Granular Activated Carbon (GAC) Biofilter for Low Strength Wastewater Treatment

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Biofilter can be a cost-effective alternative treatment unit, especially for low strength wastewater. In this study, detailed experimental investigation of a GAC biofilter was carried out in a laboratory-scale unit using low strength synthetic wastewater and biologically treated sewage effluent (BTSE). Performance of the biofilter was evaluated in terms of total organic carbon (TOC) removal. The TOC removal efficiency of the biofilter was found to be stabilized at around 40-45 % after 30 days (even for a short depth of GAC column of 7-15 cm). The maximum biomass retained on the activated carbon was measured to be 44 mg/ g of GAC after 49 days of continuous operation. Filter backwashing provided at 30% bed expansion for 5 minutes on a daily basis to overcome physical clogging of the filter by attached mass, did not have any adverse effect on the active biomass attached to the media and thus the organic removal efficiency of the filter remained unchanged. Molecular size distribution analysis showed that a significant removal of organics of small molecular weight (MW) at the initial stage of operation of biofilter followed by mainly large MW organic matter after one day of operation. This shows that adsorption was the main mechanism at the initial period and biological degradation as the predominating mechanism after one day of operation throughout the rest of the operation. The biofilter was found to remove a majority of hydrophilic organic compounds.

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KEY WORDS

biofilter, biomass, GAC, organics, wastewater

INTRODUCTION

Wastewater contains significant levels of organic contaminants. A number of organic substances of the wastewater are not removed by the conventional wastewater treatment processes. The conventionally used sewage treatment processes may remove those organics measured by biochemical oxygen demand (BOD_5) test but are not as effective in removing the so-called refractive organic materials measured by the chemical oxygen demand (COD) test. Advanced wastewater treatment is therefore required to meet the quality of the sewage effluent that can be reused for various purposes. Biofilter can be utilized in the advanced sewage treatment processes to remove majority of organic matters (effluent organic matters) that are not removed in the secondary (biological) treatment processes. Biofilter is a conventional filter with biomass attached onto the filter media as a biofilm, where the organics are adsorbed on it and biodegraded by the microorganisms. Since the organic concentration in the secondary effluent is low, biofiltration is the only biological treatment option in the advanced wastewater treatment. The biofiltration process is also economical and environmentally friendly in treating wastewater of relatively small volume (e.g. wastewater from hotel, small industries or small communities). Previous studies on biofilter have shown that it could remove organics and nutrients in significant quantities and produce high quality effluent (Chaudhary et al., 2003a; Yang et al., 2001; Boon, 1997; and Sakuma et. al., 1997).

Many studies have been carried out on biofiltration in last decade especially with GAC as filter media (Chaudhary et al., 2003b, 2002; Hozalski et al., 1995; Sevais et al., 1994; LeChevallier et al., 1993). However, theoretically, it is still difficult to explain the behavior of a biofilter. The growth of different types of microorganisms in different working conditions makes it impossible to generalize the microbial activities in a biofilter. The efficiency of a biofilter operated at different filtration rates and influent characteristics can vary significantly for different target pollutants. Besides, some of the operational drawbacks of the biofilter such as performance fluctuation, maintenance of biomass, release of microorganisms, have made the research on it more imperative.

The performance of a biofilter mainly depends on the microbial activities. Therefore, a constant source of substrates (organic substance and nutrients) is required for its consistent and effective operation. The bacterial mass attached onto the filter media as biofilm oxidizes the most of the organics and uses as an energy supply. The microbial activities can vary with seasonal variation. The performance of a biofilter can be better in summer than in winter. It is very important to control and maintain the biomass in the filter for its successful operation. The major factors that affect the performance of the biofilter are the characteristics of filter media, empty bed contact time, backwashing techniques, and the substrate concentration of the feed solution. The microporous structure and irregular surface of the GAC offer more sites appropriate for biomass attachment.

In this study, detailed experimental investigation of a GAC biofilter was carried out using low strength synthetic wastewater and biologically treated sewage effluent. The main objective of the study was (i) to evaluate the long-term performance of the GAC bed filter, (ii) to assess the effect of backwashing on the organic removal efficiency in terms of attached biomass on GAC media, and (iii) to identify the category of organic matter removed by GAC filter.

EXPERIMENTAL INVESTIGATION

Detailed column experiments were conducted using low strength synthetic wastewater. Filter columns with ports for influent feed, effluent collection, and backwashing were employed for this study. The columns were packed with granular activated carbon (GAC) (porosity 0.65). The GAC used in the experiments was washed with distilled water and dried in an oven at 103.5° C for 24 hours. It was kept in desiccators before packing into the column. The physical properties of the GAC are shown in Table 1. The GAC bed was acclimatized at a low filtration rate. The filters were backwashed at 30% bed expansion for approximately 5 minutes every 24 hours of filtration run. Total organic carbon (TOC) was measured on a daily basis using the UV-persulphate TOC analyzer (Dohrmann, Phoenix 8000). Total adsorbed biomass (as dry weight) was calculated on a regular basis. The GAC with the retained biomass was dried in an oven at 103.5° C for 24 hours and desiccated prior to the measurement of the total adsorbed biomass (as dry weight).

The chemical composition of the synthetic wastewater used is shown in Table 2.

Table 1. Physical properties of GAC used.

Specification of the GAC	Estimated Value
Iodine number, mg /(g.min)	800
Maximum Ash content	5 %
Maximum Moisture content	5 %
Bulk density, kg/m^3	748
BET surface area, m^2/g	1112
Nominal size, m	3×10^{-4}
Average pore diameter, Å	26.14

Table 2. Constituents of the Synthetic Wastewater used

Compounds	Weight (mg/L)
Beef extract	1.8
Peptone	2.7
Humic acid	4.2
Tannic acid	4.2
Sodium lignin sulfonate	2.4
Sodium lauryle sulphate	0.94
Acacia gum powder	4.7
Arabic acid	5.0
$(NH_4)_2SO_4$	7.1
K_2HPO_4	7.0
NH_4HCO_3	18.8
$MgSO_4.3H_2O$	0.71

Experiments were also conducted with biologically treated sewage effluent.

High pressure size exclusion chromatography (HPSEC, Shimadzu Corp., Japan) with a SEC column (Protein-pak 125, Waters Milford, USA) was used to determine the MW distribution of organic matter. All the samples were previously filtered on a 0.45 μm filter prior to the DOC measurement. This procedure also protects the HPSEC column. Standard solutions of different polystyrene sulfonates with known MW (PSS: 210, 1800, 4600, 8000, and 18000 daltons) were used to calibrate the equipment. Thus, the range of SEC column used in this study is from about 100 daltons to 0.45 μm. Here, the response (mV) is proportional to aromaticity of organic matter. Since the majority of organic matter could be absorbed by UV, the UV detector at 254 nm was used to relate the MW distribution. The details on the measurement methodology are given elsewhere (Her et al., 2002).

RESULTS AND DISCUSSION

Synthetic Wastewater

Attached Biomass

The performance of a biofilter depends on the biomass attached to the filter media. The biomass growth and its maintenance over the surface of the filter media, on the other hand, depend mostly on the surface characteristics of the filter media itself. Several methods have been adopted in practice to measure the biomass attached to the filter media depending on the availability of the analytical facilities. Ahmad et al. (1998) used heterotrophic plate count (HPC) to represent biomass growth in the biofilter. Wang et al. (1995), and Carlson and Amy (1998) used phospholipid analysis to estimate the biomass in the biofilter. In this study, since the biomass growth with synthetic wastewater was significantly large, the total dry weight of the attached mass was measured as the active biomass. This method is simple and more practical. As shown in Figure 1, the growth of biomass was nearly stabilized after 4 weeks of continuous filtration operation.

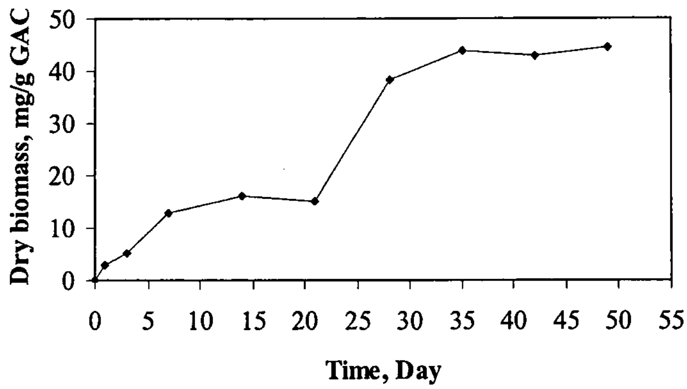

Figure 1. Biomass accumulation in GAC.
(GAC amount = 250 mg in batch mode, average influent TOC = 6.5 mg/L)

The maximum biomass was nearly 44 mg per g of GAC after 49 days. The biomass concentration profile with time depends on both hydraulic and organic loading rates (Chaudhary et al., 2003; Carlson and Amy, 1998). The higher the loading rate, the greater was the initial biomass and deeper the penetration into the filter bed. The daily filter backwash provided to overcome the clogging of the filter appeared to have no adverse effects on the performance of the biofilter.

Long-term Performance of the Biofilter

The TOC removal efficiency of the biofilter is presented in Figure 2. This result shows that the GAC biofilter can be operated for a long time without regeneration of carbon. Even after 41 days of continuous run, the biofilter maintained the organic removal efficiency of 40-50 %. It should be noted that this result was obtained with a short GAC column depth. The TOC removal could be increased by increasing the GAC column depth. The results with 5 cm GAC bed depth are shown in Figure 3. The daily backwash adopted to avoid the physical clogging of the biofilter did not affect the organic removal efficiency of the filter. Some of the biomass may naturally be lost during backwashing of the filter but the loss of biomass can create more sites for adsorption of organics and thus impairment is balanced.

Effect of Filtration Rate

In this study, the filter column was acclimatized with low filtration rates of 0.2 m/h and 1 m/h for the gradual growth of biomass in the filter media. The effects of filtration rate on the organic removal efficiency of the biofilter were experimentally investigated. The filtration rate was kept constant during the experimental run using a constant head tank. The filtration rate could be kept constant as the headloss development through the medium was very low. As can be seen from Figures 4 and 5, with the increase in filtration rates, the effluent quality became inferior to that with lower filtration rate (at which the filter was acclimatized) but the organic removal pattern remained unchanged with time.

The drop in the organic removal efficiency of the biofilter with the increase in the hydraulic loading rate was because of the decrease in the EBCT of the biofilter. Previous researchers have also observed the decreases in the organic carbon removal with decreased EBCT (Chaudhary et al., 2002; LeChevallier et al., 1992).

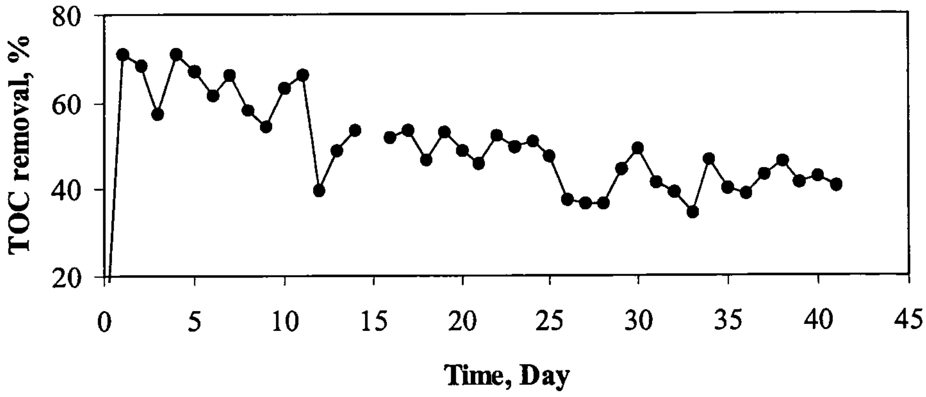

Figure 2. TOC removal efficiency of the GAC biofilter. (Filtration rate = 2 m^3/m^2h, GAC amount = 20 gm, GAC column depth = 15 cm, Column diameter = 2 cm, average influent TOC = 6.5 mg/L)

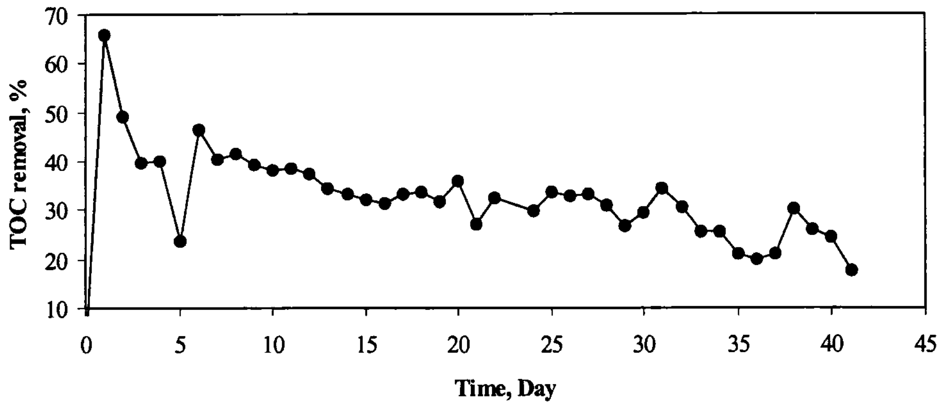

Figure 3. TOC removal efficiency of the GAC biofilter. (Filtration rate =0.3 m^3/m^2h, GAC amount = 20 gm, GAC column depth = 5 cm, Column diameter = 4.5 cm, average influent TOC = 6.5 mg/L)

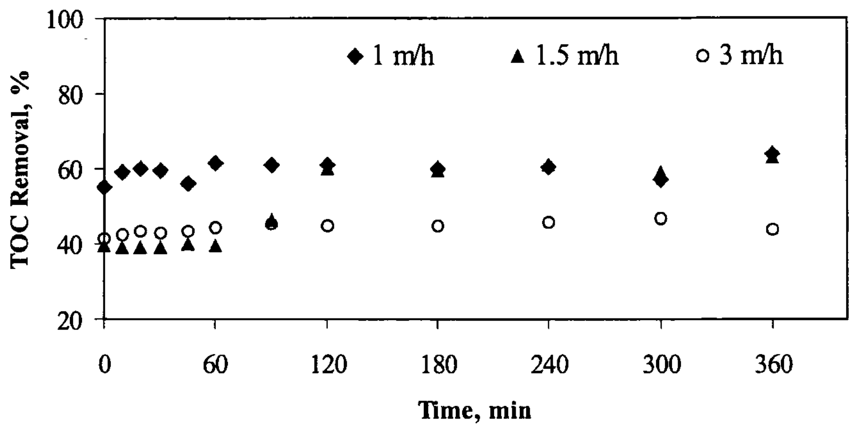

Figure 4. Effect of filtration rate on the performance of GAC biofilter.
(Filter acclimatization at 1m/h, average TOC = 12.7 mg/L, GAC depth = 15 cm, column diameter = 2 cm)

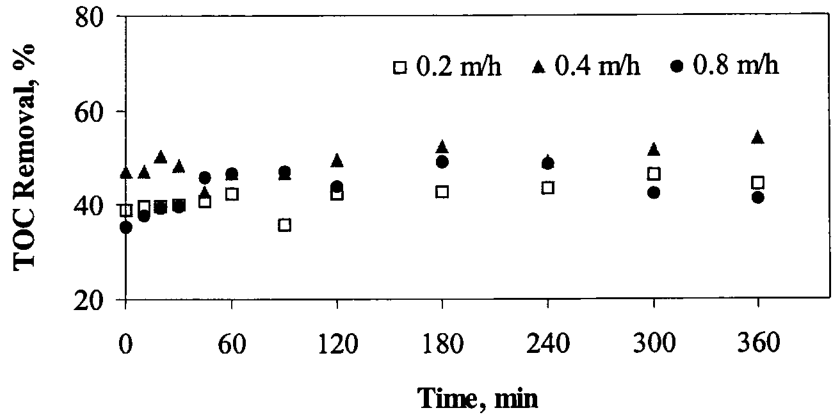

Figure 5. Effect of filtration rate on the performance of GAC biofilter. (Filter acclimatization at 0.2 m/h, average TOC = 10.7mg/L, GAC depth = 5 cm, column diameter = 4.5 cm)

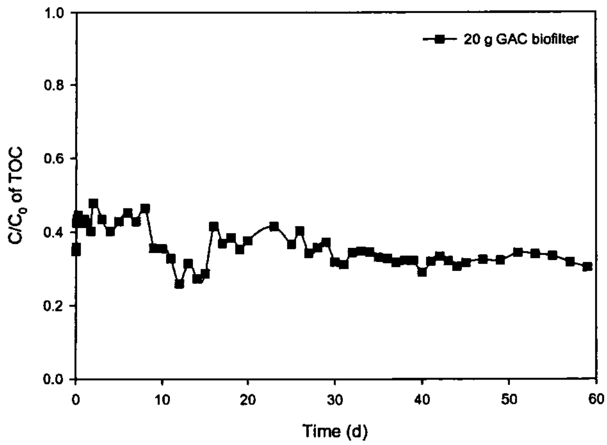

Figure 6. Performance of biofilter with BTSE. (TOC = 6-10 mg/L, BOD_5 = 9-18 mg/L, SS = 3-5 mg/L, velocity = 1 m/h, GAC amount = 20 gm, GAC column depth = 7 cm, column diameter = 3.5 cm)

BIOLOGICALLY TREATED SEWAGE EFFLUENT

After the successful operation of biofilter with synthetic wastewater, the biofiter was tested with biologically treated sewage effluent (BTSE). The long-term organic removal efficiency of the biofilter in removing organics from BTSE is shown in Figure 6. The TOC removal efficiency of the biofilter with BTSE was stabilized at 35-40% after 30 days of continuous operation, and lasted for 60 days. Here again, the low removal efficiency was due to the shorter GAC depth used.

Molecular Size Distribution of the Biofilter Effluent

It is important to study the range of molecular size distribution (MSD) of organic in order to investigate the type and size of organic matters by biofilter in order to optimize the design parameters of biofilter. In addition, information on MSD of organics provides a more fundamental understanding of the complex interactions that occur in the unit operation and treatment process.

The molecular weight (MW) of the BTSE ranged from 300 daltons to about 400,000, the highest fraction being 300 – 5000 daltons. The MW size distribution of GAC biofilter was first examined for the initial 24 hours of GAC operation. Figures 7 and 8 show the MW size distribution of GAC biofilter effluent with time. Significant removal of the small MW occurred at the initial stage, suggesting that the adsorption was predominant mechanism at the initial process. However, as time proceeded, the small molecule could not be removed.

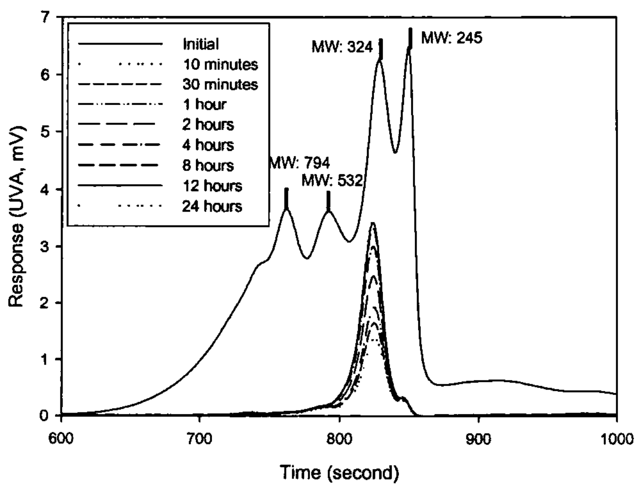

Figure 7. MW size distribution of batch GAC adsorption in the biologically treated sewage effluent (velocity = 1 m/h; bed depth = 7 cm)

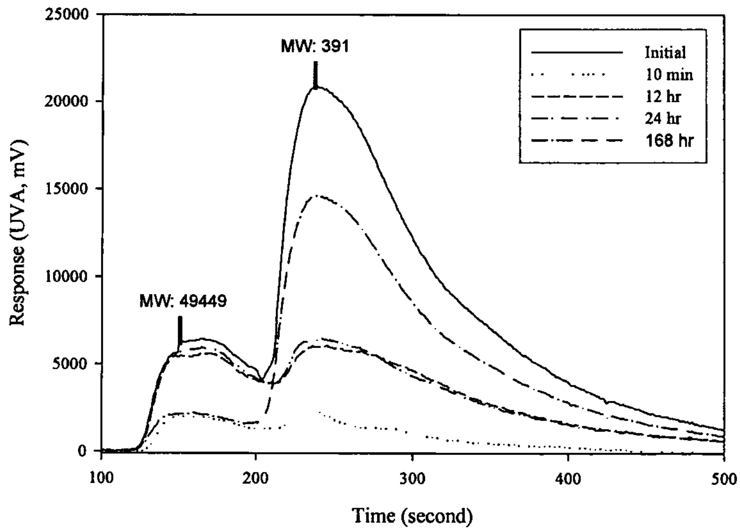

Figure 8. Molecular size distribution of GAC biofilter effluent with time. (velocity: 1 m/h, bed depth: 7 cm)

The organic matter removed by GAC biofilter was also measured in terms of colloids and hydrophobic, trasphilic and hydrophilic fractionations. The fractionation and colloid were determined in the influent and after 30 days of operation of GAC biofilter (Tables 3 and 4). The removal of colloidal compounds was 76.2% by GAC biofilter, indicating that GAC biofilter was sufficient to remove the relatively large MW after 30 days. It should be noted that the colloidal portion are the particles between 3500 daltons and 0.1 μm. The removal of hydrophobic fraction by GAC biofilter was only 23.5% of DOC. The removal of hydrophilic fraction was 61.1%. This suggested that GAC biofilter was better in removing hydrophilic organic fraction.

Table 3. Organic colloidal portion (in DOC) in the secondary effluent with biofilter after 30 days.

	Colloidal portion of EfOM, mg/L (rejection, %)
Secondary effluent	4.04
After biofiltration	0.96 (76.2%)

Table 4. Hydrophilic, hydrophobic, and transphilic fractions in the secondary effluent with biofiltration after 30 days.

Fraction	DOC of secondary Effluent, mg/L	DOC of the effluent after biofiltration, mg/L (rejection, %)
Hydrophobic	4.98	3.81 (23.5)
Transphilic	1.68	1.42 (15.5)
Hydrophilic	3.19	1.24 (61.1)

CONCLUSIONS

1. GAC biofilter can effectively be used in an economical manner to produce better quality of effluent due to its consistent TOC removal efficiency, long operational life, and simplicity in operation.
2. The biological activity led to consistent effluent organic concentrations over a long period. The daily backwash adopted did not affect the biological mass growth thus the effluent quality.
3. Molecular weight distribution results indicated that GAC filter can remove majority of organic matters above 300 daltons.
4. The removal of hydrophilic, transphilic and hydrophobic was 61.2%, 15.5% and 23.5% by GAC biofilter, respectively.

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