Environmental Technology, Vol. 16. pp 301-314

STUDY ON AERATED BIOFILTER PROCESS UNDER HIGH TEMPERATURE CONDITIONS

C. VISVANATHAN[1]* AND T.T.H. NHIEN[2]

[1]Environmental Engineering Program, Asian Institute of Technology, GPO Box 2754, Bangkok 10501, Thailand
[2]CEFINEA, Training and Research Center for Water Supply and Environmental Technology, Polytechnic University of HCM City, Vietnam

(Received 16 July 1994; Accepted 28 October 1994)

ABSTRACT

A biological aerated filter combines bacterial degradation of pollutants by fixed biomass with physical filtration in a single reactor at a pilot plant, was utilized for organics removal under tropical climatic conditions. Modified domestic wastewater was used as feed, in the upflow mode. The process consisted of a granular media bed of polystyrene with a specific gravity less than water. Headloss during biofiltration was studied as a function of wastewater temperature, flow velocity and time. Experiments were conducted at 4 different temperatures (30, 38, 45 and 56°C) with 4 velocities (2, 4, 6 and 8 m h^{-1}). The lowest filter run time range was 5.5-10 hours at 38°C, with over 84% of the soluble COD removal at all velocities investigated. A decreasing gradient of biomass from bottom to top of the reactor was observed. The optimal suspended solids removal occurred at 30°C with 6 m h^{-1} velocity indicating that at lower temperatures, maximum suspended solids removal could be obtained. The results indicated that effluent SS could be less than 30 mg L^{-1} meeting the typical standard for secondary treated effluent.

Keywords: Upflow filtration, biological aerated filter, domestic wastewater, polystyrene, floating media

INTRODUCTION

In traditional domestic wastewater treatment, carbonaceous and nitrogenous pollutants are removed from wastewater using aerobic biological processes such as activated sludge units or trickling filters. Although both these methods are proven to be reliable, they occupy large land areas and are regarded as incomplete processes which cannot really accommodate major changes in load, due to limited biomass or steady aeration.

Aerobic biological treatment is possible in small reactors by using support media, with subsequent shorter contact and response times, provided that: (a) concentration of active biomass in the reactor remains high; (b) aeration system is reliable and effective enough to meet the oxygen demand of the medium; and (c) excess biomass is kept under strict control.

In these reactors, usage of suitably sized granular support media gives rise to a filtration phenomenon, which retain the suspended matter, eliminating the need for a secondary clarifier. These fixed growth techniques combine the advantages of quick maturation which give higher operational flexibility in terms of applied load with filtration capacity. Thus, high treatment capacities can be achieved in space-saving installations.

The Biological Aerated Filter (BAF) is an attached growth aerobic biofilm process where wastewater is filtered downward through a fully submerged bed of small rocks, which act as the biofilm support media. The bed is aerated mechanically. There is no settling tank. This filter requires periodic backwashing to remove the excess biomass and retained solids.

On the otherhand the floating filter which was used in this study is a modified form of aerobic biological reactor features fixed biomass attached to a single-layer fixed bed support medium positioned in cocurrent upward air and wastewater flows. This process is technically a combination of the conventional trickling filter and upward rapid sand filtration. The filter medium applied is granular polystyrene of which specific gravity is much less than that of water. These beads which physically resemble the sand media, float just below the water surface. By adjusting the position of the air injection level, a combination of aerobic and anaerobic zones can be created within a single filter bed.

Rogalla and Bourbigot (1) reported that the floating filter process allows complete degradation of carbonaceous material, retention of suspended solids, ammonia oxidation and denitrification, with loading rates close to 10 kg COD m^{-3} d^{-1} in one reactor. An effluent requirement of less than 8 mg L^{-1} of total Nitrogen, together with residual of less than 10 mg L^{-1} BOD and suspended solids (2) could be achieved at temperatures around 10°C and detention time of around 2 hours. The high performance of the floating filter is due to the carefully selected support media, efficient aeration system, cocurrent upward flow of air and wastewater and the effective washing process. This process permits easy backwash of synthetic media as a result of its light-weight. Therefore energy consumption during downflow washes is minimized as the energy required to fluidize the bed is much lower than other comparative processes.

Although much research work has been conducted on the use of this process in temperate climates (e. g. ≤20°C), little is known about its operation in tropical climates. This experimental work focused on replacement of the conventional high specific gravity porous media by synthetic media (polystyrene). Due to its low specific gravity, the media was always maintained in suspension, which facilitated easy backwash.

The objective of this research was to verify the limits of floating biofilters to achieve secondary treatment level, for domestic wastewater in tropical climatic conditions, where the wastestream temperature is expected to be well above 20°C. The clogging phenomenon due to accelerated microbial growth at high temperature, the stability of the process under highly variable temperature and hydraulic loads and the stability of filter media to support different specific microorganisms (e.g. mesophilic and thermophilic) were also studied.

MATERIALS AND METHODS

The experimental study was carried out in a pilot scale unit as schematized in Figure 1. The filter column was made of an acrylic tube of 0.2 m diameter and 4 m height. The height of the supporting bed of polystyrene media was 2.9 m, while 0.7 m was available for bed expansion during downward backwashing. Influent percolated in an upflow direction cocurrent with air, through the submerged fixed-bed. The air was introduced at a distance of 0.44 m from the bottom of the filter bed. The non aerated zone thus created at the bottom was used for prefiltration and for rendering organic material more easily biodegradable.

The cocurrent upflow arrangement offered the following advantages: (a) suspended matter was retained in a uniform fashion; (b) fluid distribution was free of air pockets, blockages or irregular flow patterns throughout the filter run; (c) highly effective oxygenation due to the fact that the bubbles do not coalesce and therefore retain their optimal surface/volume ratio; (d) an even pattern of filter soiling enabling higher flow velocities which can only be achieved in upflow systems through greater medium penetration, where the finest particles accumulate in the upper reaches of the support and preventing sudden system clogging (via straining).

Since the suspended matter becomes attached across the full height of the support, the length of the treatment cycle is considerably increased, thus saving energy and reducing the quantity of wash water.

In an upflow system, pressure inside the supporting media is always positive, a fact which encourages expansion. The combined loss of head and hydraulic load eliminate the danger of gas pockets causing local clogging, which would lead to local accelerations in flow, thus shortening the mean contact time and diminishing the efficiency of the purification process.

Characteristics of the floating granular support media are summarized in Table 1.

Settled Asian Institute of Technology wastewater was fed into the reactor from its bottom, using three pumps connected in series. Wastewater characteristics were modified by adding glucose to simulate the average characteristics of the domestic wastewater of Bangkok metropolitan area. Average characteristics of the wastewater are: total COD = 300 mg L^{-1}, filtered COD = 250 mg L^{-1}, BOD_5 = 240±10 mg L^{-1} and SS = 60±20 mg L^{-1}. Temperature

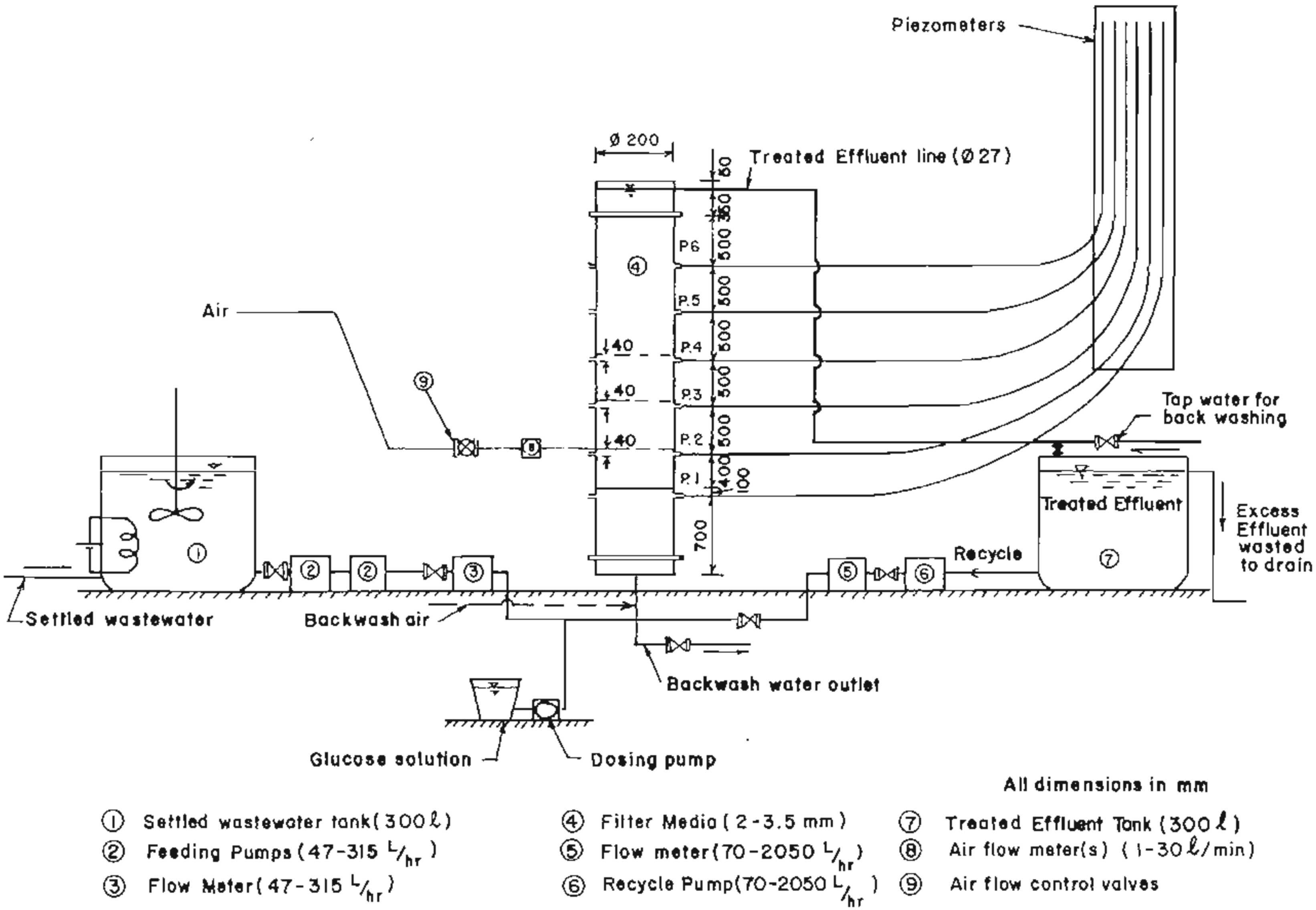


Figure 1. Schematic diagram of the experimental set-up.

Table 1. Characteristics of floating granular support media.

Media Type	Polystyrene
Nature	Spherical, white color, light weight
Size	2-3.5 mm
Apparent density of the media	46 g L^{-1}

of wastewater was maintained constant at 30, 38, 45 or 55°C using thermostats as shown in the Figure 1.

Backwashing Procedure

Since the filters progressively clogged due to the development of excess biomass and the retention of suspended solids, occasional backwashing was required. The wash must be efficient enough to maximize the length of the purification cycles while minimizing energy consumption and the quantities of wash air and wash water (3). Further, the wash must cause no damage to the support media and the fraction of biomass required for the rapid restart of the bioreactor. In these experiments, washing cycles varied according to particular operating condition (temperature and velocity). A General washing cycle consists of: 1) high velocity initial water backwashing approximately for 5 minutes; 2) air scour for 2 minutes; 3) 2 minutes delay time for separation of floating media; 4) repetition of steps 1 to 3 for 3 times; 5) final water rinsing for 15 minutes. The time for triggering the backwash was based on headloss build up, which was typically 1.7-1.8 m.

Analysis of Fixed Biomass

Samples of granular medium were taken at three points as shown in Figure 2 to represent the three zones viz. anaerobic, transition and aerobic zones. Each sample was composed of ten media grains. The grains were rinsed with distilled water in order to remove loosely fixed or adsorbed biomass and organic matter. The amount of biomass fixed on the grains was estimated by measuring the dry weight. A sample of 10 grains was put in the oven (103°C) for 15 minutes. The difference in weight of the sample and the blank gave the weight of dry biofilm. The results were expressed as mg fixed biomass per 100 grains (4).

Effluent Analysis

Filtered COD, BOD_5 and SS measurements were carried out on effluent samples, according to Standard Methods (5).

Experimental Procedure

The experiments were conducted in two different stages namely: (a) start-up, and (b) study of carbonaceous (BOD) removal kinetics on fixed biomass, under steady state conditions.

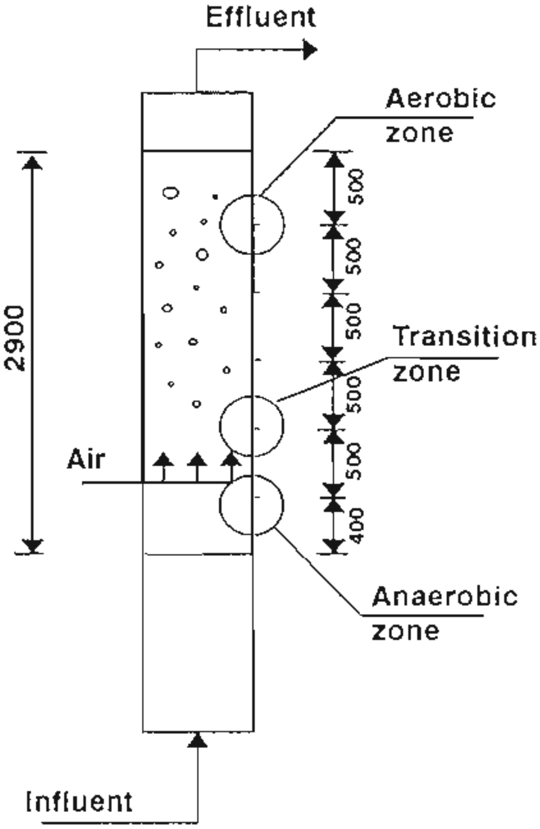


Figure 2. Sampling positions in the filter bed.

Start-up experiments (acclimatization tests):

A low hydraulic loading of 0.5 m^3 m^{-2} h^{-1} with a temperature of 30°C, and aerobic: anaerobic depth ratio of 5:0.7 were applied until steady-state carbonaceous (BOD) removal was observed in the reactor (11). During this period effluent was recirculated with a recirculation ratio of 2:1 to avoid potential limitations due to lack of active microorganisms.

After the steady state was attained, hydraulic loading was gradually increased to 1 m^3 m^{-2} h^{-1} with a recirculation ratio of 1:1 and to the final hydraulic loading of 2 m^3 m^{-2} h^{-1} without recirculation.

During the acclimatization period, typical physico-chemical and fixed biomass parameters were analyzed accordingly, for the three sampling zones (Figure 2).

Carbonaceous removal tests:

Working experiments consisted of 13 runs under preset operating conditions. Each set of run was performed with a different temperature and velocity. For example, the first run was conducted with temperature of 30°C, velocity of 2 m h^{-1}, the second run for the same temperature but with a velocity of 4 m h^{-1}, etc. Table 2 shows operational variables for the experimental series.

RESULTS AND DISCUSSION

Clogging and Headloss Development in the Biofilter

In a biological filter, clogging occurs mainly due to accumulation of large quantities of bacterial precipitates within the entire filter bed. The characteristics of this phenomenon were affected by velocities. At a low velocity of 2 m h^{-1} the clogging occurred mainly at the lower end of the media bed. This event caused the rapid increase in headloss at points No.1 and No.2 from the bottom of the reactor as shown in Figures 3(a), (b) and 4(a). This infers that mainly the bottom 1 m of the bed is responsible for SS removal. The remaining portion of the bed is used for polishing.

As the filtration velocity was augmented by a factor of 2 (to 4 m h^{-1}), it was noted that bacterial precipitate accumulation occurred from points 1 to 4, i.e. the bottom 2 m of the bed. With the increase of filtration velocity, an increase of the bacterial mass accumulation was seen, which eventually curtailed the filter run time, from 24 hours at 2 m h^{-1} to 7 hours at 4 m h^{-1}. Further increase in filtration velocity showed improvement in terms of using total bed depth for solids accumulation and distribution of headloss, throughout the bed.

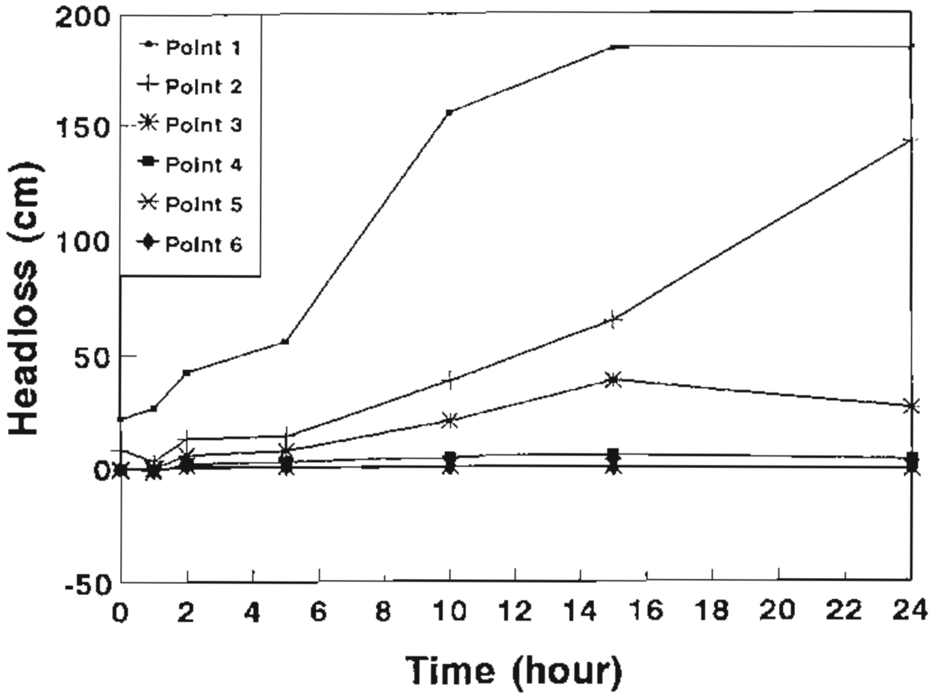
The filtration mechanism in a biological filter is more complex, than in a conventional rapid sand filter used for water treatment. In a biological filter, the micro-biological growth within the filter media will reduce the pore volume. The bioflocculated particles attach on to the surface of the filter medium as they pass by, enhancing the removal of particles. As the filtration velocity is increased, some of the attached material is sheared away from the media and pushed further into the filter bed. This increases headloss throughout the bed depth (refer to Figure 4(a) & (b)). When the headloss increases, the local surface shear force increases to a point at which no additional material can be retained within the media and sloughing or breakthrough occurs. This is the major cause for increase of SS in the effluent, with the increase in filtration velocity. For example SS removal at 8 m h^{-1} was 60-79%, while that at 2 m h^{-1} was 74-80%. Similar observations were made at the influent wastewater temperatures of 38, 45 and 55°C (Refer Figures 6 & 8 and Table 3).

Effects of Temperature and Velocity on Organics and Suspended Solids Removal

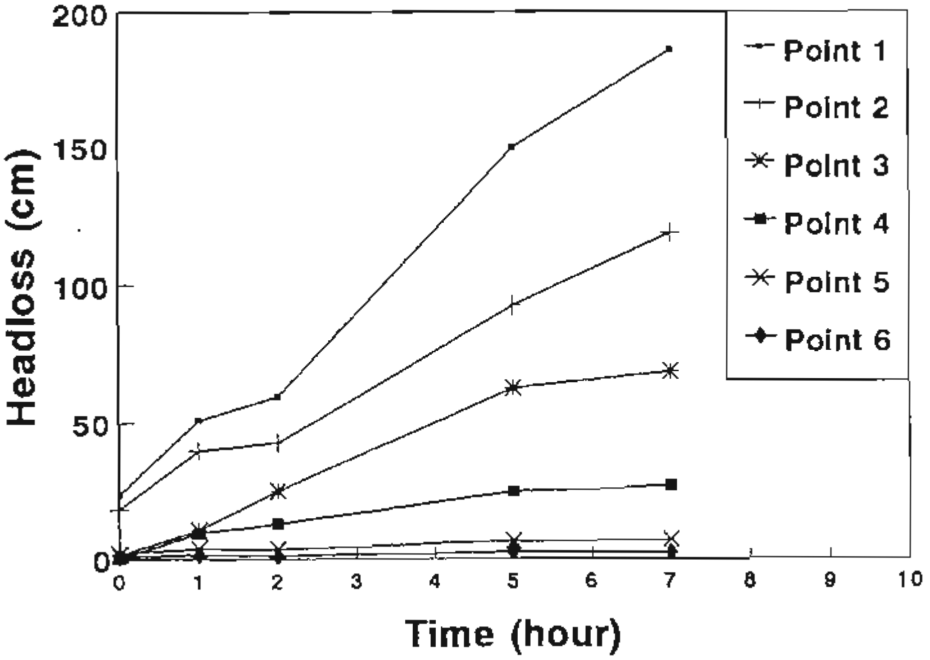
A set of typical experimental results are presented in Figures 5 and 6. Here, for the feed wastewater temperature of 30°C at 4 m h^{-1},

Table 2. Operating parameters of the filter runs with BOD_5 = 250 mg l^{-1} and air supply 20 m^3 kg^{-1} BOD applied.

Experiment	Start-up	Working (at steady state)												
Temperature (°C)	30	30				38				45				55
Velocity (m h^{-1})	0.5 &1	2	4	6	8	2	4	6	8	2	4	6	8	6
Run No.		1	2	3	4	5	6	7	8	9	10	11	12	13



3(a) Filtration velocity 2 m h^{-1}.



3(b) Filtration velocity 4 m h^{-1}.

Figure 3. Headloss profile for different filtration velocities at 30°C.

extremely good quality of effluent in terms of SS and organic removal was observed. The curves on Figure 5 show that the effluent COD of the anaerobic zone seemed to be quasi equal to the influent COD. It means that the 0.44 m long anaerobic reactor could not eliminate organic matter at all and the decomposition of retained solids in the anaerobic zone increases organic concentration. When the filtration velocity was doubled (8 m h^{-1}), the effluent quality deteriorated for both SS and organic removal.

Although high temperature may kill microorganisms by destroying RNA and by injuring the cytoplasmic membrane,

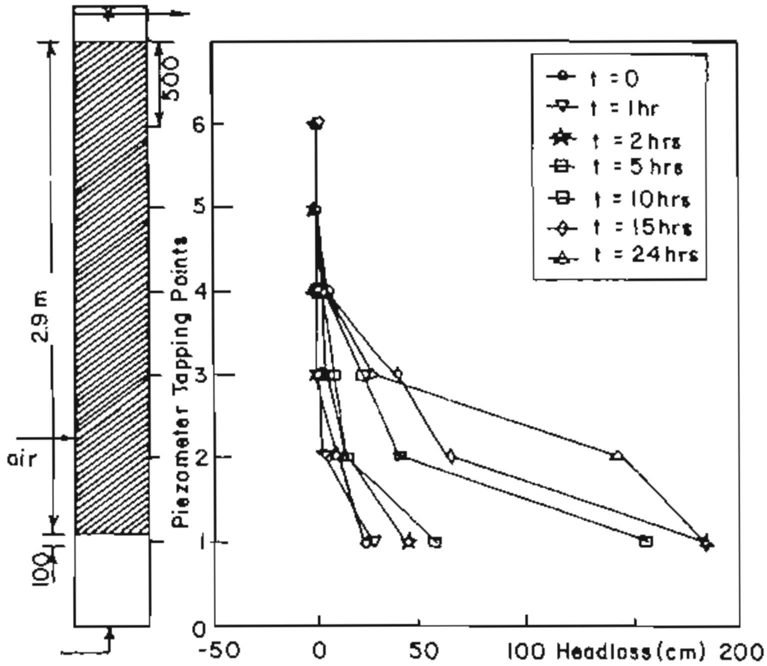


Figure 4a. Headloss profiles vs. time (filtration velocity = 2 m h^{-1}, T=30 °C).

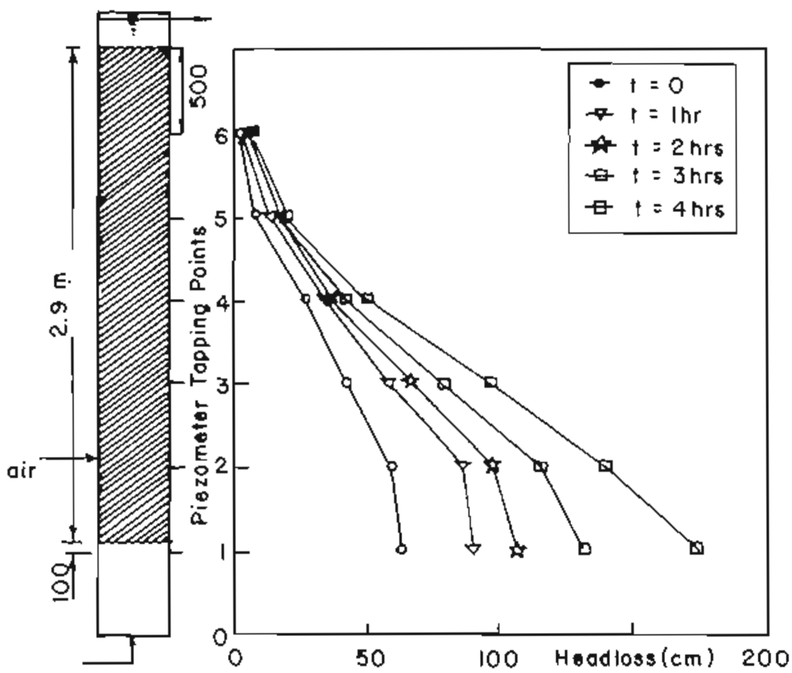


Figure 4b. Headloss profiles vs. time (filtration velocity = 8 m h^{-1}, T=30 °C).

thermophilic bacteria are able to take advantage of the greater availability of nutrients and thus are capable of growing with lower biomass and produce a better quality effluent in terms of COD.

The biomass formation process includes transport, adsorption, desorption, attachment and detachment (7). In addition, these processes are related to the characteristics of surface film, base film and bulk liquid. With the increase in temperature, the viscosity of bulk liquid decreased and the frictional resistance also decreased. Subsequently, entrapment of colloidal particles by surface biofilm also decreases, which accounts for the reduction in SS removal efficiency (Table 3).

Table 3 summarizes the relationships

Table 3. Summary of experimental results - percentage removal efficiency of COD & SS.

Velocity (m h^{-1})	T = 30°C				T = 38°C			
	Ini.head (cm)	Duration (hour)	COD (mg L^{-1})	SS (mg L^{-1})	Ini.head (cm)	Duration (hour)	COD (mg L^{-1})	SS (mg L^{-1})
0.5 (2:1)	0.5	8 days	90% 250/20					
1 (1:1)	0.5	>4 days	95.2% 250/12					
2	22	24	83.3% 240/40	78.7% 75/16	16-18	10-11	86% 253/35	80% 45/9
4	23-24	7-10	85.5% 270/40	93.2% 73.3/5	18-20	6.5-7	86.7% 256/34	76.6% 47/11
6	38-40	6-6.2	89.4% 245/26	74.5% 55/14	33-38	5-5.5	84.4% 224/35	69.4% 36/11
8	63-65	4	75.8% 256/62	78.6% 56/12	34-44	5-5.5	89.6% 259/27	63.6% 33/12

Velocity (m h^{-1})	T = 45°C				T = 55 °C			
	Ini.head (cm)	Duration (hour)	COD (mg L^{-1})	SS (mg L^{-1})	Ini.head (cm)	Duration (hour)	COD (mg L^{-1})	SS (mg L^{-1})
0.5 (2:1)								
1 (1:1)								
2	2.4-2.5	40	87.9% 248/30	73.6% 53/14				
4	6-7	20	83.9% 249/40	64.9% 57/20				
6	17	8	77.1% 240/55	64.3% 72/25.5	6	9	78.5% 251/54	41.5% 82/48
8	30.7	6-6.5	82.8% 250/45	60% 80/32				

Note: 250/20: influent concentration is 250 mg L^{-1}, and the effluent concentration is 20 mg L^{-1}
Duration: Duration of filter cycle

between wastewater temperature, organics removal and SS removal. Here, the efficiencies for COD removal were 76% to 89% at 30°C, from 84% to 87% at 38°C and 77% to 88% at 45°C. It was found that during steady state, stable COD could be achieved within the first hour. The SS removal efficiencies obtained at 30°C were 75-92 %, 64-80% at 38°C and 60-74% at 45°C.

For most microorganisms, the growth rate increases two to threefold for each 10°C rise in temperature between the minimum and the optimum. This was true in cases of 30°C and 38°C, because both values are in the cardinal temperature range (i.e. 11-41°C; (6)) of mesophilic bacteria. The experimental results show that organic removal efficiencies of 38°C runs were mostly higher than those of 30°C runs, proving that at an appropriate temperature, microorganisms could increase the uptake of organic matter.

When increasing the temperature to 45°C, the high biological growth did not occur as expected. This is due to the inability of mesophilic bacteria to exist even only a few degrees above their specific temperature range. Their growth rate is abated because this maximum limit was exceeded. Figures 7 and 8 show the biomass reduction in this case.

The experimental results of run 55°C and 6 m h^{-1} (Table 3) showed that organic removal efficiency is almost similar to that of the run of 45°C and 6 m h^{-1}, but SS removal efficiency

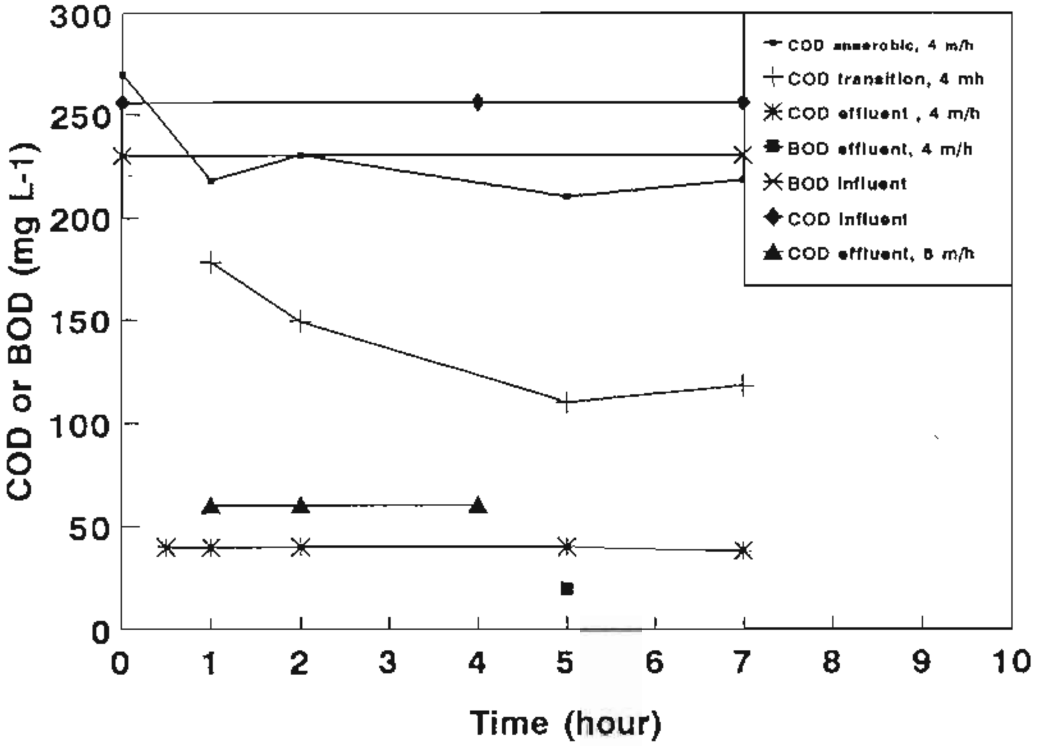


Figure 5. COD, BOD vs. time (T=30 °C, V=4 m h^{-1} & 8 m h^{-1}).

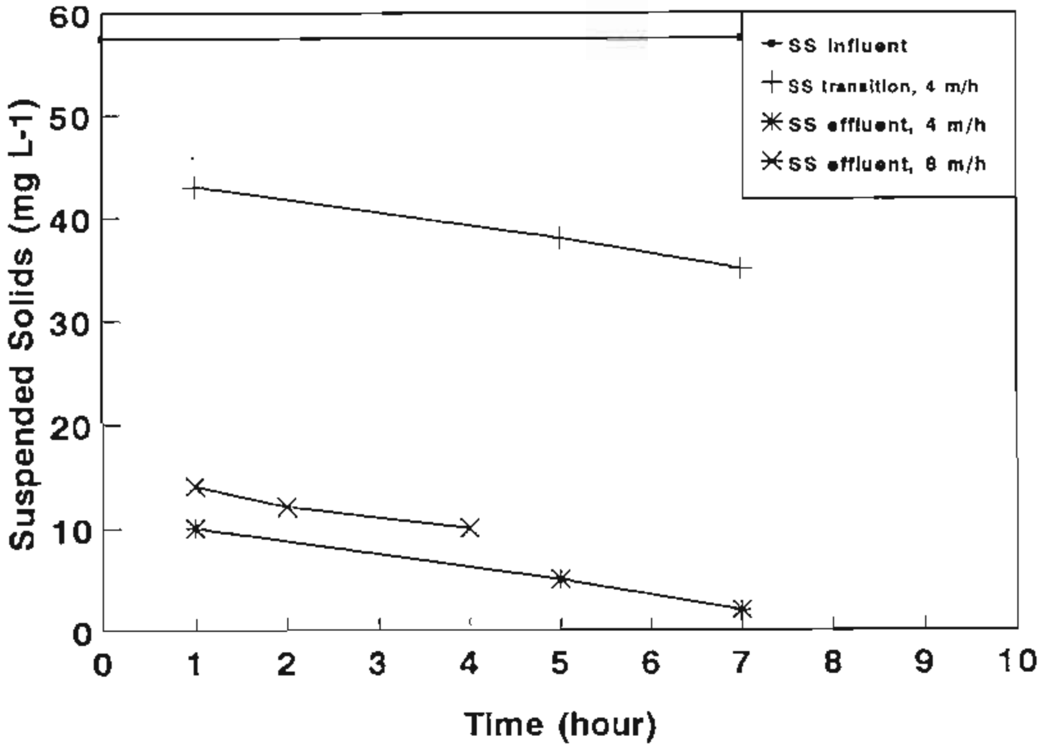


Figure 6. Suspended solids vs. time (T=30 °C, V=4 m h^{-1} & 8 m h^{-1}).

dropped from 64.3% to 41.5%. SS residual of this run could not meet the secondary treatment level (30 mg L^{-1}), while the amount of fixed biomass was still maintained at a common level of 30-40 mg/100 grains for both 45 & 55 °C (Figure 8). This indicates that the thermophilic bacteria were flourishing at this operating temperature range.

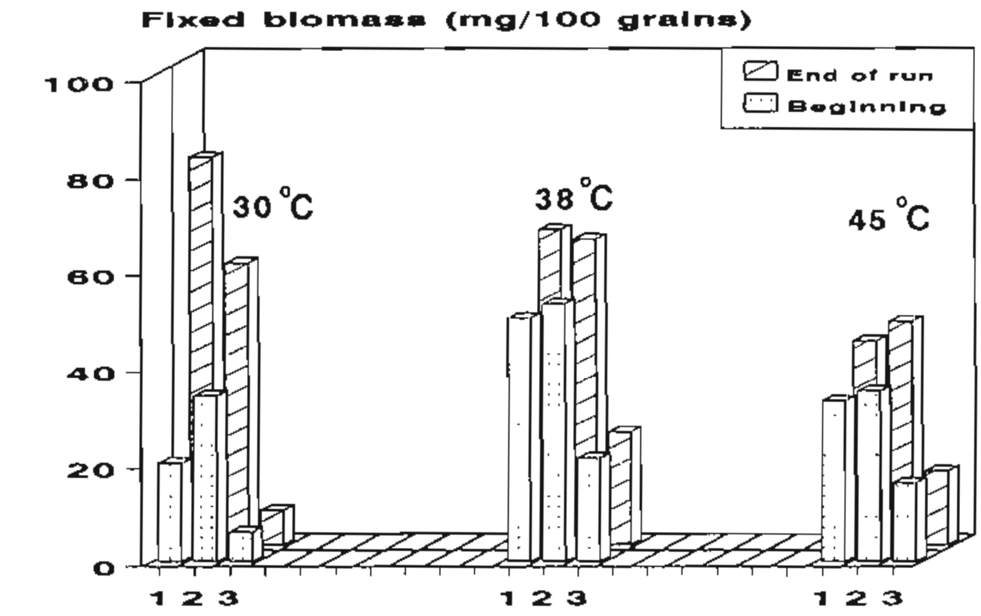


Figure 7. Fixed biomass vs. temperature (at filtration velocity 2 m h^{-1}, 1=anaerabic zone, 2=transition zone, 3=aerobic zone)

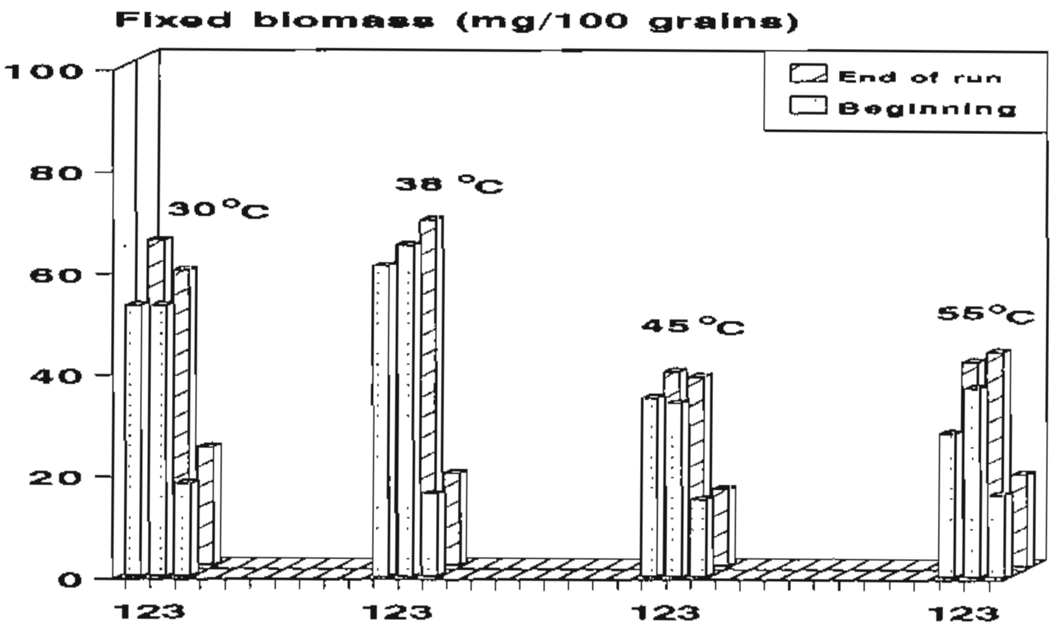


Figure 8. Fixed biomass vs. temperature (at filtration velocity 6 m h^{-1}, 1=anaerobic zone, 2=transition zone, 3=aerobic zone).

The velocity of 6 m h^{-1} was the best rate in the view of removing organic matter and 4 m h^{-1} was the best for removing SS (Table 3). Both values are close to 5 m h^{-1}, the common design velocity of rapid sand filters used in water treatment.

These experimental results showed that the maximum COD removal of 14.6 kg $m^{-3}.d^{-1}$, could be achieved at a temperature of 38°C and a velocity of 8 m h^{-1} (hydraulic loading rate of 144 m^3 m^{-2} d^{-1}). In comparasion the BAF process typically removes 2-3.5 kg BOD m^{-3} d^{-1} with maximum hydraulic loading rate of 60 m^3 m^{-2} d^{-1} at 15°C (12). Another biofilter case study in Thailand (8) reported that optimum removal efficiency could be achieved with 5.6 kg BOD m^{-3} d^{-1} at 28°C with a velocity of 1.5 m h^{-1} (hydraulic loading rate of 35 m^3 m^{-2} d^{-1}). It is evident that this research study shows a significant improvement over both these cases.

The combination of bacterial degradation of pollutants by fixed biomass and physical filtration in a single reactor, in floating filter treatment systems, make their performance independent of clarification and sludge settleability limits. In contrast, a conventional biological process would suffer from significant effluent deterioration if a widely fluctuating load were applied. This study demonstrated that, a loading of 16.6 kg COD m^{-3} d^{-1} could be achieved with a floating filter system, which is significantlly higher than 3 kg BOD m^{-3} d^{-1} for the conventional/high rate activated sludge process and 8 kg BOD m^{-3} d^{-1} for a modern (plastic media) trickling filter.

Effects of Temperature and Viscosity on Biofilter Performance

Since headloss build-up is a function of fixed biomass, it is expected to increase with the increase of temperature or organic loading rate, eventually leading to rapid filter clogging and shorter filter runs.

Figure 9 presents the experimental relationship between filter run duration and temperature for different velocities. Though a linear declination of filter run duration with increasing temperature was expected , these results clearly demonstrate shortest filter run was obtained at an optimum temperature of 38°C. This contradicting experimental result can be explained by the inverse relationship between temperature and fluid viscosity and the role of influent viscosity in the filter clogging in addition to the reduced production of biomass outside the cardinal temperature range of the mesophilic bacteria.

When temperature increased from 30 to 50°C the viscosity has diminished by 27% revealing its importance in biofilter clogging. Metcalf and Eddy (9) address this problem of the kinematic viscosity of liquid diminishing with increasing temperature and its effect on fluid motion which leads to a decrease in headloss. There are many factors that explain why optimum carboneous removal efficiency occurred at 38°C, such as temperature, ecological environment, characteristics of biofilm, strength of floc in the wastewater, hydraulic loading rate, organic loading rate, etc. However, temperature can be considered the main reason, since it strongly affects the above mentioned factors and also contributes to the removal effectiveness of organic matter as previously explained.

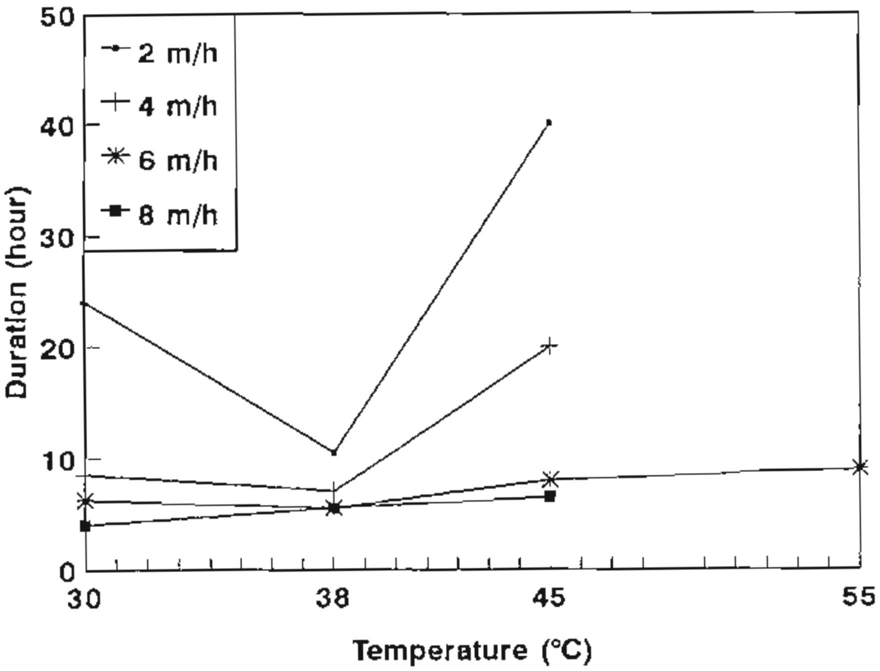


Figure 9. Filter run duration as a function of temperature and filtration velocities.

Microbial Cell Growth and Attachment within the Filter Bed

During the experimental runs, samples of media grains were taken at the beginning and end of each run, in order to determine the evolution of the biomass fixed on the granular support. Figures 7 and 8 demonstrate the biomass growth for filtration velocities 2 and 6 m h^{-1}, at the beginning and the end of the filter run at temperatures of 30, 38 and 45°C. Similar results were obtained for filtration velocities of 4 and 8 m h^{-1}.

A general decreasing gradient of biomass from bottom to top of the reactor was observed, at the end of the run. Biomass of the anaerobic zone was higher than that of aerobic zone due to nutrient content. In the aerobic zone, growth was considerably lower due to lower nutrient availability. A bright brown color was observed in the aerobic zone. The anaerobic zone was characterized a black and dark brown color while the transition zone had a mixture of these colors.

During the filter backwashing operation, the attached biofilm was subject to fierce abrasion. Thus most of the biofilm was detached and washed away with the backwash water (See Figure 10). However, the backwashing operation removed only the non active layer, while the thin active layer on the media surface remained intact. This active biofilm layer played a significant role in the second cycle of filtration where the biomass growth was accelerated. This phenomenon is presented in Figures 7 and 8. Fixed biomass at the beginning of the filter run represented the active layer and that at the end was the total layer. After a filter backwash cycle, fixed biomass tend to increase. A higher specific respiration rate per mass of bacteria are typically achieved in the remaining active layer of the biofilm (10). For the anaerobic zone, at the end of the run, the maximum biomass accumulation on the support media reached 70-80 mg/100 grains and for the transition and aerobic zones values of 68 and 23 mg/100 grains were obtained respectively.

During the run with 38°C, microbial colonies in anaerobic and transition zones developed rapidly. Here, the biomass concentration, at the start of the run was 50-53 mg/100 grains for the 2 m h^{-1}, 54-57 mg/100 grains for the 4 m h^{-1} and 61-65 mg/100 grains for the 6 m h^{-1} velocities. However, fixed biomass reduced slightly to 40-41 mg/100 grains at the 8 m h^{-1} velocity. When the temperature was increased to 45°C a significant reduction in the biomass growth was noted indicating that the micro-organisms responsible for biomass growth and the organic removal predominantly occurred at around 38°C and the increase in temperature reduced their growth. This observation is further supported by the increase in filter run and reduction in effluent quality previously discussed.

At 38°C, the filter run times for all the velocities were reduced greatly in comparison with 30°C. Figure 9 show that minimum run duration of 10.5 hours for the 2 m h^{-1} velocity was observed at 38°C. The equivalent filtration time at 30°C was 24 hours. The minimum filter run durations for 4 m h^{-1} and 6 m h^{-1} velocities were 7 hours and 5.5 hours respectively, again at 38°C.

The 38°C was regarded as the optimum temperature of stenothermal organisms leading to proliferation (6). This supports the result of

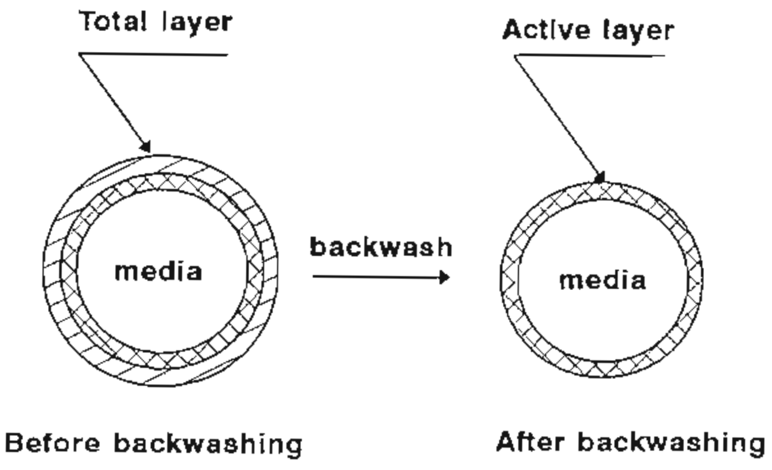


Figure 10. Fixed biomass before and after backwashing.

shortest
anticip
prolifera
velocity
shortest
(compar
explaine
is a fu
loadings
accounts
of 8 m h
layer. I
surface
the hea
filtratio

Bac
the filte
will be n
filtratio
with in
velocitie
further i
velocities
for soli
headloss
througho
subsequ
deteriora
suspend

Ten
cause th
will the
particle
suspend
at eleva
temperat
in the
from 30
for biod
tempera
microorg

1. Roge
aera
2. Roge
proc
Exhi
3. Corr
proc

shortest filter runs at this temperature. Although anticipated the phenomenon of microbial proliferation did not occur in the case of 8 m h^{-1} velocity run. For runs with 8 m h^{-1} velocity the shortest filter run (4 hours) was at 30°C (compared with 5.5 hours at 38°C). This can be explained by the fact that microbiological growth is a function of both organic and hydraulic loadings on the filter. The hydraulic loading accounts for shear velocities. Thus, high velocity of 8 m h^{-1} affected the formation of the slime layer. In other words the morphology of the surface film is more or less directly related to the headloss build-up and indirectly to the filtration period.

CONCLUSIONS

Bacterial precipitates in the biofilter cause the filter clogging. This bacterial accumulation will be near the bottom of the filter bed for lower filtration velocities and will spread upwards with increasing velocities, since the higher velocities cause the media to shear and move further into the filter bed. Thus, higher filtration velocities improve the usage of total filter depth for solids accumulation and increase the headloss throughout the bed, while distributing it throughout the bed. This solids accumulation subsequently curtail the filter run time, and deteriorating the effluent quality in terms of suspended solids.

Temperature increase of the influent will cause the bulk liquid friction to decrease, which will then decrease the adherence of colloidal particles to the media surface. Therefore suspended solids removal efficiency will reduce at elevated temperatures. Further when the temperature increases from 30 to 55°C, a change in the type of microorganism will occur, i.e. from 30 to 41°C, the microorganism responsible for biodegradation is mesophilic and after this temperature range it is thermophilic microorganism which will be the inhibitant. Hence, increase in temperature, did alters the biomass growth rate and type. In addition, organic and hydraulic loading rate too will affect the growth of biomass.

Among the four tested operating temperatures (30, 38, 45 and 55°C), the shortest filter run was obtained at 38 °C, indicating maximum microbial growth, leading to rapid filter clogging. At this temperature, carbonaceous pollutant removal rates remained almost stable (84-87% - 27 to 35 mg L^{-1}) over the filtration velocity range tested (2-8 m h^{-1}). The removal rate was approximately 14.6 kg COD m^{-3} day^{-1} under 16.6 kg COD m^{-3} day^{-1} maximum applied loading rate. Retention time less than one hour, within the biofilter is appropriate for domestic wastewater tretment. The role of stenothermal organisms was found to be directly related to removal efficiency, recycle time and backwash water consumption. It was noticed that suspended solids removal decreased with increased temperature due to the variations of characteristics of bio-flocculent particles on the filter medium.

During steady-state, although a portion of biomass was lost after backwashing, a good quality effluent was achieved within one hour. This means that there was little disturbance to active attached biomass during backwash operation. A short start-up period could be achieved within 15-18 days without external seeding, due to high surface area, of the media used (polystyrene).

ACKNOWLEDGEMENT

The authors wish to acknowledge the financial support by the French Agency for Energy and Environment (ADEME) and the Research Initiation Grant of the Asian Institute of Technology. The filter media used in the research was provided by the Compagnie Generale des Eaux (CGE), of France.

REFERENCES

1. Rogalla F. and Bourbigot M.M., New developments in complete nitrogen removal with biological aerated filter. *Water Sci. Technol.*, 22, 273-280 (1990).
2. Rogalla F., Badard M., Hansen F. and Dansholm P., Upscaling a compact nitrogen removal process. In: *Water Quality International'92*, IAWPRC Sixteenth Biennial Conference and Exhibition, 24-30 May 1992, Washington, D.C. (1992).
3. Corrand C., Elimination of carbonaceous and nitrogenous pollutants by a twin stage fixed growth process. *Water Sci. Technol.*, 22, 261-272 (1992).

4. Characklis W.G. and Marshall K.C., *Biofilms*. John Wiley and Sons, New York. U.S.A. (1985).
5. APHA, AWWA and WPCF, *Standard Method of Examination of Water and Wastewater*. 16th edition, American Public Health Association, Washington, D.C., U.S.A. (1985).
6. Gaudy J.A.F. and Gaudy E.T., *Microbiology for Environmental Scientists and Engineers*. McGraw Hill Book Company, New York, U.S.A. (1980).
7. Hunen W.A.M. and Koou K.V., The effect of low concentrations of assimilable organic carbon (AOC) in water on biological clogging of sand beds. *Water Res.*, **26**, 963-972 (1992).
8. Kitsuwannakul S., Treatment of domestic wastewater by aerated biocarbon filter. Master Thesis EV 88-24, Asian Institute of Technology, Bangkok, Thailand (1988).
9. Metcalf & Eddy, Inc., *Wastewater Engineering - Treatment, Disposal and Reuse*, McGraw-Hill Publishing Company, U.S.A. (1991).
10. Bacquet G., Joret J.C., Rogalla F. and Bourbigot M.M., Biofilm start-up and control in aerated biofilter. *Environ. Technol.*, **12**, 747-756 (1991).
11. Desbos G., Rogalla F., Sibony J. and Bourbigot M.M., Biofiltration as a compact technique for small wastewater treatment plants In: *Int. Specialized Conf. Design and Operation of Small Wastewater Treatment Plants*, 26-28 June, Trondheim, Norway (1989).