Treatment of Slaughterhouse Wastewaters with Upflow Anaerobic Pumice Bed Reactor

Erdem Kocadagistan

Department of Environmental Engineering, Faculty of Engineering, Ataturk University, 25240 Erzurum, Turkey
myecem@atauni.edu.tr

Abstract: This study aimed to decrease the chemical oxygen demand (COD) of slaughterhouse wastewater using pumice mediated upflow anaerobic fixed bed reactor (PBR). The wastewater, treated in this study, supplied from the slaughterhouse of Meat and Fish Authority of Erzurum City. Reactor was operated in batch and continuous flow mode at different organic loading rates (OLR) in the range of 0.58 to 36.77 kgCOD/m^3.day. The PBR reactor showed great performance between the loading rates of 0.58 and 5 kgCOD/m^3.day to treat COD from mentioned wastewater with the removal efficiencies of 93 and 73%, respectively. Efficiencies decreased from 73 to 34% for the loading rates of 5 and 36.77 kgCOD/m^3, respectively. Minimum effluent COD concentration and maximum removal efficiency are 8 mg/L and 93.3%, respectively, observed in this study.
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1. Introduction

Slaughterhouse wastewaters are generally considered strong due to their composition. Slaughterhouses generate meat and products marketed for human consumption, pollutant solid waste and other by-products (skins, fats, and bones), as well as substantial volumes of wastewater as a result of cleaning operations (Cuetos et al., 2008). These type of wastewaters have various organic matters at various concentrations from medium to high quantities and discharging the slaughterhouse wastewaters without any treatment leads pollution problems at the water bodies or the other receiving environments.

Biological processes are mainly preferred systems for the removal of organic pollutants found in wastewaters (Mittal, 2006). Sometimes, aerobic biological processes considered as unsuitable treatment option for the treatment of high strength wastewaters because of high-energy requirements for aeration, large quantities of sludge production and insufficient effluent concentrations to meet the discharge limitations. Otherwise, anaerobic biological treatment processes are regarded as the best choice for treating high strength wastewaters with high efficiencies and low consumptions beside the useful energy source in the form of methane generated by methane producing organisms of anaerobic processes (Sasaki et al., 2009; Hansen et al., 1998; Callaghan et al., 2002; Baere, 2004).

Fixed bed anaerobic biofilm reactors have been widely used among the anaerobic biological systems to treat the high strength wastewaters due to their stability. This stability result from their capacity of maintaining high cellular residence times, operating even at short hydraulic residence times (Villalobos et al., 2006). As a result, the advantages of this type of reactor compared to other systems include: compact areas in the treatment system, relatively short hydraulic residence time, robustness and strength towards toxic shocks, and the suitable concentration interval of organic matter for its use is between 1000 and 20,000 mg/L COD (Romero et al., 2011; Malina et al., 1992; Corredor et al., 2005).

In anaerobic degradation, firstly, complex organics are hydrolysed to sugars, amino and fatty acids, secondly, degraded to volatile fatty acids by acidogenics and degraded by acetogenics yielding acetate, carbon dioxide and hydrogen finally. Acidogenic organisms grow relatively faster and are less sensitive to pH variation than acetogens/methanogens. This usually results in the accumulation of organic acids and lowering of pH, leading to the suppression of methanogenic activities and in some cases, even process failure. Instability or failure of single-phase methanogenic reactors has been widely reported for a variety of wastewaters, especially under high loading conditions (Saddoud and Sayadi, 2007).

One of the most important aspects of projects with anaerobic fixed bed reactors is the selection of the support medium (Fia et al., 2012), which can be either natural one (river stone, pumice stone, crushed stone, volcanic rock, etc.) or synthetic one such as rasching ceramic rings, intallox saddles (Tchobanoglus et al., 2003). The most important factors to decide the supporting medium are specific surface area and cost of bed medium (Reyes-Lara and Reyes-Mazzoco, 2009). Among the materials that have been used for this aims are bamboo shoots (Colin et al., 2007), coconut shells (Torres et al., 2003), cinders from steel mill blast furnaces, porous ceramics (Gourari and Achkari-Begdouri, 1997), polyurethane foam (Ribeiro et al., 2005), nylon fibers (Chaiprasert et al., 2003) and PVC (Show and Tay,1999).

The main objective of this study was to verify the performance of an upflow anaerobic fixed bed reactor filled with pumice, low cost and easily obtainable material in Turkey, for the treatment of slaughterhouse wastewaters to prevent the receiving environments.

2. Materials and Methods

This study was actualised in a pumice mediated upflow anaerobic fixed bed reactor (PBR). The PBR reactor was a circular polyester column with an inner diameter of 10 cm and a total height of 110 cm. The working volume of this reactor was varied from 1 to 5 L depending on the hydraulic retention time. During the experiments, nitrogen gas was applied from the bottom of the reactor to strip oxygen and maintain the dissolved O_2 (DO) concentrations at the level of 0.5 mg/L and below. Synthetically prepared wastewaters were pumped directly to the bottom of the reactor, but slaughterhouse wastewater was filtered to prevent the reactor from excessive clogging caused by coarse and suspended materials. Temperature of the reactor content was kept at 35 ± 2 ^oC using a hot water circulator during the experiments.

PBR reactor was filled with pumice, which was supplied by Ercis, Turkey, as filter bed material. Pumice is used as a biofilm support material in water and wastewater treatment because of its high porosity and large surface area. It is a light and porous volcanic rock material formed during explosive eruptions. Pumice is riddled with pores of irregular or oval shape, which are usually not connected to each other. Italy, is the biggest pumice producer in the world (% 44 in total) and Turkey is the second (9% in total) (Kocadagistan et al., 2005). The chemical composition and the SEM picture of pumice are given in Table 1 and Figure 1, respectively.

Table 1. The authentic characteristics of pumice used in this study (Farizoglu et al., 2003).

Parameters	Values
Chemical compound (%)	
SiO_2	72.07
AlO_2	13.50
Fe_2O_3	1.21
Na_2O	1.60
K_2O	11.27
TiO_2	0.35
Uniformity coefficient (D_{60}/D_{10})	1.35
Effective grain size, D_{10} (mm)	0.59
Porosity (%)	69.24
Density (0.5–1.0 mm grain size) (g/cm^3)	0.689

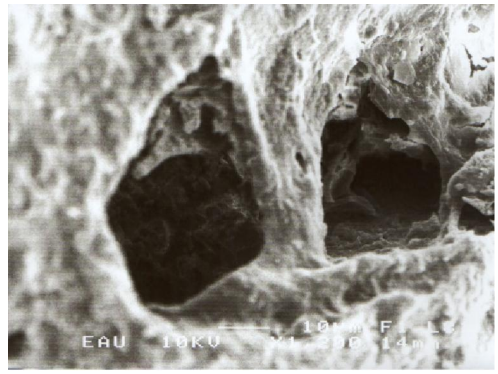

Figure 1. SEM picture of pumice used in this study (upsizing =1200 x).

Anaerobic microorganisms used in this study were taken from the secondary settling tanks waste sludge line of the Erzincan Municipality wastewater treatment plant and were acclimated to anaerobic conditions in a laboratory scale anaerobic jar for four mounts. During this period, sludge microorganisms feed with synthetically prepared solution containing some nutrients such as $C_6H_{12}O_6$, $CO(NH_2)_2$, $MgSO_4$, $CaCl_2$, KH_2PO_4, K_2HPO_4 and $FeCl_3$. pH of the jar content was controlled regularly and if needed adjusted in the range of 6-9 using with 0.1 M H_2SO_4 or 0.1 M NaOH solutions. At the end of the acclimation period, anaerobic sludge was put in to the reactor.

Analyses were accomplished according to Standard Methods (AWWA, 1998).

3. Results and Discussion

This study was carried out in two different operating modes that were batch and continuous. In batch mode, synthetically prepared solution with the carbon source of sodium acetate (C_2H3NaO_2) and required nutrients, mentioned above, used for acclimating the microorganisms to more difficult conditions and supplying the attaching of them to the reactor media of pumice. During this period, COD concentrations of the feeding solution were increased slowly at beginning of each new experiment in the range from 125 to 500 mg/L. The plots of COD concentrations versus time for various initial COD values are given in Fig. 2. As can be seen from this figure, after 2 or 3 hours from the beginnings, concentrations decrease rapidly for all different initial values. Contrary to expectations, removal efficiencies increased with increasing initial concentrations. This can be explained with the requirement of anaerobic microorganisms to the higher substrate levels because the low wastewater strength involves slow biochemical reaction rates such as growth rate of methanogens (Martinez-Sosa et al., 2012). Final removal efficiencies at the end of the experiments are

38, 56, 64, 68 and 77% for 125, 150, 200, 250 and 500 mg/L initial concentrations, respectively.

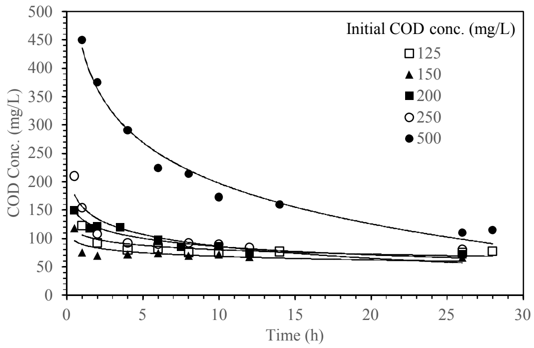

Figure 2. COD concentrations versus time plots for batch mode experiments.

Thereafter, continuous operating modes were carried out. In this mode, organic loading rates (OLR) were used instead of initial COD concentrations, which take account of flow rates and reactor volumes together with initial COD concentrations (Eq.1). OLR values were altered with changing the COD and flow rates in al experiments. Thus, higher organic matter levels were supplied for reactor organisms with higher COD concentrations or with flow rates, if COD concentrations of slaughterhouse wastewater are insufficient too enough to do this.

$$OLR = \frac{Q.S_o}{V} \qquad (1)$$

Where, Q is the flow rate (m^3/day), S_o is the initial COD concentration (kg/m^3) and V is the volume of the reactor (m^3).

Firstly, synthetically prepared wastewater used to observe the performance of PBR reactor in continuous mode with the OLR values from 1.056 70 24.67 kgCOD/m^3.day and finally real slaughterhouse wastewater, taken from Meat and Fish Authority of Erzurum City, used with the OLR values from 0.58 to 36.77 kgCOD/m^3.day. The composition of slaughterhouse wastewater used in this study is given in Table 2.

Table 2. The composition of slaughterhouse wastewater used in this study.

Parameters	Range
COD (mg/L)	500-2500
Oil and grease (mg/L)	36.94-52.5
Total nitrogen (mg/L)	53.5-182.2
Total carbon (mg/L)	168.45-748.36
Suspended solids (mg/L)	5240-54220
Dissolved O_2 (mg/L)	1.6-1.8
PO_4-P (mg/L)	12-76
pH	7.1-9.15
Temperature (°C)	11.2-17.5

Figure 3 and 4 represents the changing of COD concentrations with time at various OLR values for synthetic and slaughterhouse wastewater, respectively.

When synthetic wastewater was used, PBR showed a good performance, seen in Fig. 3a, for lower OLR values below 5 kgCOD/m^3.day. COD removal efficiencies are 93, 91.2, 90, 80.4 and 72.8% for the OLRs of 1.06, 1.92, 2.47, 3.14 and 4.94 kgCOD/m^3.day, respectively. At the end of these experiments, COD concentrations decreased from 500 mg/L to the low levels such as 33, 44, 50, 98 and 136 mg/L for the above high OLRs, respectively.

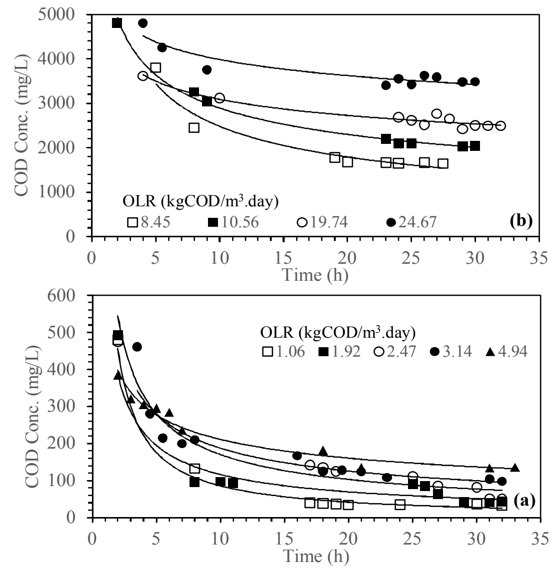

Figure 3. Variation of COD concentrations with time at various OLR values for synthetic wastewater.

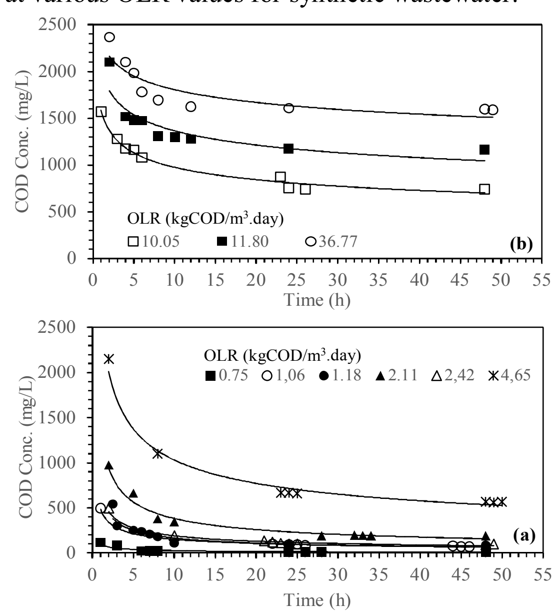

Figure 4. Variation of COD concentrations with time at various OLR values for slaughterhouse wastewater.

When the OLR values were increased more (Fig.3b), COD removal efficiencies decreased but still high for this high level of OLRs. At the end of these experiments COD concentrations decreased from 5000 mg/L to the levels of 1642, 2042, 2492 and 3480 mg/L for 8.45, 10.56, 19.74 and 24.67 kgCOD/m^3.day OLR values, respectively. These OLR values are very high for biological wastewater treatment processes. Nevertheless, 59.2, 58.9, 37.7 and 30.4% of removal efficiencies were observed with mentioned OLRs, respectively.

The PBR showed similar performance with real slaughterhouse wastewater up to the OLR of 5 kgCOD/m^3.day but higher efficiencies than those of synthetic wastewaters were observed above this OLR value. The variation of COD concentrations with time at various OLR values for slaughterhouse wastewater is given in Figure 4. Removal efficiencies did not decrease below the level of 75% up to the OLR values of 4.65 kgCOD/m^3.day and higher efficiencies were observed in the range between 74.2 and 93.4% (Fig. 4a). Removal efficiencies, obtained for high OLR values of slaughterhouse wastewater such as 10.05, 11.80 and 36.77 kgCOD/m^3.day (Fig. 4b), are observed as 53.75, 52.25 and 34.8 %, respectively. 36.77 kgCOD/m^3.day is the highest OLR applied to the PBR in this study and its removal efficiency (34.8%) is higher than the efficiency of 30.4 % observed with synthetic wastewater for the lower OLR of 24.67 kgCOD/m^3.day.

4. Conclusios

Slughterhouse wastewater was treated with PBR in this study with high COD removal efficiencies especially at OLR values up to 5 kgCOD/m^3.day.

Final COD removal efficiencies versus OLR values, applied to the PRB for both type of wastewater, were compared in Fig. 5 and two model equations (seen in Fig. 5) were derived from these plots. For further studies, these equations might be used for determining the COD removal efficiency at any OLR value. The correlation coefficients of the removal efficiency versus OLR plots were observed as 0.956 and 0.962 for synthetic and slaughterhouse wastewaters, respectively.

As can be seen from Fig. 5, COD removal efficiencies obtained from slaughterhouse wastewater experiments are greater for higher OLR values than the efficiencies obtained from synthetic wastewater experiments. It is thought that, this phenomena result from the weakness of synthetic wastewater contents in comparison to slaughterhouse wastewaters for the PBR organisms.

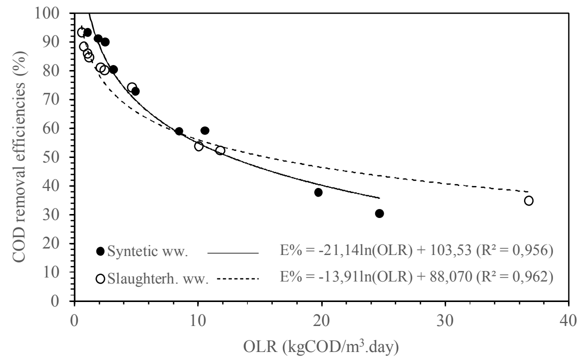

Figure 5. Final COD removal efficiencies versus OLR.

As a result, it seems that, pumice mediated upflow anaerobic fixed bed reactor (PBR) designed for this study is a useful system to treat slaughterhouse wastewaters, which pollutes the receiving environments if discharged without treatment. Moreover, it can be stated that, pumice is a practicable low cost biofilter material to reach this aim.

Corresponding Author:
Dr. Erdem Kocadagistan
Ataturk University,
Engineering Faculty,
Environmental Engineering Department,
25240 Erzurum, Turkey.
E-Mail: myecem@atauni.edu.tr

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