the Al and Fe contents in fly ash are 26.078 % and 7.509 %

XRD and SEM Analysis of Fly Ash

The XRD pattern of fly ash is given in Figure 3a. XRD pattern of coal fly ash shows small peaks which can be associated with the small amounts of quartz and mullite thus confirming its presence. The morphological

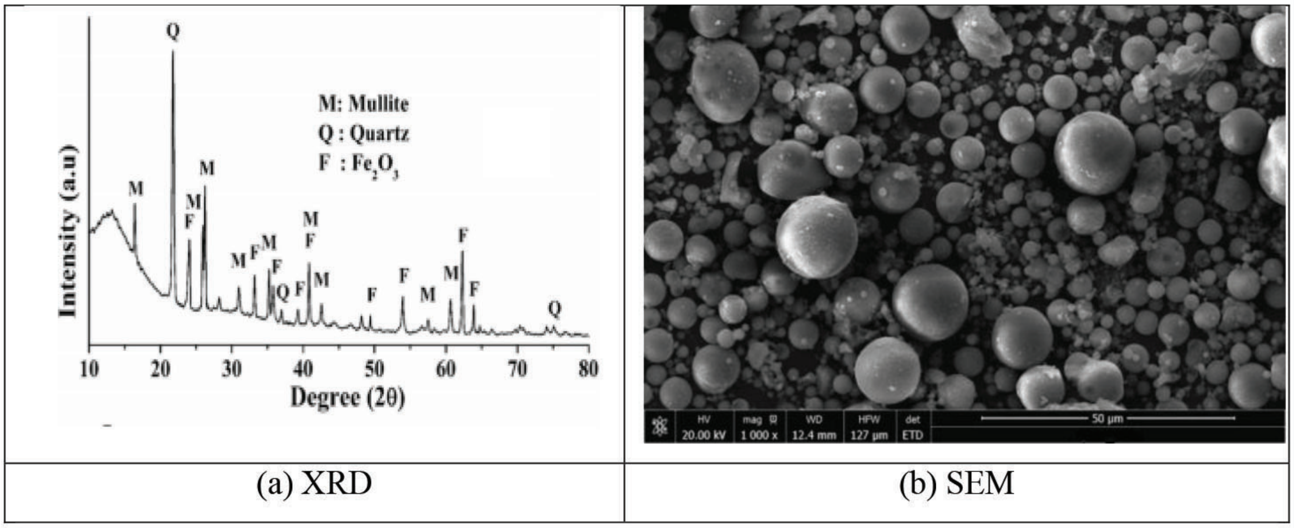


Figure 3: XRD and SEM analysis of fly ash.

Table 2: Chemical composition of fly ash

Analyte	*Si*	*Al*	*Fe*	*K*	*Ca*	*Mn*	*Cr*	*Pb*	*Zn*
Weight (%)	59.512	26.078	7.509	1.888	1.492	0.075	0.048	0.024	0.039

study of fly ash using SEM shows that the samples are composed mostly of small, spherical particles (Figure 3b).

FTIR Analysis of Fly Ash

The FTIR spectrum for fly ash is plotted in Figure 4. The region from 4000 to 400 cm^{-1} observes sharp and narrow peaks. Three broad bands representative of aluminosilicates are observed. The most prominent peak is at 1069 cm^{-1} corresponds to asymmetric stretching vibrations of Si–O–Si and Al–O–Si. The bands that appeared at 794 and 460 cm^{-1} are attributed to Si–O–Si and O–Si–O symmetric bending vibrations and imply the presence of quartz. The peak at 584 cm^{-1} is ascribed to Al–O–Al stretching vibrations specifying the presence of mullite.

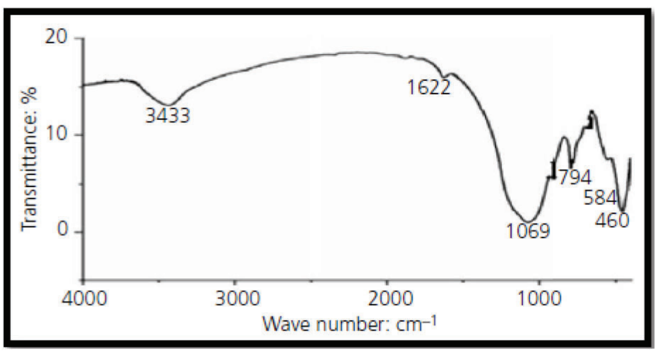


Figure 4: FTIR analysis of fly ash.

SEM Analysis of FFC

The microstructure at the fracture surface of FFC is shown in Figure 5. The adequate intra-particle pore sizes are found in the range of 0.2-0.5 µm. Large inter-particle porosity has been observed in this microstructure, which is not continuous but is interlinked by small intraparticle pores. The highly porous structure of the filter candle is found to be responsible for >92% filtration efficiency.

Compressive Strength and Porosity

The porosity of FFC specimens was reduced with a decrease in the percentage composition of wood dust and the compressive strength of FFC showed an increase with the increase in porosity. The porosity and pore size plays an important role in filter manufacturing. FFC

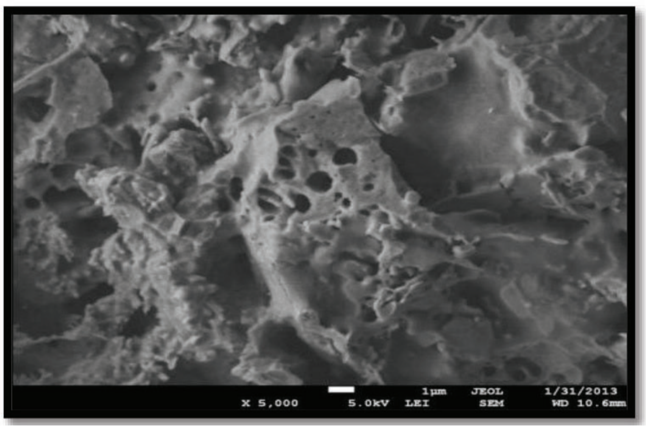


Figure 5: SEM from fracture surfaces of FFC.

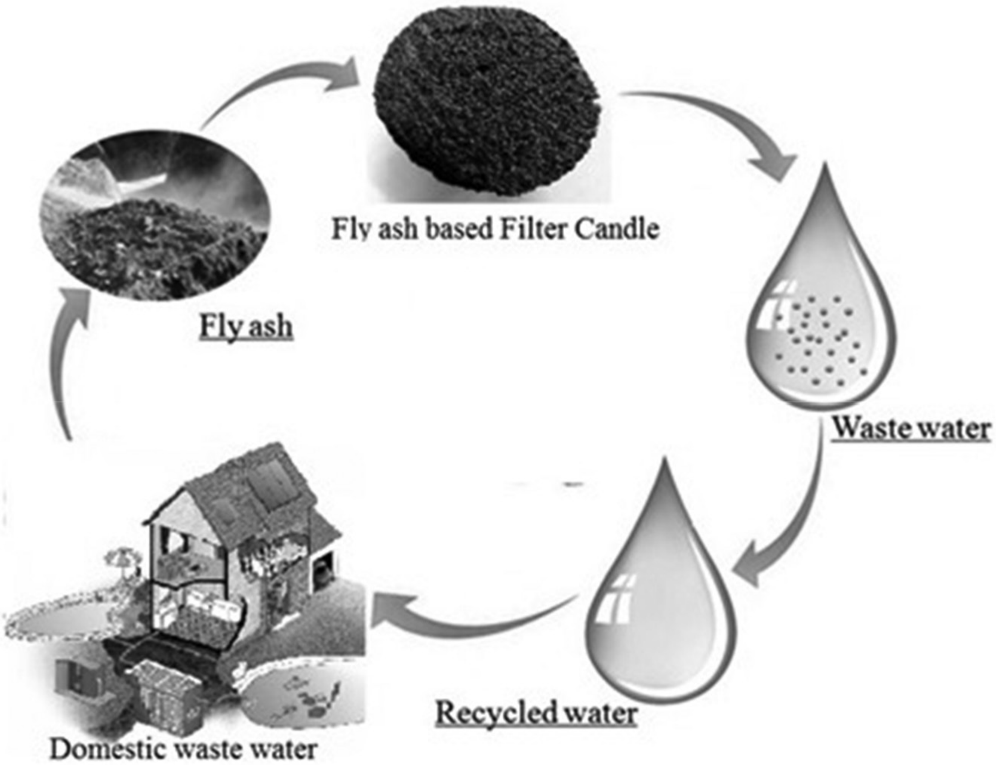
exhibited a median pore size of 2 mm and porosity in the range of 24.55-27.26 % (Figure 6). This is because FFC specimens with more combustible materials have more void spaces. The porosity of the fired mass is proportional to the volume of combustible matter added. All FFCs had pore sizes in the range of nano- and micron-scales. The micron-scale and nanoscale pores are capable to trap multicellular organisms/ larger microbes, and viruses respectively. Pore sizes of FFC were found between 0.05 and 1 μm in size. The filter codes for FFC specimens with the corresponding thickness (mm), porosities (%), compressive strengths (MPa), and flow rates (ml/h) are tabulated in Table 3.

Figure 6: Fly ash filter candle (FFC) specimen.

Table 3: Thickness, porosities, compressive strengths, and flow rates of different filter specimen codes

Filter code	*Porosity (%)*	*Compressive strength (MPa)*	*Flow rate (ml/h)*	*Thickness (mm)*
1	27.26	1.5	290	10
2	26.29	1.7	265	20
3	25.63	2.1	215	30
4	24.55	2.3	180	40

The flow rate is increased when the combustible material ratio is increased while combined with fly ash. The combustible materials after burning off leave networked pores responsible for a better flow rate of the FFC. This may be a result of the firing temperature employed in the preparation of FFC. Filters comprising large surface areas exhibit greater flow rates whereas filters having small surface areas observe lower flow rates. The test results for 10 mm, 20 mm, 30 mm, and 40 mm FFC observed flow rates of 290, 265, 215, and 180 ml/hr, respectively.



Graphical Abstract - Domestic waste water treatment by Fly ash filter candle.

Removal of Total Dissolved Solids from Domestic Wastewater

TDS (total dissolved solids) refers to solids that are absolutely dissolved in water. Estimation of TDS helps to determine whether water is appropriate for drinking, agriculture, and industrial purposes. The amount of TDS was 400 ppm before treatment. TDS value was decreased from 400 ppm to 376, 358, 328, and 302 ppm with 10, 20, 30, and 40 mm of FFC after treatment.

Removal of Total Suspended Solids from Domestic Wastewater

TSS (total suspended solids) indicate solids whatever do not dissolve in water. TSS was found to be 300 ppm before treatment. After treatment, the TSS value was decreased from 300 ppm to 280, 268, 233, and 218 ppm with 10, 20, 30, and 40 mm thickness of FFC.

Decrease in DO Level of Domestic Wastewater

The amount of oxygen naturally present in water is known as dissolved oxygen (DO). DO estimation is an important parameter in water pollution control and wastewater treatment methods. The oxygen content diminishes when there is an increase in nutrients and organic materials from sewage discharges, industrial wastewater, and surface runoff. The DO level of domestic wastewater increases after the inclusion of surf, detergent, etc. After treatment, the DO value was decreased from 8.9 to 8.5, 8.3, 7.9, and 7.7 mg/L in the thickness of 10, 20, 30, and 40 mm of FFC.

Removal of Turbidity from Domestic Wastewater

Turbidity in influent and effluent water samples was examined using a turbidity meter (Model No. CL52 D NEPHELOMETER). Before treatment, the level of turbidity was 7 NTU. After treatment, the turbidity value was decreased from 7 to 6.7, 6.5, 6.2, and 5.9 NTU, in the thickness of 10, 20, 30, and 40 mm of FFC.

Reduction of pH

Before treatment, the pH level of domestic wastewater was 11.5. After treatment, the pH value was decreased from 10.6 to 9.35, 8.54, 8.1, and 7.9, in the thickness of 10, 20, 30, and 40 mm of FFC.

Reduction of BOD

Before treatment, the BOD level of domestic waste water was 9.5. After treatment, the BOD value decreased from 9.5 to 9.1, 8.7, 8.3 and 7.9, the thickness of 10, 20, 30, and 40 mm of FFC. The water quality parameters for domestic wastewater before and after treatment are given in Table 4.

Table 4: Water quality parameters before and after treatment

Water quality parameters	*Before treatment*	*After treatment*
TDS (mg/L)	400	302
TSS (mg/L)	300	218
pH	10.6	7.9
Turbidity (NTU)	7	5.9
DO(mg/L)	8.9	7.7
B.O.D	9.5	7.9

Conclusion

This study throws light on the potential use of fly ash as a media filter in domestic wastewater treatment systems. The water quality parameters were estimated using an experimental method of physical filtration. The main outcomes of this study are as follows:

1. FFC is a low-priced efficient model for removing TDS, TSS, turbidity, pH, and BOD reduction as a result of its immense porosity and adsorption capacity.
2. The observed porosity falls in the range of 24.55-27.26 % and compressive strength of 1.5-2.3 MPa.
3. The filtration tests using FFC exhibited good performance with >92 % filtration efficiency.
4. It is concluded that FFC having a 30 mm bed thickness is the optimum standard and it can be recommended in domestic wastewater treatment systems.

Conflict of Interests

The authors declare no conflict of interest in the present work.

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