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AERATED BIOFILTER TREATMENT OF TROPICAL WASTEWATERS

C.Visvanathan[1], T.T.H.Nhien[2] and F.Rogalla[3]

[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.*
[3] *Deputy Director, Compagnie Generale des Eaux Research Center, Chemin de la Digue, BP 76, 78600, Maisons-Laffitte, France.*

ABSTRACT

A biological aerated filter which combines bacterial degradation of pollutant by fixed biomass with physical filtration in a single reactor, was utilized for organics removal at a pilot plant 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 of approximately 0.06.

Headloss during biofiltration was studied as a function of wastewater temperature, flow velocity and time. Experiments were conducted at 4 temperatures (30, 38, 45 and 55°C) with 4 velocities (2, 4, 6 and 8 m/h). The lowest filter run time range was 5.5-10 hours at 38°C. Over 84% of the soluble COD was removed at all velocities investigated. At 30°C, 76 - 89% COD removal was noticed, the 89% COD removal being with 6 m/h velocity and 8.5 hour filter run time.

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 velocity indicating that at lower temperature, maximum suspended solid removal could be obtained. The results indicated that effluent SS could be less than 30 mg/L meeting the standard for secondary treatment 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 are incomplete processes and cannot accommodate major changes in load. Aerobic biological treatment is possible in small reactors, with shorter contact and response times, provided that: (a) the concentration of active biomass in the reactor remains high. (b) the aeration system is reliable and effective enough to meet the oxygen demand of the medium and (c) The excess biomass is kept under strict control.

In these conventional 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 Biostyr, a modified form of aerobic biological reactor features fixed biomass attached to a single-layer fixed bed support medium positioned in upward air and water flows. This process is technically a combination of the conventional trickling filter and upward rapid sand filtration. The filter medium is granular polystyrene of which specific gravity is much less than that of air. 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 et al.(1990) report that Biostyr process allows complete degradation of carbon pollution, retention of suspended solids, ammonia oxidation and denitrification with loading rates close to 10 kg COD/m^3.day in one reactor. An effluent requirement of less than 8 mg/L of total Nitrogen could be achieved at temperatures around 10°C and empty bed contact time around 2 hours, together with residual of less than 10 mg/L BOD and suspended solids (Rogalla et al., 1992).

Although much research work has been conducted on the use of Biostyr in temperate climates (e.g ≤20°C), little is known about its operation in tropical climates. The objective of this research was to demonstrate the ability of the Biostyr process 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 variable temperature and hydraulic loads were also studied.

MATERIALS AND METHODS

The experimental study was carried out in a pilot scale unit, where 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 2.9m, while 0.7 m was available for bed expansion during backwashing. Influent percolated in upflow direction concurrent 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. Since the suspended matter become 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.

Settled AIT wastewater was fed into the reactor from its bottom, using two pumps connected in series. Wastewater characteristics were modified by adding glucose to simulate the average Bangkok domestic wastewater. Average concentration of the wastewater was total COD = 300 mg/L, filtered COD = 250 mg/L, BOD_5 = 240±10 mg/L and SS = 60±20 mg/L. Temperature of wastewater was maintained constant at 30, 38, 45 or 55°C.

Backwashing Procedure

Since the filters progressively clogged due to the development of excess biomass and the retention of suspended solids, occasional backwashing was required. According to Corrand (1990), 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. 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). The time for triggering the backwash was based on headloss build up, which was 1.7-1.8 m. Filter column was backwashed according to the following procedure:

(a) 2 minutes for 30°C experimental runs, 5 minutes for 38°C runs, 12 minutes for 45°C and 55°C runs, backwash water was sent downflow with a velocity of 50 m/h

(b) 2 minutes air scour with a velocity 15 m/h.

(c) Sufficient time delay for separation of granular medium.

The above three steps were repeated three times. Final step was 15-18 minute water backwash to evacuate the excess sludge.

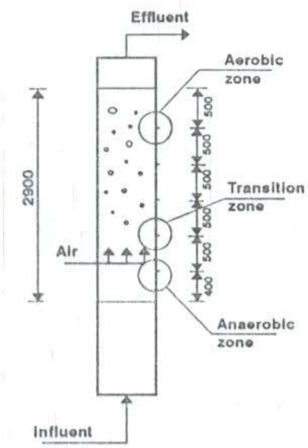


Fig 1. Sampling Positions in the Filter Bed

Analysis of fixed biomass

Samples of granular medium were taken at 3 points as shown in Figure 1 to represent the 3 zones viz. anaerobic, transition and aerobic zones. Each sample was composed of 10 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 (Characklis and Marshall, 1986).

EXPERIMENTAL PROCEDURE

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

(a) Start-up Experiments (Acclimatization test)

A low hydraulic loading of 0.5 m^3/m^2.h 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. 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 with a recirculation ratio of 1:1 and to the final hydraulic loading of 2 m^3/m^2.h without recirculation.

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

(b) Working Experiments (Study on BOD Removal Kinetics)

Working experiments consisted of 13 runs under preset operating conditions. Each 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, the second run for the same temperature but with a velocity of 4 m/h, etc. Table 1 shows operational variables for the experimental series.

Table 1. Operating Parameters of the Filter Column

With BOD_5 = 250 mg/L and air supply 20 m^3/kg BOD applied

Experiment	Start-up	Working												
Temperature °C	30	30				38				45				55
Velocity (m/h)	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

Experiment	Start-up		Working			
Velocity (m/h)	0.5	1	2	4	6	8
Real retention time (min)	174	84	43	22	14	11
Flow rate Wastewater (m^3/h)	0.010 + 0.005	0.016 + 0.016	0.063	0.126	0.190	0.252
BOD loading (kg/m^3.d)	0.4	1.1	4.2	8.3	12.5	16.6
Air flow rate (L/min)	1.3	2.6	5.23	10.5	15.7	20.9
Recycle amount (%)	2:1	1:1	0	0	0	0

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 filter media along the entire bed. The characteristics of this phenomenon were affected by velocities. At 30°C with low velocity of 2 m/h 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 2 (a) to (c) and 3. This infers that mainly the bottom 1 m of the bed is responsible for the 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), 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 to 7 hours at 4 m/h. Further increase in filtration velocity showed improvement in terms of using total bed depth for solids accumulation and distribution of headloss, throughout the bed.

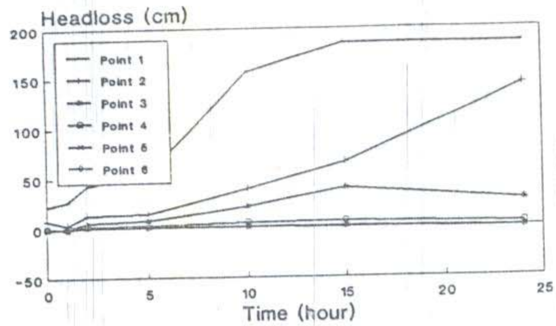


Fig. 2(a) T = 30°C, V = 2 m/h

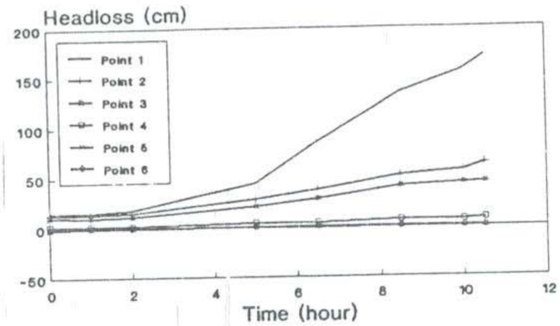


Fig. 2(b) T = 38°C, V = 2 m/h

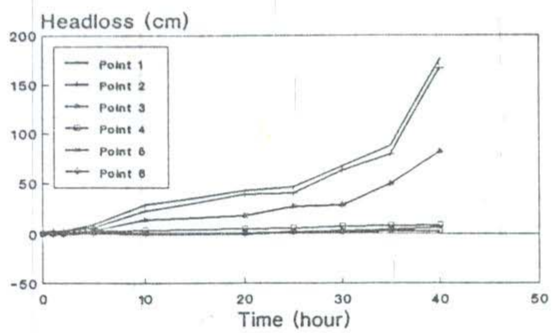
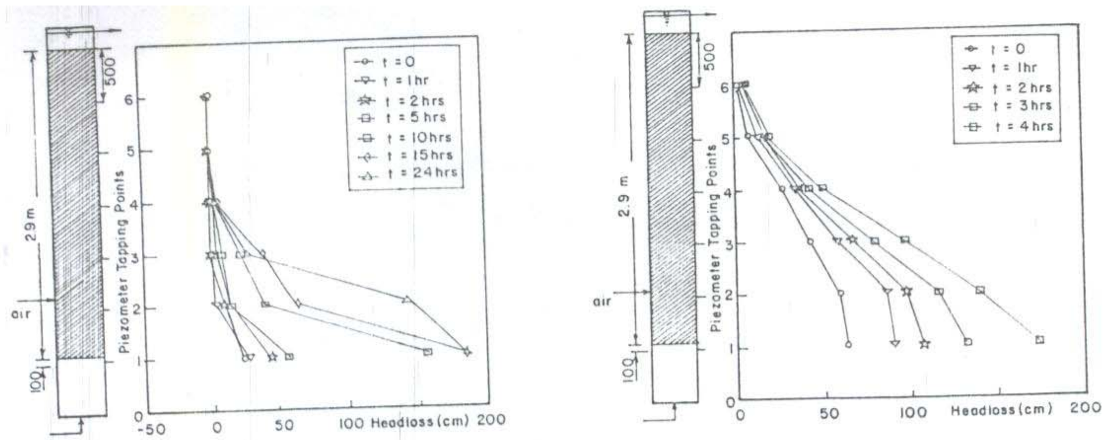


Fig. 2(b) T = 38°C, V = 2 m/h

Figure 2 (a) to (c) Headloss Vs Time for 2 m/h Filtration Velocity

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 3). When the headloss increases, the local surface shear force increases to a point at which no additional material can be retained within the media. 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 was 60-79%, while that at 2 m/h was 74-80%. Similar observations were made at the influent wastewater temperatures of 38, 45 and 55°C.



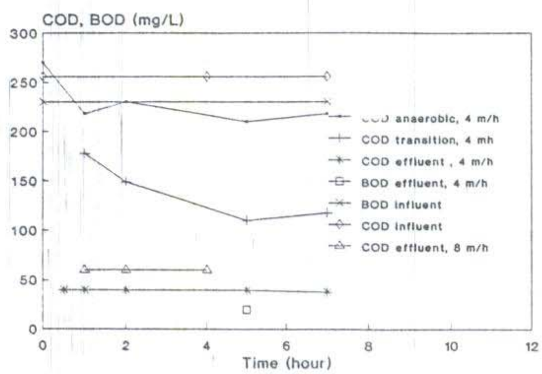
3 (a) V = 2 m/h

3 (b) V = 8 m/h

Fig 3 Headloss Vs. Position in the Filter Column

Effects of Temperature and Velocity on Organics and Suspended Solids Removal

A set of typical experimental results are presented in Figures 4 and 5. Here, for the feed wastewater temperature of 30°C at 4 m/h, extremely good quality of effluent in terms of SS and organic removal was observed. When the filtration velocity was doubled (8 m/h) the effluent quality deteriorated for both SS and organic removal. The curves on Fig. 4 show that the effluent COD of the anaerobic zone seemed to be equal to or higher than influent COD. It means that the 0.44 m long anaerobic reactor could not eliminate organic matter at all. The decomposition of retained solids in the anaerobic zone increases organic concentration.



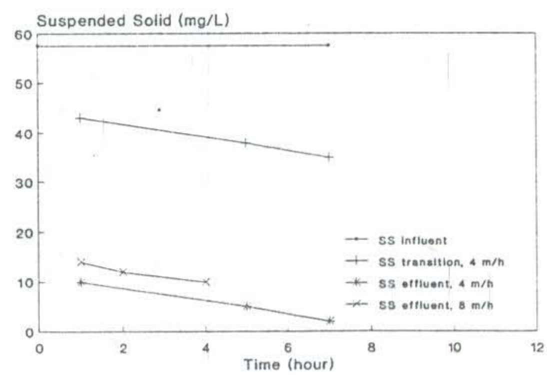


Fig 4. COD, BOD vs Time, T = 30°C

Fig 5. SS vs Time, T = 30°C

Figures 6 and 7 give the relationships 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 filtered COD could be achieved within the first hour. The SS removal efficiencies were obtained from 75-92 % at 30°C, from 64-80% at 38°C and from 60-74% at 45°C.

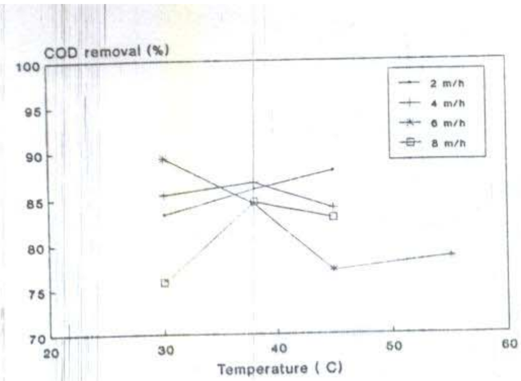


Fig 6. COD Removal Efficiencies vs Temperature and Velocities

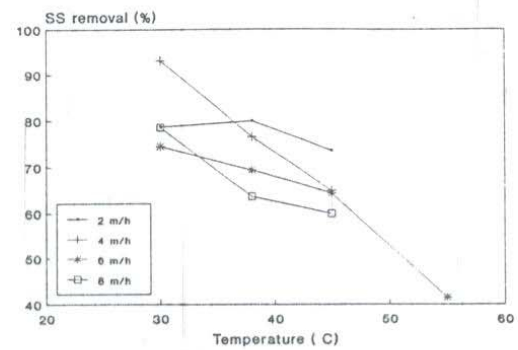


Fig 7. Removal Efficiencies vs Temperature and Velocities

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; Gaudy and Gaudy, 1980) 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 a suitable temperature, microorganisms could increase the uptake of organic matter.

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. 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 was presented in figures 8 and 9. 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. Bacquet et al.(1991) also reported of a higher specific respiration rate per mass of bacteria being achieved in the remaining active layer of the biofilm. For the anaerobic zone, 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, 54-57 mg/100 grains for the 4 m/h and 61-65 mg/100 grains for the 6 m/h velocities. However, fixed biomass slightly slowed down to 40-41 mg/100 grains for the 8 m/h 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 were predominant only 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.

Hunen and Koou (1992) noted that the biomass formation process includes transport, adsorption, desorption, attachment and detachment. Besides, 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 friction resistance also decreased. Thus entrapment of colloidal particles by surface biofilm became less. This accounts for the reduction in SS removal efficiency as illustrated in Figures 6 and 7.

For a temperature of 38°C, even with increasing velocities, organic removal efficiencies remained almost the same. The velocity of 6 m/h was the best in the view of removing organic matter and 4 m/h was the best for removing SS. Both values are close to 5 m/h, the common design velocity of rapid sand filters at modWerate temperatures.

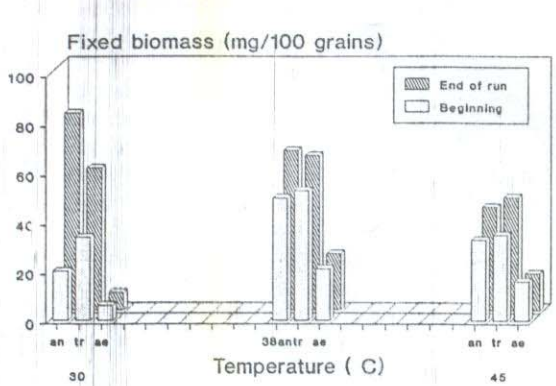


Fig 8. V = 2 m/h

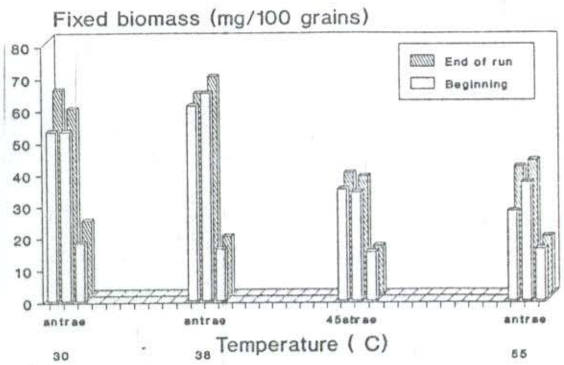


Fig 9. V = 6 m/h

Fig 8 and 9, Fixed Biomass vs Temperature
an = anaerobic, tr = transition, ae = aerobic

For 45 °C, with a lower velocity, lower COD and SS residuals were obtained. As the biofloc become less strong as the temperature is increased, higher filtration rates tend to shear the floc particles and carry much of the materials through the filter. This explanation is also valid for the case of 55 °C. Effluent suspended solids at 55 °C and 6 m/h was 48 mg/L while that for the same velocity at 45 °C was only 25.5 mg/L.

The experimental results showed that the maximum COD removal of 14.6 kg/m^3.d, could be achieved at a temperature of 38 °C and a velocity of 8 m/h (equivalent to a hydraulic loading rate of 192 m^3/m^2.d). Biocarbone process could remove 2-3.5 kg BOD/m^3.d with maximum hydraulic loading rate of 60 m^3/m^2.d at 15 °C (French case study, OTV, 1991). Another biocarbone case study in Thailand (Kitsuwannakul, 1988) reported that optimum velocity of 1.5 m/h (equivalent to hydraulic loading rate of 35 m^3/m^2.d) could be achieved simultaneously with 5.6 kg BOD/m^3.d elimination at 28 °C. Therefore this research study shows a significant improvement over both these cases.

The combination of bacterial degradation of pollutant by fixed biomass and physical filtration in a single reactor, in the above advanced treatment systems, make their removal rates independent of clarification and sludge settleability limits. Also a conventional biological process would face major effluent deterioration if a widely fluctuating load were applied. In the Biostyr used in this research, a loading of 16.6 kg BOD/m^3.d could be achieved, a value much higher in comparison with 3 kg/m^3.d for activated sludge process or 8 kg BOD/m^3.d for a modern trickling filter.

CONCLUSIONS

Although an inverse relationship between filtration time and temperature was expected in this fixed biomass organic degradation process, the maximum sensitivity to clogging and therefore the shortest filter run, were obtained at 38 °C among the four operating temperatures 30, 38, 45 and 55 °C. This different behavior in relation to clogging, shows different efficiencies in organics and suspended solids removal.

At the reference temperature 38°C, carbonaceous pollutant removal rates remained almost stable (84 - 87%)over the filtration velocity range tested (2-8 m/h). The removal rate was approximately 14.6 kg BOD/m^3.day under 16.6 kg BOD/m^3.day maximum applied loading rate. It was noticed that suspended solids removal decreased with increased temperature due to the variations of characteristics of flocculent particles on the filter medium.

During steady-state, though a portion of biomass was lost after backwashing, a good quality effluent was achieved within one hour. It means that there were no 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).

A 10-15 minute retention time within the biostyr unit is appropriate for domestic wastewater treatment, under tropical climatic conditions. A loading of 16.6 kg BOD/m^3.day could be treated in this unit compared with 3 kg BOD/m^3.day for activated sludge process or 8 kg BOD/m^3.day for a modern trickling filter. Thus the Biostyr process gives considerable savings in space utilization to treat a given loading of wastewater.

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