

EFFECTS OF ORGANIC LOADING ON PERFORMANCE OF AEROBIC FLUIDIZED USING DILUTED PALM OIL MILL EFFLUENT

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Received: Apr 18, 2006; Revised: Aug 17, 2006; Accepted: Sept 13, 2006

Abstract

Biological treatment using sand as supporting material on a fluidized bed reactor (FBR) was set up in the laboratory for the treatment of wastewater from Palm Oil Mill industries, which contains high strength organic compounds, COD of about 52,308 mg/l. An acclimatized *Saccharomyces cerevisiae* with POME was used as the initial biomass for the FBR. After 5 days, 92% BOD removal was achieved in a batch experiment. Ninety five percent removals of COD were obtained with 12 h HRT. High surface COD loading of 4.70 - 10.82 kg COD/m³/day was implemented. Eighty five percent TKN, 94% SS, and 95% VSS removal were obtained in the bench scale FBR. The maximum reduction of turbidity for 12 h of HRT was 90%.

Keywords: Fluidized bed reactor, POME, *Saccharomyces cerevisiae*, attached growth

Introduction

The purpose of wastewater treatment plants is to remove pollutants from the wastewater streams so that the treated effluent is safe to be discharged into the environment. It is common in most industrial wastewaters that the suspended solids are generally removed by physical treatment, such as screening, grit removal chamber, floatation and sedimentation units, but the dissolved solids must be physically, chemically and/or biologically treated (Rodriguez *et al.*, 2000). Biological wastewater treatment processes are classified as either attached growth or suspended growth.

Palm oil is an important crop in Malaysia. Approximately 11.9 million tonnes of crude palm oil (CPO) were produced that amounted to RM 14.8 billion in the year 2002 (Malaysia Palm Council, 2003). The process to extract the oil requires significantly large quantities of water for steam sterilizing the palm fruit bunches and clarifying the extracted oil. It is estimated that for each 1 tonne of crude palm oil produced, 5.0 - 7.5 tonnes of water are required, and more than 50% of the water will end up as palm oil mill effluent (POME). Thus, while enjoying a most profitable commodity, the adverse

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environmental impact from the palm oil industry cannot be ignored.

POME has a colloidal suspension of 95 - 96% water, 0.6 - 0.7% oil and 4 - 5% total solids including 24% suspended solids originating from the mixture of a sterilizer condensate, separator sludge and hydrocyclone wastewater (Abdul latif *et al.*, 2003). The raw or partially treated POME has an extremely high content of degradable organic matter, which is due in part to the presence of unrecovered palm oil. This highly polluting wastewater can therefore cause severe pollution of waterways due to oxygen depletion and other related effects (Abdul latif *et al.*, 2003). In order to regulate the discharge of effluent from the crude palm oil industry as well as to exercise other environmental controls, the Environmental Quality Order, 1977, and the Environment Quality Regulations, 1977, were promulgated under the Environmental Quality Act, 1974 (Department of Environment Malaysia, 1999).

Due to these factors, the palm oil industry faces the challenge of balancing environmental protection, its economic viability and sustainable development. There is an urgent need to find a way to preserve the environment while keeping the economy growing.

Several innovative treatment technologies have been developed and applied by palm oil mills to treat POME; conventional biological treatments of anaerobic or facultative digestion are the most commonly used (Quah *et al.*, 1982; Shaw *et al.*, 2002). However, this biological treatment system needs proper maintenance and monitoring as the processes rely solely on microorganisms to break down the pollutants. The microorganisms are very sensitive to changes in the environment and thus great care has to be taken to ensure that a conducive

environment is maintained for the microorganism in which to thrive. The biological treatment system also generates vast amount of biogas containing methane, carbon dioxide, and trace amounts of hydrogen sulphide. These gases are corrosive and odorous; the treated wastewater cannot be reused in the plant and has to be discharged into the environment.

Several high rate anaerobic reactor configurations have been developed for treating wastewaters at relatively short hydraulic retention times. Of these, the fluidized bed reactor (FBR) has been one of the technological advances, which has successfully employed in a broad spectrum of wastewaters including both readily and hardly biodegradable wastes (Hickey and Owens, 1981; Denac and Dunn, 1988; Mahdavi *et al.*, 2001). No study has been reported using FBR in POME wastewater treatment. Table 1 provides summaries of the performance of different systems treating POME as reported in the literature.

Therefore, the aim of this study was to investigate the performance and treatment of Palm Oil Mill Effluent (POME) as a high strength wastewater in a FBR. To achieve this purpose, aerobic FBR with sand as supporting material was used.

Materials and Methods

Palm Oil Source

Palm Oil Mill Effluent (POME) collected from Rantau, Negeri Sembilan was used as feed. The raw palm oil mill effluent was collected directly by using sealed polythene containers and then kept in a refrigerator at 4°C. Concentrated feed was diluted to obtain the desired chemical oxygen demand (COD) concentration. The raw

Table 1. Performance of different anaerobic systems treating Palm Oil Mill Effluent

Anaerobic system	Influent COD (mg/l)	OLR gCOD/l/d	HRT	Removal Rates, %	References
Tropical marine yeast	250,000	-	2 days	99%	Osawal <i>et al.</i> , 2002
Two stage UASB	30,000	60	0.9 days	90%	Rafael <i>et al.</i> , 1996
Rotating Biological Contractor	16,000	38-210	55 h	88%	Ghasem <i>et al.</i> , 2005

POME samples were characterized and the result of the analyses is given in Table 2.

Experimental Set up

A laboratory scale fluidized bed reactor was designed and set up to investigate the effects of the aerobic treatment of Palm oil mill effluent (Figure 1). The reactor was made of a clear acrylic column with 80 mm in diameter, 75 cm in height, and had a volume of 3.75 liters. The expanded section acted as a solid settling chamber. It had a diameter of 150 mm with a volume of 2.32 liters base on liquid phase volume. The conical flow distributor supplies a uniform fluidization a long the height of the column and has a volume of 0.12 liters. The untreated POME was fed with the volumetric flow rates of 12.48, 18.72, and 37.20 l/d. The high strength of organic compounds in POME was diluted to COD of 2,338 mg/l and fed to the FBR. The samples were taken for analysis for each volumetric flow rate after two times of corresponding retention time, based on the steady state assumption.

Media and Biomass Loading

Sand having a diameter of 0.5 - 0.8 mm was used as the media. The height of the sand in the reactor is 25 cm. Small gravel (2-cm height) was placed at the reactor bottom to provide uniform flow distribution and prevent backflow of the media. The sand was fluidized during experiments and the gravel remained stationary. In the start up of the FBR the seed culture of *S. cerevisiae* was selected because it has rapid growth on POME environment and also eliminates a long duration for start up of the

process. Batch experiments were conducted in 20 BOD bottles and BOD measurements. A 24 h incubated cultured medium was used as inoculums for a large volume and was introduced into the FBR system. After a biofilm of the organisms was developed on the sand medium an additional 24 h of incubation secured the system for sufficient biofilm formation and cell growth. FBR was used in continuous mode of POME treatment in all experiments. A special strain of yeast was isolated from non penicillinic wastewater to produce and tolerate a high concentration of ethanol. After acclimation of the specified yeast with POME, small amounts of supplementary nutrients were provided for maximum cell growth. Petri-dishes of cultures were provided to monitor the dominant micro-organisms.

Analytical Method

Liquid effluents were analyzed according to Standard Methods for Examination of Water and Wastewater (APHA, 1998). The following parameters were determined, pH, Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), volatile suspended solids

Table 2. Characteristics of raw POME

Parameter	Concentration (mg/l)
COD	52,308
TS	41,530
BOD ₅	25,701
TSS	17,547
VSS	12,281
Oil and grease	4,750
TKN	450
pH	4.48

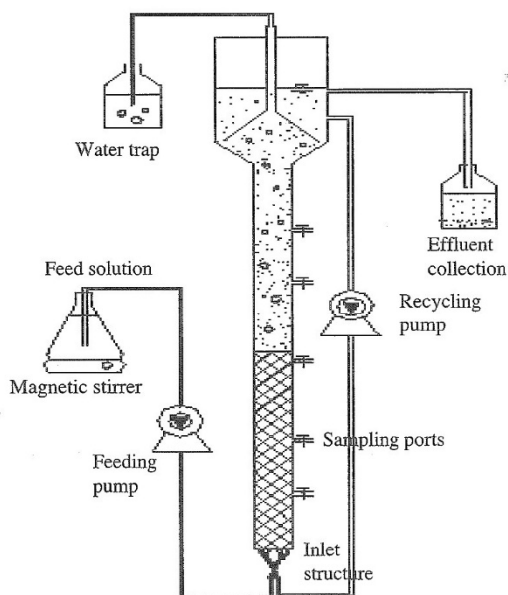


Figure 1. Schematic diagram of fluidized bed reactor

(VSS), total suspended solids (TSS), settle able solids, total Kjeldal nitrogen (TKN), and turbidity.

A spectrophotometer (Cecil 1000, Cecil Instrument, Cambridge, England) at 600 nm was used to measure the absorbance of COD samples. A semi-micro Kjeldahl method was used for total Kjeldahl nitrogen. The dissolved oxygen concentration in wastewater was monitored with a DO probe. A DO meter was supplied by WTW DO Cell OX 325, electro DO probe, Germany. The pH meter model 320 from WTW (Germany) was used to measure pH. Turbidity was also measured by a turbidity meter model Turbo 350IR, WTW (Germany). BOD and all other routine tests followed the Standard Methods (APHA, 1998).

Results and Discussions

The characteristics of the treated Palm Oil Mill effluent are presented in Table 3. The treated POME is brown thick waste, the final concentration of COD and BOD was 116.9 and 55.44 mg/l respectively. The total nitrogen content of the treated POME sample was 12.5 mg/l (Table 3). One of the newly developed techniques for the treatment of POME is continuous treatment by using attached growth microbial film on a biological fluidized bed reactor (FBR). Based on special criteria of the attached-growth process, FBR retains very high biomass, therefore it has the capacity to treat high strengths of influent and it can also tolerate high organic and hydraulic shocks.

In the first 5 days of operation, the yeast cell was the dominant microorganism. In the

second week of operation, the habitat of the biofilm gradually changed. A rod-shape bacillus appeared in the biofilm. The gradual transition of microorganisms in the biofilm did not show any significant changes in the course of POME treatment.

The fluidized bed reactor was started up successfully with seed sludge at 12 h HRT as shown in Figure 2. A previous start up using long HRT had failed. This is probably because at long HRT, biomass in anaerobic fluidized reactor grows partly in suspension and partly as a biofilm i.e. the suspended bacteria are mainly acidogens and most of the methanogens bacteria are attached to the surface of the carrier (Balaguer *et al.*, 1991). At short HRT, the suspended bacteria are washed out, and the growth occurs mainly in attached form and the start-up of the reactor is faster (Balaguer *et al.*, 1991). Usually one month is long enough to make sure that steady state biofilms are reached.

Figure 2 shows that during the first 20 days of the start up period, there is only 35% in COD reduction, after 31 days, the COD reduction increased to 60% and the reactor had achieved a steady state condition with 88% reduction in COD after 33 days for organic loading rate held at 4.34 - 4.80 kg COD/m³/d and HRT at 12 h.

The bed expansion was 15% during the start-up period. It was increased to and kept between 30% and 35% in the operation period which is in the typical range reported in the literature (Stronach *et al.*, 1987; Balaguer *et al.*, 1991).

Figure 3 shows that by increasing COD surface loading rate, the FBR efficiency of COD

Table 3. Characteristics of treated POME and its respective standard discharge limit by the Malaysian Department of the Environment (Hanif, 1994)

Parameter	Treated POME (mg/l)	Standard limit (mg/l)
COD	116.90	150
BOD	55.44	100
TSS	45.87	400
Oil and grease	45.00	50
TKN	12.50	150
VSS	9.15	-
pH	7.44	5-9

removal gradually decreased. The decline in FBR efficiency from 95% to 80% was the result of increasing the COD surface loading rate from 4.70 to 10.82 kg/COD/m³/day. The rate of COD removal significantly increased at low surface loading with an increase of HRT from 4 to 12 h, while at very high surface loading the rate slightly decreased with HRT. The maximum COD removal efficiency obtained was 95% with HRT of 12 h. The biological treatment of POME in FBR was successfully conducted in the bench scale.

Figure 4 shows the BOD of POME in batch experiments. The BOD was gradually reduced after 5 days and the BOD removal in 5 days was 92%. The BOD removal curve showed that nitrification started after 5 days and resulted from carbon source depletion. The DO level at early stage was 10.4 mg/l, and then at 5 days the

DO decreased to 4.2 mg/l. The DO level remained constant after 5 days.

SS removal and removal rate with respect to solid loading are shown in Figure 5. The percentage of SS removal was slightly decreased (94 - 82%), while the solid loading was increased (1.5 - 3.5 KgSS/m³/day). The rate of SS removal was strictly dependent on the solid loading, as the loading increased the rate was also increased.

The nitrogen content of untreated POME was very low. TKN reduction was successfully achieved in POME treatment in the FBR. Figure 6 shows TKN removal and removal rate with respect to nitrogen loading rate. The nitrogen loading increased as the HRT was decreased. The trend of TKN reduction was similar to SS removal. The maximum TKN removal at 12 h of HRT was 85%. A slightly

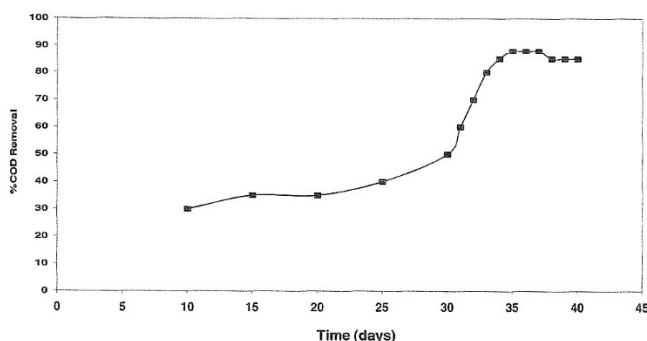


Figure 2. Starting up of the anaerobic fluidized bed reactor. (HRT = 12 h; OLR = 5 kg COD/m³/d)

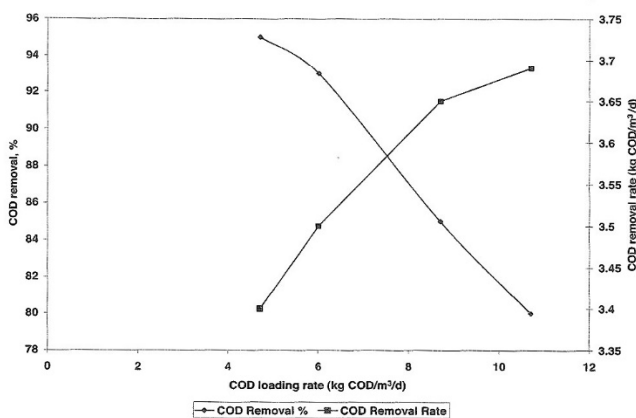


Figure 3. COD removal rate and COD removal, %

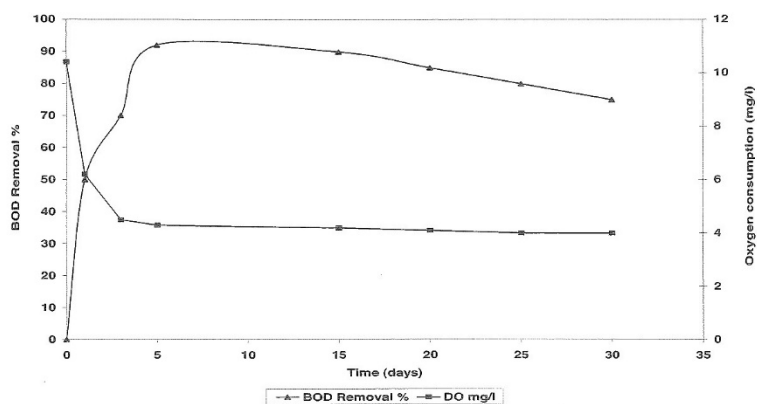


Figure 4. BOD removal, % and oxygen consumption

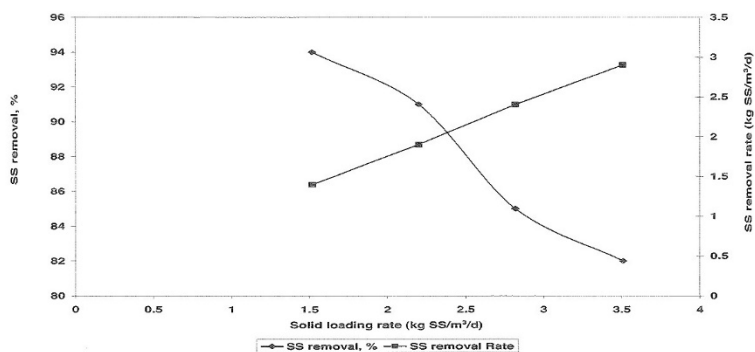


Figure 5. SS removal, % and SS removal rate

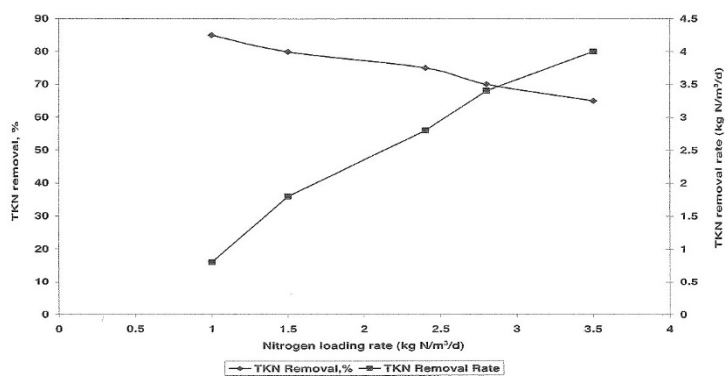


Figure 6. TKN removal and TKN removal rate

decrease in TKN removal rate was observed with an increase in the nitrogen loading rate.

The turbidity of the settled treated POME with various HRT was measured. The retention time in the settling tank was 1 h. Turbidity removal and reduction of solid loading rate with respect to HRT is shown in Figure 7. The maximum reduction of turbidity for 12 h of HRT was 90%.

The percentage of VSS removal and the removal rate with respect to volatile suspended solid loading rate are shown in Figure 8. The percentage of VSS removal was decreased from 95 to 85, while the volatile suspended solid loading was increased from 1.16 to 2.76 KgVSS/m³/d. The rate of VSS removal was strongly dependent on the volatile suspended solid loading, as the loading increased, the rate was also increased.

Conclusion

Continuous laboratory scale FBR resulted in the successful treatment of POME. About 95%

COD was removed with the lowest flow rate of 12.48 l/d of POME. When the flow rate was increased to 37.20 l/d, the COD decreased to 80%. It has been concluded that the initial biomass loading and the fixing of biofilm of *S. cerevisiae* on the surface of the sand media in the FBR significantly improved the treatment of POME, after 5 days of operation. The population of *S. cerevisiae* gradually decreased and other dominant bacteria were replaced. TKN reduction was successfully conducted even with low nitrogen content of POME.

Appendix A

FBR	fluidized bed reactor
COD	biochemical oxygen demand
BOD	biological oxygen demand
POME	palm oil mill effluent
H	hour
HRT	hydraulic retention time
TKN	total Kjeldal nitrogen
SS	suspended solid
VSS	volatile suspended solid
DO	dissolved oxygen

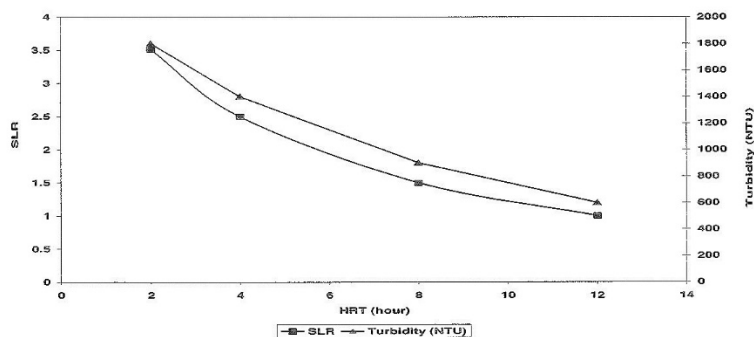


Figure 7. Solid loading rate and turbidity of settled effluent vs HRT

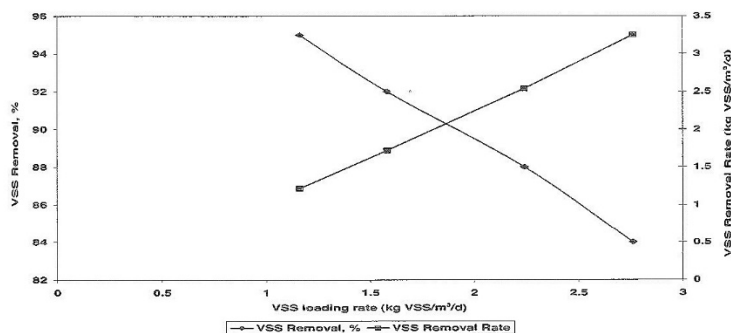


Figure 8. VSS removal, % and VSS removal rate

NTU	nephelometric turbidity unit
SLR	solid loading rate
TSS	total suspended solid
RM	ringgit Malaysian

References

- Abdul Latif, A., Suzylawati I., and Subhash, B. (2003). Water recycling from palm oil mill effluent (POME) using membrane technology. *Desalination*, 157:87-95.
- APHA. (1998). *Standard Methods for the Examination of Water and Wastewater*. 20th ed. American Public Health Association, Washington, D.C., 1200 p.
- Balaguer, M.D., Vicent, M.T., and Paris, J.M. (1991). Utilization of pumice stone as support for the anaerobic treatment of vinasse with a fluidized-bed reactor. *Environ. Technol.*, 12:1,167-1,173.
- Denac, M. and Dunn, I.J. (1988). Packed-bed and fluidized bed biofilm reactor performance for anaerobic wastewater treatment. *Biotech. Bioeng.*, 32:159-173.
- Department of Environment Malaysia. (1999). *Industrial processes and the environment, Crude Palm Oil Industry. Handbook No. 3:5-10*.
- Ghasem N., Hii A.Y., Habibollah, Y., and Aliakbar, Z. (2005). Effect of organic loading on performance of rotating biological contactors using Palm oil mill effluents. *Process Biochemistry*, 40:2, 879-2,884.
- Hanif, J. (1994). Environmental management on Palm oil and rubber waste. *Proceedings of 2nd International Conference on Biological Processes in Pollution Control*. Kuala Lumpur, p. 98-103.
- Hickey, R.F., and Owens, R.W. (1981). Methane generation from high strength industrial wastes with the anaerobic biological fluidized bed. *Biotech. Bioeng Suppl.*, 11:399-413.
- Kapdan, I.K., and Sabiha, A. (2005). Application of anaerobic-aerobic sequential treatment system to real textile wastewater for colour and COD removal. *Enzyme and Microbial Technology*, 36:273-279.
- Mahdavi, A., Donnelly, T., and Anderson, G.K. (2001). Colour removal from a simulated dye wastewater using a two-phase anaerobic packed bed reactor. *Water Research*, 35(2): 425-432.
- Malaysia Palm Oil Promotion Council. (2003). *Anaerobic treatment of palm oil mill effluent in a two-stage up-flow anaerobic sludge blanket (UASB) system*. Kuala Lumpur. Available from: www.mpopc.org.my. Accessed date: January 2003.
- Oswal, N., Sarma, P.M., Zinjarde, S.S., and Pant, A. (2002). Palm oil mill effluent treatment by a tropical marine yeast. *Bioresource Technology*, 85:35-37.
- Quah, SK., Lim, K.H., Gillies, D., Wood, B.J., and Kanagaratnam, J. (1982). Practical experience in production and use of biogas. *Proceedings of Regional Workshop on Palm Oil Mill Technology and Effluent Treatment*, PORIM, Kuala Lumpur, p. 193-200.
- Rafael, B., Charles, J.B., and Enrique, S. (1996). Anaerobic treatment of palm oil mill effluent in a two-stage up-flow anaerobic sludge blanket (UASB) system. *J. of Biotechnol.*, 45:125-135.
- Rodriguez-Roda, I., Poch, M., and Banares-Alcantara, R. (2000). Conceptual design of wastewater treatment plants using a design support system. *J. Chem. Technol. Biotechnol.*, 75:73-81.
- Shaw, C.B., Carliell, C.M., and Wheatley, A.D. (2002). Anaerobic/aerobic treatment of coloured textile effluents using sequencing batch reactors. *Water Research.*, 36: 1,993-2,001.
- Stronach, S.M., Diazbaez, M.C., Rudd, T., and Lester, J.N. (1987). Factors affecting biomass attachment during startup and operation of anaerobic fluidized-beds. *Biotech. Bioeng.*, 30:611-620.