ORIGINAL ARTICLE

Oxygen enriched air using membrane for palm oil wastewater treatment

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Abstract

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A research aimed to explore new method of aeration using oxygen enriched air performance on BOD reduction of palm oil wastewater was conducted. The oxygen enriched air was obtained from an Oxygen Enriched System (OES) developed using asymmetric polysulfone hollow fiber membrane with composition consisting of PSF: 22%, DMAc: 31.8%, THF: 31.8%, EtOH: 14.4%. Palm oil wastewater samples were taken from facultative pond effluent. These samples were tested for its initial biochemical oxygen demand (BOD), total suspended solids (TSS), pH, conductivity, turbidity, dissolved oxygen (DO), suspended solids (SS), and total dissolved solids (TDS) before being subjected to two modes of aeration system, that is diffused air and oxygen enriched air. These water quality concentrations were tested for every 20 minutes for two-hour period during the aeration process. Results of BOD, TSS, pH, conductivity, DO, SS and TDS concentrations against time of samples from the two modes of aeration were then compared. It was found that DO concentration achieved in oxygen enriched air aeration was better than aeration using diffused air system. Aeration using OES improve the DO concentration in the wastewater and thus improve the BOD reduction and also influence other physical characteristics of wastewater. This phenomenon indicates the advantage of using air with higher oxygen concentration for wastewater aeration instead of diffused air system.

Key words : oxygen enriched system, hollow fiber membrane, biochemical oxygen demand, dissolved oxygen

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The major uses of aeration in wastewater treatment plant include pre-aeration, aerated grit removal, grease floatation, aerobic biological treatment (activated sludge, aerated lagoons, aerobic digestion, and a variety of aerobic fixed-film processes), and post aeration (Aeration A Wastewater Treatment Process, 1988). Aeration process involved air, oxygen-enriched air or pure oxygen being introduced into several wastewater treatment unit processes designed for contaminants removals. These contaminants are the one that exert oxygen demand; they are carbonaceous biochemical oxygen demand, nitrogenous biochemical oxygen demand and inorganic chemical oxygen demand.

There are several types of aeration systems used for wastewater treatment. These systems were used depending on the function to be performed such as the type and geometry and cost to install and operate the system (Tchobanoglous, *et al.,* 2003). The commonly used are diffused-air system, mechanical aeration system and high-purity oxygen system. However, this study was carried out to investigate the application of newly developed aeration system known as Oxygen Enriched Air System (OEAS). The OEAS is able to enriched oxygen in the air by passing normal air through an asymmetric polysulfone hollow fiber membranes. Details of the system are described in the later section in this paper.

The main aim of this study was to determine the effect of aeration using diffused air and oxygen enriched air from the newly developed system on the characteristics of palm oil wastewater. Based on the experimental data, the feasibility of oxygen enriched air used in aeration for palm oil wastewater treatment will be determined.

Background of palm oil wastewater treatment

Currently palm oil wastewater is being treated using several combination or modified unit operations and processes to form a wastewater treatment system, which suited the requirements of palm oil mill under consideration. Faisal and Unno (2001) recently studied the kinetic analysis of palm oil mill wastewater treatment by a modified anaerobic baffled reactor (MABR) under steady state conditions for treating palm oil mill wastewater. They found that methane gas production was in the range of 0.32 – 0.42 – CH_4 (g- COD)$^{-1}$ removed; which corresponded to the methane content of 67.3 – 71.2 % within the range of examined hydraulic retention time (HRT) of 3 – 10 days. The removal ranges of COD and grease/oil were from 87.4 to 95.3% and from 44.1 to 91.3% respectively. The total volatile fatty acid production was 1450 mg/l at HRT of 3 days and gradually decreased to 608 mg/l at 10 days HRT. Based on the experimental data, a kinetic model was discussed (Faisal and Unno, 2001). However this study will be focusing on the aeration of palm oil wastewater when subjected to diffused air and oxygen enriched air and its effects on the wastewater quality.

Oxygen transfer

Oxygen transfer, the process by which oxygen is transferred from the gaseous to the liquid phase, is a vital part of a number of wastewater treatment processes. The functioning of aerobic processes, such as activated sludge, biological filtration, and aerobic digestion depends on the availability of sufficient quantities of oxygen. Oxygen can be supplied by means of air or pure-oxygen bubbles introduced to the water to create additional gas-water interfaces (Tchobanoglous, 2003).

An abundant oxygen supply in wastewater pond system is the key to rapid and effective wastewater treatment. Oxygen or oxygen-enriched air is needed by the bacteria to allow their respiration reactions to proceed rapidly and satisfy the biochemical oxygen demand in biological treatment processes or to act as an agent in the oxidation of undesirable contaminant (Water pollution Control, 1971; Water Pollution Control Federation and American Society of Civil Engineering, 1994). The oxygen is combined by the bacteria with carbon to form carbon dioxide. Without the present of sufficient oxygen, bacteria are not able to quickly biodegrade the incoming organic matter and degradation must occur under septic conditions, which are slow, odorous and yield incomplete conversion of pollutants. In addition, when under septic condition, some of the carbon will react with hydrogen and sulfur to form sulfuric acid and methane. Whereas, other carbon will be converted to organic acids that create low pH conditions in the ponds and make water more difficult to treat. For example, treated ponds designed to biodegrade wastewater pollutants without oxygen often must hold the incoming sewage for six months or longer to achieve acceptable levels of pollution removal. This is because the biodegradation of organic matter in the absence of oxygen is very low kinetic process (Hammer, and Hammer, 1996; Gibbon, 1974; Eckenfelder, 1989). Aerobic decomposition in wastewater treatment can be represented by Figure 1.

From Figure 1, organic matter and nutrients are impurities present in wastewater which need to be treated by their decomposition that will be carried out by the microorganisms. These microorganisms require dissolve oxygen to stabilize he impurities used for their growth and reproduction and at the same time will release carbon dioxide and water. Concentration of dissolve oxygen in the wastewater can be control by aeration.

The two basic reasons of aerating wastewater are (1) to introduce air or pure oxygen into the wastewater with submerged diffusers or other aeration devices or (2) to agitate the wastewater mechanically so as to promote solution of air from the atmospheres. By doing this the dissolved oxygen concentration can be maintained more than 2 mg/l at all time so as to promote biological reaction to take place in the reactor.

Oxygen enriched air system

The typical schematic arrangement of oxygen enriched air system is shown in Figure 2. The system typically consists of air compression, pretreatment, air separation and wastewater aeration sections. The overall system was installed with the standard measuring instruments and equipments, and the whole system was using join stainless steel fittings and tubing. The fabricated oxygen enrichment system is very easy to operate and suitable for lab scale testing. In addition, this system is applicable to low purity oxygen enrichment applications (Kiong, 2003).

Ambient air was used as a feed gas for air separation. A *Puma* Compressor (1) was used to compress the ambient air into the system. Air was typically compressed to pressures in the order of 155.14 cmHg gauge to 517.15 cmHg gauge (30 to 100 psig). Pressure ranges were controlled by a *Koganei* regulator (3). The compressed air was passed through several pre-treatment parts, such as air filter (4), carbon dioxide trap (5), and moisture trap (6), to remove undesired substances such as large particles, compressor oil, carbon dioxide and moisture from the air feed stream (2). The undesired substances were extracted from the system in order to avoid product purity being contaminated. In addition, this undesired product could affect the system's operation conditions (Kiong, 2003).

The newly developed system can be operated either in co-current and countercurrent flow patterns. Due to the higher efficiency of the countercurrent flow pattern in air separation (Hammer and Hammer, 1996 ; Narinsky, 1991 ; Thundyil and Koros, 1997), the system was operated in countercurrent flow. In this configuration, air was delivered and fed at shell and the permeate

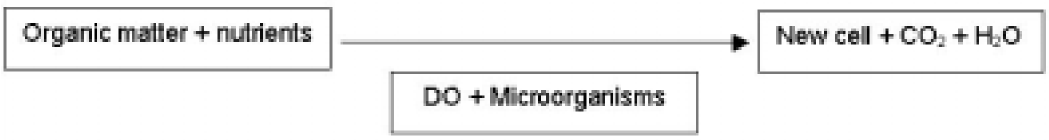


Figure 1. Aerobic process in wastewater treatment

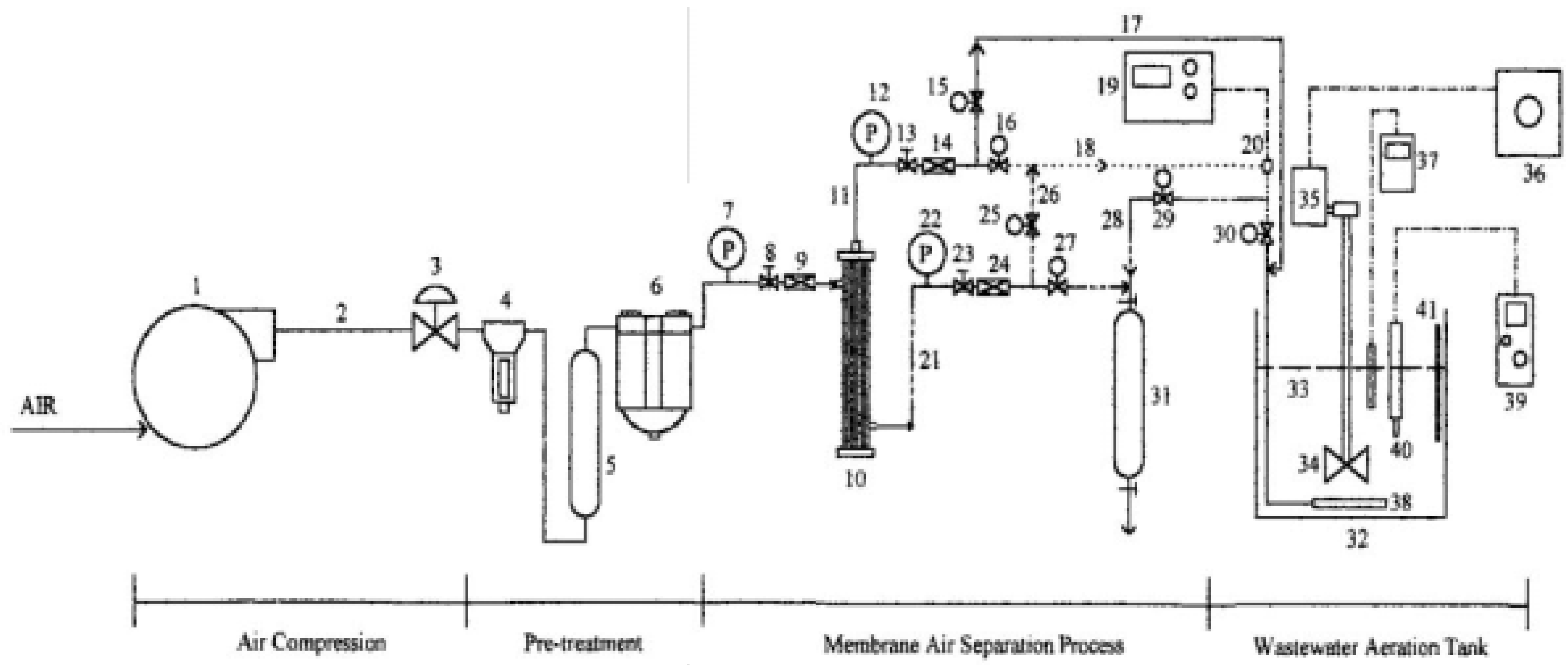


Figure 2. Schematic diagram of combination membranes oxygen enrichment system and wastewater aeration tank.
(1) Compressor; (2) Air feed stream; (3) Air regulator; (4) Air filter; (5) Carbon dioxide trap; (6) Moisture trap; (7) Feed pressure gauge; (8) Feed flow control valve; (9) Feed flow indicator; (10) Hollow fiber membrane module; (11) Permeate stream 1; (12) Permeate pressure gauge; (13) Permeate flow control valve; (14) Permeate flow indicator; (15, 16) Ball valve; (17) Permeate stream 2; (18) Share way; (19) Oxygen Analyzer; (20) Oxygen membrane probe; (21) Retentate stream 1; (22) Retentate pressure gauge; (23) Retentate flow control valve; (24) Retentate flow indicator; (25) Ball Valve; (26) Retentate stream 2; (27) Ball valve; (28) Retentate stream 3; (29, 30) Ball valve; (31) Sampling cylinder; (32) Wastewater aeration tank; (33) Wastewater; (34) Stirrer); (35) Motor; (36) Motor controller; (37) pH meter; (38) Diffuser; (39) Dissolved oxygen meter; (40) Dissolved oxygen probe; (41) Thermometer. (Kiong, C.F.; 2002)

stream was collected at the bore side of hollow fibers. Pressure and flow rate of pretreated air were measured with *Wika* pressure gauge (7) and *Dwyer* flow indicator (9). In the membrane module, air separation process occurred and air is separated into two streams, viz., oxygen enriched-air and nitrogen enriched-air.

Tests were carried out to verify the feasibility of the oxygen enrichment system in wastewater aeration system. Two processes, viz. aeration using compressed air and aeration with oxygen-enriched air, have been compared. The para-meters observed in this experiment include BOD, pH, conductivity, DO, turbidity, SS, TDS, and temperature.

Experimental set – up

Preparation of wastewater sample

Samples were taken by grab sampling from the facultative pond effluent at Bukit Besar Palm Oil mill, Kulai, Johor, Malaysia. Currently the wastewater treatment plant of this palm oil mill consist of an anaerobic pond, two facultative ponds and one aerobic pond. Raw sewage from the mill will enter the anaerobic pond. Its HRT was in the range 45 to 60 days. In this anaerobic pond it was expected that the BOD reduction would be reduced from 25,000 ppm to 2,000 ppm. Effluent from anaerobic pond will then enter facultative ponds and will be retained for another 20 days. Effluent from the facultative ponds will enter the aerobic pond before finally discharged into a nearby river. The HRT in aerobic pond was 7 days.

Aeration process

Two five-liter samples were placed in two separate containers. The wastewater was then aerated with diffused air and oxygen enriched air at a rate of 1 l/min concurrently for two hours. These wastewater samples were tested for their initial characteristic which involves parameters such as BOD, DO, TSS, pH, conductivity, turbidity, TDS and temperature before being subjected to the two modes of aeration mentioned earlier. During the 120 minutes of aeration process, samples were taken from the two containers for every 20 minutes interval. These aerated wastewater samples were then tested for BOD, DO, TSS, pH, conductivity, turbidity, TDS and temperature. Aeration set up for oxygen enriched air aeration and diffused air aeration are represented by Figure 3a and Figure 3b.

Results and Discussion

The removal of dissolved and particulate carbonaceous BOD and the stabilization of organic matter found in wastewater are accomplished biologically using a variety of microorganisms, principally bacteria. Microorganisms

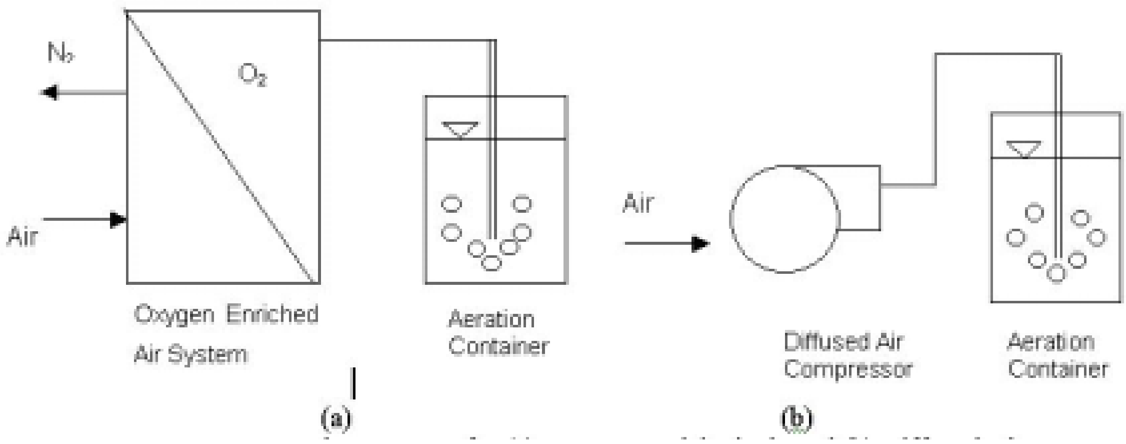


Figure 3. Aeration systems for (a) Oxygen Enriched Air and (b) Diffused Air

are used to oxidized the dissolved and particulate carbonaceous organic matter into simple end products and additional biomass, as represented by the following equation for the aerobic biological oxidation of organic matter (Tchobanoglous, *et al.*, 2003) and can be illustrated by Figure 4.

In addition, the equation reveals that the availability of dissolved oxygen in the wastewater is very crucial because it can affect the microorganism's activities efficiency. Thus affecting the efficiency of biological treatment process of wastewater. To investigate the efficiency of wastewater treatment subjected to the two modes of aeration mentioned earlier, several water quality parameters were measured and summarized in Table 1.

Comparison of changes between water quality parameters taken from the two aeration systems were made and illustrated in Figure 5 (a), (b), (c), (d) and (e). Whereas Figure 6 (a) and (b), summarizes the behavior of each water quality parameter in the two reactors when subjected to aeration by Oxygen Enriched Air System and Diffused Air System for the period of two hours.

Figure 5 (a), (d) and (e) shows that the turbidity in both aerated reactor increases but the biochemical oxygen demand and total dissolved solids decreases respectively. At time 120 minutes after aeration the turbidity in OEAS increases by 15.7% and 15.3% in DA. Whereas the total dissolved solids concentration decreased by 45.3% in OEAS and 36.3% in DA at time 80 minutes after aeration. The biochemical oxygen demand concentration in OEAS and DA decreases by 29.1% and 22.8% respectively after 120 minutes aeration. The increase in turbidity and decrease in total dissolved solids and biochemical oxygen demand concentration were due to the production of new cell and the consumption of dissolved substrate during the biological process. This phenomena explained that the efficiency of biological degradation in OEAS is better than DA.

Figure 5(b) showed that the dissolved oxygen concentration was increased about 77.1% in both aeration system when compared to the dissolved oxygen saturation standard, i.e at tem-

Table 1. The summary of the results

Time	Oxygen Enriched Air								Diffused Air							
(min) 0	Temp °C	BOD_3, 30°C, mg/l	pH	Cond. MS	DO mg/l	Turb. FAU	TSS mg/l	TDS mg/l	Temp °C	BOD_3, 30°C, mg/l	pH	Cond. mS	DO mg/l	Turb. FAU	TSS mg/l	TDS mg/l
0	20.8	1053.33	11.6	6.7	1.0	1326	1.16	452.0	20.8	1053.33	11.2	6.7	1.0	1327	1.16	452.0
20	20.8	461.54	11.3	7.3	5.1	1357	1.56	416.0	20.8	969.23	11.3	7.2	5.1	1275	-0.2	428.0
40	20.8	1046.15	11.3	7.4	6.7	1382	0.9	425.0	20.8	1046.15	11.3	7.4	6.5	1370	0.96	432.0
60	20.8	1015.38	11.3	7.4	7.0	1427	0.74	214.0	20.8	1076.92	11.3	7.5	7.1	1406	0.94	298.0
80	20.8	1030.77	11.4	7.5	7.6	1447	1.08	248.0	20.8	830.77	11.3	7.6	7.5	1439	0.76	288.0
100	20.8	853.33	11.7	7.7	6.6	1514	1.16	NA	20.8	933.33	11.7	7.7	7.0	1490	0.2	NA
120	20.8	746.67	11.7	7.7	7.0	1575	1.12	NA	20.8	813.33	11.6	7.8	7.2	1566	0.97	NA

$$v_1(\text{organic matter}) + v_2O_2 + v_3NH_3 + v_4PO_4^{3-} \rightarrow v_5(\text{new cells}) + v_6CO_2 + v_7H_2O$$

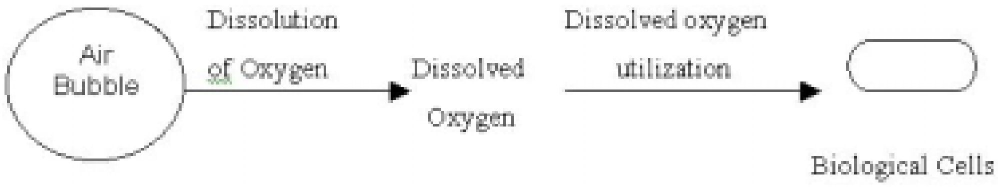
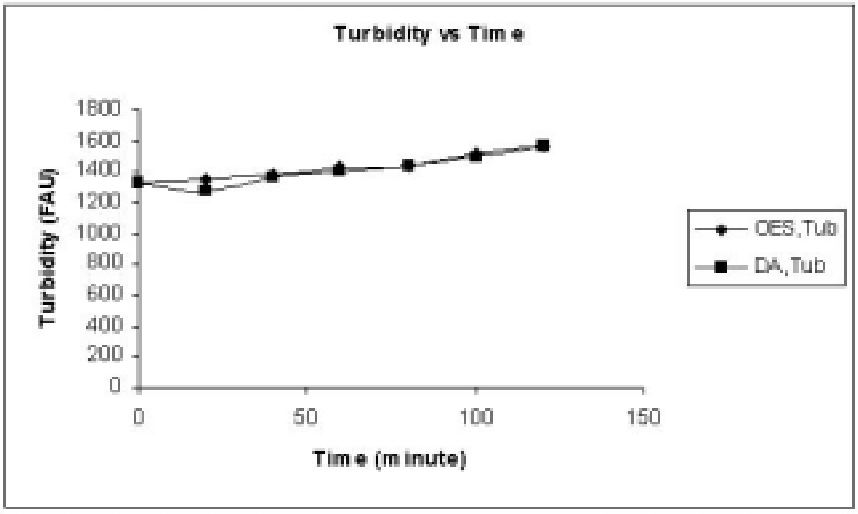
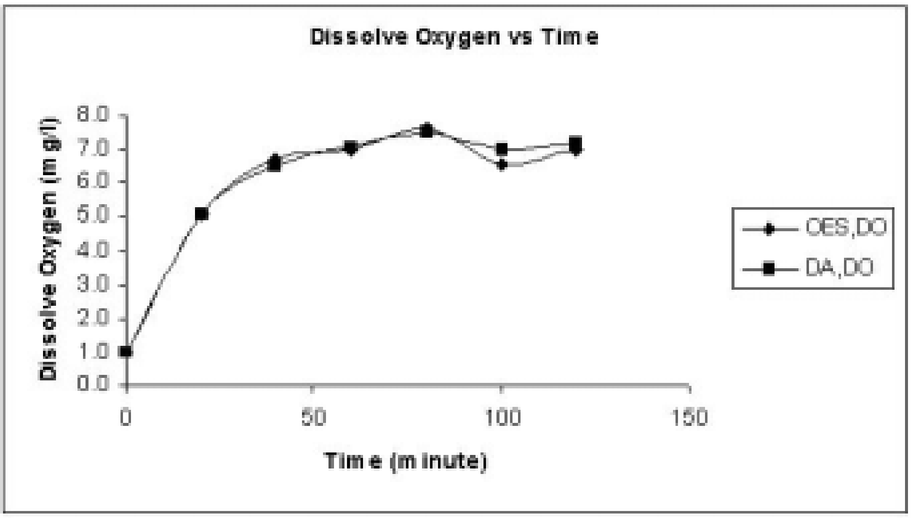


Figure 4. Two-phase oxygen transfer in waste-water aeration (Metcalf and Eddy, 2003)

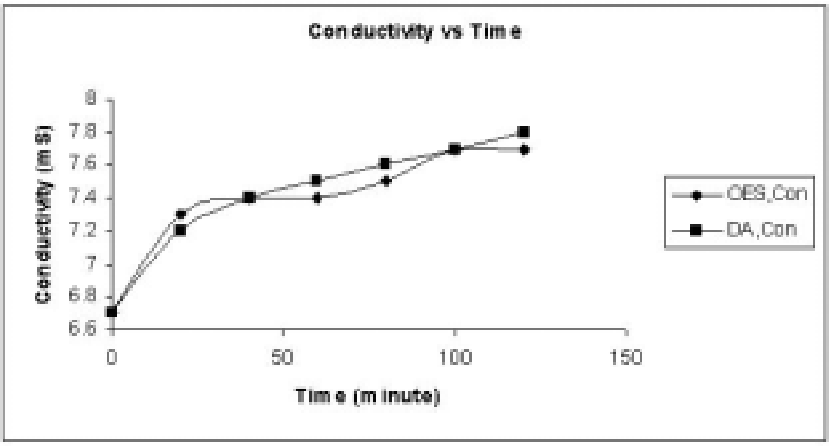


(a)

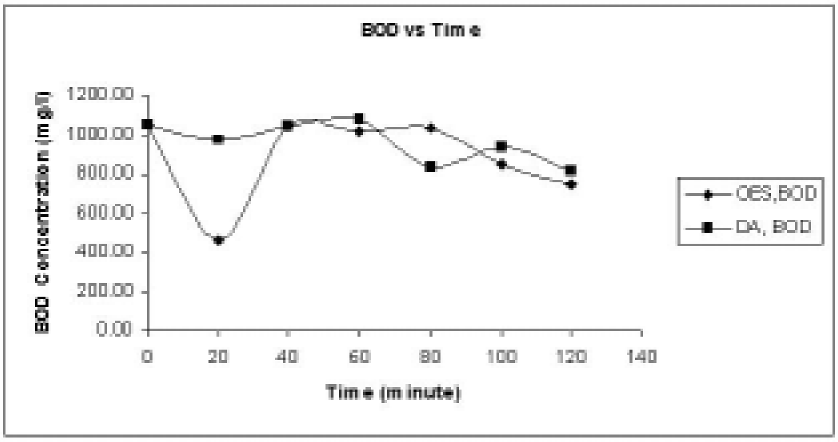


(b)

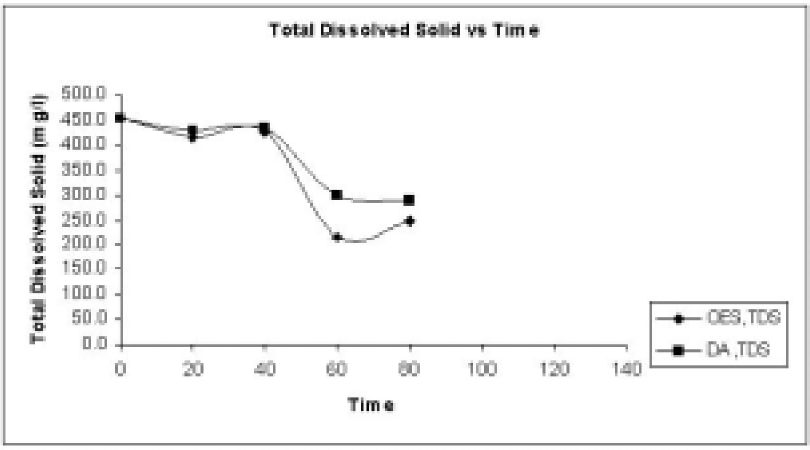
Figure 5. *(to be continued)*



(c)

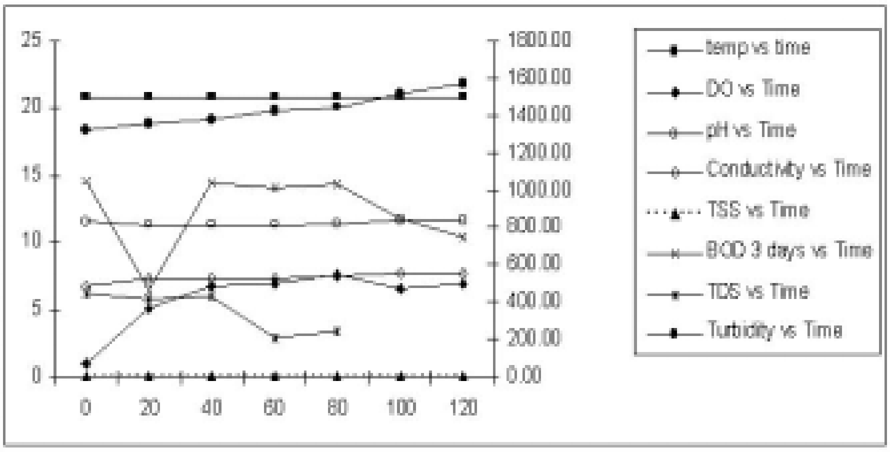


(d)

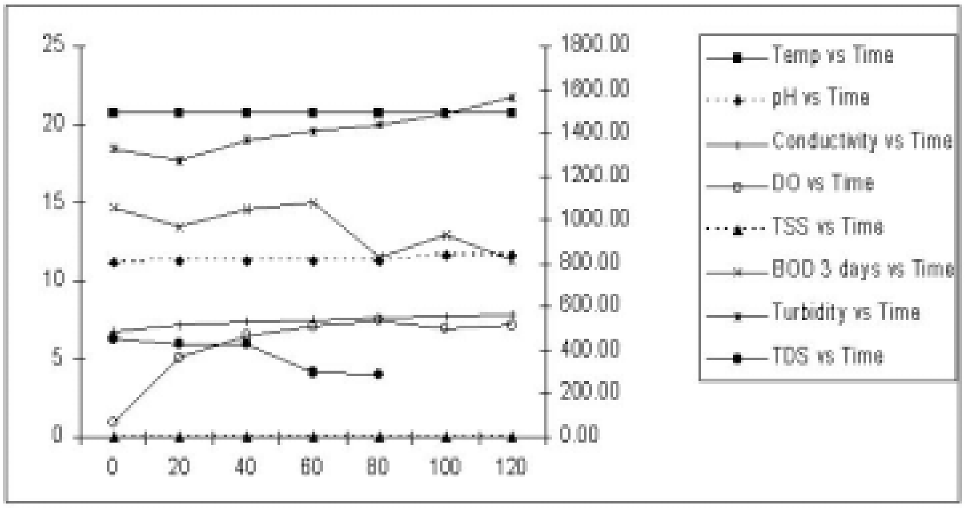


(e)

Figure 5. Effect of Aeration on (a) Turbidity (b) Dissolved Oxygen (c) Conductivity (d) Biochemical Oxygen Demand and (e) Total Dissolved Solid



(a)



(b)

Figure 6. Summary of wastewater characteristiscs vs time when subjected to (a) Oxygen Enriched Air Aeration System (b) Diffused Air Aeration System

perature 20^{o}C and salinity concentration 0 the saturated dissolved oxygen is 9.08.

Figure 6(a) and (b) shows the relationship between the water quality parameters in Oxygen Enriched Air System and Diffused Air System. From these graph it can be seen that as biochemical oxygen demand and total dissolved solids decreases, the turbidity and conductivity increases. This relationship was true in both type of aeration system. It also showed that the types of aeration adopted has no effect on pH and temperature of the palm oil wastewater.

Conclusion

From this experiment several conclusions were made:

(a) Biochemical Oxygen Demand reduction in palm oil wastewater when aerated by Oxygen Enriched Air System was 21.6% more than when it was aerated by Diffused Air System.

(b) Total Dissolved Solids reduction in palm oil wastewater when aerated by Oxygen Enriched Air System was 19.9% more than when it was aerated by Diffused Air System.

(c) Methods of aeration adopted can influence the efficiency of the biological activities in palm oil wastewater treatment.

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