



(RESEARCH ARTICLE)



BIOLOGICAL TREATMENT OF WASTE WATER FROM FAST FOOD OUTLETS USING TRICKLING BED FILTER

Stow Eyebiabo JUSTIN * and Kingsley Chibuzo EGEMBA

DEPARTMENT OF CHEMICAL ENGINEERING UNIVERSITY OF UYO, UYO, AKWA IBOM STATE.

* Corresponding Author

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ABSTRACT

Fast-food outlets generate wastewater containing substantial concentrations of biodegradable organic matter, suspended solids, dissolved solids and nutrients, which may pose environmental risks when discharged without adequate treatment. This study investigated the biological treatment of wastewater from a fast-food outlet in Uyo, Akwa Ibom State, Nigeria, using a laboratory-scale trickling bed filter packed with locally sourced granite media. The effects of hydraulic loading rate, filter-bed height and biofilm-support particle size on treatment performance were investigated. The filter was operated with granite media of different particle sizes and bed heights, while wastewater was recirculated through the system under aerobic conditions. Biological and physicochemical characteristics of the wastewater were determined using standard analytical procedures. The biodegradability assessment gave a BOD/COD ratio of 0.79, indicating a substantial biodegradable fraction and suitability for biological treatment. The simulated treatment results showed BOD removal efficiencies of 86.40–90.33% and COD removal efficiencies of 83.99–86.95% across the investigated operating conditions. Removal performance generally improved with increasing bed height and decreased with increasing hydraulic loading rate and media particle size. Reductions were also observed in TDS, TSS and nitrate concentrations. Regression models developed for BOD and COD removal gave coefficients of determination (R^2) of 0.8187 and 0.8779, respectively, indicating useful predictive capability within the experimental range. The study demonstrates the potential of locally available granite media in trickling bed filtration for biological treatment of fast-food wastewater and provides a basis for further pilot-scale investigation and process optimization.

Keywords: Fast-Food Wastewater, Trickling Bed Filter, Biological Treatment, Granite Media, BOD, COD

1 INTRODUCTION

Rapid population growth, urbanization and expansion of the commercial fast-food sector have increased the generation of wastewater from fast-food outlets in Uyo, Akwa Ibom State, Nigerian. Fast-food wastewater originates mainly from kitchen and cleaning activities, including meat and fish processing, washing of vegetables and utensils, floor washing, hand washing and equipment sanitation. Such wastewater commonly contains high concentration of biodegradable organic matter, suspended solids, dissolved solids, nutrients, fats and oils (EIA, 2017)

When untreated wastewater is discharged into open drains, the organic matter can increase oxygen demand in receiving water bodies, while suspended solids and nutrients may contribute to deterioration of water quality and eutrophication

(Akinawo, 2023). In Uyo, Akwa Ibom State, the inadequate availability of dedicated wastewater treatment systems for some commercial food establishments creates a need for simple, affordable and efficient treatment technologies.

The collection of waste waters for treatment and reuse is not new. It's treatment dates to the late 1800s and 1900s (Chow *et al*, 1972). Modern knowledge of the need for sanitation and treatment of polluted waters started with the frequent cited case of John snow in 1855, in which he proved that the cholera outbreak in London was due to sewage contaminated water obtained from the Thanies river (Cooper 2001)

Waste water treatment practices vary from country to country across the globe. The biological oxygen demand (BOD) and Chemical Oxygen Demand (COD) ratio of waste indicates the biodegradability of organic matter in the waste water sample. Hence this ratio is used to determine the sustainability of a waste water sample for biological treatment. A ratio higher than 0.5 suggest a higher percentage of biodegradable organic matter and the sustainability of biological treatment of waste water and ratio lower than 0.3 indicates biological treatment alone may be insufficient (Doorn *et al*, 2006; Zulaikha *et al.*, 2014).

Biological treatment is particularly appropriate where wastewater contains a substantial biodegradable fraction. The BOD/COD ratio is commonly used as an initial indicator of biodegradability (Rudaru *et al.*, 2022). In a biological treatment of waste water, we attach microorganism growth to the filter bed (granites) known as biofilm of fixed film technology. Their core principles are substrate attachment, biofilm formation and diffusion layer and striated ecology been done. While their benefit is that biological process creates high bio mass concentration, process slow-growing nitrifying bacteria without washout risks.

Conventional biological treatment technologies such as activated sludge and aerated lagoons can provide effective treatment but may require considerable energy, land area, operational control and sludge management (Zhang and Liu 2022). Attached-growth systems provide an alternative in which microorganisms develop as a biofilm on a solid support medium. Trickling bed filters are based on this principle. Wastewater is distributed over the supporting medium while air passes through the bed, providing conditions for microbial degradation of organic matter (Tekerlekopoulou *et al.*, 2020; Ita, 2020).

The use of locally available granite as biofilm-support media could reduce dependence on specialized synthetic filter media and potentially reduce construction and operational costs (Compaore *et al.*, 2022). However, treatment performance depends on factors including media size, bed depth and hydraulic loading rate (Vera-Puerto *et al.*, 2021; Rahman *et al.*, 2021)

Therefore, this study investigated the biological treatment of fast-food wastewater using a laboratory-scale granite-media trickling bed filter. Specifically, the study evaluated the effects of hydraulic loading rate, biofilm-support particle size and bed height on BOD, COD, nitrate, TDS and TSS removal; developed predictive models for BOD and COD removal; and investigated operating conditions suitable for improved treatment performance.

2 MATERIAL AND METHOD

2.1 Sample description and collection

The wastewater used for this study was from a fast-food outlet in Uyo, Akwa Ibom state Nigeria. Wastewater sample were obtained from the rubber drain outside the outlet where all the spent water is stored to be throwing away when the day gets dark. The wastewater studied was strictly discharge from kitchen activities involving processing of meats and fish discharging, sink washing vegetables washing, pot washing, floor washing, hand washing and oral hygiene residue. The sample was collected in a labelled container and transported to the laboratory for characterization and treatment experiments. Granite particles obtained locally were washed, rinsed, dried, and used as the biofilm-support medium. A well labelled 10-litre plastic container was washed, dried and rinse with what was used to collect sample in the evening and taking to the chemical engineering laboratory and kept under room temperature.

This wastewater sample was used to bath the granites of different sizes for five days. The granite of various sizes used for granite bed filtration were collected from a construction site at the University of Uyo, Uyo. Akwa Ibom State. Two liters of the waste water was taking to microbiology laboratory to determine the microbial population of the wastewater that is to determine the number of organic pollutants such as BOD, COD, TAS, TSS, pH and Nitrate that are in the wastewater. The wastewater was characterized for the earlier mentioned parameters. Microbiological characterization was also performed using the pour-plate method. Standard analytical procedures based on American Public Health Association (APHA) methods were adopted. BOD was determined using the five-day incubation method, while COD was determined using dichromate oxidation followed by titrimetric analysis. TDS was measured using a TDS meter, while TSS was determined gravimetrically after filtration and drying of the retained solids.

2.2 Experimental Procedure

The laboratory-scale trickling bed filter consisted of a cylindrical filter vessel 11.2 cm in diameter and 50 cm in height. The system included a wastewater influent tank, a trickling bed packed with granite media, a peristaltic pump, a wastewater distribution device, an under-drain system, an aeration system and a clarifier. Granite media were used as the fixed-film support for microbial growth. Wastewater was pumped from the influent tank and distributed over the media through a shower-rose-type distributor. The treated wastewater passed through the under-drain into the clarifier. Aeration was supplied from the bottom of the bed to maintain aerobic conditions.

2.3 Biofilm Development

The granite media were exposed to the wastewater for approximately five days to facilitate microbial attachment and biofilm development. Microorganisms naturally present in the wastewater served as the inoculum.

2.4 Experimental Variables

The principal independent variables were hydraulic loading rate, filter-bed height and granite particle size. The investigated bed heights were 5.5, 12.0, 18.5 and 25.0 cm, while the experimental modelling dataset used particle sizes of 2, 4 and 9 mm and hydraulic loading rates of 6, 12 and 18 m³/m²·day.

3 RESULTS AND DISCUSSION

Result of the analysis for raw and treated samples of the wastewater from fast food outlet in Uyo and the permission limits are shown in Table I with a comparison of raw and treated values and percentage reductions

Table 1: Initial Physiochemical Parameters (Raw fast food outlet scores)

Parameters	Unit	Raw fast food wastewater value	Treated fast food wastewater	Permission Limits	Percentage Removal (%)
p H		11.3	7.17	6.5 – 9.0	36.59%
Biochemical oxygen demand (BOD)	Mg/s	290.55	3.40	20 - 50mg/l	88.51%
Chemical oxygen demand (COD)	Mg/s	370.12	58.55	50 - 100mg/l	85.45%
Total dissolved solid (TDS)	Mg/s	36.7	121.11	500 - 2000mg/l	67.00%
Total suspended solid (TSS)	Mg/s	66.19	30.17	30 - 50mg/l	54.42%
Nitrate	Mg/s	2000.12	73.79	10mg/l	63.13%

3.1 Results of the Analysis of the Microbial Population in the Wastewater.

Table 2 shows the result of microbial presence in the waste water sample from fast-food outlet in Uyo, while Table 3 shows the microbial population in the wastewater.

Table 2: Microbial presence in wastewater sample

Sample	THBC (CFU/ml)	TCC (CFU/ml)	FC (CFU/ml)	SSC (CFU/ml)	SC (CFU/ml)	VC (CFU/ml)	CC (CFU/ml)	FC (CFU/ml)
Waste water	2.0 x 10 ⁷	1.4 x10 ⁷	NG	NG	7.0 x 10 ⁶	NG	4.0 x10 ⁵	6.2 x 10 ⁵

Table 3: Microbial population in the waste water

Organisms	Sample
Bacteria	Waste water
<i>Bacillus cercus</i>	+
<i>Micrococcus sp</i>	+
<i>Staphylococcus aureus</i>	+
<i>Clostridium sp</i>	+
<i>Enterobacter sp</i>	+
Fungi	Waste water
<i>Candida albicans</i>	+

Key: (-) represent isolate absent, while (+) represents isolate present

The observed results from the wastewater treatment process show that from Table 1, the BOD to COD ratio (29.55/37.17) is 0.79. This value is higher than 0.6, suggesting that the wastewater is suitable for biological treatment. The wastewater's nitrate, TDS, and TSS contents are high and require treatment to bring them to an accepted regulatory standard. It can be observed that Table 2 and Table 3 show the microbes present in the wastewater (Zulaikha *et al.*, 2014; Ita 2020)

It can be observed from Figures 1 and 2, that both the % BOD removal and % COD removal decreased with increase in hydraulic loading rate for all bed heights. Both Figures also show that the % BOD removal and the % COD removal, decreased with increasing size of biofilm support. The BOD removal ranged between 86.40% and 90.33%, while COD removal was between 83.99% and 86.95%. As the hydraulic loading rate increased, the contact time between wastewater and the biofilm decreased, resulting in reduced biodegradation and by extension, reduced BOD and COD removal efficiencies (Doorn *et al.*, 2006; Tekerlekopoulou *et al.*, 2020) However, a hydraulic loading rate that is too low, may limit oxygen transfer, and result in clogging and slime build-up. The lower the biofilm support size, the lower the specific surface area for biofilm growth, leading to lower microbial population. The effect is that the contact between the wastewater and the microbes is reduced, resulting in lower BOD and COD removal efficiencies. The use of a support size that is too small, may however lead to clogging (Rahman *et al.*, 2023; Vera-Puerto *et al.*, 2021)

3.2 Simulation dataset

For clarity, the 36-run dataset supplied for the modelling work is arranged below by bed height, hydraulic loading rate and particle size. Each row represents one combination. BODR and CODR are the reported simulated removal efficiencies (%). The optimization analysis indicated that high organic-matter removal was associated with relatively low hydraulic loading, greater bed height and smaller media size within the investigated ranges. These results should be interpreted as optimization within the model domain rather than as a universal optimum. The optimization section should be finalized only after the experimental variable ranges and objective function have been reconciled with the 36-run dataset. Empirical predictive models were developed for BOD and COD removal using hydraulic loading rate, bed height and media particle size as explanatory variables. The coefficients of determination were $R^2 = 0.8187$ for BOD removal and $R^2 = 0.8779$ for COD removal (Akinawo (2023; Campaore *et al.*, 2022)

The COD model therefore explained a larger proportion of the variation in the simulated/experimental response within the stated model domain than the BOD model. These models provide a basis for estimating treatment performance within the investigated range. Independent validation data are required before applying the models to full-scale design (Zhang and Liu, 2022).

The results for the BOD reduction and the COD reduction were shown in Table 4

Table 4: BOD and COD reduction

Run	Bed height (cm)	Particle size (mm)	HLR (m ³ /m ² ·day)	BOD removal (%)	COD removal (%)
1	5.5	2	6	89.55	85.69
2	5.5	4	6	89.22	85.21
3	5.5	9	6	88.83	84.98
4	5.5	2	12	88.70	85.00
5	5.5	4	12	86.92	84.82
6	5.5	9	12	86.79	84.35
7	5.5	2	18	86.59	84.25
8	5.5	4	18	86.50	84.20
9	5.5	9	18	86.40	83.99
10	12.0	2	6	89.84	86.25
11	12.0	4	6	89.45	85.48
12	12.0	9	6	89.06	85.78
13	12.0	2	12	88.99	85.71
14	12.0	4	12	88.76	85.17
15	12.0	9	12	87.22	85.41
16	12.0	2	18	87.11	84.90
17	12.0	4	18	87.72	84.57
18	12.0	9	18	86.88	85.03
19	18.5	2	6	90.04	86.62
20	18.5	4	6	89.74	86.04
21	18.5	9	6	89.34	86.24
22	18.5	2	12	89.16	85.88
23	18.5	4	12	89.24	85.70
24	18.5	9	12	88.38	85.70
25	18.5	2	18	87.61	85.28
26	18.5	4	18	88.58	85.20
27	18.5	9	18	87.12	85.44
28	25.0	2	6	90.33	86.95
29	25.0	4	6	90.04	86.46
30	25.0	9	6	89.77	86.39
31	25.0	2	12	89.44	86.39
32	25.0	4	12	89.58	86.19
33	25.0	9	12	88.66	85.95
34	25.0	2	18	88.16	85.77
35	25.0	4	18	88.99	86.54
36	25.0	9	18	87.61	85.62

3.3 Effect of Hydraulic Loading Rate

The simulated results showed BOD removal of 86.40–90.33% and COD removal of 83.99–86.95% across the 36 modelled combinations. In general, removal efficiency decreased as hydraulic loading rate increased. At lower loading rates, wastewater had greater contact time with the microbial biofilm, providing more opportunity for adsorption, biodegradation and substrate utilization. Increasing hydraulic loading rate can reduce effective contact time and increase the possibility of incomplete treatment. The wastewater investigated in this study had a BOD/COD ratio of approximately 0.79 based on the influent concentrations, indicating that a significant proportion of the organic matter was amenable to biological degradation.

However, excessively low hydraulic loading may also produce undesirable conditions, including poor distribution, excessive biofilm accumulation and clogging. Consequently, an appropriate operating range rather than simply the lowest possible loading rate should be selected (Zulaikha et al., 2014; Cooper, 2001).

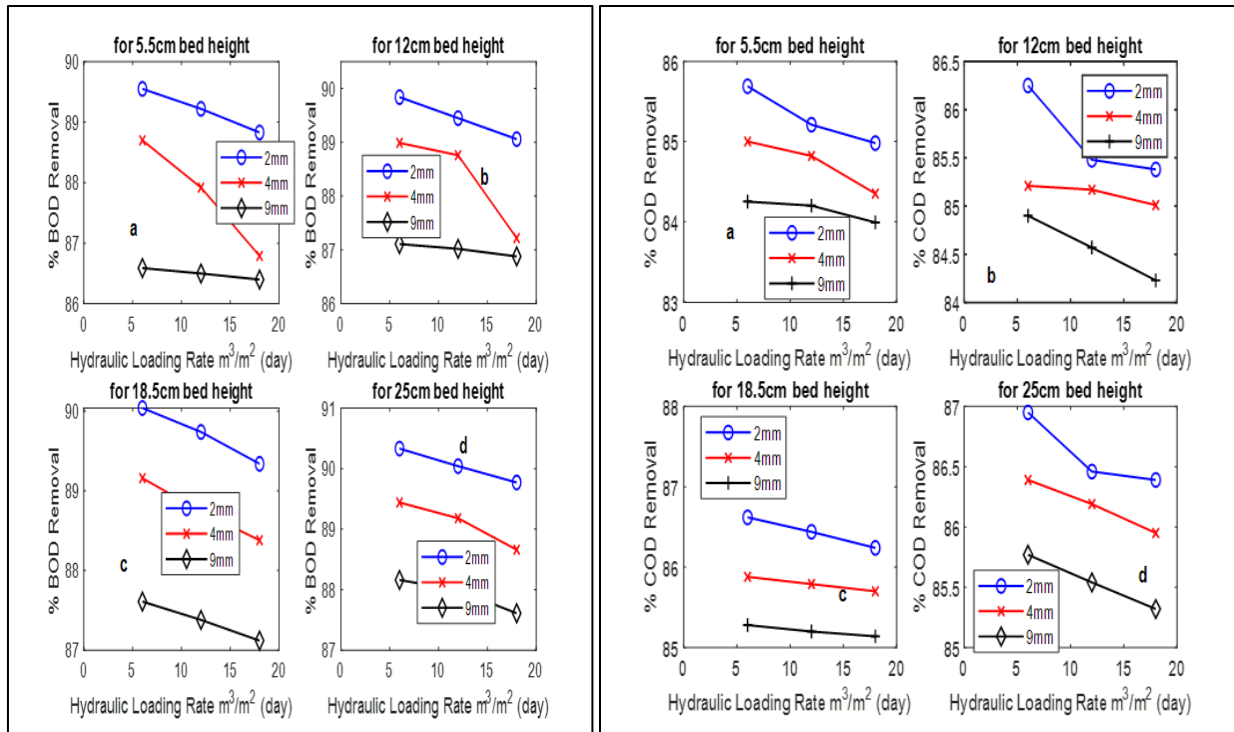


Figure 1: BOD and COD Removal against Hydraulic Loading Rate at different bed Height

3.4 EFFECT OF BIOFILM SUPPORT PARTICLE SIZE:

The results indicated that smaller media generally produced greater BOD and COD removal within the modelled range. Smaller particles generally provide greater specific surface area per unit volume and consequently more potential sites for microbial attachment. Extremely small media, however, can reduce void space, increase hydraulic resistance and increase the risk of clogging and oxygen-transfer limitations. Media selection should therefore balance surface area against hydraulic conductivity (Ita, 2020; Campaore *et al.*, 2022; Zhang and Liu, 2022).

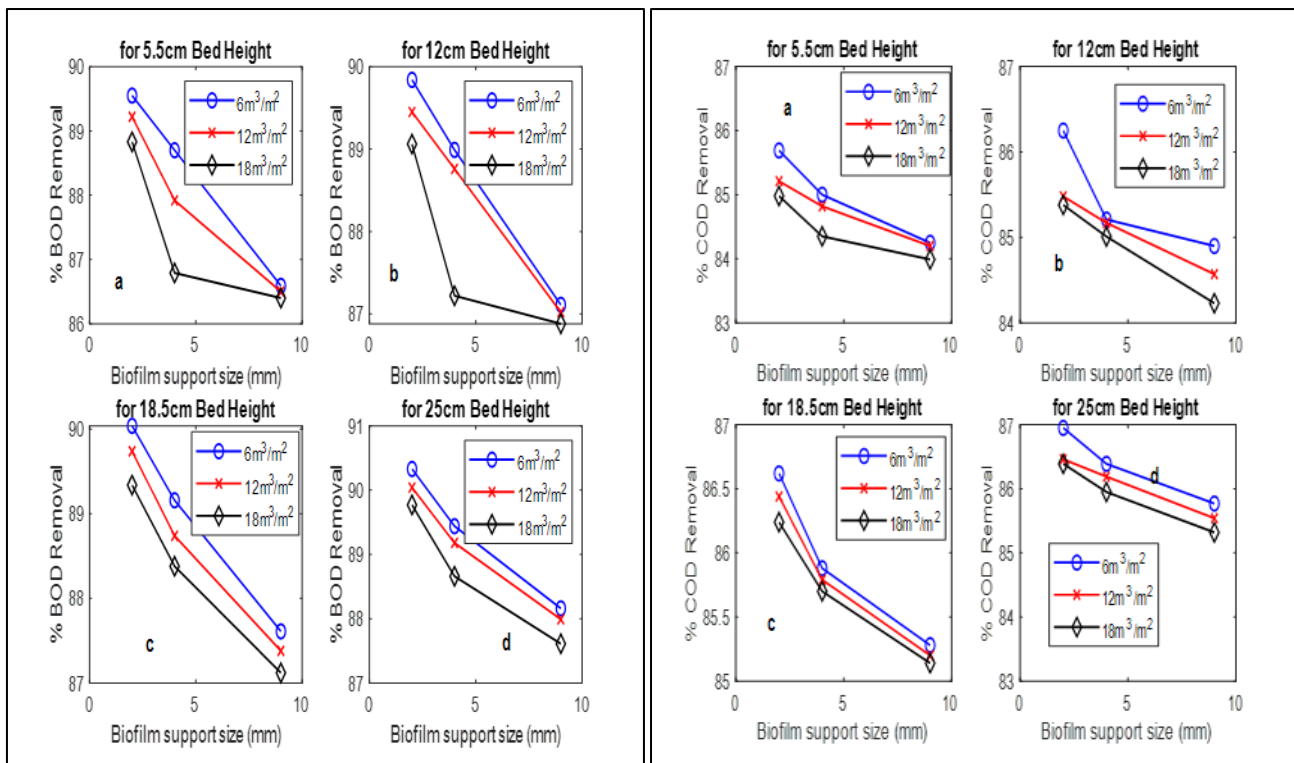
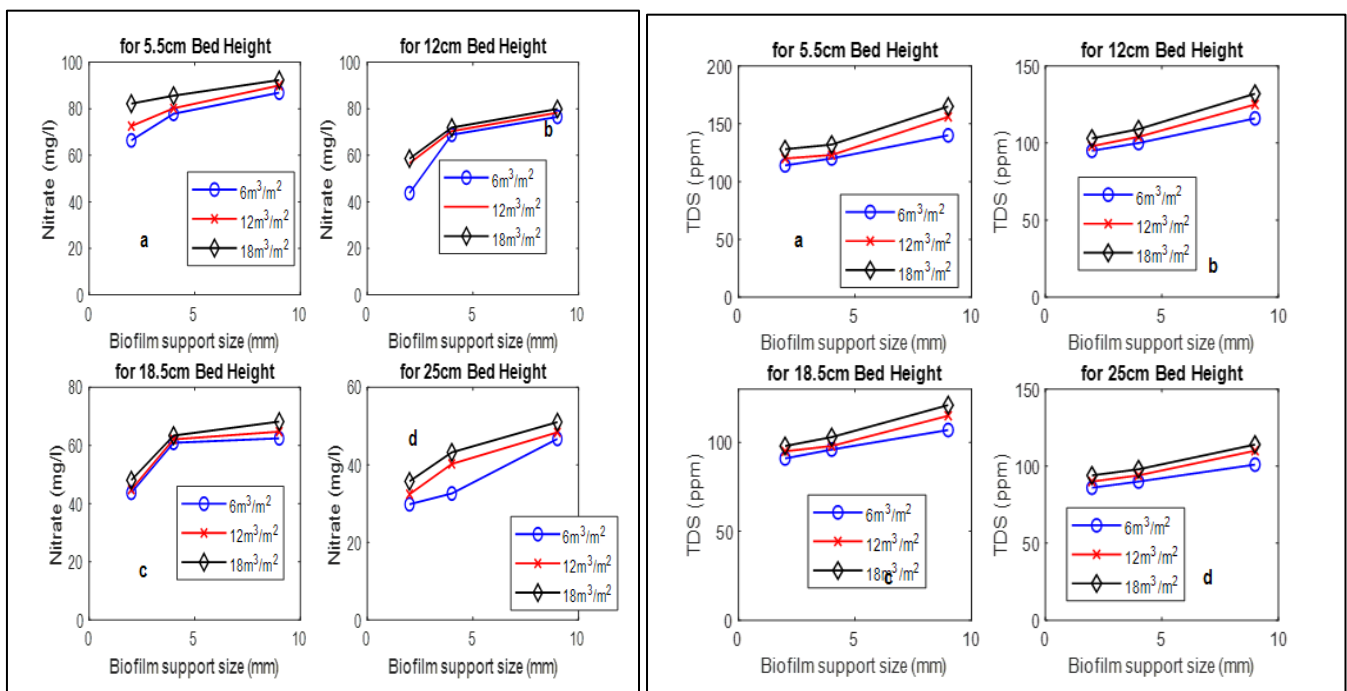


Figure 2: % BOD And % COD Removal Versus Biofilm Support Size at Different Bed Heights

3.5 REMOVAL OF NITRATE, TDS AND TSS:

The treatment system also produced reductions in nitrate, TDS and TSS. The reported nitrate removal was approximately 53.35–85.09%, while TDS and TSS removal ranged approximately from 55.04–76.57% and 44.95–66.01%, respectively. The reductions may be associated with a combination of biological transformation, filtration, adsorption onto biofilm/media and physical retention of suspended materials. The nitrate dataset and units should be verified before these values are treated as final publication data (Ita, 2020; Campaore *et al.*, 2022; Zhang and Liu, 2022; Zulaikha *et al.*, 2014). Figure 3 shown the relationship between the TSS and Biofilm at different bed height. Figures 4 and 5 are the diagrams of the relationship.



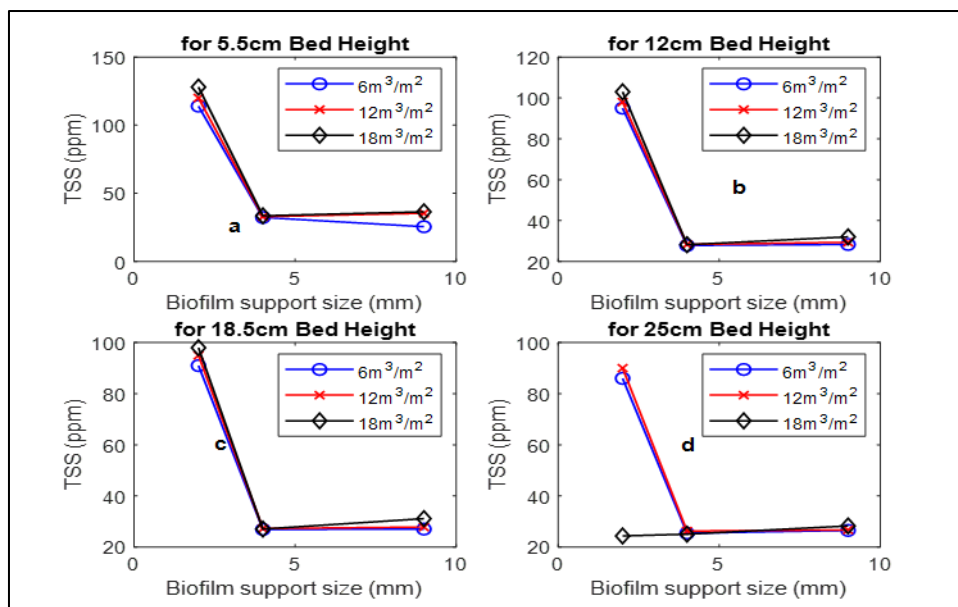


Figure 3: TSS against Biofilm Support Size for different Bed Height

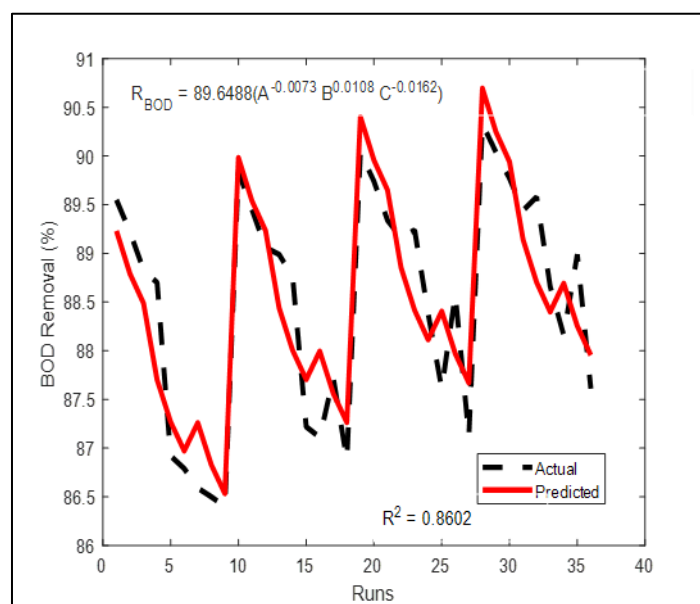


Figure 4: BOD reduction prediction

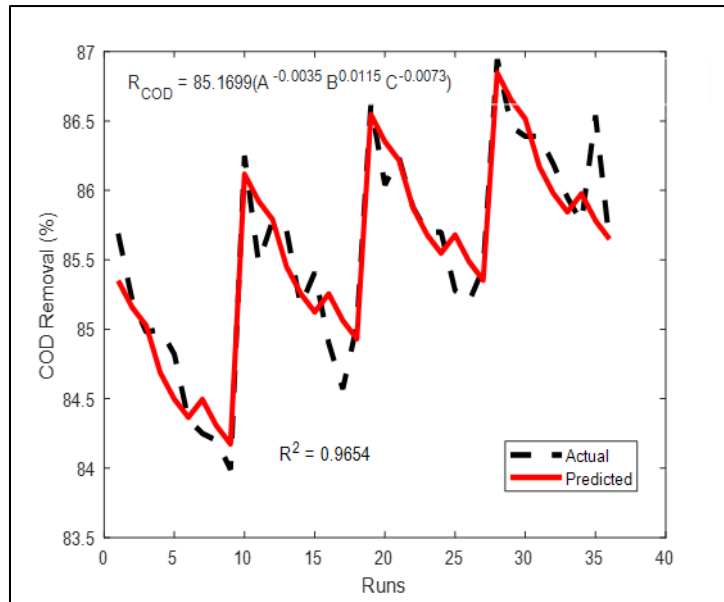


Figure 5: COD reduction prediction

Table 5 is the Optimization for the Biological Oxygen Demand and Chemical Oxygen Demand reduction. This was simulated to have different runs at bed height, particle size and hydraulic loading rates, and this was done for 13 runs. At 13 run, the BOD was 83.517 while COD was 77.720 with the initial values of 90.571 and 86.799 respectively.

Table 5: Optimization for the BOD AND COD reduction

iterations	Hydraulic rate m ³ /m ² (day) (A)	Bed height (cm) (B)	Particle size (mm) (C)	COD _R
1	6	25	2	86.7994
2	6	25	2.1314	84.2177
3	6	25	2.2621	83.8211
4	6	25	2.3188	83.8199
5	6	25	2.4193	83.8198
6	6	24.8221	2.4193	81.2241
7	6	24.6317	2.4193	81.2183
8	6	24.4172	2.4193	81.2181
9	6	24.2134	2.4193	81.2181
10	6.1221	24.2134	2.4193	78.3312
11	6.2199	24.2134	2.4193	77.7214
12	6.3123	24.2134	2.4193	77.7201
13	6.4417	24.2134	2.4193	77.7201

iterations	Hydraulic rate m ³ /m ² (day) (A)	Bed height (cm) (B)	Particle size (mm) (C)	BOD _R
1	6.00	25.00	2	90.5711
2	6.18	25.00	2	88.8177
3	6.31	25.00	2	88.7813
4	6.64	24.00	2	88.7810
5	7.51	24.00	2	88.7809
6	7.51	24.32	2	86.3329
7	7.51	23.67	2	85.9121
8	7.51	22.01	2	85.9119
9	7.51	21.22	2	85.9119

10	7.51	21.22	2.13	83.6616
11	7.51	21.22	2.28	83.5174
12	7.51	21.22	2.41	83.5171
13	7.51	21.22	2.67	83.5170

4 CONCLUSION

This study investigated the biological treatment of wastewater from a fast-food outlet using a laboratory-scale granite-media trickling bed filter. The wastewater demonstrated substantial biodegradability, with a calculated BOD/COD ratio of approximately 0.80 based on BOD = 29.55 mg/L and COD = 37.12 mg/L. The experimental and simulated results demonstrated substantial removal of organic pollutants. Across the supplied 36-run simulation dataset, BOD removal ranged from 86.40 to 90.33%, while COD removal ranged from 83.99 to 86.95%.

Treatment performance was influenced by hydraulic loading rate, bed height and media particle size. Increasing bed height generally improved removal efficiency, while increasing hydraulic loading rate generally reduced removal efficiency. Smaller media generally provided improved organic removal within the investigated range because of their greater potential specific surface area for biofilm development, although excessively small media may increase the risk of clogging.

The reported BOD and COD predictive models produced R^2 values of 0.8187 and 0.8779, respectively, demonstrating useful predictive capability within the investigated operating range. Further independent experimental validation is required before the models are used for full-scale design.

Overall, the findings demonstrate the potential of a granite-media trickling bed filter as an attached-growth biological treatment technology for fast-food wastewater. Further pilot-scale studies are required to establish long-term performance, biofilm management requirements, operating costs and compliance with applicable discharge or reuse standards.

The study provides preliminary engineering information for scaling up granite-media trickling bed filtration for fast-food wastewater. Successful design should consider the interaction between bed depth, media surface area, hydraulic loading, oxygen transfer and clogging potential.

For practical application, the laboratory findings should be followed by pilot-scale testing at an actual fast-food outlet. Such testing should evaluate variations in wastewater flow and composition, fats and oils, shock loads, biofilm development, maintenance requirements and long-term hydraulic performance.

The locally available granite medium may reduce dependence on manufactured packing materials. Before full-scale implementation, the physical properties of the selected granite—including particle-size distribution, porosity, specific surface area, density and resistance to attrition—should be characterized.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

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Disclosure of conflict of interest

There was no conflict of interest.

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