H_2 Production and Treatment of Cake Wastewater Industry via Up-Flow Anaerobic Staged Reactor

Manal A. Mohsen, Ahmed Tawfik

***Abstract*—**Hydrogen production from cake wastewater by anaerobic dark fermentation via upflow anaerobic staged reactor (UASR) was investigated in this study. The reactor was continuously operated for four months at constant hydraulic retention time (HRT) of 21.57 hr, PH value of 6 ± 0.6, temperature of 21.1°C, and organic loading rate of 2.43 gCOD/l.d. The hydrogen production was 5.7 l H_2/d and the hydrogen yield was 134.8 ml H_2 /g $COD_{removed}$. The system showed an overall removal efficiency of TCOD, TBOD, TSS, TKN, and Carbohydrates of 40 ± 13%, 59 ± 18%, 84 ± 17%, 28 ± 27%, and 85 ± 15% respectively during the long term operation period. Based on the available results, the system is not sufficient for the effective treatment of cake wastewater, and the effluent quality of UASR is not complying for discharge into sewerage network, therefore a post treatment is needed (not covered in this study).

***Keywords*—**Cake wastewater industry, chemical oxygen demand (COD), hydrogen production (HP), up-flow anaerobic staged reactor (UASR).

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I. Introduction

GREENHOUSE effect resulted from excess carbon dioxide in the atmosphere, is the main concern about global climate. Carbon dioxide directly resulted from fossil fuel combustion from coal-fired power plants or automobiles. Hydrogen is a promising alternative energy source to fossil fuels due to its clean product, which is only water. Moreover, hydrogen has high energy content per unit mass of 120.21 MJ/kg (while CH4 is only 50.2 MJ/kg), which is about 2.75 times greater than that of hydrocarbon fuels, so hydrogen can be directly used in fuel cells for generating electricity [1], [2]. Hydrogen can be generated in a number of ways, such as electrochemical processes, thermo-chemical processes, photochemical processes, photocatalytic processes, or photo-electrochemical processes [3], [4]. But unfortunately, these processes do not achieve both of goals of waste reduction and energy production. In addition, these methods consume large amount of electricity resulting from fossil fuel combustion.

Dark fermentation process or the anaerobic biological hydrogen production, is the most efficient way corresponding to photo fermentation process due to not depending on the availability of light sources [5]. Furthermore, anaerobic process is considered as the most effective technology for the removal of organic compounds not only in domestic wastewater, but also in industrial effluents, and it has different advantages like its relatively low cost technology and producing of useful byproducts [6], [7]. Different studies have been reported that both of mixed and pure culture inoculums are able to produce hydrogen [8], [9].

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Food processing wastewaters are distinguished by their generally high BOD concentrations, high levels of dissolved and/or suspended solids [including fats, oils, and grease (FOG)], nutrients such as ammonia, and minerals (e.g., salts). One or multi stages fermentation systems include batch, semi-continuous, continuous, have been applied for H2 production from food waste [10].

Upflow anaerobic staged (UASR) reactor is simple, economic, and applicable for H2 production from wastes [11]. Moreover, the main advantages of this bioreactor are rapid biodegradation, low yields of sludge, excellent process stability, reduced land area required, and easy construction. Also, Upflow Anaerobic Sludge Blanket (UASB) and anaerobic sequencing batch reactors (ASBR) have been reported to produce high H_2 production rates depending on high reactor biomass concentrations [12].

This study aims to investigate and assess the performance of the UASR reactor for continuous hydrogen production from cake wastewater. Therefore, extensive investigation of the factors affecting hydrogen production rate was accomplished with emphasis on the COD removal and carbohydrate conversion.

II. Material and Methods

A. Cake Wastewater Characteristics

The wastewater was sampled from Ocean Foods, the industry for cake and wafer production in Borg El Arab City, Egypt. It was characterized by appreciable pollutant load, noticeable amounts of suspended matter and high concentrations of total chemical oxygen demand. The characteristics of the wastewater are presented in Table I.

B. Experimental Setup of the Pilot Scale

Fig. 1 shows a novel schematic diagram of the up-flow anaerobic staged reactor (UASR) manufactured from Perspex material with a pyramid shape at the bottom, fed with cake wastewater. Up-flow anaerobic staged reactor (UASR) has a working volume of 42 liters, and its dimensions are (23 cm × 22.4cm × 89.7 cm) for length, width, and height respectively. To achieve longer contact time between hydrogen producing bacteria and substrate, inclined baffles was designed along the height of the reactor.

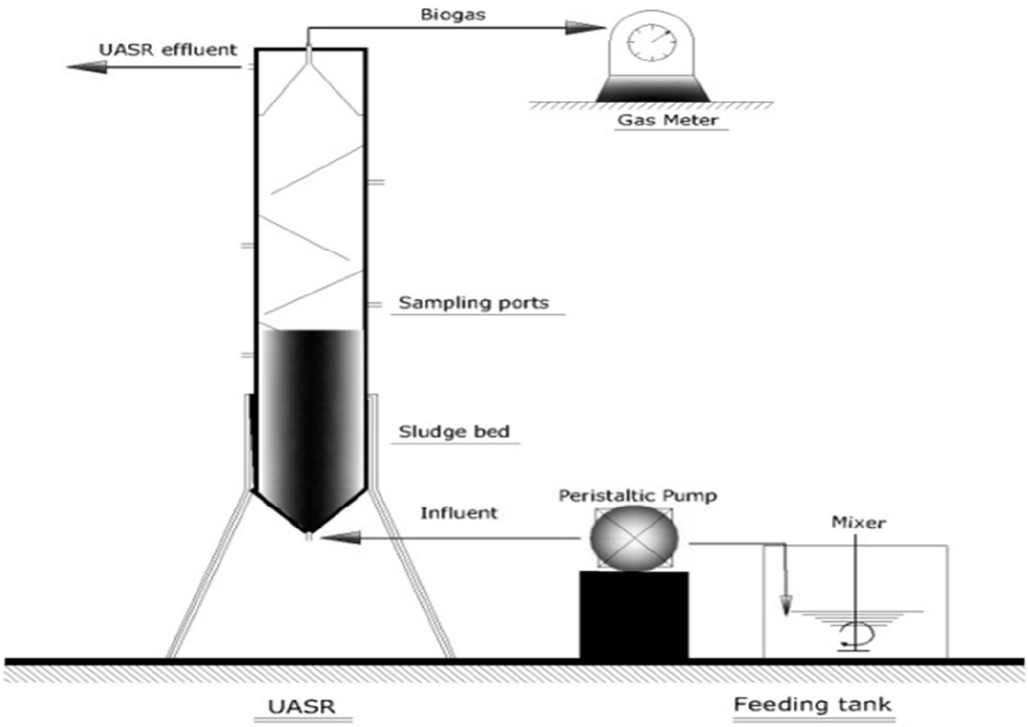

Fig. 1 Schematic diagram for the experimental setup of UASR fed with cake wastewater

TABLE I
CHARACTERISTICS OF THE CAKE WASTEWATER USED IN THE EXPERIMENTS

Parameters	Unit	Value
Total COD	mg/L	2185 ± 339
Soluble COD	mg/L	1237.9 ± 443.6
Particulate COD	mg/L	947.4 ± 100
Total BOD	mg/L	523 ± 90.9
Soluble BOD	mg/L	194.6 ± 40.5
Particulate BOD	mg/L	328.4 ± 92
Total Carbohydrate	mg/L	875.3 ± 90
Soluble Carbohydrate	mg/L	82.5 ± 10
Particulate Carbohydrate	mg/L	792.8 ± 100
Total VFAs	mg/L	400 ± 70
NH4-N	mg/L	28.5 ± 17.2
TKj-N	mg/L	52.1 ± 4.5
PH	-	5.5 ± 0.8
TSS	mg/L	1634.6 ± 943.6
VSS	mg/L	1496 ± 979.5

COD: Chemical Oxygen Demand; TSS: Total Suspended Solids, and VFAs: Volatile Fatty Acids.

TABLE II
OPERATIONAL CONDITIONS OF UASR TREATING CWW

Parameters	Unit	Value
Flow rate	L/hr	1.96
HRT	hr	21.57
OLR	gCOD/l.d	2.43
PH	-	6.5
HLR	cm3/cm2.d	5.77
TSS	mg/l	210

C. Operational Conditions

Cake wastewater flows from the feeding stock towards an opening in the bottom of UASR reactor by using peristaltic pump operate with flow rate of1.96 l/h. During all the experimental period, the organic loading rate and hydraulic retention time were kept constantat2.43 gCOD/l.d and 21.5 h respectively. Table II summarize the operational conditions of UASR reactor. Before starting operation of UASR reactor, it was inoculated with 15 l sludge obtained from El-Agamy domestic wastewater treatment plant (WWTP). To inactivate methanogenic bacteria, pre-heated of inoculums sludge was performed at 90 C for 20 minutes.

D. Analysis and Method

Three times per week analysis were carried out on grab samples at certain time of raw wastewater and of the effluent from UASR system. COD fractions (CODt, CODs and CODp); BOD fractions (BODt, BODs and BODp); TSS; VSS; total Kjeldhal nitrogen (TKj-N); Ammonia and nitrate were measured according to [13] APHA (2005).Soluble COD (CODs) and Soluble BOD (BODs) was determined by filtration using0.45 µm membrane. Particulate COD (CODp) was calculated by the difference between CODt and CODs respectively. Measuring of carbohydrate concentration was achieved according to the phenol– sulfuric acid method, using glucose as the standard [14]. Protein was calculated as (6.26 × organic nitrogen) [15].

III. Results and Discussion

A. Organic Removal Performance

Fig. 2 shows the results of the removal efficiency of CODt, CODs, and CODp for UASR reactor, treating cake wastewater during the operation period at HRT = 21.57 hr. The removal efficiency was 40 ± 13 % and 39 ± 21 % for CODt and CODs respectively. For BODt, the efficiency of the removal was found 59 ± 18% and for BODs of 41 ± 11%. Total Carbohydrate removal efficiency was 83 ± 13%, and for soluble carbohydrate the removal efficiency was 50 ± 25%. TSS and VSS removal efficiency was 84 ± 17% and 87 ± 19% respectively at the same operational conditions Fig. 3.

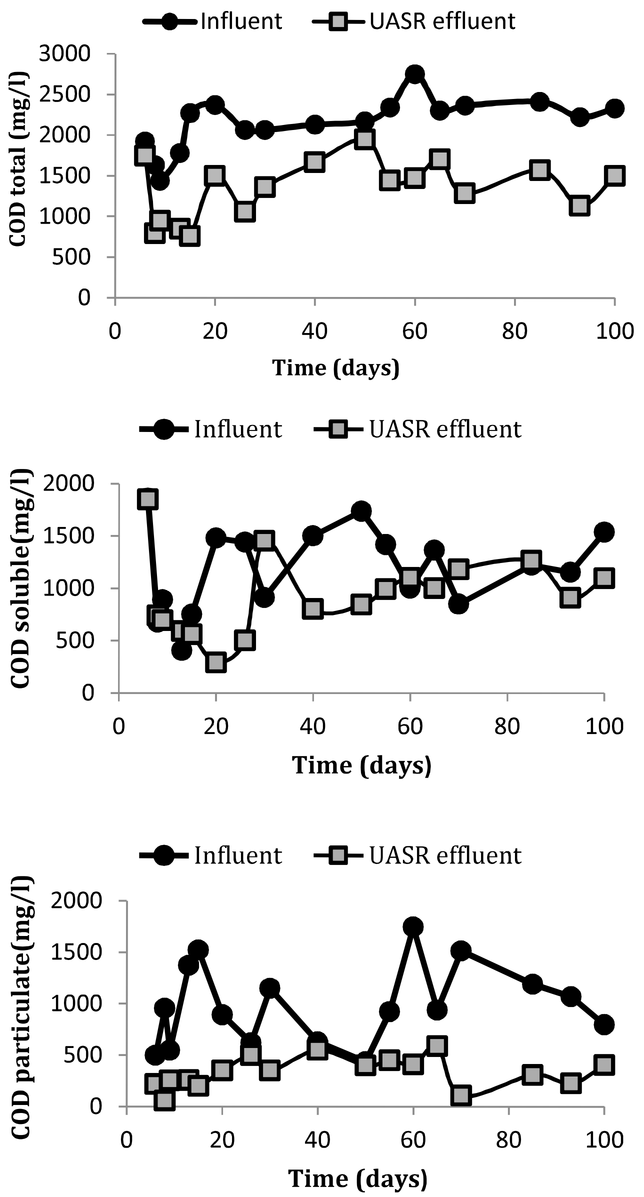

Fig. 2 Time course of Influent and effluent COD fractions (Total, soluble, particulate) for UASR

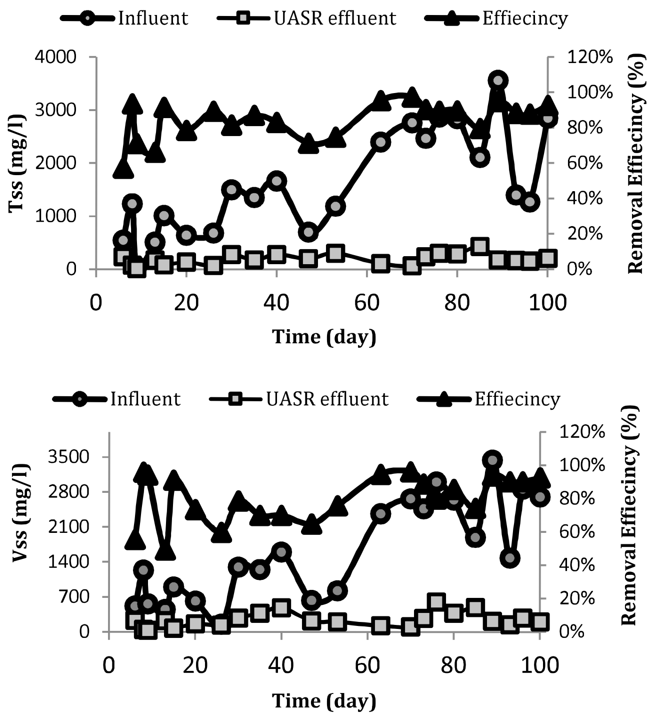

Fig. 3 Time course of Influent and effluent TSS and VSS association with the removal efficiency for UASR

B. Volatile Fatty Acids (VFAs)Generation and pH Drop of the UASR

Volatile fatty acids are one of the most important parameters indicating bio-hydrogen production from the dark fermentation of organic substrates [16], [17]. Fig. 4 shows an increase in VFAs from 370 ± 49 mg/l to 466.8 ± 76.5 mg/l, accompanied with a slight drop in PH from 6.8 ± 0.8 to 6.3 ±0.6 during the operating period of the experimental work. A previous study reported that the optimum PH range for bio-hydrogen production was from 5.5 – 6.0 [18], however, the optimum pH values of bio- hydrogen production differ significantly among studies (pH 4–7).

C. Hydrogen Yield and Hydrogen Production

Fig. 5 shows hydrogen yield and its association with the values of the removed COD. Clearly, Portion of COD was converted to VFAs to increase the H2 production. The average hydrogen production obtained at the UASR in this study was observed as 5.7 l H2/d, and the hydrogen yield was 134.8 ml H2 /g $COD_{removed}$.

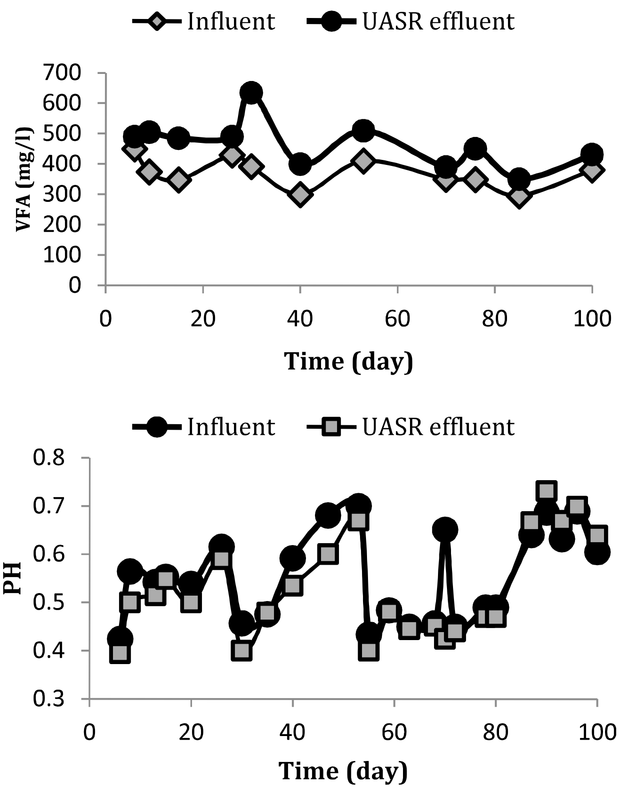

Fig. 4 PH and VFAs sequence of the influent and effluent from UASR reactor during the operation period

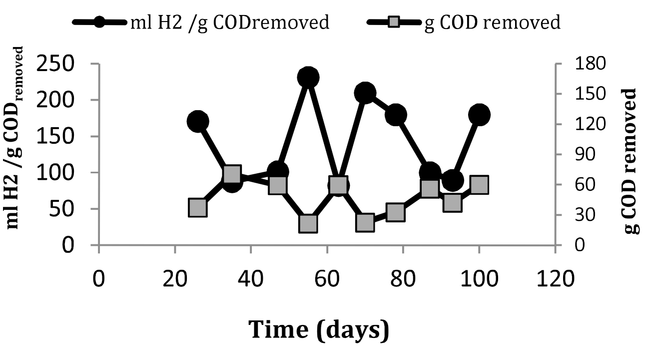

Fig. 5 Hydrogen yield and its association with the values of the removed COD during the operation period

IV. Conclusion

The performance of the UASR reactor for continuous hydrogen production from cake wastewater was investigated. Bio-hydrogen was successfully produced from cake wastewater via up-flow anaerobic staged reactor (UASR) reactor, thus, hydrogen yield (HY) and hydrogen production were 134.8 ml H2 /g $COD_{removed}$ and 5.7 l H2/d respectively. The results obtained in this study showed that the removal efficiency of CODt was 40 ± 13%, and 39 ± 21% for CODs at HRT of 21.57 hr. An increase in VFAs from 370 ± 49 mg/lto 466.8 ± 76.5 mg/l, accompanied with a drop in PH from 6.8 ± 0.8 to 6.3 ± 0.6 during the operating period of up-flow anaerobic staged reactor (UASR). The performance of the UASR reactor for continuous hydrogen production from cake wastewater was investigated. Bio-hydrogen was successfully produced; thus, hydrogen yield (HY) and hydrogen production were 134.8 ml H2 /g $COD_{removed}$ and 5.7 l H2/d respectively. The results obtained in this study showed that the removal efficiency of CODt was 40 ± 13%, and 39 ± 21% for CODs at HRT of 21.57 hr. An increase in VFAs from 370 ± 49 mg/l to 466.8 ± 76.5 mg/l, accompanied with a drop in PH from 6 ± 0.8 to 5.5 ± .6 during the operating period of up-flow anaerobic staged reactor (UASR) was observed.

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