ORIGINAL ARTICLE

High-rate anaerobic treatment of palm oil mill effluent

Monticha Pechsuth[1] Poonsuk Prasertsan[2] and Masao Ukita[3]

Abstract

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Palm oil mil effluent (POME) contains high amount of organic matter, oil & grease, total solids and suspended solids. Anaerobic treatment of POME was conducted at room temperature (30±2ºC) and high temperature (50±0.5ºC). The effects of hydraulic retention time (HRT), organic loading rate (OLR), COD:N ratio and temperature on the anaerobic digestion of POME were investigated. The optimum conditions were found to be 10 days HRT, OLR of 9.50 kg COD $m^{-3}d^{-1}$, COD:N ratio of 65 and the optimum temperature at 50ºC. The highest COD reduction of 81.1% was achieved. Biogas production in general was greater than 0.30 m^3/kg COD/d. Comparison on anaerobic treatment using POME and POME treated by thermotolerant polymer-producing fungi *Rhizopus* sp. ST4 revealed that the biopretreated POME gave higher COD removal (72.6%) but lower biogas production (0.97 m^3/m^3/d or 0.27 m^3/kg COD/d) than the POME without pretreatment (56.1% and 1.16 m^3/m^3/d or 0.37 m^3/kg COD/d, respectively).

Key words : palm oil mill effluent, anaerobic treatment, high rate, biogas, biopretreatment

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การบำบัดน้ำทิ้งโรงงานสกัดน้ำมันปาล์มในสภาวะไร้อากาศแบบอัตราสูง

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น้ำทิ้งจากโรงงานสกัดน้ำมันปาล์มประกอบด้วยสารอินทรีย์ น้ำมันและกรีส ของแข็งทั้งหมดและของแข็งแขวนลอยในปริมาณสูง มีการศึกษาการบำบัดน้ำทิ้งโรงงานสกัดน้ำมันปาล์มแบบไร้อากาศที่อุณหภูมิห้อง (30 ± 2^{o}C) และอุณหภูมิสูง (50 ± 0.5^{o}C) พร้อมทั้งศึกษาผลของระยะเวลาที่ของเหลวอยู่ในระบบ ภาระการรับสารอินทรีย์ อัตราส่วนซีโอดีต่อไนโตรเจนและอุณหภูมิต่อระบบการย่อยแบบไร้อากาศ พบว่าสภาวะที่เหมาะสมคือ ระยะเวลาที่ของเหลวอยู่ในระบบ 10 วัน ภาระการรับสารอินทรีย์เท่ากับ 9.5 กก.ซีโอดี/ลบ.ม/วัน อัตราส่วนซีโอดีต่อไนโตรเจนเท่ากับ 65 และอุณหภูมิที่เหมาะสมเท่ากับ 50^{o}C ค่าซีโอดีลดลงสูงสุด 81.1% การผลิตก๊าซชีวภาพโดยเฉลี่ยมากกว่า 0.3 ลบ.ม./ลบ.ม./วัน เมื่อเปรียบเทียบการบำบัดแบบไร้อากาศของน้ำทิ้งโรงงานน้ำมันปาล์มที่ไม่ผ่านและผ่านการบำบัดขั้นต้นจากการใช้เชื้อราทนร้อนที่ผลิตพอลิเมอร์คือ *Rhizopus* sp. ST4 พบว่าน้ำทิ้งที่ผ่านการบำบัดขั้นต้นมีค่าการลดลงของซีโอดี (72.6%) สูงกว่า แต่การผลิตก๊าซชีวภาพ (0.97 ลบ.ม./ลบ.ม./วัน หรือ 0.27 ลบ.ม./กก.ซีโอดี/วัน) ต่ำกว่าเมื่อเปรียบเทียบกับค่าที่ได้จากน้ำทิ้งที่ไม่ผ่านการบำบัดขั้นต้น (มีค่า 56.1% และ 1.16 ลบ.ม./ลบ.ม./วัน หรือ 0.37 ลบ.ม./กก.ซีโอดี/วัน ตามลำดับ)

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Palm oil mill effluent (POME), is one of the major sources of agro-industrial pollutants. The process to extract oil from fresh fruit bunches requires a large amount of water, mainly for sterilizing the fruits, extraction and clarification of oil. This results in the discharge of about 2.5 tons of effluent per ton of crude oil processed. Palm oil mill effluent (POME) is a brownish colloidal suspension, characterized by high organic content, and high temperature (70-80ºC) (Anon, 1995). Anaerobic system is the most common technology preferred to treat this concentrated wastewater (Idris and Al-Mamun, 1998). All palm oil mills in Southern Thailand employ conventional ponding system to treat the POME because of their low capital and operating costs. The disadvantages of this system are that it requires large area of land and long retention time (1-2 months). Treatment of POME at high temperature would give higher digestion rate and eliminate the requirement of cooling facilities prior to biological treatment, therefore, the cost of treatment could be reduced (Ma, 1990).

This study was undertaken to determine the efficiency of treating POME by anaerobic process at high temperature and the effect of biopretreatment on anaerobic digestion.

Materials and Methods

Microorganism

Rhizopus sp. ST4 used in this study was selected from previous studies (Pechsuth *et al*., 2001).

Palm oil mill effluent (POME)

Decanter effluent samples were taken from Pure Oil Co., Ltd., Hat Yai, Thailand. They were analyzed for chemical oxygen demand (COD), biological oxygen demand (BOD), total solids (TS), suspended solids (SS), pH, oil & grease, total acidity, total alkalinity (APHA, AWWA, and WEF, 1998) and total nitrogen (A.O.A.C., 1984).

Factors affecting treatment efficiency and biogas production

The starter culture was developed in 2 L reactors (10.5 cm dia. x 22 cm height) containing 1.9 L POME. Acclimatization was carried out at room temperature (30±2ºC) and high temperature (50±0.5ºC). The effects of various parameters were studied: effect of temperature at room temperature (30±2ºC) and high temperature (50±0.5ºC), effect of HRT at 12, 10, 7 and 5 days with organic loading rate (OLR) of 7.92, 9.50, 13.57 and 19.00 kg/m^3/d, respectively. The effect of COD:N ratio of 85, 65 and 50 was investigated using ammonium chloride as nitrogen source. Samples were taken every 2 days for 30 days and analyzed for COD, total alkalinity and total acidity, and measured for pH. Biogas production was measured by water replacement method (Prasertsan *et al*., 1994).

Effect of biopretreated substrate

Biopretreated POME was prepared by inoculating 10% starter culture of *Rhizopus* sp. ST4 into 500 ml Erlenmayer flasks containing 100 ml septic POME (without sterilization) and then cultivated at 45ºC on a shaker (200 rpm) for 3 days (Pechsuth *et al*., 2001). High rate anaerobic treatments under the optimum temperature, HRT and COD:N ratio using POME with and without biopretreatment were investigated. Samples were taken and analyzed as described previously.

Results and Discussion

Factors affecting treatment efficiency and biogas production

The characteristics of decanter effluent were determined. It was found to contain high organic matter (BOD and COD values of 58,475 mg/l and 110,400 mg/l, respectively), high total solids and suspended solids (71,930 mg/l and 43,280 mg/l respectively), high oil & grease (25,600 mg/l), low nitrogen content (900 mg/l), total acidity (2740 mg/l), total alkalinity (700 mg/l) and acidic pH (4.5) (Pechsuth *et al*., 2001). On dry basis, the solids obtained from the POME contains about 50% fibers, 10% protein, 15% sugars and 15% ash (Suwandi, 1989).

Effect of HRT and temperature

Effect of HRT on anaerobic digestion of POME was investigated at room temperature (30ºC±1.0ºC) and high temperature (50ºC±0.5ºC). The POME was treated at HRT of 12, 10, 7 and 5 days with OLR of 7.92, 9.50, 13.57 and 19.00 kg/m^3/d, respectively, and COD: N ratio of 85 (without any chemical added). At room temperature, the optimum HRT was found to be 7 days giving the highest average COD removal of 62.5% (Figure 1). This result was lower than 85% COD removal from treatment of POME using anaerobic fluidized bed reactors (Idris and Al-Mamun, 1998) and 91.7-94.2% from treatment of POME using membrane anaerobic system (Fakhru'l-Razi and Noor, 1999). The lowest COD removal of 31.7% was obtained at HRT of 5 days. Therefore, at room temperature the optimum HRT for treatment of POME was at 7 days. However, biogas production was highest at 12 days HRT and significantly different from that at 10, 7 and 5 days HRT. This was due to the fact that at low HRT with high OLR, the organic matter was degraded to volatile fatty acids (VFA), resulting in lower pH, at a higher rate than the degradation of VFA to biogas production. High concentration of VFA resulting in lower pH would cause the growth inhibition of the methanogen.

At high temperature with COD:N ratio of 85 (Figure 2), the highest COD removal of 67.5% was achieved at 10 days HRT which was significantly (at 0.05 level) higher than those at 12 and 5 days HRT, respectively but not significantly different from that at 7 days HRT. This value was less than those reported earlier with 72% and 66-73% COD removal (Chin and Wong, 1983, Hwu *et al*., 1998). COD removal (43.3%) was lowest at 5 days HRT, the same as that at room temperature condition. Treatment efficiency of this work

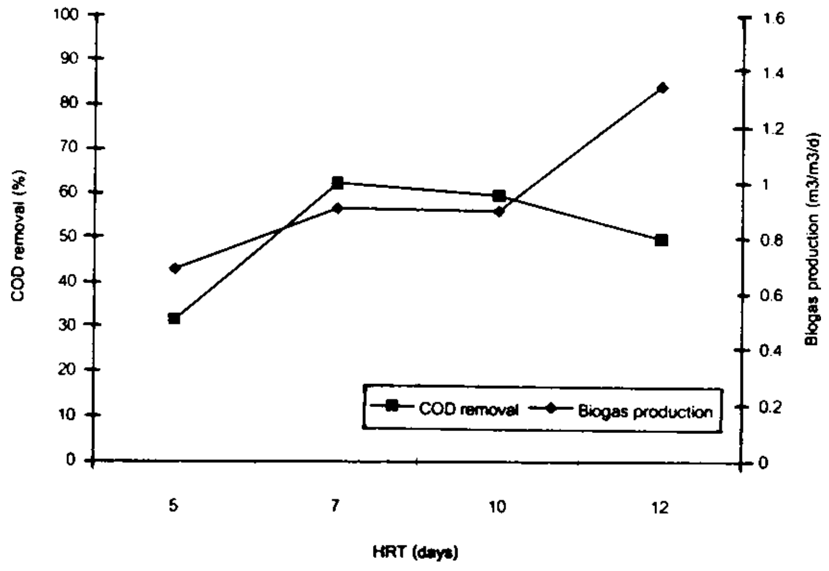

Figure 1 Effects of hydraulic retention time (HRT) on COD removal and biogas production from anaerobic digestion of palm oil mill effluent at room temperature (30±2ºC)

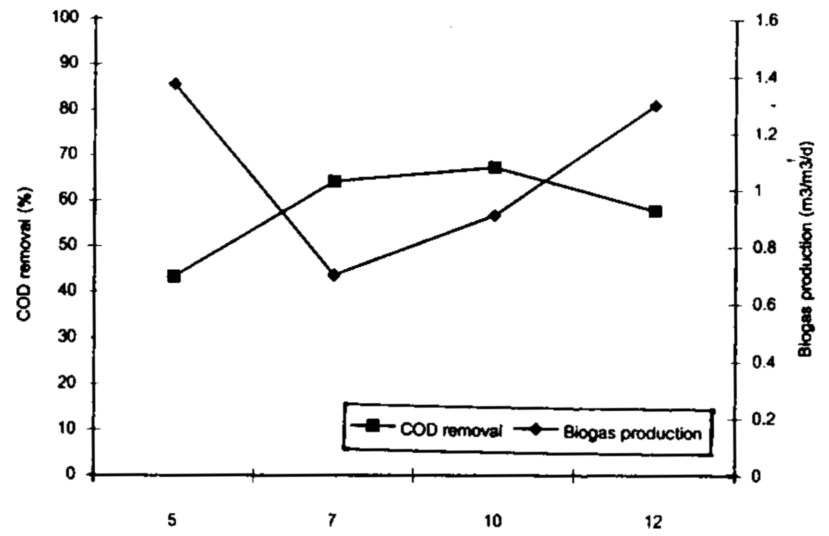

Figure 2 Effects of hydraulic retention time (HRT) on COD removal and biogas production from anaerobic digestion of palm oil mill effluent at high temperature (50±0.5ºC)

(67.5%) was lower than that (72%) of thermophilic anaerobic digestion at 5 days HRT and more than 90% for units having retention time of 15 days or more (Chin and Wong, 1983). COD removal seemed not to be correlated to the biogas production as higher COD removal gave less biogas production. This might be caused by the microorganisms degrading organic matter to other metabolites rather than biogas.

The above results demonstrated that the highest COD removal was achieved from 7 days HRT at room temperature (62.5%) and 10 days HRT for high temperature (67.5%) (Figure 3). The lowest COD removals at both temperatures were at the same HRT (5 days HRT). The COD removal and biogas production at high temperature treatment were higher than that at room temperature because the digestion rate increased with the increase of temperature in certain limit (Anon, 1984).

Effect of COD:N ratio and temperature

Effect of COD:N ratio on anaerobic digestion of POME was investigated at room temperature and high temperature (50ºC). The POME had the COD:N ratio of 85, therefore no NH_4Cl was added. At room temperature, COD removal was highest at COD:N ratio of 65 (79.4%) with 5 days HRT (Figure 4) followed by COD:N ratio of 50 (66.9% COD removal) and the ratio of 85 (62.5% COD removal), respectively. Therefore, the COD:N ratio of 65 was the optimum value for anaerobic treatment of POME at room temperature.

At high temperature (50ºC), the highest COD removal (81.1%) was achieved from COD:N ratio of 65 with 10 days HRT (Figure 5). It was much higher than those at COD:N ratio of 85 (67.5% COD removal) and COD:N ratio of 50 (67.1% COD removal), respectively. COD:N ratio of 65 was the optimum for anaerobic treatment at high temperature, which was the same as that at room temperature.

COD removal at high temperature (67.1-81.1%) was better than that at room temperature (62.5-79.4). The difference in COD removal values between these two temperatures were 5%, 0.7% and 0.2% at COD:N ratios of 85, 65 and 50, respectively. The mean difference of COD removal was significant at COD:N ratio of 85 and 65 (at 0.05 level). These indicated that the effect of temperature was more pronounced on POME without any ammonia nitrogen added than POME with ammonia nitrogen added. Treatment of high

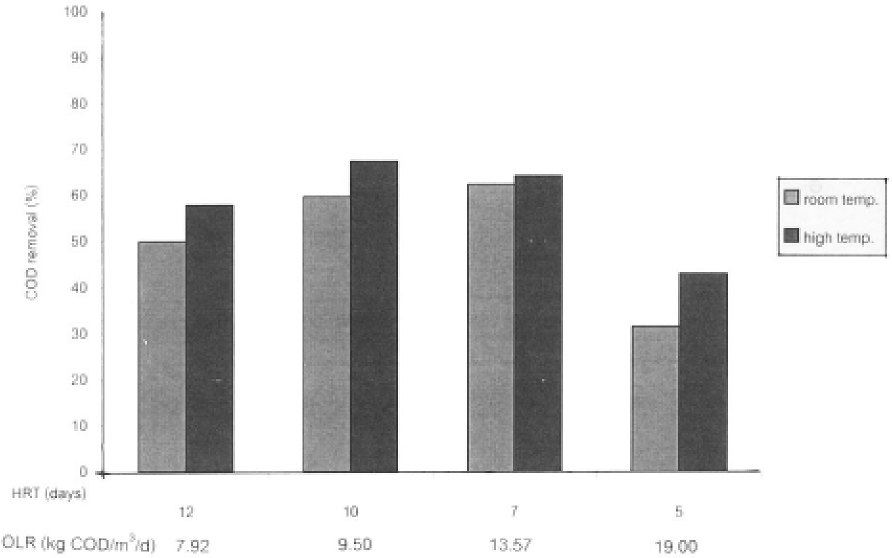

Figure 3 Comparison on the COD removal at different hydraulic retention time (HRT) and anic loading rate (OLR) of the anerobic treatment of palm oil mill effluent at two temperatures

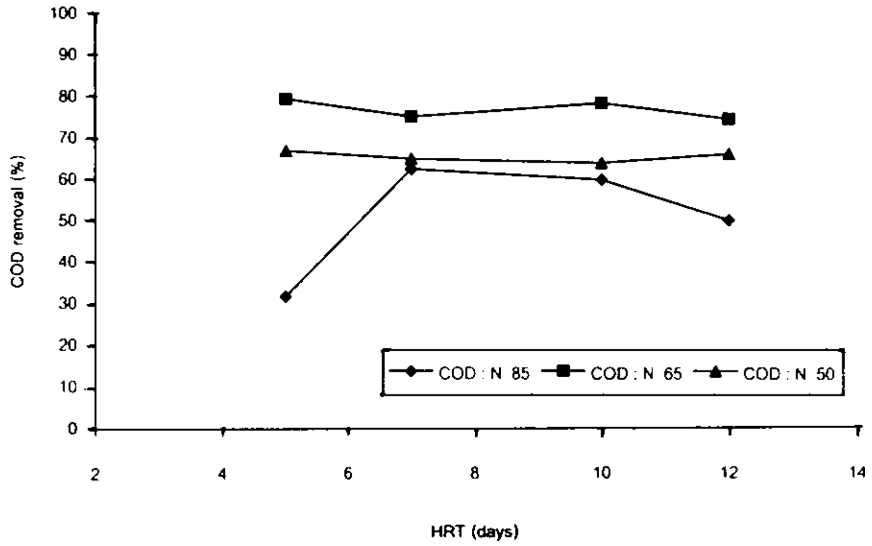

Figure 4 Effects of COD:N ratio at different hydraulic retention time (HRT) on anaerobic treatment of palm oil mill effluent at room temperature (30±2ºC)

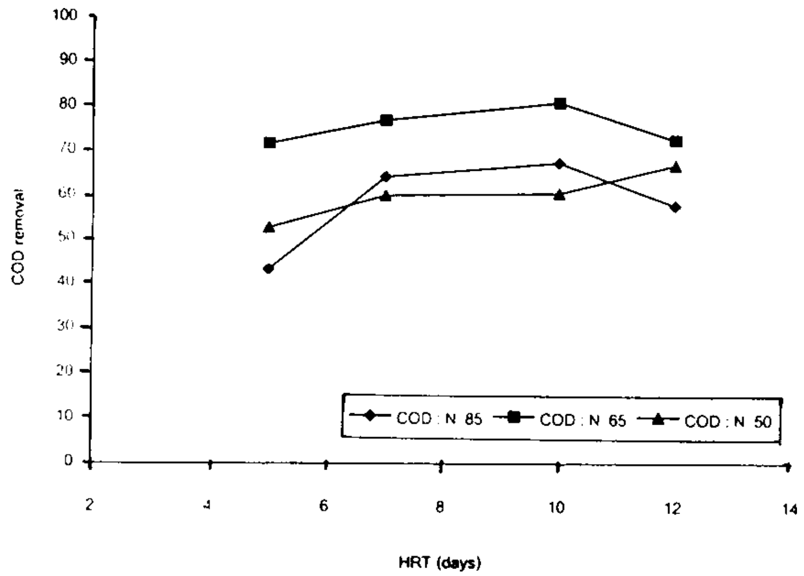

Figure 5 Effect of COD:N ratio at different hydraulic retention time (HRT) under anaerobic digestion of palm oil mill effluent at high temperature (50±0.5ºC)

ammonia wastewater such as swine manure with thermophilic (55ºC) anaerobic degradation was possible even at ammonia content of 6 g-N/l, with a low methane yield of only 67 ml CH_4/g volatile solid (VS) and a high concentration of volatile fatty acids (Hansen *et al.*, 1999). For biogas production, high temperature condition gave higher biogas production which was consistent with the thermophilic anaerobic contact digestion of POME by Yeoh and Idrus (1989). It was reported, however, that increased temperature increased the volume of biogas but the methane content fell (Mudrack and Kunst, 1986).

The above results indicated the lower efficiency of process performance with the higher amount of nitrogen. Although it was reported that the process practically ceased at COD:N ratio of 50 (Poggi-Varaldo *et al.*,1997), the operation still worked at COD:N ratio of 50 in this experiment. The inhibitory effect of high ammonia nitrogen concentration was characterized by less treatment efficiency and lower biogas productivity as well as a more sudden drop of methane content in biogas and pH (Poggi-Varaldo *et al.*, 1997). Shock loading of high ammonia concentration generally causes rapid production of volatile fatty acids such that the buffering capacity of the system may not be able to compensate for the decrease in pH. This had great influence in the phase of methanogenesis and other sensitive reactions. The methanogen *Methanobacterium formicicum* was partially inhibited in the presence of a total ammonia concentration of 3000 mg/l at pH 7.1 and completely inhibited at 4000 mg/l. The efficient functioning of non-methanogenic anaerobic bacteria was at ammonia concentration over 6000 mg/l and pH values of 8.0 (Anon, 1986).

Effect of biopretreated substrate

Palm oil mill effluent is a high strength wastewater and physical or chemical pretreatment may be needed (Sastry and Vickineswary, 1995). Biological pretreatment was previously studied using thermotolerant polymer-producing strain *Rhizopus* sp. ST4 (Pechsuth *et al.*, 2001). Septic POME treated by *Rhizopus* sp. ST4 for 3 days was chosen in this study. POME and biopretreated POME were treated in the reactors under high temperature with 10 days HRT. Both sources of POME were adjusted to reach the COD:N ratio of 65 by adding NH_4Cl resulting in the initial COD value of 90,683 mg/l. COD values of effluent from biopretreated POME tended to be more stable and gave higher COD removal than those from POME without pretreatment (p=0.05) (Figure 6). Alkalinity values of POME with pretreatment seem to be

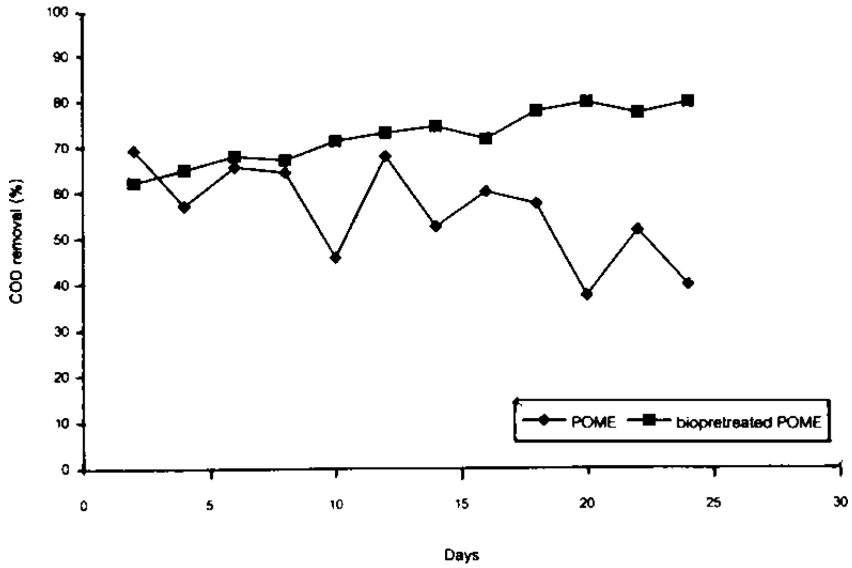

Figure 6 COD removal changes during anaerobic treatment of palm oil mill effluent with and without biopretreatment at high temperature (50±0.5ºC) and 10 days HRT

slightly higher than those of POME without pretreatment. If adequate alkalinity was present, the system could tolerate significant fluctuations of volatile acid concentrations without large changes in pH. It is difficult to specify a satisfactory alkalinity because the amount present will depend upon both the character of the carriage water and the concentration of the waste being treated (Vincenta and Pacheco, 1986). Acidity values of POME with pretreatment was lower than those of POME without pretreatment. This was due to the degradation of some oil & grease and organic matter during the biopretreatment stage which led to the lower organic loading rate.

Changes of POME characteristics during treatment at each stage of this work are summarized in Table 1. It was clearly illustrated that treatment by two-stage process (biopretreatment and anaerobic digestion) gave higher COD removal (72.6%) than one stage process (56.1%) but slightly less biogas production than one-stage process (0.97 and 1.16 $m^3/m^3/d$ or 0.27 m^3/kg COD/d and 0.37 m^3/kg COD/d, respectively). Only biopretreatment could remove more than 80% of oil & grease and suspended solid, as well as more than 60% of organic matter (COD).

Conclusion

The optimal conditions for anaerobic digestion of palm oil mill effluent were 10 days HRT, COD:N ratio of 65 and high temperature (50ºC). Under these optimum conditions, the COD removal was 81.1% and the biogas production was 0.59 $m^3/m^3/d$ or 0.16 m^3/kg COD/d. Biopretreated POME was the preferable substrate for anaerobic treatment as it gave higher treatment efficiency (72.6% COD removal) than POME without pretreatment (56.1% COD removal) at 10 days HRT and 50ºC. The biogas production (0.97 $m^3/m^3/d$), however, was slightly less than that using POME without pretreatment (1.16 $m^3/m^3/d$).

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Table 1 Characteristics of the decanter effluent before and after treatment

Parameter	POME	Biopretreatment stage*	Anaerobic digestion**	
			POME	biopretreated POME
Color	brown	dark brown	blackish brown	blackish brown
pH	4.5	4.48	5.53	5.65
COD (mg/l)	90,700	34,800	39,800	24,900
COD removal (%)	ND	61.6	56.1	72.6
Oil & grease (mg/l)	21,000	2,600	ND	ND
Oil & grease removal (%)	ND	87.5%	ND	ND
Suspended solid (mg/l)	35,300	5,000	ND	ND
Suspended solid removal (%)	ND	85.7%	ND	ND

* 3 days cultivation at 45ºC by the fungal isolate ST 4
** 10 days HRT at 50ºC
ND = not determined

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