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Biological Treatment of Dairy Wastewater in an Upflow Anaerobic Sludge-Fixed Film Bioreactor

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Abstract: An upflow anaerobic sludge-fixed film (UASFF) reactor is a granular sludge bioreactor that was used for the rapid biological conversion of organic matter to biogas with the aids of aggregated microbial consortium. The major problem associated with the conventional UASB reactor is the long duration for startup period. In this study, UASFF bioreactor with tubular flow behavior was developed in order to shorten the start-up period at low HRT. The reactor was operated at 36°C and HRT of 36 and 48h. The organic loading rate was gradually increased from 7.9 to 45.42 g COD/l.d. In this research flocculated granular sludge was built in a short period of 4 to 5 days. The core of the granular sludge was developed within 20 days. At HRT 48 h and temperature 36°C, the COD removal rate and lactose conversion of 97.5 and 98 percent were obtained, respectively. The use of an internal upflow anaerobic fixed film section caused the flocculated biomass was trapped in the sludge blanket and the delivery of biogas was easily performed.

Key words: UASFF · Dairy wastewater · Methane · COD · Lactose · Biogranules

INTRODUCTION

Dairy industry, like most other agro-industries, generates strong wastewaters characterized by high biological oxygen demand (BOD) and chemical oxygen demand (COD) concentrations representing their high organic content [1-4]. Furthermore, Cheese production worldwide generates more than 145 million tone of liquid whey per year. Dairy wastewater comes from cheese producing industries; has a large COD value of about 50000-80000 mg/l. Generally, dairy waste streams contain high concentrations of organic matters; these effluents may cause serious problems, in terms of organic load on the local municipal sewage treatment systems. [5-9].

Efforts to utilize the huge amount of dairy by-products have led to the development of various whey treatment methods. Despite of the different possibilities of whey utilization, approximately half of the cheese whey produced worldwide is discarded without treatment [10-12]. The dilution of cheese whey by mixing with other wastewater is a method for reducing the instability and low efficiency problems caused by its high organic content, especially for high-rate anaerobic systems, such as Upflow Anaerobic Sludge Blanket (UASB) reactors or up flow anaerobic filters [13-14]. Over the past decades, several cost-effective treatment technologies comprising anaerobic, aerobic and facultative processes have been developed for the treatment of whey. Recently, anaerobic treatment leading to biogas production has become an effective biological process for the treatment of many industrial organic wastewaters [15, 16]. In anaerobic processes, the major produced gas is methane, which is a valuable and renewable energy source used for heating and production of electrical energy. The lactose content of whey is readily degraded by acidogenic bacteria; this results in the occurrence of acid inhibition because of the differences in the rates of acidogenesis and methanogenesis. For an efficient level to be achieved, pH regulation is needed. Another possibility is to separate the acidogenic and methanogenic pathways, the acidogenic stage being under external pH control. Through control of the pH of the methanogenic stage, the biogas production rate and methane yield can be enhanced by reduction of COD and biosolids [17]. Great interests in anaerobic treatment process have been developed for removal of organic waste and improve the treatment efficiency. The UASB reactor is one of the chosen innovative bioreactors. However, the performance of UASB systems has not been discussed in detail. A systematic investigation of

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reactor characteristics, such as operation stability, HRT dependence, sludge granulation and sludge discharge is still lacking. A major problem associated with the UASB reactor is long duration for granulation, it may take several months. Modification of the UASB process was required to overcome the existing deficiencies [18, 19]. Use of internal packing for retaining biomass in the UASB reactor is a suitable solution to overcome the above mentioned problem. The packing medium in the reactor is intended to increase solids retention time. The upflow anaerobic sludge fixed film (UASFF) reactor is an anaerobic hybrid reactor which is a combination of upflow anaerobic sludge blanket (UASB) and upflow fixed film (UFF) reactors. The lower part of the UASFF reactor is the UASB portion where flocculants and granular sludges are developed. The upper part of the UASFF reactor serves as a fixed film bioreactor. The UASFF reactor has been used successfully for the treatment of various industrial wastewaters, such as POME, slaughterhouse, swine and starchy wastewaters [20-23].

MATERIALS AND METHODS

Cheese Whey: Dairy waste effluents are normally concentrated and the major contributors of the organic load to these effluents are carbohydrates (4-5%), mainly lactose, soluble proteins (0.6-2%), fats at about 0.4-0.5%, lactic acid less than 1% and mineral salts (0.5-0.7%) [5]. Cheese whey in this study was obtained from “Gela Factory” (Amol, Iran). Ultrafiltration process was used for the production of cheese. The whey samples were provided from the factory, collected in 20 liter containers and daily transported to the laboratory, refrigerated and stored at 4°C to avoid acidification and changes of the chemical composition of the cheese whey. During the adaptation phase, diluted whey at pH 6.5 was fed into the reactor. Based on necessity of the experiment, various dilutions of cheese whey were prepared using distilled water. The pH of the feed was adjusted to 7, using a 6M sodium hydroxide solution. The characteristics and chemical compositions of cheese whey are shown in Table 1. The notable characteristic of this effluent was the high COD content.

Table 1: Characteristics and chemical composition of cheese whey from Gela Factory

Characteristic	Unit	Value
COD	mg/l	50000-70000
Lactose	g/l	50-60
TS	g/l	55-65
VS	g/l	49
Proteins	g/l	2.2
Phosphate	g/l	0.6
Ca	g/l	0.02
pH		5.5-6.6

Experimental Set Up: The schematic diagram of the pilot scale UASFF bioreactor is shown in Figure 1. The reactor was fabricated with an internal diameter of 2.76 cm and a height of 160 cm. The total volume of the reactor was 960 ml. The column was randomly packed with seashell. The voidage of the packed bed reactor was 85 percent. A 1000ml funnel shaped gas separator was used to liberate the generated biogas from the effluent and then the gas was led to the gas collector. The gas tank was a cylindrical glass pipe ID 40mm and 1m length. The liberated gas was frequently measured for a fixed HRT and

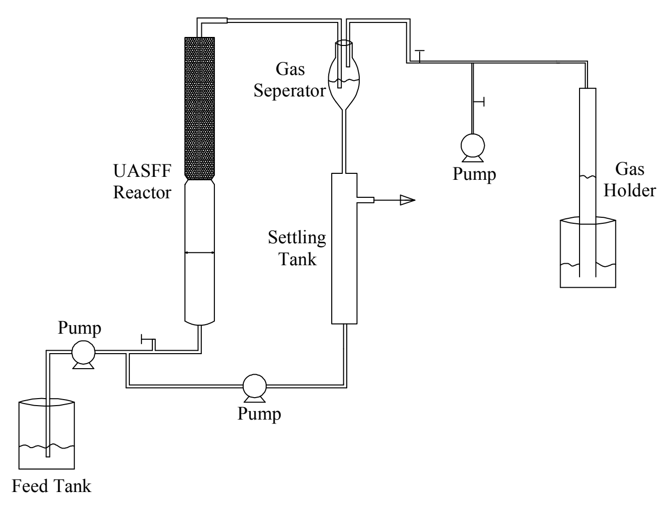

Fig. 1: Schematic diagram of the UASFF bioreactor

the gas volume was recorded with respect to time. The UASFF reactor was operated at a fixed temperature (36°C). The reactor temperature was controlled by external circulation of hot water bath. Cheese whey as a suitable substrate was continuously fed to the reactor using a peristaltic pump (SR25 adjustable flow rate, Thomas, Germany). The feed was introduced from the bottom of the column and it was distributed through the column using a perforated plate. The effluent was collected from the top of the column in a 20 liter polyethylene container.

Reactor Operation: The reactor was inoculated with 500ml seed culture contained anaerobic bacteria originated from the sludge which was originated from the wastewater treatment plant, Gela factory. In order to acclimate the sludge with Cheese whey, the reactor was batchwise fed with diluted cheese whey (7000- 20000 mg COD/l). For the first eight days of operation, the bioreactor was continuously fed in full recycle mode. Then the feed tank was gradually loaded with fresh whey. Continuous feeding the reactor was started with an initial organic loading rate (OLR) of 5 to 15 g COD/l.d and HRT of 24 h. The HRT was maintained constant throughout the start-up period for duration of seven days. The influent COD concentration was 15000 mg/l for the first eight days and then it was stepwise increased near to 60000 mg/l (OLR =11.25 to 45.43 g.COD/l.d) from 5 to 15 days operation. The reactor was continuously operated for 65 days.

Analytical Methods: COD was determined as described by Standard Methods [24]. Lactose and COD values were measured by spectrophotometer, UNICO 2100 (New Jersey, USA). A gas-tight syringe (Hamilton CO., Reno, Nevada, USA) was used to take sample from the gas sampling port. Gas chromatograph (GC) (Perkin Elmer, Auto system XL), equipped with thermal conductivity detector (TCD) and data acquisition system with computer software (Total Chrom), was used for gas composition analysis. A GC column, Carboxen 1000, with 100/120 mesh (Supelco, Park, Bellefonte, PA, USA) was used. The column temperature was initially maintained at 40°C for 3.5 min, followed by automatic temperature increase at a rate of 20°C/min till it reached to 180°C. The injector and detector temperatures were 150 and 200°C, respectively. The carrier gas (He) flow rate was set at 30 ml/min.

Scanning electron microscopy (SEM) was used to examine the external structure of the biofilm. A specimen is bombarded with a scanning beam of electrons and then the slowly moving ''secondary electrons'' are collected, amplified and displayed on the cathode ray tube. The electron beam and the cathode ray tube scan synchronously so that an image of the specimen surface is formed. Specimen preparation for SEM included fixation with 5 percent glutaraldehyde and 1% osmium tetroxide, followed by dehydration with 50-100 percent ethanol before drying, finally to make the specimen conductive to electricity. The sample was examined using a Leo Supra 50 VP Field emission SEM (UK) equipped with Oxford INCA 400 energy dispersive Xray microanalysis system [20].

RESULTS AND DISCUSSION

The UASFF was continuously operated with HRT of 36 and 48 h. The biofilm was fully established on the natural packing (seashell). Sample of the biofilm was scanned and the image was taken by SEM. Figure 2 shows the SEM monogram of the biofilm created by the anaerobic microbial consortia. The magnification scale was from 250 to 10000. The surface of the microbial granules is clearly shown in the image. The active biofilm was fully dominant and covered the packing surface.

Figure 3 depicts the COD removal and pH effluent with respect to start up duration of 27 days. The dash and solid lines are related to effluent pH and COD removal, respectively. The maximum COD removal of 65 percent was obtained in the start up operation.

The biogas production rate with respect to OLR is shown in Figure 4. As the OLR increased, the biogas production rate was increased. Also the data followed the same trend for various HRTs, however the biogas production rate for HRT of 48 h was slightly higher than HRT of 36 h. The maximum values for biogas rates were 3.6 and 3.75 l/d for HRT of 48 and 36 h, respectively. The methane content of the biogas was determined by GC, the molar composition of methane was slightly increased from 68 to 76 percent for HRT of 36 and 48h, respectively.

Figure 5 presents the COD removal and COD removal rate, with respect to OLR. The dash and solid lines are related to COD removal rate and COD removal, respectively. The maximum COD removal was 97.5 and 88 percent for HRT of 48 and 36 h, respectively. For the OLR value higher than 25 g COD/l.d, the COD removal efficiency decreased. However by increasing the OLR, the COD removal rate was also increased.

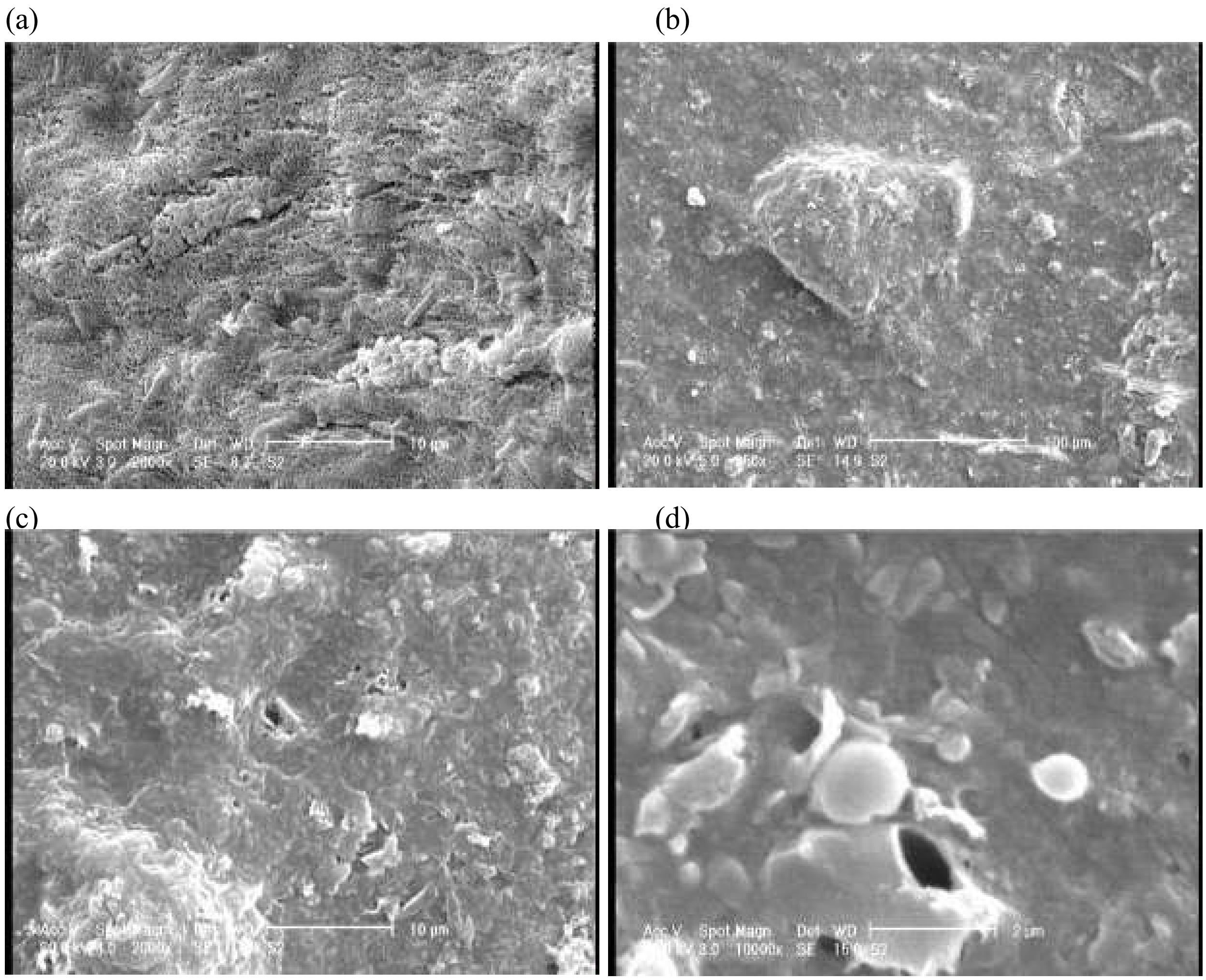

Fig. 2: Biofilm of the microorganisms built on the surface of the packing

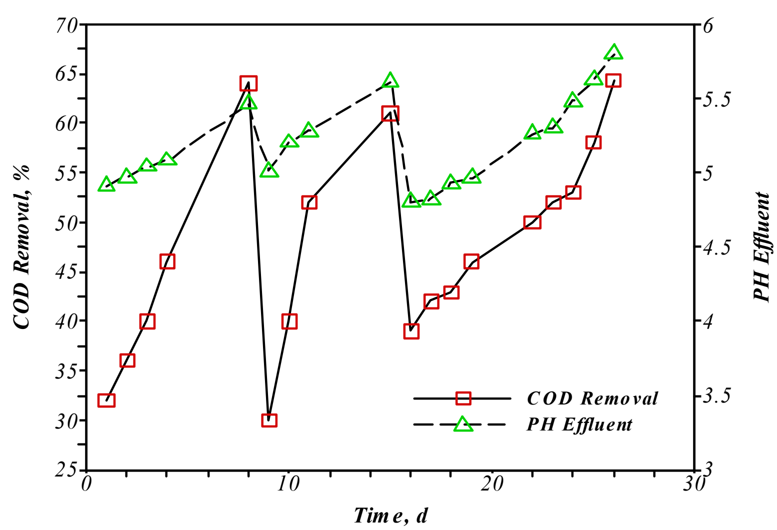

Fig. 3: COD removal and pH effluent

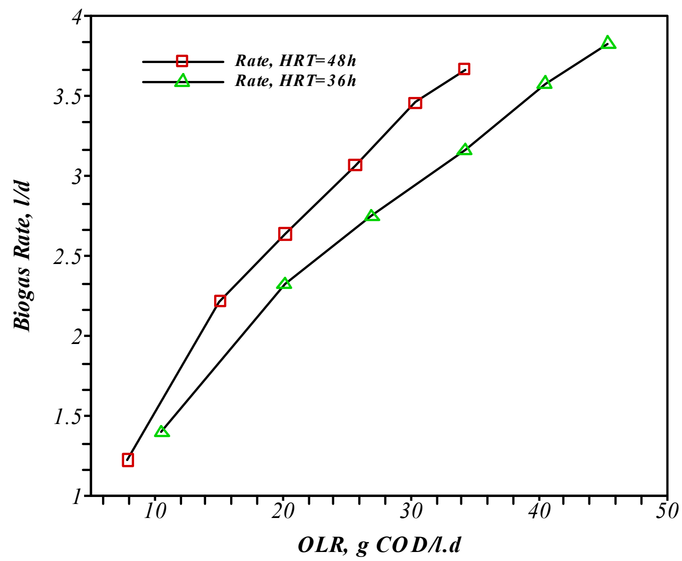

Fig. 4: Biogas production rate

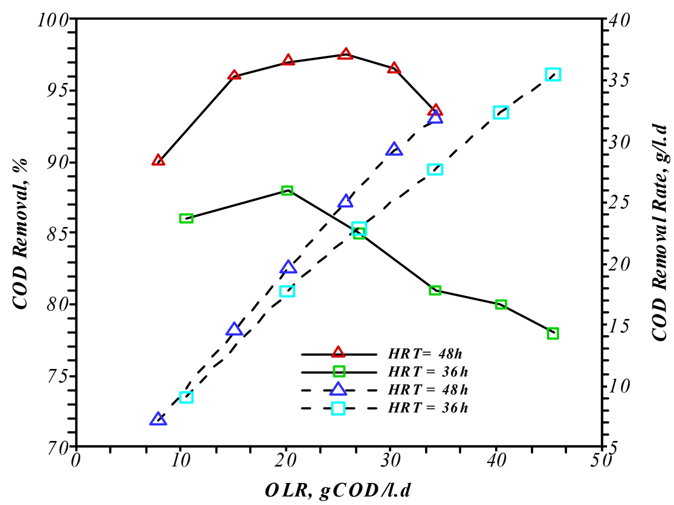

Fig. 5: COD removal and COD removal rate

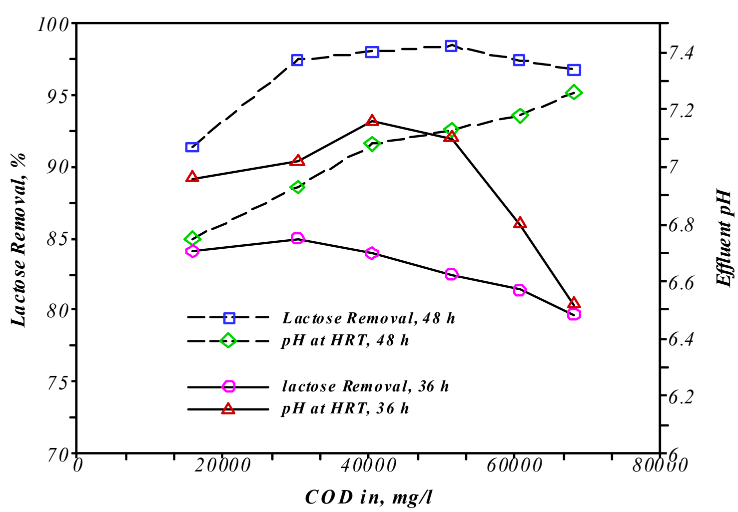

Fig. 6: Lactose conversion and effluent pH

Figure 6 shows the Lactose conversion and effluent pH with respect to inlet COD. The maximum lactose conversions for HRT of 48 and 36 h were 98 and 85 percent, respectively.

CONCLUSIONS

The present investigation was successfully conducted for the biogas production and treatability of the whey using the UASFF bioreactor as a novel film anaerobic bioreactor. The UASFF with high performance was capable to handle the high organic load and the treatment goals were successfully achieved. The use of UASFF reactor was a great strategy to achieve high COD removal efficiency in a short start up period. The reactor was very efficient in the treatment of diluted and high strength whey at high OLR and short HRT. High COD and Lactose removals of 97.5 and 98 percent at HRT of 48 hours were achieved. The highest biogas rate of 3.75 l/d was achieved at HRT of 36 h.

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