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# Performance of biofilters in GAC-sand and anthracite-sand dual-media filters in a water treatment plant in Abadan, Iran

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ABSTRACT

Biological water treatment using granular activated carbon (GAC) and anthracite improves water quality by reducing total organic carbon (TOC), colour, nitrogen content and turbidity. This study investigated the operation of aerobic biofilm on two pilot biofilters designed to remove turbidity, TOC, $NO_3^-$ and $NH_4^+$ in water. The results show that the GAC-sand pilot filter at a low hydraulic loading rate (HLR) increased the empty bed contact time and recorded the highest production of heterotrophic bacteria and biofilm, which increased the efficiency of treatment. Breakthrough occurred in the GAC-sand pilot filter at 72 h and low HLR, but occurred sooner for medium and high HLRs at 48 and 24 h, respectively. The run-time for the anthracite-sand pilot filter at high, medium and low HLRs was 70, 46 and 22 h, respectively. The microorganisms *Pseudomonas*, *Bacillus* and *Citrobacter* were identified in the GAC-sand filter.

*Keywords:* TOC; Biofilm; Anthracite; GAC; Water treatment

## 1. Introduction

Organic matter in drinking water is of major concern because it changes the colour, taste and odour of the water and leads to the formation of trihalomethane and reproduction of bacteria in the distribution systems [1–4]. The control of organic matter is an influencing factor in drinking water treatment and distribution. Reducing the amount of organic matter during water treatment improves the aesthetic quality of the water and controls bacteria without employing additional disinfection or formation of disinfection by-products [5]. Interest is increasing for modification of conventional rapid sand filters into dual- or multi-media filters for the production of drinking water. A dual-media filter is a filter bed in which media with lower specific gravity and larger grain size lie over media with higher specific gravity and smaller grain size [6].

Biologically active filters are commonly used to treat surface water containing total organic carbon (TOC). As filtration proceeds, microorganisms in the

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water operate as an energy supply and carbon source [7]. These attach to the filter media and gradually form a biofilm in which they grow, oxidize and remove most pollutants by biodegradation rather than filtration [8,9]. The biofilm on the filter media can work cooperatively to remove natural organic matter, colour, nitrates, iron and manganese. The process can also help prevent formation of halogenated compounds in the water.

Biofilm microorganisms include heterotrophic bacteria, nitrifying bacteria, *Nitrosomonas*, *Nitrobacter* and rotifers that feed on dead biomass [10–14]. The composition of the media in a biofilter strongly affects the biofilm formation. Activated carbon is commonly used as media in biofiltration. The activated biofilm in the filter adsorbs the contaminant from the water, which is then held on the surface of the carbon particles. Adsorption efficiency is influenced by the characteristics of both the carbon material and the contaminate [7]. Anthracite and granular activated carbon (GAC) have been used as biofilter media to remove natural organic material [15–19].

Important factors affecting the removal of organic matter by biofilters are media type, temperature and run-time. Removal of organic matter appears to relate to microbial propagation in the GAC. Many studies have focused on biofiltration systems, yet it is theoretically difficult to explain the behaviour of a biofilter. The most important parameters that affect biofilter performance are filter media, filtration rate and contact time. The latter is expressed as empty bed contact time (EBCT) and is a key parameter in the design and definition of operating conditions of a biofilter because it demonstrates the degree of contact between the activated carbon particles (filter media) and the water flowing through the filter. As EBCT increases, the time available for organic particles to be adsorbed and removed increases [20–22].

This study evaluated the effect of the composition of the media, filter loading rate, and EBCT on biofilter removal efficiency for turbidity, TOC, $NO_3^-$ and $NH_4^+$ in the Abadan Water Treatment Plant (AWTP) in the city of Abadan in Iran. For this purpose, two pilot-scale dual-media filter units were set up and operated at AWTP. The performance of the pilot units for removal of turbidity, TOC, $NO_3^-$ and $NH_4^+$ were compared with the results of the full-sized filter unit at AWTP.

## 2. Materials and methods

### 2.1. Experimental design

AWTP is one of the oldest treatment plants in the city of Abadan and provides the usual treatment processes of coagulation and flocculation, sedimentation and rapid sand filtration followed by disinfection. The pilot plant was installed at this water treatment plant in Abadan. This pilot plant consisted of two filter columns (CPVC pipes 15.5 cm in diameter) with different hydraulic loading rates (HLRs) and EBCTs. The HLR is the ratio of flow divided by the surface area of the filter. Fig. 1 shows a schematic of the pilot-scale plant. Tables 1 and 2 provide the technical properties and operating conditions, respectively, of the pilot plant.

The first pilot filter consisted of a layer of anthracite (37.5 cm in height, ES = 0.8 mm, UC = 1.7) and a layer of sand (37.5 cm in height, ES = 0.7 mm, UC = 1.6). The second pilot filter was filled with GAC (37.5 cm in height, ES = 0.8 mm, UC = 1.4) and sand (37.5 cm in height, ES = 0.7 m, UC = 1.6). The HLRs for slow and rapid sand filters were 10 and 120 $m^3/m^2$ d according to the standard definition [23]. The biofilters under this study were biofilters between of these two types of filters based on the formation of biological layer, adsorption mechanism and washing.

The pilot filters were fed with effluent from sedimentation tanks pumped into the inlet of each filter at

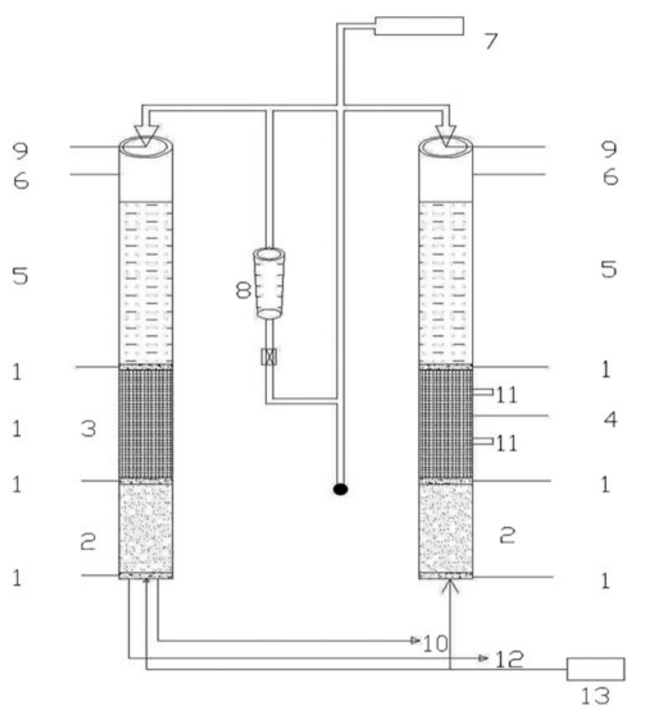


Fig. 1. Pilot plant schematic.
Notes: (1) Support layer, (2) Sand layer, (3) GAC layer, (4) Anthracite layer, (5) Water level, (6) Free board, (7) Effluent of sedimentation tank, (8) Flow meter, (9) Influent valve, (10) Effluent valve, (11) Sampling port for measuring biofilm concentration, (12) Backwash water and (13) Backwash air compressor.

Table 1
Pilot plant technical properties

| Properties | Amount | Properties | Amount |
|---|---|---|---|
| Free board of filter (cm) | 15 | Gender of pilots | CPVC |
| Surface loading ($m^3/m^2$ d) | 35,80,120 | Form | Cylindrical |
| The diameter of the cross section (cm) | 15.24 | Type of drainage system | Porous plastic tube |
| Filter total Height (cm) | 200 | The method of filter Washing | Back wash |
| Bed depth without protective layer (cm) | 75 | Base of filter washing | Outlet turbidity of filter |
| Support layer depth (cm) | 20 | Inlet valve position | At the top of each pilot |
| The depth of water in the filter (cm) | 90 | Outlet valve position | Under of drainage system |

Table 2
Operating conditions of the pilots'

| Steps | Gender of bed | | HLRs ($m^3/m^2$ d) | | |
|---|---|---|---|---|---|
| | Pilot no. 1 | Pilot no. 2 | 35 | 80 | 120 |
| 1 | Silica sand: 37.5 cm and Anthracite: 37.5 cm | Silica sand: 37.5 cm and GAC 37.5 cm | * | | |
| 2 | Silica sand: 37.5 cm and Anthracite: 37.5 cm | Silica sand: 37.5 cm and GAC 37.5 cm | | * | |
| 3 | Silica sand: 37.5 cm and Anthracite: 37.5 cm | Silica sand: 37.5 cm and GAC 37.5 cm | | | * |

a set flow rate controlled by a flow meter with a range of 0.4–5 L/min. A flow meter was installed before the water inlet of the pilot filters to control the filtration rate. The water flow rate at the outlet was adjusted using a volumetric control valve. The pilot filters operated for about two weeks to allow for maturation of the biomass. Turbidity, TOC, $NO_3^-$ and $NH_4^+$ of the influent and effluent of each filter were measured and those of the full-sized filters at AWTP were measured over a period of several weeks. Samples of influent and effluent water for both pilot filters were collected during the winter season. Table 2 shows the parameter values at HLRs of 35, 80 and 120 $m^3/m^2$ d for each pilot for turbidity, TOC, $NO_3^-$, $NH_4^+$ and heterotrophic plate count (HPC) measured during the 15 d of operation of each HLR.

Two sampling ports were installed 15 cm apart on the wall of pilot filter 2 to measure biomass concentration. It has been extensively reported that GAC shows superior performance because higher amounts of biomass attach to it than to other media; thus, only the weight of the biomass was measured in the GAC-sand filter at the different HLRs [23]. Filter backwash was performed when the number of heterotrophic bacteria reached the appropriate level and the biofilm formation on filter bed was complete to ensure maintenance of the biomass on the biofilter during backwashing [24–27].

A backwashing cycle using non-chlorinated water (effluent from pilots) was performed every 72, 48 and 24 h for the low, medium and high HLRs, respectively. Backwashing with chlorinated water can remove a significant portion of the biomass and will decrease the performance of the biofilter for TOC removal [28]; thus, the run-times in pilot filter 1 at high, medium and low HLRs were recorded at 70, 46 and 22 h, respectively. A set of sprinklers poured water over the pilot filter surface and into the pilot zone. These sprinklers were located about 1.1 m above the bedding in the pilot filters. The large air–water interface and other advantages of this type of filling material decreased the likelihood of pilot filter blockage.

### 2.2. *Material and analytical procedures*

#### 2.2.1. *TOC analysis*

The amount of organic matter was based on TOC measurement using a TOC-VCSH analyser of the influent and effluent of both pilots and filtration units. TOC was measured by oxidizing samples of water to evolve $CO_2$ from organic matter and measure it with a non-dispersive infrared detector as recommended in Section 5310 of the Standard Methods for Examination of Water and Wastewater [29].

#### 2.2.2. *Microbial identification*

The identification of the heterotrophic bacteria was conducted by incubating a sample of filtered water from the pilot filters on R2A agar plates using the spread method. The HPC on each plate was then recorded after 7 d of incubation at 20 ± 1˚C and designated as a colony-forming unit (CFU/ml). To identify the bacteria as an isolated colony, it was streaked on tryptic soy broth agar in a quadrant streak pattern using an inoculation loop sterilized in a flame, then incubated at 20 ± 0.5˚C for 72 ± 3 h. The colonies were harvested from the most dilute quadrant exhibiting confluent growth along the streaking axis using quadrant 3 methods as suggested by Section 9215B of the Standard Methods for Examination of Water and Wastewater [29].

#### 2.2.3. Other analyses

$NO_3^-$ and $NH_4^+$ were measured using a Hach DR 5000 spectrophotometer. Turbidity was measured by nephelometry with a calibrated Hach 5000P turbidity meter. All parameters were measured according to Sections 4500, 4500 and 2130B of the Standard Methods for Examination of Water and Wastewater [28]. The total dry weight of the biomass attached to pilot 2 was quantified using gravimetric methods after reaching a steady state [8]. The EBCT was calculated as empty bed volume divided by the flow rate through activated carbon particles [30].

#### 2.2.4. Statistical data analysis

One-sample and bivariate *t*-tests were used to determine the *p*-value and significance for statistical comparison of the results.

## 3. Results and discussion

### 3.1. Pilot plant performance

This study investigated the performance of pilot filters at 3 HLRs. Table 3 shows that the turbidity of the filtered effluent in all three cases was higher than limits deemed desirable for drinking water (5 NTU) by the Iranian Water Work Association [28]. The value for pilot filter 2 fell into the required range for the low and medium HLRs. The turbidity for the low HLR was less than 5 NTU for the effluent of the filtration unit.

The results shown in Table 4 indicate that there are significant differences in the average turbidity removed for pilot filter 2 and the sand filter at low and medium HLRs. Although this difference was also significant for pilot filter 1 and the sand filter at the low and medium HLRs, the turbidity removal efficiency was lower in pilot filter 1. Table 5 indicates that the performance of pilot filter 2 was better than both pilot filter 1 and the sand filters at the lowest HLR (89.36 ± 4.468% turbidity removal). This value was 85.07 ± 4.25% for the rapid sand filter and even lowers for pilot filter 1 at 70.28 ± 3.514%. Although the efficiency of turbidity removal at the medium loading rate was higher in pilot filter 2, it was not as significant as that for the low loading rate.

Previous studies have reported similar results of 90% average water turbidity removal at 0.3 NTU turbidity [31]. Table 4 also shows that the highest overall TOC removal occurred in pilot filter 2 (89.62 ± 4.481%) at the low HLR (Table 5). This was 53.16 ± 2.658% for the rapid sand filter and 40.23 ± 2.01% for pilot filter 1. The medium and high HLRs did not result in higher efficiency for TOC removal. Table 4 shows no significant difference between pilot filters and the sand filter for medium and high HLRs. The difference between the effluent of the filtration unit and pilot filters at low HLR was significant, although previous works on performance of GAC filters have primarily centred on organic carbon removal.

No significant difference was observed between pilot filters and sand filters for $NO_3^-$ removal. An effective decrease in ammonia has been reported to occur in these biofilters [32,33]. Mohamed et al. [34] also applied a GAC-sand filter to remove ammonia and reported results of higher than 80% in both summer and winter. Tables 4 and 5 shows that the difference in $NH_4^+$ between pilot filter 2 and the filtration unit for low HLR is important because removal of $NH_4^+$ decreased as the HLR increased.

Pilot filter 2 showed higher efficiency for removal of turbidity, TOC and $NH_4^+$ for low HLR when compared with pilot filter 1 and the sand filter. A recent investigation of full-scale bioreactors has shown that the removal efficiency of organic matter using a GAC-sand dual-media filter was greater than for the sand filter [12]. Fig. 2 shows the average turbidity removal efficiency for samples collected every day. The slope for pilot filter 1 for filter efficiency of turbidity removal decreased as filter run-time increased (41.32 ± 47.54%) after 15 d. Run-time for pilot filter 1 does not appear to have a direct effect on removal efficiency of the filter (a positive sign for *X* in the equation). The positive and negative signs for *X* denote an increase or decrease, respectively, for turbidity removal after 15 d; the run-time for pilot filter 2 had a positive effect.

TOC removal efficiency is shown in Fig. 3. The higher trend for reduction was observed in pilot filter 1 after 15 d of operation time. TOC measurements were made every 3 d and compared to pilot filter 2. The error bars for standard deviation of mean indicates that there was no statistically significant decrease

Table 3
The average parameters in various HLRs

| Parameters | HLRs level ($m^3/m^2$ d) | Influent of filtration unit | Effluent of pilot filter no. 1 | Effluent of pilot filter no. 2 | Effluent of filtration unit |
|---|---|---|---|---|---|
| Turbidity (NTU) | Low | 35.17 | 7.29 | 3.60 | 4.20 |
| | Medium | 51.03 | 18 | 4 | 9.93 |
| | High | 51.03 | 14.52 | 7.45 | 8.47 |
| TOC (mg/l) | Low | 7.24 | 3.34 | 0.7 | 4.18 |
| | Medium | 9.8 | 6.35 | 4.4 | 5.4 |
| | High | 9.2 | 5.9 | 5.6 | 3.718 |
| HPC (CFC/ml) | Low | 805.67 | 930.33 | 1,027 | 366 |
| | Medium | 775.67 | 816.67 | 827.67 | 330 |
| | High | 831.33 | 841.33 | 871 | 366 |
| $NO_3^-$ (mg/l) | Low | 1.58 | 1.24 | 1.22 | 1.24 |
| | Medium | 1.7 | 1.44 | 1.42 | 1.42 |
| | High | 2.32 | 2 | 1.96 | 1.98 |
| $NH_4^+$ (mg/l) | Low | 0.25 | 0.178 | 0.12 | 0.18 |
| | Medium | 0.292 | 0.222 | 0.204 | 0.222 |
| | High | 0.24 | 0.188 | 0.18 | 0.22 |

Table 4
The results of *t*-test at low HLR between effluent of pilots and filtration unit

| Parameters | HLRs level ($m^3/m^2$ d) | | |
|---|---|---|---|
| | Low | Medium | High |
| Turbidity (NTU) | + * | + * | + - |
| TOC (mg/l) | + * | - - | + * |
| $NO_3^-$ (mg/l) | - - | - - | - - |
| $NH_4^+$ (mg/l) | * - | - - | - - |

Notes: +: The average removal of parameters in pilot no. 1 and effluent of filtration unit is significance ($p < 0.05$).

*: The average removal of parameters in pilot no. 2 and effluent of filtration unit is significance ($p < 0.05$).

-: The average removal of parameters in pilot sand effluent of filtration unit is insignificance ($p > 0.05$).

after 15 d. The average temperatures of the influent water at low, medium and high HLRs were 15.2, 15.39 and 15.78˚C, respectively. The average temperatures in the effluent water for low, medium and high HLRs were 17.04, 16.7 and 17.13˚C, respectively.

Bivariate testing for all HLRs showed that in pilot filter 1, there was a significant difference between the levels of effluent of HPC and TOC ($p = 0.044$), but the relationship between temperature and TOC and temperature and HPC were not significant ($p = 0.705$ and 0.662, respectively). It was expected that the HPC level would decrease as HLR increased of HLR and TOC. Although the exact reasons for the decrease in HPC could not be described, the high TOC concentrations may have played a role [35]. The bivariate test for all HLRs showed no significant differences in pilot filter 2 between HPC and TOC, temperature and TOC, and temperature and HPC of the effluent ($p = 0.283$, 0.945 and 0.661, respectively). At low HLR, HPC was higher than at the other HLRs because the bacteria had sufficient time for reproduction.

Similar results were observed for $NO_3^-$ removal efficiency. The error bars in Fig. 4 show a greater reduction in pilot filter 1 for $NO_3^-$ removal efficiency after 15 d. $NO_3^-$ measurements were made every 5 d. No significant decrease was observed for $NO_3^-$ removal efficiency for pilot filter 2. Filter operation length had a negative effect on removal efficiency for both pilot filters, especially in pilot filter 1. Decreases of 21.72 ± 23.57% and 2.27 ± 3.92%, respectively, were observed.

Fig. 5 indicates that both pilot filters 1 and 2 show increased $NH_4^+$ removal efficiency during filter operation. The percentage of removal of $NH_4^+$ in pilot filters 1 and 2 were 22 ± 20.8% and 8 ± 4.8%, respectively, after 15 d. This was denoted by a positive sign for *X* in the equations. The potential of nitrification correlated with the type of biofilm and can be an index of the population of microorganisms. One major factor affecting nitrification is temperature [36]. When the temperature dropped below 15˚C, nitrification rate dropped sharply [37]; thus, it is important to maintain the average temperature of the influent and effluent water at above 15˚C. The population of microorganisms in the biofilm in the pilot GAC-sand at low HLR was the main factor for better removal of $NH_4^+$.

Table 5
Effect of various HLRs on the removal of parameters

| Parameters | Removal % | | | |
|---|---|---|---|---|
| | HLRs level ($m^3/m^2$ d) | Effluent of Pilot no. 1 | Effluent of Pilot no. 2 | Effluent of filtration unit |
| Turbidity (NTU) | Low | 70.28 | 89.36 | 85.07 |
| | Medium | 68.56 | 88.61 | 81.79 |
| | High | 67.26 | 82.84 | 83.23 |
| TOC (mg/l) | Low | 53.16 | 89.62 | 40.23 |
| | Medium | 34.47 | 54.63 | 44.72 |
| | High | 34.03 | 39.04 | 59.07 |
| $NO_3^-$ (mg/l) | Low | 20.64 | 22.27 | 20.15 |
| | Medium | 14.43 | 15.68 | 16.69 |
| | High | 13.56 | 14.10 | 14.74 |
| $NH_4^+$ (mg/l) | Low | 28.66 | 35.09 | 27.06 |
| | Medium | 23.06 | 29.56 | 23.14 |
| | High | 21.29 | 24.59 | 20.23 |

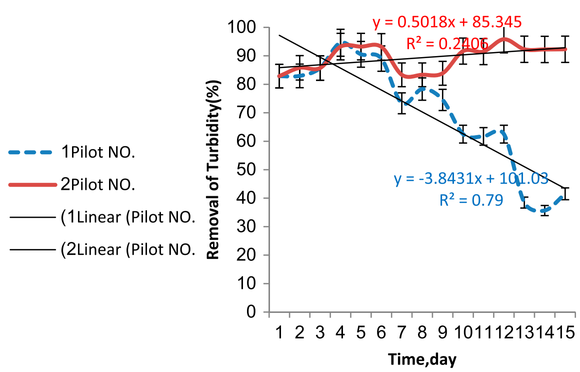


Fig. 2. Variation of Turbidity removal from each pilot during low HLR.

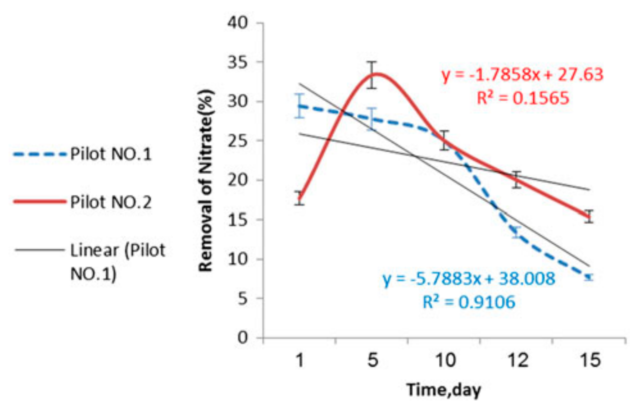


Fig. 4. Variation of $NO_3^-$ removal from each pilot during low HLR.

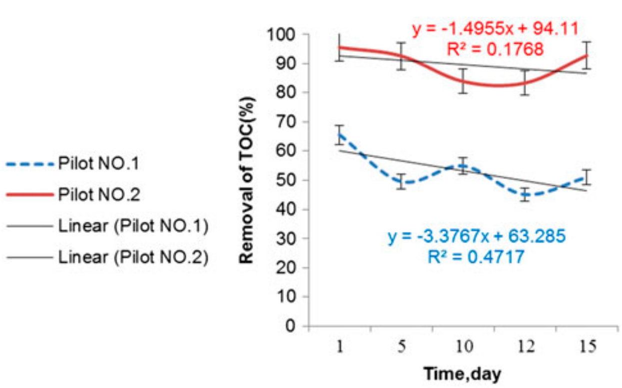


Fig. 3. Variation of TOC removal from each pilot during low HLR.

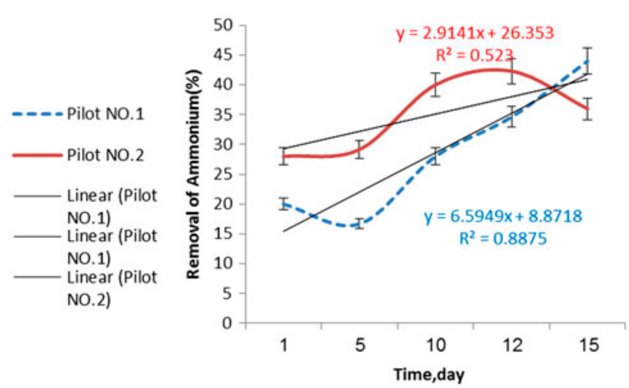


Fig. 5. Variation of $NH_4^+$ removal from each pilot during low HLR.

### 3.2. Biomass growth and identification of microorganisms in GAC-sand filter

Fig. 6 shows that biomass formation is highly dependent on HLR. Maximum biomass formation occurred at sampling port 1 of pilot filter 2 at low HLR (0.1 ± 0.005 g per g of GAC) and minimum biomass occurred at sampling port 2 at high HLR (0.02 ± 0.001 g per g of GAC) after 15 d of continuous operation. Biomass accumulation was found to be dependent on HLR and TOC. Table 3 shows that bacterial growth in pilot filter 2 was greater than in pilot filter 1 at low HLR. The decrease in biomass for at the higher HLR could be the result of die-off of the microorganisms and their consequent elimination during backwashing.

With an increase in HLR, TOC removal efficiency decreased in the biofilter. The average HPC in the influent of the filtration unit was 805.67 CFU/ml. The effluent HPC in pilot filters 1 and 2 were 930.33 and 1,027 CFU/ml, respectively. This research determined that the predominant species attached to the surface of GAC were *Pseudomonas*, *Bacillus* and *Citrobacter* at ports 1 and 2 of pilot filter 2. Biofilm microorganisms often include heterotrophic bacteria, nitrifying bacteria, *Nitrosomonas*, *Nitrobacter* and rotifers that feed on dead biomass [10–14]. The biomass concentration decreased as HLR and filter depth increased. Some biofilm may naturally be washed away through backwashing of the filter; this loss of biomass can generate new places for adsorption of organics and will balance out the loss.

Adsorption and biological degradation of organics adsorbed onto the GAC are two major mechanisms for the consistent removal of organics in a GAC biofiltration system [38]. Most adsorption onto the surface appears to result from van der Waal forces and the increased space between particles [39]. This was mainly caused by the short contact time between microorganisms and organic matter which reduces the growth of microorganisms at high HLR and the deeper points in the filter bed. Biomass concentration at port 1 was higher than at port 2.

### 3.3. EBCT of GAC-sand Filter

Fig. 7 shows the volume of water filtered by GAC per mo and EBCT at different HLRs. The calculations show that the EBCTs were 15 ± 0.75, 6. 8 ± 0.34 and 4.7 ± 0.235 min for HLRs of 35, 80 and 120 $m^3/m^2$ d, respectively. This value falls into the typical EBCT range for water treatment applications of 5–25 min. This study also indicates that the volume of water filtered by GAC per mo was 20.88, 47.952 and 72 $m^3$ at low, medium and high HLR, respectively.

Turbidity, TOC and $NH_4^+$ removal were strongly affected by filter media composition, HLR and EBCT. The percentage of removal of organic substances increased as contact time increased up to an optimum value. Both filter depth and HLR can be changed to increase the EBCT. In general, the TOC removal efficiency of the biofilters increased at higher EBCTs and decreased at higher HLRs. Previous research has observed a similar decrease in EBCT [20,40] for removal of TOC, $NO_3^-$ and $NH_4^+$ using GAC and anthracite. For turbidity, in addition to GAC and anthracite, sand also plays a role.

### 3.4. Backwashing and run-times

Backwashing of biological filters with water partially removes attached biomass but maintains the ability of the filter to remove biodegradable organic carbon. The objective of filtration is particle removal and TOC reduction through biofilm formation. Filter beds should be cleaned to prevent turbidity and organic matter breakthrough. The pilot filters are

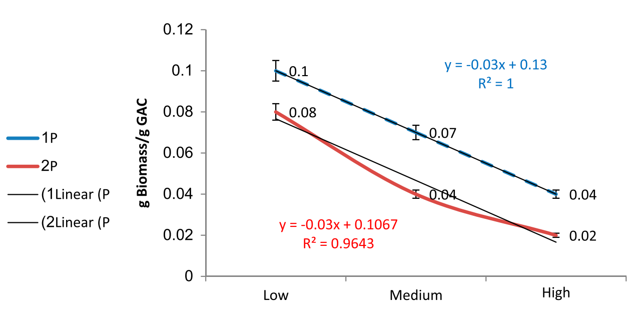


Fig. 6. Biomass concentration measured according to pilot no. 2 in sampling ports.

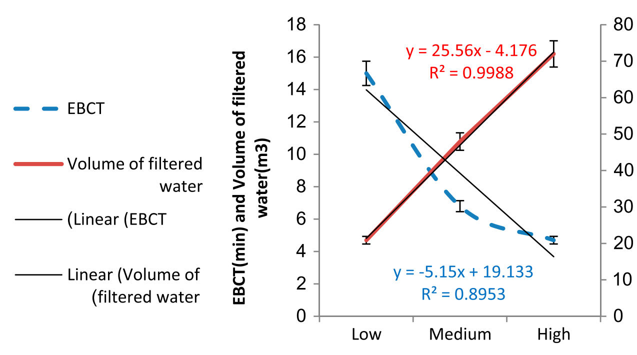


Fig. 7. EBCT and Volume of filtered water in pilot no. 2 during low HLR.

backwashed when head loss in filter is greater than the designated level as pilot effluent turbidity increases [35]. Organic matter removal can be maximized when there is no prechlorination stage prior to filtration and formation of a biofilm leading to removal of TOC and other parameters [28].

Post-chlorination is very effective for inactivating heterotrophic bacteria. In dual-media filters, the removal of particles occurs in all beds, but in a single media filter, deep removal does not occur and the density of the particles is high and the space between the particles is low. As a result, clogging of the bed is greater than in dual-media filters. Backwashing of sand particles is used to pulverize and remove floc to increase water and energy, which is an important economic aspect of the issue.

Bed filters improved 20% after backwash and stable removal of turbidity was observed at the different HLRs. The backwashing times required for pilot filters 1 and 2 were 7.5 and 6 min, respectively, to maintain stability. The flow rate of the backwashing pump was 40 L/min. The volume of backwash water was 300 and 240 L/min for pilot filters 1 and 2, respectively. The effect of turbidity and HLR on run-time is shown in Fig. 8. The filter run-time was inversely related to the HLR. The run-times were carried out after termination of the filter cycles. Pilot filter 2 at low HLR showed a longer run-time than pilot filter 1. Fig. 8 indicates that breakthrough occurred in pilot filter 2 at high HLR at 24 h. The increase in turbidity began at 48 h for medium loading and exceeded critical value at 72 h for low loading. The run-times for pilot filter 1 at low, medium and high HLRs were 22, 46 and 70 h, respectively. This indicates that a longer operating time is needed with less backwashing, consuming less energy and water in the biofilter with GAC-sand. The amount of water used in the single media filters was approximately 1.5 to twice that of dual-media filters.

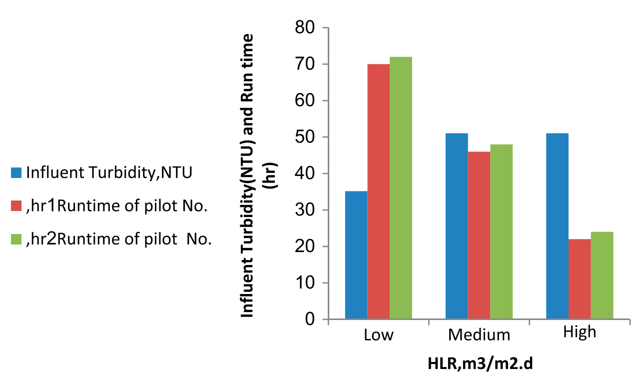


Fig. 8. Role of influent turbidity and HLRs on pilot filters run-times.

HLR had a direct effect on filter run-time. This is in agreement with the results reported by Ko et al. for evaluation of a pilot-scale dual-media biological activated carbon system for drinking water. They reported that breakthroughs for the low, medium and high HLRs occurred at 72, 48 and 24 h [41].

## 4. Conclusions

The performance of a biofilter depends on the biomass attached to the filter media, biomass growth rate, retention capacity and the organic content of the influent water. GAC, sand and anthracite are some of the common biofilter media used at water and wastewater treatment plants. Other factors that can affect the biomass accumulation are filtration rate, filter backwashing techniques and the organic content of the influent water.

The results show that the GAC-sand filter when operating under low HLR has the greatest efficiency for removing these parameters. The removal efficiency of ammonium by the GAC-sand filter was greater than for nitrate, which can be explained by nitrification as evidenced by a corresponding increase in nitrates. Part of the ammonium was adsorbed onto the media, which increased the nitrate level and the removal efficiency of ammonium. Moreover, the GAC-sand filter was more successful for heterotroph bacteria production in the biofilm layer than the anthracite-sand filter. It can be concluded that the HPC decreased as the TOC and HLR increased and that temperature had little effect. The biofilm concentration decreased as the filter depth and HLR increased. The HLR filter was shown to strongly affect EBCT, which increased as the flow rate through the filter decreased.

A longer EBCT can delay breakthrough and decrease GAC replacement/regeneration frequency. The correct choice of HLR and GAC media depth can increase the EBCT and lead to a long-term operation of consistent and superior effluent quality. The filter run-time decreased during backwashing within an increase in HLR and the type of changes in the bed. It is clear from the results that treatment to improve bacterial growth on GAC produced biological activated carbon for which the GAC-sand biofilter is a good candidate for binding organic substances. It is recommended for TOC reduction and results in cost savings with reduced chlorine demand.

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