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Assessment of Bio-Trickling Filter Startup for Treatment of Industrial Wastewater

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ABSTRACT: The aim of the present study was to assess the bio-trickling filter startup for the treatment of wastewater produced by Pegah Dairy Company at psychrophilic condition. The startup time of a bio-trickling filter is directly proportional to the concentration of microbial population. A bio-trickling column with a height of 150 cm was packed with lava rocks with the liquid recirculated through the packing. The startup flow rate for the pilot was 0.0035 L/min, with hydraulic retention time (HRT) of 10 days at 7-13ºC. Results indicated that for HRT of 10 days, the efficiency of chemical oxygen demand (COD) removal was more than 85% for less than 100 g COD/m^3/h. Subsequently, dairy wastewater was added to the reminder of activated sludge with the HRT of 8 days, and the nutrients were added to the pilot tank with a daily ratio of carbon/nitrogen/phosphorous: 100/5/1. For the subsequent 5 days, the pilot was maintained in a steady state. The results revealed that the pilot startup was performed completely.

Key words: Bio-degradation, Bio-trickling filter, Industrial wastewater, Lava rocks, Startup

INTRODUCTION

High costs of wastewater treatment in food industry have increased the application of biological treatment process more than before. In recent years, biological treatment of wastewaters by bio-filters and bio-trickling filters has been known as an established and cost-effective technology (Van den Akker *et al.*, 2011). Startup of biological treatment systems has a significant role in achieving a proper removal and satisfying performance in treatment processes. Bio-trickling filtration is a change of bio-filtration where a neutral support is utilized and an abrading solution is continuously or intermittently recycled over the packing to provide the process culture with the necessary humidity, nutrients, and optimal conditions (Cox and Deshusses, 1998; Fortin and Deshusses, 1999; Puhulwella *et al.*, 2014). The effective parameters for startup process include the amount of biomass, control of temperature and pH, efficiency of removal and biological growth (Liu *et al.*, 2013). The bio-trickling filter often consists of inert filter bed, containing microorganisms and nutrients, in which water contaminants are degraded (Fortin and Deshusses, 1999). Bio-trickling filters are non-submerged, firmed film biological reactors applied for organic removal and nitrification of municipal and industrial sewages (Amal Raj and Murthy, 1998). The wastewater is passed through a porous packed bed on which contaminant-degrading mixed cultures form a bio-film (Cox and Deshusses, 1998; Cox and Deshusse, 2002). Bio-trickling solution contains the essential inorganic nutrients such as carbon, nitrogen, phosphorous, potassium and other trace elements and is often reused (Cox and Deshusses, 1998; Cox and Deshusse, 2002; Zhao *et al.*, 2013). The contaminants are moved from the wastewater to the bio-film where they are subsequently bio-degraded (Almstrand *et al.*, 2011; Novotny *et al.*, 2011; Ottengraf and Van Den Oever, 1983). A bio-trickling filter system is composed of a fundamental reactor packed with solid materials (such as compost, peat, wood chips, or ceramic) on which a bio-film with a proper microbial population is created (Chou and Huang, 1997; Dorado *et al.*, 2009; Ottengraf and Van Den Oever, 1983).The packed bed is almost always made of inert materials such as a random dump plastic, lava rocks, structured plastic packing and open pore synthetic foam. In a bio-trickling filter, the packed solid media supply the pH buffer and matrix for the annexation of microorganisms (Mehrdadi *et al.*, 2012; Zapotocky and Svab, 2012).

Iran Dairy Industries Company (Pegah) produces 700 tons of dairy products and approximately 3000 m^3 of wastewater every day. The dairy industries

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produce a considerable amount of wastewaters, characterized by high concentration of chemical oxygen demand (COD), biochemical oxygen demand (BOD), total Kjeldahl nitrogen (TKN), total phosphorus (TP) and nitrate (Abdulgader *et al.*, 2009).

The dairy wastewater of Pegah Plant contains COD of 4300 to 4900 mg/L and pH of 6.8 to 7.2. Moreover, the activated sludge from Pegah Plant contains COD of 14750 to15100 mg/L, pH of 6.8 to 7.2, and mixed liquid suspended solids (MLVSS) ranging between 5200 to 5900 mg/L. The activated sludge from this plant has high COD, TKN, TP and active microorganisms for bio-degradation of pollutants. The packing used in bio-trickling filter is capable of growing bio-films and increasing microbial communities, by the re-circulation of the activated sludge from wastewater treatment plant.

In the present study, it was attempted to assess the startup of a bio-trickling filter by using activated sludge of dairy wastewater.

MATERIALS & METHODS

The experimental setup consisted of a laboratory-scale bio-trickling filter as illustrated in Fig. 1. The bio-trickling filter was made of stainless steel with an internal diameter of 20 cm. The head space and bottom space were both 30 cm. Bio-trickle column was packed with a 150 cm height layer of lava rocks (in the size range of 1–5 cm with average of 3 cm, specific surface area of 80 m^2/m^3, initial bed porosity of 65%, and a 52-Liters packing volume). It was equipped with a liquid recirculation system holding a total liquid volume of 50 L (liquid volume was 15 L during the whole experiment), as illustrated in Table 1. In order to understand the physical absorption capacity of the liquid recirculation system, the experiment was performed in the activated sludge. As the startup of bio-trickling filter was carried out at cold weather, the experiments were concluded based on temperatures of 7-13 °C.

Table 1. Characteristics of lava rocks medium

Parameter	Value
Size Range (cm)	1-5
Porosity (%)	65
Specific Surface Area (m^2/m^3)	80

The lava rocks packed in the bio-trickling filter were taken from mountains in the vicinity of Tehran. They are relatively inexpensive and easily obtainable in most parts of the country. Activated sludge and

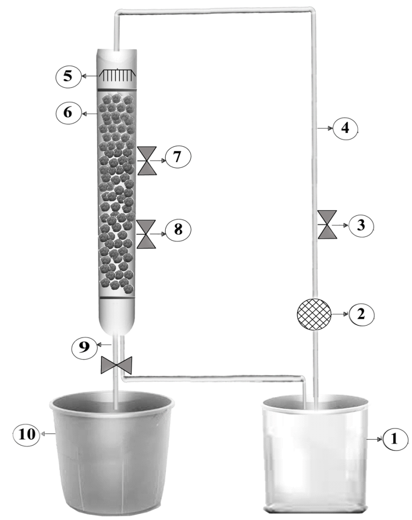

Fig.1. Schematic diagram of the pilot system 1. Liquid tank; 2. Liquid pump; 3. Flow meter; 4. Recycled water line; 5. Liquid distributor; 6. Lava rocks (media); 7. Liquid sampling port (50 cm); 8. Liquid sampling port (100 cm); 9. Treated water; 10. Sedimentation tank

dairy wastewater for seeding were collected from Pegah dairy plant in Tehran-Iran.

The samples were collected from the inlet, outlet, and the heights of 50 cm and 100 cm from bio-trickling filter bed. The flow rate of activated sludge was 500 mL/min for the sampling time of 30 min. The amount of COD in activated sludge was determined spectrometrically by a Dr 5000 instrument (COD High Range 0-15000 mg/L, Low Range 0-150 mg/L) at the wavelength of 420 nm. The measurement of TKN, TP and nitrate was also done using a Dr 5000 at the wavelengths of 460 nm, 420 nm and 410 nm, respectively. An acidity analyzer (pH meter-Metrohm691) was used to record pH (Zhang *et al.*, 2009). The analyses were done in accordance with Standard Methods for the Examination of Water and Wastewater, 20th edition, 1998 (Carta- Escobar *et al.*, 2005; Carta *et al.*, 1999; Zhang *et al.*, 2009). The amounts of TKN and TP were measured every day until the sufficient feed for growing biomass on the lava rocks in the pilot column was supplied in the liquid tank. The MLVSS was measured to burn the remained suspended solids on the no-ash filtration paper in a muffle furnace at 550 °C. The dissolved oxygen amount was determined by MI605 organic oxygen metal instrument (Manufactory of Romania). In this study, the startup of bio-trickling filter was performed in three phases. In phase 1, the activated sludge from Pegah wastewater treatment plant with high amount of COD, TKN and TP was pumped from a tank on the media into the steel column for 10 days. The activated sludge from dairy wastewater with high COD, nitrogen and phosphorous contents, was added to 10-20% of bio-trickling column volume with packing (15 L). The startup process was initiated with a flow rate of 0.0035 L/min (5.04 L/day) for HRT of 10 days, while operating at low temperature (7-13 °C). For the first 10 days, the characteristics of activated sludge such as COD, TKN, TP, temperature, pH, turbidity, MLVSS and dissolved oxygen (DO) were measured, and carbon, nitrogen, and phosphorous were calculated to be more than 100, 5, and 1 respectively. A trivial amount of nutrients was added to the liquid tank. Because of the high concentrations of TKN and TP, nutrients addition was not necessary at this stage. A proper startup was basically attributed to the use of pH controller which also maintained pH constant (6.7-7.2) during the startup phase. The COD of activated sludge effluent considerably decreased due to the hydraulic circulation, and the biomass formation on lava rocks increased gradually during the 10 days. The liquid was continuously circulated into the bio-trickling filter column, and the hydraulic loading rate was maintained at 0.16 m^3/m^2 per day. Since it was impossible to pull out lava rocks from pilot column to weight biomass formed on the medium, the daily measurement of MLVSS in outlet for circulating liquid showed the increase of the biomass formed on the media (Table 2).

The psychrophilic condition is an important criterion for slowly biodegraded organic loads (or slow biodegradation of organic loads). At the beginning of the 11th day, in order to supply sufficient nitrogen and phosphorous, the amount of wastewater to be added was calculated in a way to maintain the average COD on 4650 mg/L and discharge on 0.0045 L/min in the activated sludge. The composition of real dairy wastewater (RDW) varied widely according to the production process in the factory. In phase 1, the RDW was collected three times a day, mixed and stored at 4 °C to be used for the investigation. The characteristics of studied RDW were: COD of 4650±100 mg/L, TOC of 45±10 mg/L, total Kjeldahl N of 105±10 mg/L, total P of 75±10 mg/L, TSS of 608±45 mg/L, and TDS of 420±22 mg/L. With the HRT of 8 days, the amount of COD decreased to 1120 mg/L.In this phase, the wastewater was simultaneously circulated through the filter. Furthermore, the MLVSS of the circulated liquid was also decreasing, showing that formation of biomass on the lava rocks layer was gradually reaching the proper conditions for the treatment of dairy wastewater. In phase 2, in order to set TKN and TP according to C/N/P ratio (100/5/1), the calculated amount of feed was seeded to the tank. The COD decreasing procedure was gradually implemented and the sufficiency of oxygen was observed through DO control. The flow rate reached 0.0045 L/min in 8 days. The pilot was in contact with cold weather (7-13 °C). Thus the COD decreasing procedure was applied after 18 days. In this study, an advanced startup method was applied by controlling the pH in the range of 6.5–7 during the measurement of different wastewater characteristics (Maestre *et al.*, 2010). As soon as the sample was collected from each sampling valve, the sample pH in all stages was measured by available pH meter in the pilot site.

For the next 5 days, as wastewater was mixed with the circulated liquid, the COD decreasing rate became constant and the biomass growth rate on lava rocks was subjected to steady state conditions.

RESULTS & DISCUSSION

Biological treatment processes, relying on both suspended growth and bio-trickling filters, are known to be as the most achievable and cost effective processes for the elimination or reduction of organic and inorganic compounds from municipal and industrial wastewaters (Kornaros and Lyberatos, 2006). Characteristics of the activated sludge and dairy wastewater used in this study are presented in Table 3. Fig. 2 indicates the decrease of COD concentration without adding nutrients and wastewater during the first 10 days. Fig. 3 shows the obvious increase of COD removal efficiency at cold ambient temperature in the first 10 days. In phase 1, organic loads were degraded due to carbon, nitrogen and phosphorous consumption. This reduced the amount

Table2. Characteristics of the activated sludge and dairy wastewater

Type	COD (mg/L)	TKN (mg/L)	TP (mg/L)	MLSS (mg/L)	TSS (mg/L)	pH	Temperature (°C)
Sludge	14920	1120	280	5840	5580	6.8-7.2	15
Wastewater	4650	105	75	1200	608	6.8-7.2	13

Table 3. Operation sequence and conditions

Phase	purpose	Duration (d)	Discharge (L/min)	COD_{in} (mg/L)	COD_{eff} (mg/L)	pH	COD removal (%)
1	Adaption	10	0.0035	14920	2000	6.7-7.2	86.6
2	Startup	8	0.0045	4650	1120	6.7-7.2	77.9
3	Steady state	5	0.0072	4720	1030	6.7-7.2	78.5

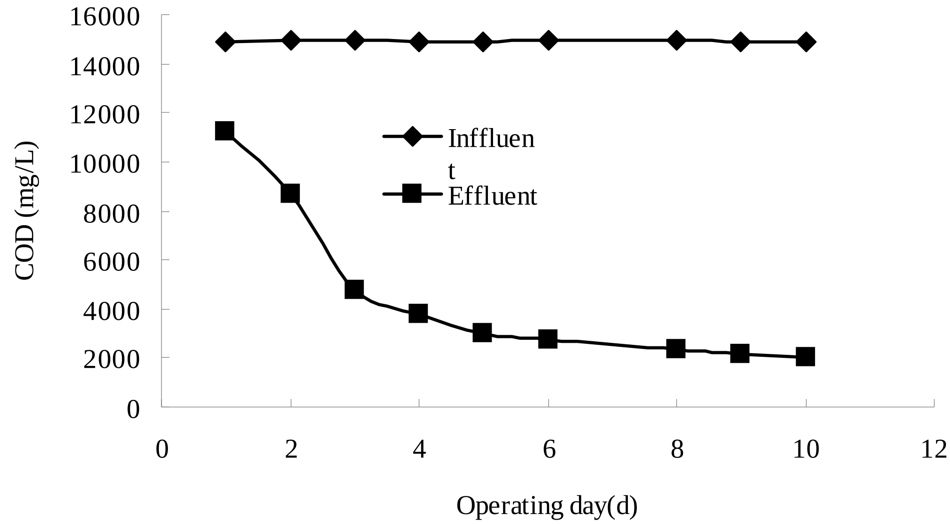

Fig. 2. COD concentrations of the activated sludge versus operating time (Q=0.0035 L/min)

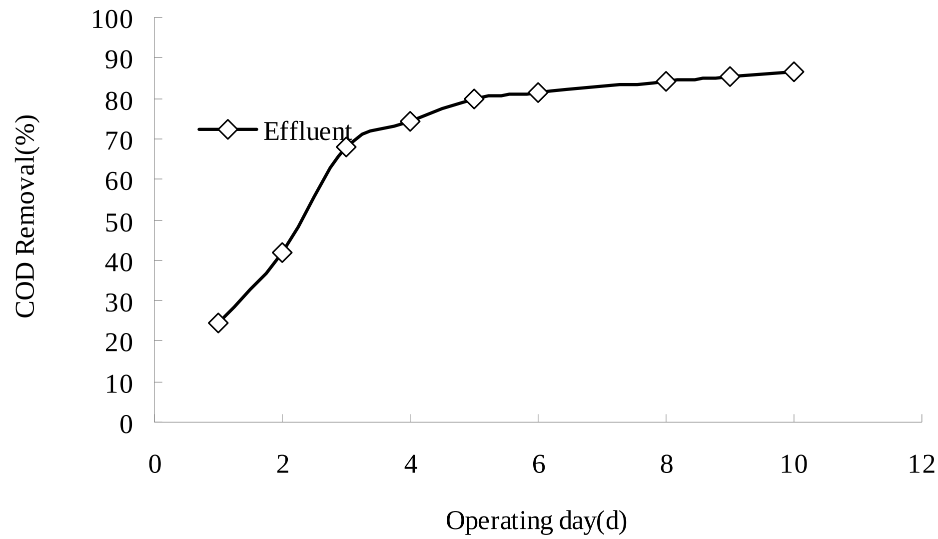

Fig. 3. COD Removal percentage of the activated sludge versus operating time

of organic loads and increasingly made the biomass layer formed on the lava rocks thinner. In addition, the hydraulic circulation enabled microorganisms to function in a greater space.

After 10 days of the circulation, the removal efficiency of COD reached 85% when the influent COD was 14920 mg/L and the effluent pH was maintained in the range of 6.7 to 7.2 which was less than 100 g COD/m^2/h. Fig. 4 illustrates the decrease of effluent MLVSS as biomass growth on the natural media is increasing considerably. The results indicated that rapid startup of the reactor was accomplished when circulation was occurred.

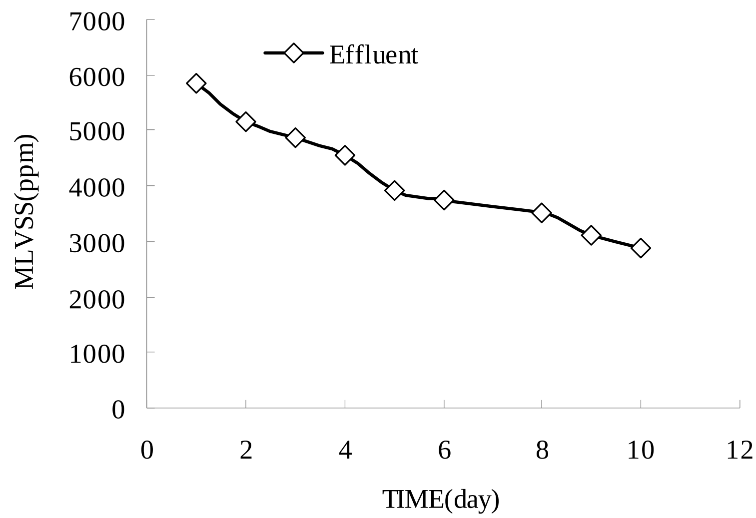

Fig. 4. MIVSS concentration of the activated versus operating time

During the adaptation period, the seed is first transferred from the activated sludge via peristaltic pump to the surface of the lava rocks. Low mass transfer due to low hydraulic load in the feed would limit the performance of the startup, including microbial growth and biodegradation. However, hydraulic circulation enhanced the mass transfer between the activated sludge and media, thereby accelerating the startup procedure. By the time the adaption was complete, the amount of suspended solids in the effluent was 3.8 kg MLSS/m^3. After inoculation by the activated sludge, the reactor was initially operated in a continuous mode with an influent COD of approximately 4650 mg/L and organic loading rate of less than 40 g COD/m^2/h. In continuous mode, the wastewater in the reactor was released to the recycled liquid tank every 24 hours. The aims of startup stage were to form sufficient bio-film over the media prepared by the bio-trickling filter for the treatment of dairy wastewater and to ensure complete utilization of reactor.

In phase 2, the amount of effluent COD continued to reduce until it became constant in steady state conditions (Figs. 5 and 6). In this period, the liquid recirculation enhanced mass transfer between the dairy wastewater and the surface of lava rocks, thereby accelerating the startup procedure. However, as shown in Fig. 6, the rate of COD removal slightly decreases as the hydraulic discharge increases. This occurs as a result of decreased residence time of the liquid due to higher flow rate, which ultimately reduces the contact of liquid with the biomass formed on the medium.

In phase 3, the COD removal efficiency reached over 85%. This implied that the biomass growing rate was ascending for the treatment of dairy wastewater, and determined the right time for the wastewater to be mixed with the circulated liquid in the tank. According to results, the maximum COD removal efficiency was obtained to be more than 85% in HRT of 10 days at 7-13 °C. During the next 13 days, the bio-trickling filter startup was subjected to steady state conditions and COD removal efficiency was observed to be more than 78%. By controlling pH and temperature, complete startup of bio-trickling filter was performed. To expedite the startup and accumulation of biomass on the media, temperature increase was required.

In phase 3, COD removal efficiency tended to a constant amount within 5 days, showing the proper time for adding the wastewater to be treated. The efficiency of bio-trickling filter startup reached over 78% in 23 days at low temperature. The obtained results indicated that COD removal rate did not increase with the hydraulic circulation increase. After the completion of startup process, the amount of suspended solids in the effluent was 1.2 kg MLSS/m^3. Therefore, the wastewater circulation flow rate was adjusted to maintain the MLSS of the reactor liquid approximately constant. The COD (and most of the MLVSS) decrease observed in Figs. 2 to 4 and 6 (up to day 10) was merely attributed to the attachment of microbes to the packing material.

Mostly a standard inoculation protocol is applied by re-circulating the inoculums liquid over the packing bed for a few hours before or directly upon startup of the bio-trickling filters (Sercu *et al.*, 2005). It was attempted to assess the ability of biological trickling filter to treat the main industrial waste

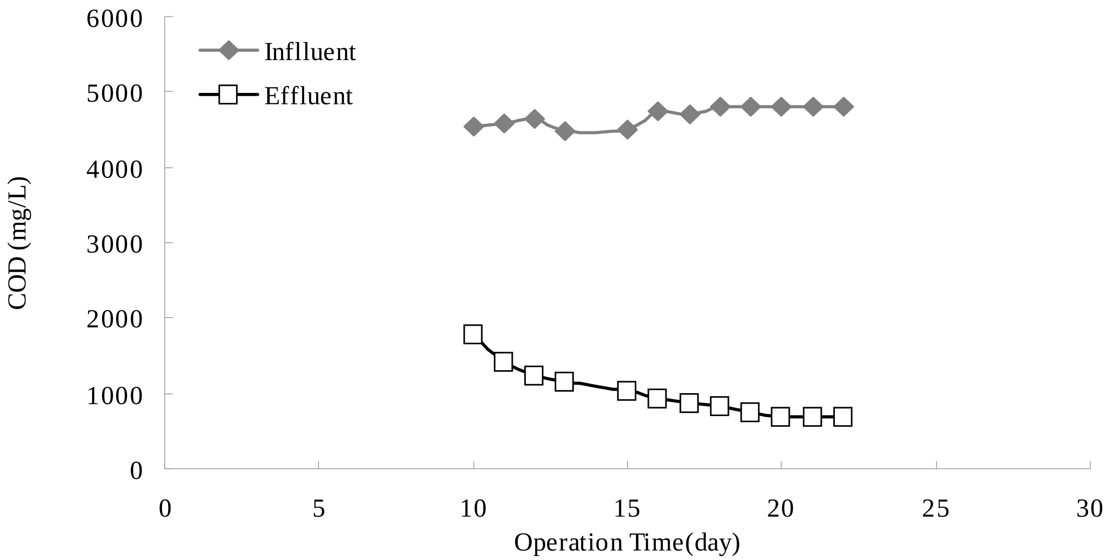

Fig.5. COD concentrations of the activated sludge with extra nutrients versus operating time (Q=0.0045 L/min)

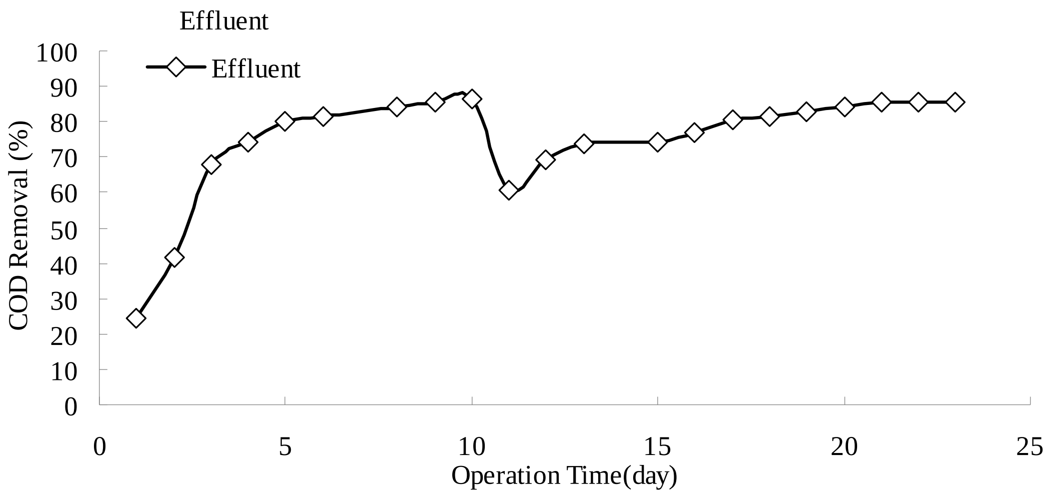

Fig.6. COD removal percentage versus operating time during the startup process of bio-trickling filter

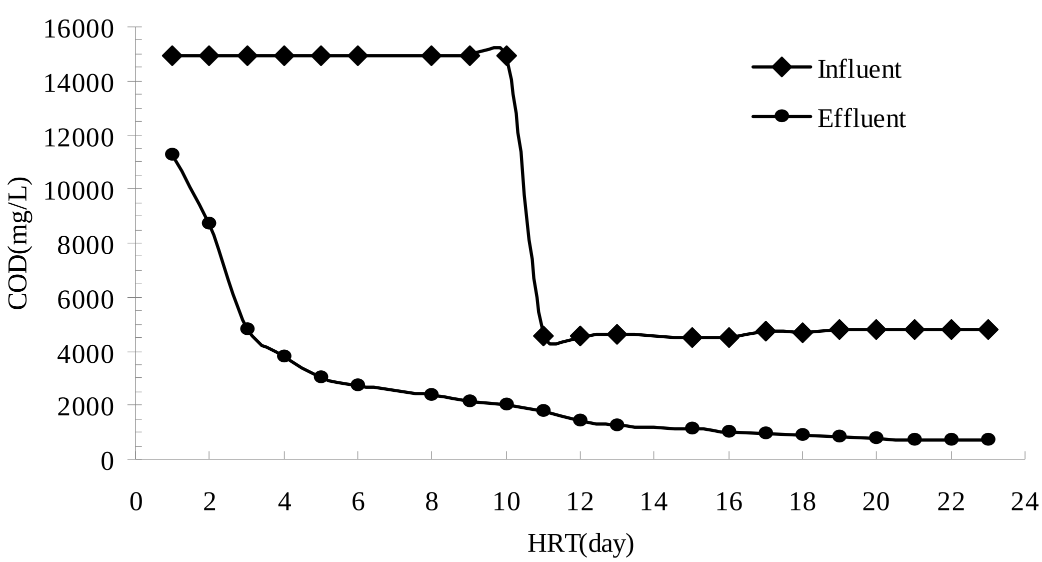

Fig. 7. COD concentration versus operating time during the startup process of bio-trickling filter

streams, as a pretreatment step, and then to mix the effluent with the low strength municipal-type wastewater giving a final wastewater that could be poured into the municipal wastewater (Kornaros and Lyberatos, 2006). Amal Raj and Murthy (1999) studied carbon oxidation and nitrification of dairy wastewater in a trickling filter to startup the pilot. They collected the activated sludge from Nessapakkam sewage treatment plant (Chennaijndia), mixed it with synthetic ammonium substrate with the ratio of 1:10 and pumped the obtained mixture into the trickling filter column at the rate of 7 L/h (Amal Raj and Murthy, 1999). They initially concluded that the reactor must operate in a batch mode for 20 days to initiate the growth of nitrifies. Later on, they continuously operated the reactor for an additional period of 40 days to enhance the attachment of nitrifiers to the media (Amal Raj and Murthy, 1998). In the present study, the time for the startup of biological treatment bio-trickling filter is directly proportional to the concentration of microbial population. A bio-trickling filter with lava rocks packing (in the size range of 1-5 cm with the average of 3 cm and specific surface area of 80 m^2/m^3) was also used to treat dairy wastewater. The startup of bio-trickling filter was performed at cold weather (7-13 °C) and pH was set to be 6.7-7.2 in all periods. In this study, pH was kept constant; however, we intend to use changing pH values in our future study. The activated sludge from Pegah wastewater treatment plant was collected and used as seeding during the first 10 days. At the HRT of 10 days and with flow rate of 0.0035 L/min no nutrients were added to the effluent, so that the COD removal efficiency was achieved to be about 86%. During the next 8 days, with the flow rate of 0.0045 L/min, the COD removal efficiency was achieved to be over 77%, and the bio-trickling filter was subjected to steady state condition. Within 18 days from the filter startup, the MLVSS of the returned liquid decreased and became constant. The results indicate that for a test period of 23 days, COD removal efficiencies were over 78% for organic loading less than 100 g COD/m^3/h. Turbidity and MLVSS are found to be indicators of assessment of bio-film growth on lava rocks during the test period. In this study, the total time for filter startup was obtained to be 23 days, and it was divided into 3 continuous phases. It should be noted that the available DO must be more than 2 mg/L to provide the medium with enough oxygen and to make it possible to subject the biological treatment to aerobic condition without using an air pump. One of the advantages of this method was that it was applied in cool temperature of biological growth on lava rocks bed and formation of biomass with the study of sludge organic load was carried out within 10 days.

CONCLUSIONS

In this study, the activated sludge from Pegah wastewater treatment plant was collected and used as seeding during the first 10 days. A bio-trickling filter with lava rocks packing for dairy wastewaters (in a size range of 1–5 cm with average of 3 cm, and specific surface area of 80 m^2) was also used. The time for startup of biological treatment bio-trickling filter was directly proportional to the concentration of microbial population. The startup of bio-trickling filter was performed at cold weather (7-13 °C) and pH was set to be between 6.7 and 7.2 in all periods. In this study, the total time of bio-trickling startup was determined to be 23 days, and was divided into 3 continuous phases. At HRT=10 days, with flow rate equal to 0.0035 L/min, no nutrients were added to the effluent, so that the COD removal efficiency was obtained to be about 86%. During the next 8 days, at flow rate equal to 0.0045 L/min, COD removal efficiencies were obtained to be over 77%, and bio-trickling filter was subjected to steady state conditions. During 18 days of bio-trickling filter startup, MLVSS of returned liquid decreased to become constant. The results indicated that for a test period of 23 days, the COD removal efficiencies of over 78% can be obtained for organic loading less than 100 g COD/m3/h. The turbidity and MLVSS were also found to be good indicators for assessment of bio-film increase on lava rocks during the test period.

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