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ANAEROBIC FLUIDIZED BED TREATMENT OF PALM OIL MILL EFFLUENT

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ANAEROBIC FLUIDIZED BED TREATMENT OF PALM OIL MILL EFFLUENT

By

ABDULLAH-AL-MAMUN

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LIST OF ABBREVIATIONS

AFBR : Anaerobic fluidized bed reactor.

b : Bacterial decay rate.

BOD : Biochemical oxygen demand.

BBLR : Biological loading rate in terms of BOD.

BOLR : Organic loading rate in terms of BOD.

C : Carbon.

cc : Cubic Centimetre.

CBLR : Biological loading rate in terms of COD.

C_c : Coefficient of gradation.

C_d : Drag coefficient.

C_u : Uniformity coefficient.

COD : Chemical Oxygen Demand.

COLR : Organic loading rate in terms of COD.

D : Diameter of any reactor.

d : Average film thickness.

D_{10} : Sieve aperture through which 10% of the material passes.

D_{30} : Sieve aperture through which 30% of the material passes.

D_{60} : Sieve aperture through which 60% of the material passes.

DBLR : Biological loading rate in terms of TDS.

D_m : Diameter of the model AFBR.

DOLR : Organic loading rate in terms of TDS.

D_p : Diameter of the pilot plant AFBR.

d_p : Average particle diameter.

d_t : Diameter of the fluidized bed.

E : Effluent.

e : Bed porosity with biofilm.

e_0 : Bed porosity without biofilm.

Efflu. : Effluent.

Eqn. : Equation.

η : Efficiency (%).

Fig. : Figure.

G : Biogas.

Ga : Galileo number.

g/l : Gram per litre.

H : Height of any reactor.

h : Height of media with biofilm.

H_{bp} : Static bed height of the pilot plant AFBR.

H_{mp} : Static bed height of the model AFBR.

h_0 : Height of media without biofilm.

HRT : Hydraulic retention time.

I : Influent.

Influ. : Influent.

k : Maximum substrate utilization rate.

K_d : Microbial decay coefficient.

KPa : KiloPascal.

K_s : Half velocity constant.

l : Litre.

L_e : Effective depth of biofilm.

MJ : MegaJoul.

MPa : MegaPascal.

μ : Microbial growth rate

mg/l : Milligram per litre.

N : Nitrogen.

n : Bed expansion.

O&G : Oil and Gas.

OLR : Organic loading rate.

P : Phosphorus.

POME : Palm oil mill effluent.

R : Recycle.

R1, R2, ...: Operation numbers or steady states.

Re_t : Reynolds number based on u_t.

Re_m : Minimum fluidization Reynolds number.

r^2 : Coefficient of correlation.

RR : Removal rate.

ρ_{bd} : Biomass dry density.

ρ_{bw} : Biomass wet density.

ρ_f : Fluid density.

ρ_p : Particle density.

SBLR : Biological loading rate in terms of total solids.

S_e : Effluent substrate concentration.

S_{eC} : Predicted effluent COD by Contois model.

S_{eCH} : Predicted effluent COD by Chen and Hashimoto model.

S_{eM} : Predicted effluent COD by Monod model.

S_i : Influent substrate concentration.

SL : Sludge wastage.

S_m : Minimum substrate concentration for microbial survival.

S_o : Substrate concentration in bulk fluid.

SOLR : Organic loading rate in terms of total solids.

S_s : Substrate concentration in the biofilm surface.

SRT : Solid retention time.

STP : Standard temperature nad pressure.

SVI : Sludge volume index.

t : Time.

TBLR : Biological loading rate in terms of TSS.

TDS : Total dissolved solids.

θ : Hydraulic retention time (HRT).

θ_c : Solids retention time (SRT).

θ_{cm} : Minimum cell retention time.

TN : Total Nitrogen.

TOLR : Organic loading rate in terms of TSS.

TP : Total Phosphorus.

TS : Total solids.

TSS : Total suspended solids.

u : Superficial velocity.

U : Substrate utilization rate.

u_t : Terminal velocity of any particle.

U_m : Minimum fluidization velocity.

V_a : Applied upflow velocity.

V_b : Volume of biofilm.

VBLR : Biological loading rate in terms of VSS.

V_{bu} : Biomass volume per unit volume of expanded bed.

VFA : Volatile fatty acid.

VOLR : Organic loading rate in terms of VSS.

VSS : Volatile suspended solids.

V_m : Volume of unseeded media.

V_s : Volume of seeded media.

X : Reactor biomass concentration.

x : Reactor biomass concentration in terms of VSSper unit volume of expanded bed.

w_{bu} : Reactor biomass weight in terms of VSS per unit volume of expanded bed.

Y : Yield coefficient.

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ANAEROBIC FLUIDIZED BED TREATMENT OF PALM OIL MILL EFFLUENT

By

ABDULLAH-AL-MAMUN

October 1997

Chairman: Dr. Azni bin Idris

Faculty: Engineering

A 2 m^3 pilot scale anaerobic fluidized bed reactor (AFBR) was designed, constructed and operated to study its ability to treat high-strength industrial wastewater, at ambient temperature. Besides performance evaluation, kinetic coefficients of three models were determined. Reactor response to pH shock load was also carried out.

An early start-up of 17 days was experienced with diluted palm oil mill effluent (POME) of 2000 mg/l COD. The hydraulic retention time (HRT) was reduced step wise from 24 hr to 4 hr which resulted in volumetric loading rates of 4.0 kgCOD/m^3.d to 13.8 kgCOD/m^3.d respectively. Maximum COD removal efficiencies achieved at those loading rates were between 65% and 85%. BOD and TSS removal rates were varied in the range of 64% - 91% and 68% - 89% respectively. The raw substrate was rich in nitrogen nutrients and 17% to 55% of total nitrogen could be removed. Optimum HRT for the

COD removal was found to be 12 hour, which was much less than that of conventional tank digester system. Reactor performance was found to be a function of loading rate, which decreased steadily with the increased loading rates.

The AFBR exhibited low sludge production with sludge volume indices (SVI) of between 11 l/mg and 35 l/mg. General kinetic coefficients for Monod, Contois and Chen & Hashimoto's models were b = 0.23, Y = 0.79, μ_m = 4.63 and K = 2.47. Specific coefficients for Monod's model were k = 1.22 and K_s = 577, and for Contois' model, B = 0.05 and u_m = 0.86. The pilot plant exhibited good buffering ability when pH shock load of 5.0 was imposed on the AFBR.

Performance comparison with two other smaller AFBRs revealed that, plant efficiency decreases by 10% - 20%, perhaps due to poor control over the system, with the increase in reactor size. Superiority and suitability of AFBR over other systems were justified by comparing with existing treatment facilities. Promising performance at ambient temperature and at HRT shorter than the conventional practice supported the feasibility of AFBR to treat high strength palm oil mill effluent.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Master Sains.

PERAWATAN EFLUEN KILANG KELAPA SAWIT DENGAN REAKTOR LAPISAN TERBENDALIR (FLUIDIZED BED) ANAEROBIK

Oleh

ABDULLAH-AL-MAMUN

Oktober 1997

Pengerusi: Dr. Azni bin Idris

Fakulti: Kejuruteraan

Reaktor lapisan terbendalir (fluidized bed) anaerobik (AFBR) 2 m^3 berskala perintis telah direka, dibina and digunakan untuk mengkaji kemampuannya merawat air sisa industri yang berkepekatan tinggi, pada suhu persekitaran. Selain daripada menilai kemampuannya, koefisien-koefisien kinetik bagi tiga model telah ditentukan. Tindakbalas reaktor terhadap beban kejutan pH turut dikaji.

Kajian permulaan (start-up) dalam tempoh 17 hari telah diperolehi dengan efluen kilang kelapa sawit (POME) yang dicairkan kepada 2000 mg/l COD. Masa tahanan hidraul (HRT) telah dikurangkan secara berperingkat (step wise) dari 24 jam hingga 4 jam dan masing-masing menyebabkan kadar beban organik di antara 4.0 kgCOD/m^3.d dan 13.8 kgCOD/m^3.d. Kecekapan pengurangan COD maksimum yang didapati pada kadar-kadar tersebut adalah di antara 65% dan 85%. Kadar pengurangan BOD dan TSS

masing-masing merangkumi julat di antara 64% - 91% dan 68% - 89%. Substrat mentah adalah kaya dengan nutrien nitrogen dan 17% hingga 55% daripada jumlah nitrogen ini telah dapat dikurangkan. HRT optimum untuk pengurangan COD didapati dalam masa 12 jam yakni lebih rendah daripada sistem tangki penghadaman biasa. Kecekapan reaktor merupakan fungsi kadar beban, iaitu penurunannya secara beransur-ansur dengan pertambahan kadar beban.

AFBR menghasilkan enapcemar dan skum yang sedikit dengan indeks isipadu enapcemar yang rendah, pada 11 l/g hingga 35 l/g. koefisien-koefisien kinetik am bagi model Monod, Contois, serta Chen & Hashimoto adalah b=0.23 day^{-1}, Y=0.79 VSS/COD, μ_m=4.63 day^{-1} and K=2.47. Koefisien spesifik untuk model Monod adalah k=1.22 COD/VSS dan K_s=577 mg/l, dan untuk model Contois, B=0.05 dan u_m=0.86 day^{-1} Kebolehan penampan yang baik didapati pada loji perintis bila AFBR menerima beban kejutan pH 5.0.

Perbandingan skala dengan dua buah AFBR yang lain yang kecil mendapati bahawa kecekapan proses berkurangan sebanyak 10% - 20%, kemungkinan disebabkan oleh kelemahan kawalan ke atas system, dengan pertambahan saiz reactor. Kebolehan dan kesesuaian AFBR mengatasi sistem-sistem yang lain dapat dijustifikasikan melalui bandingan dengan cara rawatan sediaada. Kemampuannya yang begitu menyakinkan pada suhu persekitaran serta HRT yang lebih singkat daripada amalan biasa kebanyakan kilang, menyokong alasan mengguna AFBR dalam rawatan efluen berkepekatan tinggi secara besar-besaran.

CHAPTER I

INTRODUCTION

Treatment of wastewater (domestic and industrial) can be performed by primary, secondary and tertiary methods. Over the past three decades, a wide variety of treatment technologies have been studied, developed and applied for pollutant removal from the concerned wastewater. Although not all processes are applicable to handle each type of wastewater, biological unit processes are being widely applied to abate the pollution concentration from them. Anaerobic treatment of industrial wastewater is, by now, a well established technology, and has been proven to be the cheapest and versatile method for a wide range of applications (Borghans et al., 1986). New process innovations like high-rate filtration, fluidized bed (Heijnen et al., 1991), up-flow sludge blanket (Lettinga et al., 1979) and hybrid reactors (Reynolds and Colleran, 1988) have already emerged as today's most viable anaerobic treatment technologies.

Anaerobic fluidized bed reactors (AFBRs) have been used for wastewater treatment since early 1970s. Promising features of the AFBRs are the capability of treating low and high strength wastewater at both ambient and elevated temperatures (Bull et al., 1983; Jewell et al., 1981) for a minimum energy, with minimum sludge production and ability to tolerate shock loads in terms of organic loading rates (OLRs), pH and temperature without any substantial long term detrimental effects. Most of the studies on fluidized beds are performed in aerobic conditions and for nutrient removals (Hermanowicz and Cheng, 1989). Therefore, an improved and better understanding of the kinetics, response to shock load, process efficiency of an AFBR for different substrates is still required. Overall performance of an anaerobic fluidized bed reactor in treating palm oil mill effluent (POME) was evaluated in this study.

Objective of the Study

In order to understand the process performance of an anaerobic fluidized bed reactor (AFBR), palm oil mill effluent (POME) was used as the substrate. Easy availability, established study of waste constituents, appreciable biodegradability with no potential toxicity, together with the strength of POME were the key features for selecting this agro-industrial effluent as a substrate for the AFBR pilot plant. The overall objective of this research project was to study the performance of an AFBR pilot plant for a better understanding of the process itself for a new substrate - POME. More specifically:

- to study the start-up of the AFBR treating POME;
- to evaluate the influence of loading rate (OLR) on reactor performance;
- to evaluate nutrient content in POME before and after treatment;
- to determine kinetic coefficients for biological modelling of the AFBR;

- to study the effect of reactor size on reactor performance;
- to comment on the feasibility of full scale AFBR to treat palm oil mill effluent in ambient temperature.

Characteristics of the Substrate

As far as high strength wastewater is concerned, palm oil mill effluent is termed to be highly concentrated in terms of generated organic loading or volume. Its high solid content makes the treatment method costly and relatively complex. Various types of solids, semisolids and liquid wastes are generated from different steps of oil processing. In practice, all these wastes are bulked, a situation which gives a yellowish liquor containing both dissolved and fine suspended matter and residual oil with very high BOD and COD. The slightly acidic wastewater consists of about 90-95% water, 5-10% solids (roughly half in solution and the rest in suspension) and 0.5-1% residual oil and grease (Ma et al., 1993). The major contributor to this effluent is 10% protein, 12% fibre, 20% fatty materials, 11% ash and 47% nitrogen-free extract (Ma et al., 1993).

General characteristics of raw POME necessary for any biological treatment are summarised in Table 1.

Table 1

General characteristics of POME

Parameter	Hwang, 1978	Chin, 1981	Ma, 1992	Kam, 1995	This study
BOD	20000	26222	25000	34000	31240
COD	47500	62934	50000	62000	59700
TSS	10000	26456	18000	37000	30230
VSS	30000	22149	34000	26000	25300
O & G	-	-	6000	-	8000
TN	-	1000	750	-	1940
TP	300	294	-	-	268
pH	-	4.1	4.2	4.3	4.5

(Note: Except pH all units are in mg/l.)

Significance of the Study

High energy requirement for aerobic treatment, together with huge sludge and CO_2 generation, helped researchers pay attention to anaerobic digestion. Anaerobic digestion has played a significant role in high strength wastewater treatment technology for almost a century. To make this process more effective, new approaches are being designed to improve conventional anaerobic digestion. Among the latest unit processes, Anaerobic Fluidized Bed Reactor (AFBR) is being treated as a prospective researchable treatment method. This recent innovation is already accepted as an efficient method to handle high strength wastewater in many parts of the world (Wheatly, 1990). However, still there is lack of enough study conducted in order to draw conclusion on the commissioning of AFBR to treat POME more efficiently. Naturally, the significance of this type of research project is very obvious as long as the palm oil mill effluent remains as one of the most polluting source, not only in Malaysia, but also in other palm oil producing countries.

Present Practices

Wastewater treatment methods can be broadly categorised as physical, chemical, biological and thermal. There are several techniques that can be used to accomplish these latter methods; some are old, others are modern. Most of the time, combinations of treatment methods are implied to take care of the wastewater. In Malaysia, more than 85% of palm oil mills are practising ponding system as a method of their wastewater treatment (Ma and Ong, 1987). Most of the ponds are anaerobic; others are facultative or aerobic. Starting from recently, many industries have began upgrading their present treatment facilities with the introduction and combination of digesters or reactors.

Application of the Study

Like the up-flow anaerobic sludge blanket reactor (UASBR), AFBR is also accepted as an efficient high-rate wastewater treatment process. Different sizes and shapes of AFBRs are in vogue in the UK, Germany, Holland, Spain, France, Italy, Belgium, USA and in other countries around the world (Frankin et al., 1992; Coombs, 1990; Wheatley, 1990; Jewell et al., 1981; Switzenbaum and Jewell, 1980). Since full