Determination of dairy wastewater treatability by bio-trickling filter packed with lava rocks – case study PEGAH dairy factory

N. Mehrdadi, G. R. Nabi Bidhendi and M. Shokouhi

ABSTRACT

This paper investigates the effectiveness of a biological trickling filter for the treatment of wastewaters produced by a company manufacturing dairy products. First a bio-trickling column with a height of 150 cm was packed with lava rocks from north mountain of Tehran. It operates with the recirculation of liquid through the packing. In order to startup the pilot scale, steady state condition was gained by pumping activated sludge and dairy wastewater for 23 days. Afterwards, dairy wastewater was added to liquid tank for treatment. Hydraulic retention time (HRT) of treatment decreases from 5 days to 1 day then at HRT of 12, 8, 7, 6 and 4 h. Results show that the average chemical oxygen demand (COD) decreased from 2,750 to 98 mg/L at HRT of 7 h and efficiency of TKN removal was more than 70%. The microorganisms developed in the bio-trickling filter were able to efficiently remove COD levels up to 2,750 mg/L, under aerobic conditions at pH values between 6.8 and 7.2 under low temperature condition between 10 and 13 °C.

Key words | aerobic treatment, bio-trickling filter, COD, dairy wastewater, lava rocks

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INTRODUCTION

The need for determination of new sources of water could, in many cases, be solved by the recovery and reuse of certain stream effluents (Carta *et al.* 1999).

The high cost of wastewater treatment for food industry wastes has led to widespread application of the biological treatment process. In recent years, biological treatment of wastewaters in bio-filters and bio-trickling filters has been found to be a suitable and cost-effective technical method. Biological treatment processes, both suspended growth as well as bio-trickling filters, are perhaps the most suitable and cost-effective processes for the removal or elimination of organic and inorganic compounds from municipal and industrial wastewater (Kornaros & Lyberatos 2006). The bio-trickling filter often consists of organic filter medium containing microorganisms and nutrients, in which water contaminants are degraded (Fortin & Deshusses 1999). Moreover, the bio-trickling filters are non-submerged fixed film biological reactors applied for organic removal and nitrification of municipal and industrial wastewaters (Fortin & Deshusses 1999) and bio-trickling filtration is a change of bio-filtration where an inert support is used and a rubbing solution is continuously or intermittently recycled over the media to make the process culture with the necessary moisture, nutrients, and optimal stipulations (Fortin & Deshusses 1999).

Most comparisons of packing media for bio-trickling have focused on the elimination of biological oxygen demand (BOD), chemical oxygen demand (COD) and total suspended solids (TSS). The sewage is passed through a porous packed bed on which contaminant-degrading mixed cultures form a bio-film (Oh & Bartha 1997; Cox & Deshusses 1998, 2002). The contaminants are transferred from the wastewater to the bio-film where they are subsequently biodegraded (Chou & Huang 1997). The packed bed is nearly always made of neutral material such as a random dump plastic, lava rocks, structured plastic packing or open pore synthetic foam (Mehrdadi *et al.* 2010). The recycled liquid make possible a better control of the conditions hence bio-trickling filters are always more effective than bio-filters (Cox & Deshusses 2000; Cox *et al.* 2001). Bio-trickling filters need inoculation, as the usual bio-trickling filter packing is inert and does not contain any

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indigenous microbial populations. In the case of nitrogen elimination, the most accepted systems for large-scale wastewater nitrification are continuous stirred-tank reactors (CSTR), packed towers, and rotating biological contactors (RBC). The packed tower, the CSTR, and the fluidized media are used for denitrification. In the packed tower, the feed is pumped up-flow through a column filled with stone or synthetic media (Koren *et al*. 2000). The bio-trickling filter with packing lava rock was done to purify waste air and were used to study the structure and chemical composition of lava rock (Li *et al*. 2005).

There are various materials which may be used in bio-trickling filter packing. Main parameters considered in selection of the material for biological trickling filter packing are as follows:

- high specific surface;
- sufficient porosity;
- high resistance to chemicals and appropriate strength of the packing;
- low weight;
- sufficient surface for attachment and growth of the bacteria;
- low price.

In this study, lava rock with high specific surface, porous structure suitable for the growth of bacteria clone and low price was used as packing rock. Many researchers use plastic packing which, in spite of low price and easy transferability, needs a long-term process for setup, because formation of bio-film on the surface of this packing is weak.

PEGAH milk industries usually process 700 tons of dairy products daily for which it generates approximately 3,000 m^3 of wastewater per day. The dairy industries produce considerable quantity of wastewaters, characterized by high concentration of COD, BOD, total Kjeldahl nitrogen (TKN), total phosphorus (TP) and nitrates (Schwarzenbeck *et al*. 2005; Sirianuntapiboon *et al*. 2005; Abdulgader *et al*. 2009). Different methods are being employed to purify dairy wastewater (Demirel *et al*. 2005; Kushwaha *et al*. 2011). For instance, continuous flow experiments were carried out to reach effluents with low COD and a minimum of ammonium and nitrogen concentration (Carta *et al*. 1999; Demirel *et al*. 2005).

In this study, an investigation was made to enhance the treatment of dairy wastewater of PEGAH plant by bio-trickling filter with lava rocks under low temperature condition between 10 and 13 °C. One of the purposes of this paper is to determine the optimized hydraulic retention time (HRT) for treatment of real dairy wastewater (RDW).

MATERIALS AND METHODS

Experimental setup

The experimental setup consisted of a laboratory-scale bio-trickling filter as illustrated in Figure 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 high lava rocks and a 52 L packing volume equipped with a liquid recirculation system holding a total liquid volume of 52 L as illustrated in Table 1. Volume of the returned liquid, i.e. dairy activated sludge, used during the startup period was 15 L. In order to understand the physical absorption capacity of the liquid recirculation system, an experiment was performed in activated sludge. As the startup of bio-trickling filter was done under low temperature condition, the experiments were carried out at 10–13 °C.

Lava rock is a commercial term attributed to lightweight vesicular volcanic rocks used for horticulture (culture

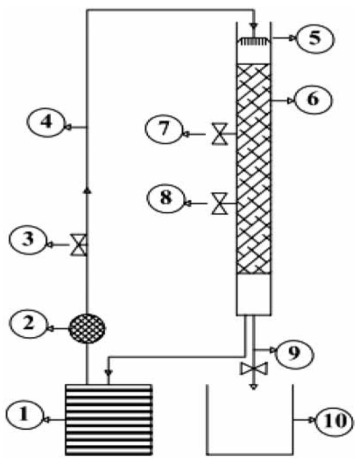

Figure 1 | Schematic diagram of the experimental apparatus. 1. Liquid tank, 2. Liquid pump, 3. Flow meter, 4. Recycled water line, 5. Liquid distributor, 6. Lava rocks (media), 7. Liquid sampling port (50 cm), 8. Liquid sampling port (100 cm), 9. Treated water, 10. Sedimentation tank.

Table 1 | Characteristics of lava rocks medium

Parameter	Value
Size range (cm)	2–4
Average size (cm)	3
Porosity (%)	60
Specific surface area (m^2/m^3)	77

medium), landscape, ground cover and construction. These rocks are normally naturally fragmented and deposited around volcanic craters. Lava rocks are classified on the basis of their chemical composition and physical properties. Chemical composition and physical characteristics of the lava rocks play an important role in determining whether it can be used as a culture medium or not. Chemically, the material should be inert – that means it should not react with the wastewater, water or added nutrients. No harmful elements should be released from lava rock into the solution during long-term treatment process. Therefore, it is important to analyze the material for trace elements together with the major oxides during evaluation. Physical characteristics such as particle size, bulk density and porosity also play an important role in determining their feasibility as culture media.

Materials

The lava rocks packed in the bio-trickling filter were taken from the mountains near Tehran. They are relatively inexpensive and easily obtainable in most parts of the country. Activated sludge and dairy wastewater for seeding was collected from a PEGAH dairy plant in Tehran, Iran.

Analytical methods

The samples were collected from the inlet, outlet, and the height from the 50 cm as well as 100 cm of bio-trickling filter bed. The influent and effluent samples were analyzed for parameters such as COD, TKN, TP, nitrate, pH, dissolved oxygen (DO), turbidity and temperature. The amount of COD in influent and treated effluent were determined spectrometrically by a DR 5000 instrument (COD high range 0–15,000 mg/L, low range 0–150 mg/L) at a wavelength of 420 nm. Moreover, the measurement of TKN, TP and nitrate (NO_3^--N) was carried out using a Hack DR 5000 at a wavelength of 460, 420 and 410 nm, respectively. An acidity analyzer (pH meter-Metrohm691) was used to record pH. The analyses were performed in accordance with Standard Methods (1998) (Koren *et al.* 2000). Table 2 reports the values of operation variables used in continuous mode. To find out the mechanism of COD removal in lava rock bio-trickling filter, it is significant to understand the key physical and chemical properties of lava rock in addition to the predominant microorganisms in lava rock bio-trickling filter. A few pieces of lava rock randomly taken from the upper 1 m of the full-scale bio-trickling filter were used to analyze the particle porosity (ratio of the pore volume to the total volume of the particle) according to the methods provided by Li *et al.* (2005) and the results illustrated in Table 1.

Table 2 | Range of operation variables

Variable	Range
Hydraulic loading rate (m^3/m^2 per day)	0.33–9.95
Organic loading rate (g COD/m^2 per min)	0.6–18
Influent COD concentration (mg/L)	2,580–2,680

Operation

In this study, we investigated the HRT for treating PEGAH dairy wastewater at an ambient temperature of 10 to 13 °C. Sampling three times from out-stream of the equalization tank in PEGAH wastewater plant, the characteristics of dairy wastewater were calculated and are given in Table 3. After the acclimatization period, the reactor operated continuously for HRT of 5, 4, 3, 2 and 1 days and the recycled liquid tank volume was 52 L; therefore, the hydraulic flow rates were respectively considered as 0.0072, 0.009, 0.012, 0.0181 and 0.0361 L/min. Passing through the HRT, effluent samples were collected at the outlet, 50 and 100 cm from the medium, and all of the required parameters were measured. Thus, retention time was decreased to 12, 8, 7, 6 and 4 h and hydraulic flow rates were respectively determined as 0.072, 0.108, 0.124, 0.144 and 0.217 L/min. By decreasing HRT, in spite of TKN and TP removal efficiencies were increased but increase in values was negligible. All results were documented for low temperature conditions. The reactor operated in aerobic process with natural aeration; hence, daily DO of effluents was measured to be more than 2 mg/L (2 ppm).

Table 3 | PEGAH dairy wastewater characteristics

Parameters	Value
COD	2,600 mg/L
BOD_5	1,450 mg/L
TSS	670 mg/L
pH	6.8–7.2
TKN	85 mg/L
Total unfiltered P (PO_4^{-3})	75 mg/L
Total filtered P (PO_4^{-3})	71 mg/L
Nitrate (NO_3 - N)	100 mg/L

RESULTS AND DISCUSSION

Effect of HRT

Based on the detailed characteristics of dairy wastewater in Table 3, dairy feed was used to fill the liquid tank and first HRT was started. The system performance was studied using RDW and COD in the feed stream was kept constant at 2,500 and 2,750 mg/L for all hydraulic loadings. To increase the bio-filter efficiency through recirculation, the run was performed in continuous mode where 25% of the returned effluent was returned to the system. This situation could be addressed by the fact that the hydraulic flow rate gradually increases as HRT decreases and ultimately the contact between liquid and formed bio-film on the lava rocks is reduced. The effect of decrease in HRT on COD is shown in Figure 2. It is observed that the decrease in COD remains approximately constant with the increase in hydraulic flow rate. As observed in Figure 2, decreasing HRT negligibly decreases the COD removal efficiency, therefore, sufficient treatment of dairy wastewater can be done at lower HRT. It can be derived that as the HRT decreases from 12 to 7 h, COD removal percentage changes negligibly and COD removal efficiency remained more than 96%. After passing the HRT of 7 h, COD removal percentage begins to reduce despite lower influent COD concentration while removal efficiency does not increase any further.

The COD removal percentage for treating RDW is shown in Figure 3. For an influent COD concentration of 2,650 mg/L, the percentage of COD removal at a HRT of 5 days is found to be 96.98%. As shown in Figure 3, pH in the effluent of bio-trickling filter was maintained in the neutral range approximately with the apparent removal efficiency of more than 90%. These figures indicate that the biomass formation on lava rocks was able to cope effectively with the imposing change of the feed by increasing the hydraulic flow rate, although COD removal was slightly decreased during each HRT. It could be verified that the COD removal rate increases with the increase in influent COD concentration.

In order to delineate the effect of HRT on the system performance, the bio-trickling filter was subsequently operated at variable HRTs. The effect of hydraulic loading rate on COD removal percentage is shown in Figure 4. As it can be seen from Figure 4, COD removal percentage decreases with the increase of hydraulic loading rate, although this reduction is negligible. Thus, COD removal efficiency can be notable for treating RDW at HRT of 7 h. For instance, as the hydraulic loading rate is increased from 0.33 to 0.41 m^3/m^2/day, COD removal percentage decreases from 96.98 to 96.88%. However, COD removal rate will be raised subsequent to increase in influent COD

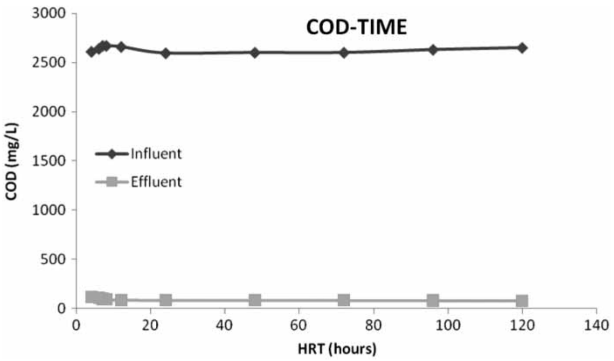

Figure 2 | The effect of COD influent and effluent variation with time.

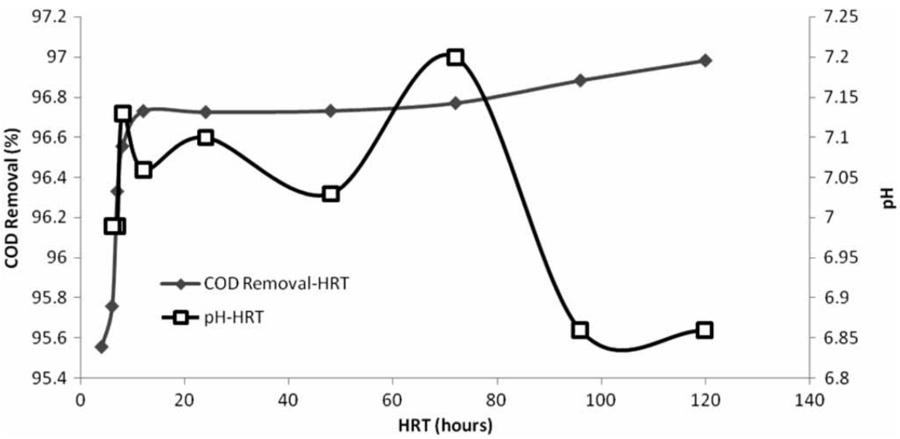

Figure 3 | The effect of pH on COD removal percentage with time.

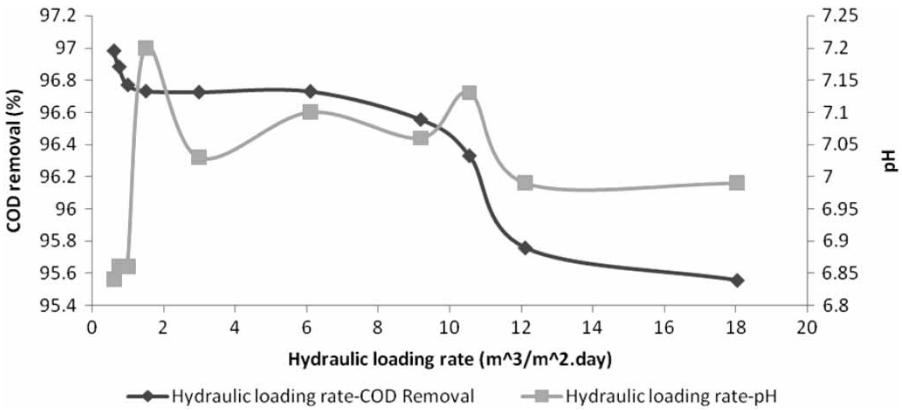

Figure 4 | The COD removal as a function of hydraulic loading rate.

concentration and hydraulic loading. It is worthy to note that the suspended solids removal decreases with the increase in hydraulic loading; hence, the treated effluent turbidity increased at HRT of 7 h is in the permitted range, and the remained suspensions will not cause an opaque fluid.

Effect of HRT on TKN and nitrate removal

It can be observed from Figure 5 that TKN removal percentage decreases slowly as influent TKN concentration varies in the range of 85–90 mg/L. Nitrifies are autotrophic bacteria that need inorganic carbon for their cell synthesis. TKN concentration of PEGAH dairy wastewater was found to be high and it can be consumed by nitrifies, therefore, the necessary TKN removal efficiency was more than 75% by bio-trickling filter with the use of lava rocks. The TKN removal depends on the condition of pH and temperature. In the treatment of wastewaters, it is popular that nitrogen removal can be accomplished by nitrification and denitrification processes in a biological treatment plant (Raj & Murthy 1998). Influent TKN concentration removal percentage increases as the hydraulic loading rate decreases.

A similar trend was observed by Canler & Perret (1994) in the case of elimination rate of Kjeldahl nitrogen in their system of investigation (Canler & Perret 1994). The upper zone of reactor was aerobic and the lower zone was anoxic (subject to oxygen deficit) so that both nitrification and denitrification would happen in one reactor (Koren *et al.* 2000). In the first part of bio-trickling filter column, nitrification occurs in aerobic conditions. With the reduction of DO in the lava rocks, denitrification takes place. The produced nitrate is the nitrogen gas, i.e. N_2. As a result, effluent exiting from the end of bio-trickling filter contains low values of NO_3^--N. Figure 6 indicates that the influent and effluent nitrate changes by passing from the bio-trickling filter with variable HRT. At HRT of 7 h, the NO_3^- removal efficiency achieved was found to be more than 70% as the hydraulic loading rate reaches 5.7 m^3/m^2/day. The TKN and nitrate removal efficiencies are shown in Figure 7 with respect to variable HRT.

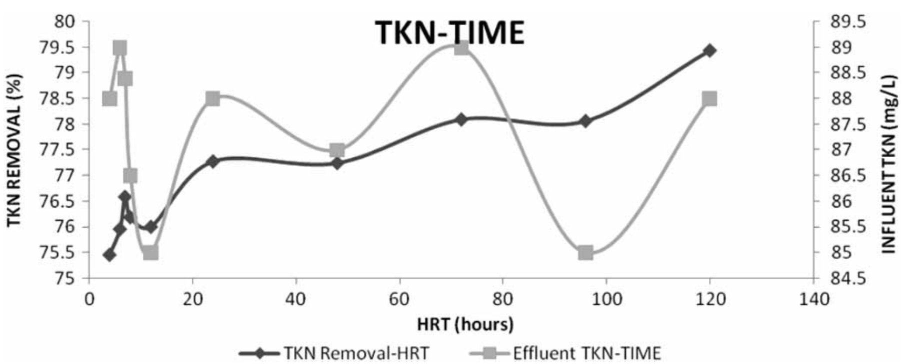

Figure 5 | The effect of HRT variation on TKN removal.

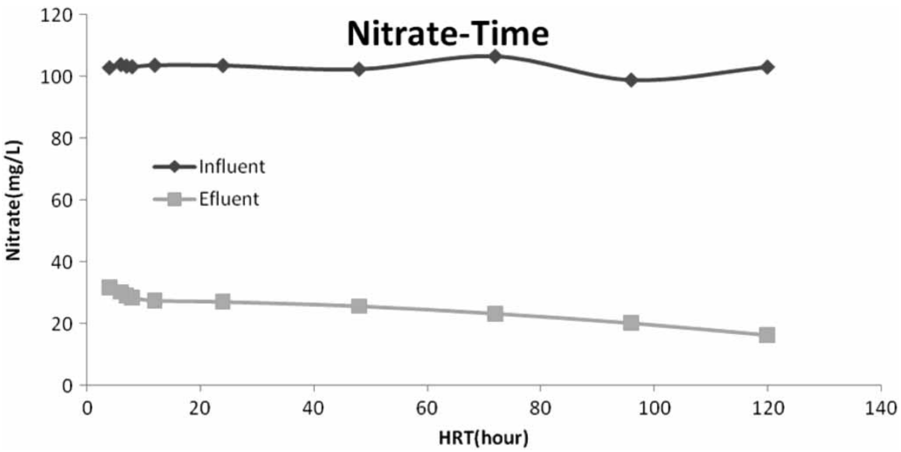

Figure 6 | The effect of time on influent and effluent nitrate.

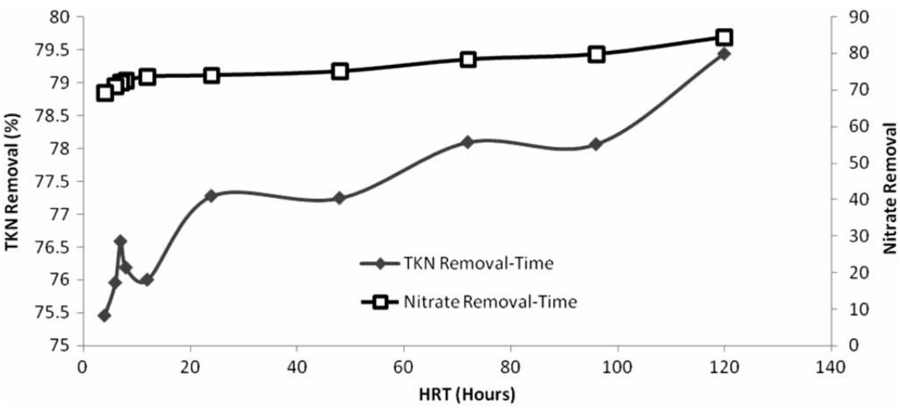

Figure 7 | The effect of HRT on TKN and nitrate removal.

As in this investigation, it can be noted that at an influent COD concentration (2,500–2,730 mg/L), COD removal percentage varied marginally for hydraulic loading rate 0.33 and 9.95 m^3/m^2/day. Raj & Murthy (1999) indicated the reason for the decrease in COD removal efficiency for higher hydraulic loading rate is that the higher hydraulic loading decreases the liquid residence time, thus ultimately reducing the contact between liquid film biomass (Raj & Murthy 1999). According to the fact that the adjustment of pH in neutral range has a positive influence on COD removal efficiency, it was exercised on dairy wastewater while decreasing HRT. In this paper, removal of the observed COD was not due to air pump and air stripping process used under this operation. Thus, the DO was always measured to be more than 2 mg/L. Kornaros & Lyberatos (2006) specified that 30–60% of total COD removal attributed to air stripping, caused by the air supply at the bottom of filter, as removal of the remained COD is clearly related to this biological process (Kornaros & Lyberatos 2006).

In their study concerning TKN and NO_3^- removal, Raj & Murthy (1999) demonstrated, if the hydraulic loading rate is increased the boundary layer thickness associated with laminar flow at the liquid bio-film coordinate is decreased (Raj & Murthy 1998). So, it was always adjusted and DO was more than 2 mg/L in the effluent. It must be noted that TKN removal percentage decreases as flow rate increases. This situation is evident from the fact that the higher flow rate reduces the residence time and consequently limits the contact between the substrate and biomass formation in the medium.

CONCLUSIONS

The ability to use a biological treatment plant and more specifically a bio-trickling filter for the removal of biodegradable compounds from the wastewater produced from a dairy manufacturing company was addressed in this paper. The bio-trickling filter sustained appropriately acclimated aerobic biomass that proves the ability to remove the organic loading. The COD removal efficiency ranged up to 90% for a variable hydraulic loading at low temperature condition between 10 and 13 °C and pH in the range between 6.8 and 7.2. However, a stable COD removal efficiency of 96% was achieved in HRT of 7 h with a hydraulic loading rate of 5.7 m^3/m^2 per day. At HRT of 7 h, TKN removal efficiency was more than 70% in the end of the bio-trickling filter column.

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