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A Comparative Study on Biogas Production between Day and Night at Sime Darby's Palm Oil Mill

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A B S T R A C T

Freely emitted biogas at palm oil mills has been regarded as untapped energy source nowadays, despite being recognised as major contributor to the global warming. Up till now, most of palm oil mills are still operating with the conventional anaerobic digestion systems which may not spur biogas industry to life. This study shall explore biogas production between day and night under existing mill operating conditions at KKS Bukit Benut Effluent Treatment Plant (ETP). Biogas produced during day time was 62% as compared to 38% during night time with the total methane emission of 490.3 kg/day. The methane concentration recorded at the digester tank ranged from 58.7 to 68.5%. The correlations between various factors that may influence biogas production were investigated. The finding shows that substrate feeding is the most influencial factor leading to high biogas production during day time.

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INTRODUCTION

In Malaysia, the oil palm is one of main agricultural crops that contributes to the annual economic growth. However, the process of extracting and separating crude palm oil and palm kernel from oil palm fresh fruit bunches (FFB) creates highly polluting wastewater known as palm oil mill effluent (POME). Typically, 65 to 70% (w/w) of POME is produced for every tonne of FFB processed, from a combination of several processes in palm oil milling which include sterilisation process of FFB, clarification of palm oil, hydrocyclone operation and washing. POME is a viscous and brownish liquid that may contain 95-96% of water with the remaining constituents of oil and solids [1]. The wastewater is frequently characterised based on the parameters tabulated in Table 1 [2].

The potent concentration of BOD associated to POME has made the efforts for their treatment difficult in terms of complying with a stringent discharge requirement imposed by Department of Environment (DOE). The discharge requirement is usually based on the mill location where currently East Malaysia has more stringent requirement compared to West Malaysia. The area with more stringent requirement normally requires up to a tertiary treatment stage to achieve the intended discharge requirement. Nonetheless, more than 85% of effluent treatment plant in palm oil mills are using ponding system which was found sufficient in achieving their BOD requirement [3]. The estimation of incurred cost for mill to run an effluent treatment plant is RM 1 to 2 per tonne of FFB processed. In terms of space requirement, the effluent treatment plant requires a huge treatment area of 1.5 to 2.5 hectares of land.

TABLE 1. Characteristics of POME

Parameter	Unit	Range	Mean
pH	-	3.4 – 5.2	4.2
Biochemical Oxygen Demand (BOD)	mg/L	10,250 – 43,750	25,000
Chemical Oxygen Demand (COD)	mg/L	15,000 – 100,000	51,000
Total Solids (TS)	mg/L	11,500 – 79,000	40,000
Suspended Solids (SS)	mg/L	5,000 – 54,000	18,000
Volatile Solids (VS)	mg/L	9,000 – 72,000	34,000
Oil and Grease (O&G)	mg/L	130 – 18,000	6,000
Ammoniacal Nitrogen (AN/NH_3–N)	mg/L	4 – 80	35
Total Nitrogen (TN)	mg/L	180 – 1,400	750

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Biogas production from the anaerobic digestion of a ponding system was studied by Yacob et al. [4]. It was stated that total methane emission of anaerobic pond was 1,043.1 kg/day with an average of 0.238 kg methane was emitted per kg carbon removed. The methane concentration ranged from 35 to 70%. In another study, Yacob et al. [5] found that the total emission of methane in an open digesting tank was 518.9 kg/day with an average of 0.109 kg methane was emitted per kg carbon removed. It was further reported that the methane concentration was lower at 13.5 to 49.0% than that reported by Ma et al. [6] at 65%, using a fully controlled bioreactor with complete anaerobic condition.

The production of biogas from an anaerobic digestion in palm oil mill is intensely affected by numerous factors such as design of digester, process conditions, organic loading rate, hydraulic and sludge retention times. In this study, monitoring of biogas production was conducted for 11 feeding days at one of Sime Darby's conventional open tank anaerobic digesters in KKS Bukit Benut. Previous monitoring of biogas production was conducted at KKS East where it was concluded that biogas production rate varied between day and night time. However, no further conclusions were made in identifying factors contributing to the differences. During the period of study, the effects of ambient temperature, organic loading rate and substrate's feeding time were studied to determine the factors influencing biogas production in anaerobic digester tank at KKS Bukit Benut.

TABLE 2. Characteristics of raw POME for KKS Bukit Benut during the period of study (all parameters in mg/L except pH)

	pH	BOD	COD	TS	SS	VSS	TN	AN	O&G
Mean	4.3	43,200	91,592	62,995	27,833	25,927	576	52	6,557
Std. Dev.	0.29	7,314	21,612	8,092	4,748	3,920	158	12	1,219
Min	3.8	30,400	49,402	47,597	19,564	18,435	383	40	5,025
Max	4.6	50,900	113,544	72,566	33,429	29,608	881	74	8,400

The production of effluent in a conventional palm oil mill is inevitable and its treatment is necessary in complying with the stipulated discharge requirements. Despite having the great difficulty in treating the effluent, POME is considered as a source of raw material for producing many products through biotechnological advances [7]. But on its own, POME, at a certain BOD level is directly applied as fertiliser as it is high in nutrients content or mixed with empty fruit bunches for composting process. The possibility of producing and utilising biogas should draw the attention of palm oil millers as not only will the millers fulfiltheir obligations to reduce greenhouse gases emission, they also stand to benefit from the investment.

The goal of effluent treatment is to improve the effluent quality to the acceptable level stipulated by DOE. At KKS Bukit Benut, the approved annual licence are based on two methods of effluent discharge,30% for watercourse discharge and 70% for land application. The mill is allowed to discharge the treated effluent to watercourse at BOD less than 100 ppm whereas, the discharge requirement for land application is set at BOD less than 5,000 ppm which may benefit oil palms' need on nutrients. KKS Bukit Benut has a processing capacity of 20 tonnes/hour of FFB where it can produce 200 to 280 tonne of POME per day. The characteristics of raw POME at KKS Bukit Benut are tabulated in Table 2.

In KKS Bukit Benut, POME in the sludge pit is pumped out to a mixing pond. The bottom solid of anaerobic liquor in sedimentation pond is recycled back to the mixing pond for acidification process. The supernatant layer from sedimentation pond is pumped out to aerobic pond. The effluent from mixing pond is transferred to anaerobic digester tanks for digestion process. All operations are only being carried out during day time under normal conditions.

Various processes have been applied in palm oil mills such as one-stage or two-stage digestion systems. KKS Bukit Benut employs two-stage digestion system which enables the digester to handle full effluent load regardless the wide variation of loading rates. The two-stage system is more efficient and more stable than one-stage system [8]. The concentrated anaerobic liquor after the gravity settling will enhance the effectiveness of acidification process.

The production of biogas in palm oil mills is greatly influenced by many factors such as digester performance [9] and mill activities [5].

Digester Operating Conditions

The operating conditions for anaerobic pond or digester tanks are considered as the main influencing factor in POME treatment thus affecting biogas production. Anaerobic digestion is dependent on temperature, pH, mixing, and organic loading rates.

i) Temperature

For a biological treatment system, temperature is one of the critical parameters in maintaining survival of specific microorganisms in the system. The temperature affects the physicochemical properties of the components found in the digestion substrate and influences the growth rate and metabolism of microorganisms [10]. Mesophilic temperature range is mostly favorable in treating POME due to its ease in operation that requires no control on temperature. Thermophilic temperature range can however give higher digestion rate at up to four times faster than mesophilic temperature ranges. It was found that substrate degradation and biogas production improved significantly at thermophilic temperature compared to mesophilic temperature [9].

ii) pH

POME is an ideal growth medium for large number of different group of microorganisms. They are particularly sensitive with changes in pH. Most of the microbial growth in anaerobic digestion operates at optimum pH of 6.6 to 7.8 whereas pH lower than 6.2 will inhibit methanogenic activity [11].

iii) Mixing

Application of mixing in any of digestion systems improves distribution of microorganisms and heat transfer. In POME treatment, mixing helps to reduce substrate particle size as digestion progresses at the same time assists in releasing biogas from the mixture [12]. A study made by Kaparaju et al. [13] stated that minimal or intermittent mixing improves methane production in comparison to continuous mixing.

iv) Organic Loading Rates (OLR)

Methane production is positively affected by OLR but only to a stage where methanogens can efficientlyconvert acetic acid to methane. Beyond this point, COD removal efficiency will be greatly reduced and the condition becomes more destructive to methanogens [9].

Mill Activities

Apart from the operating conditions, biogas production is also affected by the mill activities. Palm oil mills process large quantities of FFB which generates high volume of POME. As mentioned earlier, POME is a beneficial substrate for the anaerobic digestion system. However, consistency of its characteristics depends on estate operations and seasonal factors. The terms low or peak crop are used in describing estates' crop production. In the palm oil mills, low mill utilisation, high oil losses in effluent, machinery efficiency or breakdowns will result in high variations towards POME characteristics, resulting in inconsistencies towards biogas production. A robust and reliable ETP design are essential in order to handle seasonal variations in POME while ensuring optimum biogas production.

MATERIALS AND METHODS

Open Digester Tank System

The monitoring of biogas production was done at anaerobic digester tank No. 2 at KKS Bukit Benut. The monitoring was completed for 11 feeding days to ensure substantial data is collected to indicate effect on day and

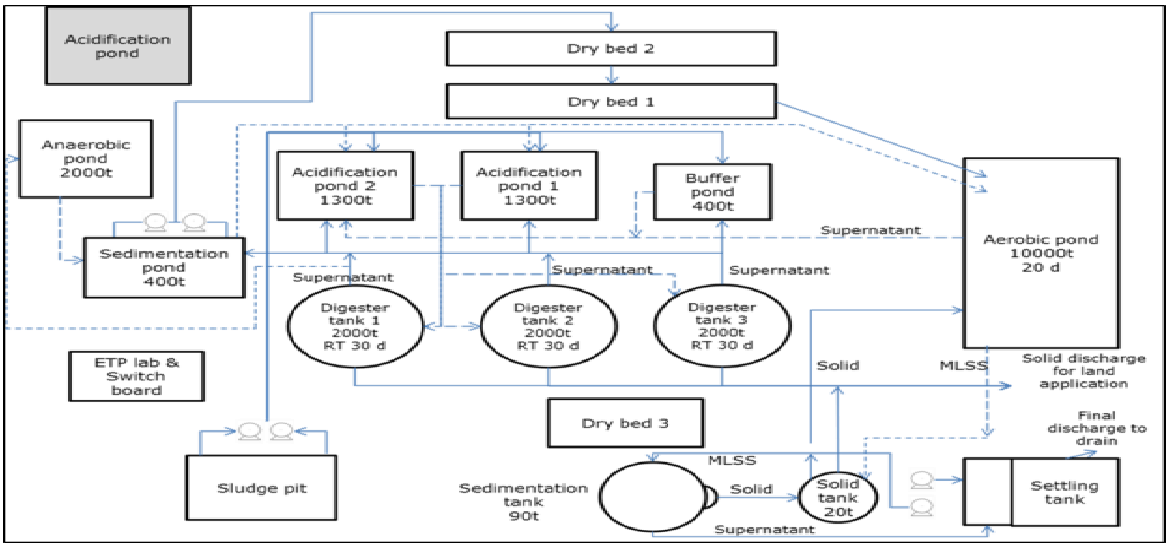


Figure 1. Current ETP layout at KKS Bukit Benut

night production of biogas. All digester tanks have the capacity of 2,000 m^3 of POME with the hydraulic retention time of 30 days. The height and diameter of each digester tank are 13.6 m and 13.45 m, respectively with an approximately 1:1 ratio of height to diameter.

Data Collection for Biogas Monitoring

Biogas was collected using two sets of gas sampler chambers with a coverage area 0.5 m^2 each (diameter of 0.8m and 5 units of diameter of 0.36m). The chambers were connected to tubes for biogas sampling and detection at two separate wet gas metres (Ritter and Shinagawa) for the determinationof gas flow rates. The records were taken starting at 7 a.m. to 7 p.m., for day time and from 7 p.m to 7 a.m. (next day) for night time. The effluent samples from three different heights were taken to determine temperature and pH.

Analytical Methods

i) Analysing Biogas Compositions

Gas compositions were determined using gas analyser (Geotech Biogas 5000). The analyser detected five major gases which were methane, carbon dioxide, oxygen, hydrogen and hydrogen sulphide.

ii) Analysing Effluent Samples

Samples of raw POME, influent and effluent of the digesters were analysed for standard parameters in accordance with standard method [14].

RESULTS AND DISCUSSION

Day and Night Production of Biogas at KKS Bukit Benut

The average production of biogas in the digester was 1,300 m^3/day with the average percentage of biogas produced during day and night at 62 and 38%, respectively. Biogas production rates are shown in Figure2. A t-test analysis was conducted to study the significance between day and night biogas production. From t-distribution table, t Critical value (one tail) for df of 10 (i.e. $n_1+n_2 - 2$) equals to 1.812. Since the obtained absolute t-value of 3.030 is larger than 1.812, the difference of biogas production day and night is significant. In addition, the trend of biogas production as illustrated in Figure2 shows that biogas production was relatively active during day time. Summarised biogas compositions are tabulated in Table 3. Biogas compositions do not vary too much between day and night productions.

The anaerobic digester has an average of 90.5 and 50.4% of BOD and COD reductions, respectively. The k-value was calculated at 0.32 per day which is comparatively low for a digester tank system. The percentage of methane conversion was calculated at 50.8% with 0.158 kg methane was emitted for every kg carbon input. The average methane emission from the digester is 490.3 kg/day.

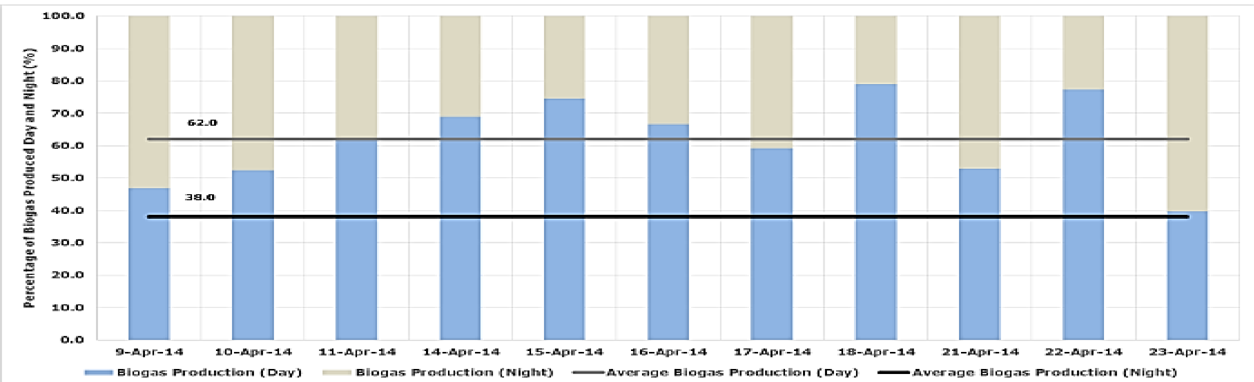


Figure 2. Day and night production of biogas at KKS Bukit Benut

TABLE 3. Summary of biogas composition at KKS Bukit Benut

	CH_4 (%)		CO_2 (%)		H_2S (ppm)	
	Day	Night	Day	Night	Day	Night
Mean	63.9	63.4	31.9	33.3	1,453	1,593
SD	2.8	3.1	2.6	3.1	267	383
Min	58.7	59.4	27.6	28.4	1,002	1,071
Max	68.5	68.3	37.6	37.3	1,808	2,135

TABLE 4. Analysis on biogas production day and night to ambient temperature, OLR, and influent VFA

	Pearson Coefficient, r	F value	Significant F	Observation, N
Temperature (Day)	0.154	0.218	0.186	11
Temperature (Night)	0.092	0.076	0.789	11
OLR	0.758	12.171	0.007	11
Influent VFA	0.656	6.811	0.028	11

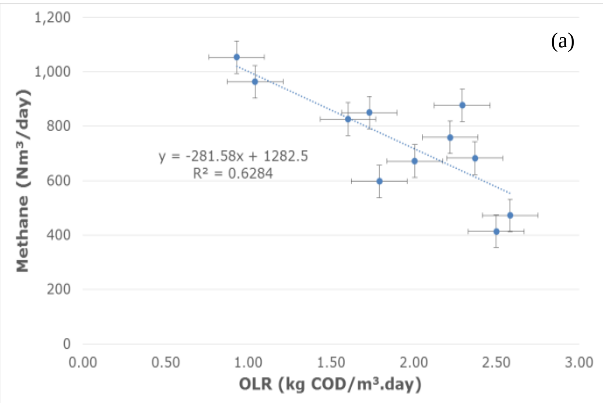
Effects of Various Factors to Biogas Production

Ambient Temperature

The regression analysis is executed on each biogas productions to the ambient temperature in finding their correlation and relationship. The average ambient temperature at KKS Bukit Benut during period of study is 32.91±0.94 °C at day time and 25.36±1.36 °C at night time [15]. From Table 4, both Pearson Coefficients' values are less than 0.20 which verifies no or negligible relationship between biogas productions and ambient temperature.

Organic Loading Rates (OLR)

As one of the factors influencing biogas production, a correlation between OLR and biogas production was studied. It was found that biogas production has a strong correlation with OLR as Pearson Coefficients' value shown in Table 4 are more than 0.70. The average OLR for the current ETP operation at KKS Bukit Benut is 1.92 kg COD/m^3.day. Figure3(a) shows significant negative correlation between methane production and OLR. The result indicates instability in methane production where with further increment of OLR will further disrupt the methane production. Thisindicates that the current performance at KKS Bukit Benut was not designed for higher OLR input.



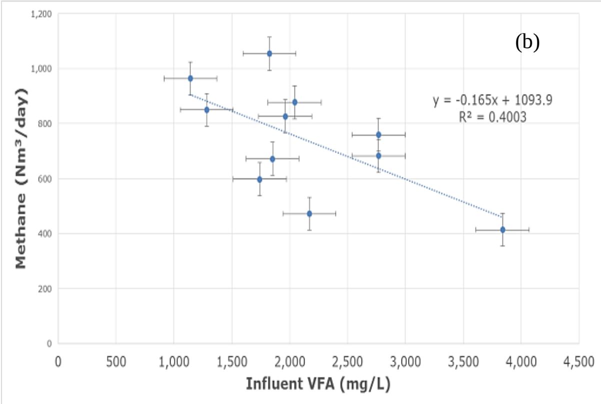


Figure 3(a), (b). Correlation between methane and OLR, and influent VFA

VFA and Total Alkalinity

The average VFA and total alkalinity of the effluent were 42 and 5,147 mg/L respectively. The ratio of effluent VFA to total alkalinity 0.008 which is acceptable for maintaining performance of the digester. The ratio should be kept below than 0.15. The correlation between biogas production and influent VFA was also studied. The Pearson Coefficient shown in Table 4 suggests that influent VFA has a strong correlation with biogas production. Besides, the correlation between methane and influent VFA shows that it has negative correlation as depicted in Figure3(b). The lower concentration of influent VFA enters the digester will produce higher methane. Acetic acid is easily converted by active methanogens to methane and carbon dioxide. However, the influent VFA must be kept at 2,000 to 4,000 mg/L as the perfect fit for mixing process. High concentration of influent VFA may alter the condition of the digester to acidic condition. It was found that the reduction of VFA is 97.93% as most of VFA were converted to gases.

Substrate Feeding

In the study, it was noted that substrate feeding was

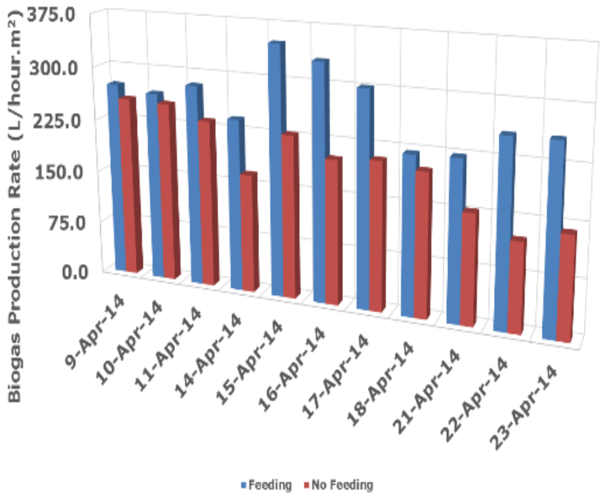


Figure 4. Biogas production rates during feeding and no feeding times

done four to seven hours during day time. The effect of substrate feeding was studied using t-Test analysis. From t-distribution table, t Critical value (one tail) for df of 53 (i.e. $n_1+n_2 - 2$) equals to 1.674. Since the obtained absolute t-value of 6.076 is larger than 1.674, the difference of biogas production and substrate feeding was found to be significant. Figure4 shows the distinct biogas production rates with respect to feeding and no feeding times. During feeding, the production rate was higher than without feeding. During substrate feeding, more biogas was released from the mixture as feeding provided better mixing for sludge and effluent.

CONCLUSIONS

The comparative study on biogas production between day and night at KKS Bukit Benut has statistically found that production of biogas is 62% during day time as compared to 38% during night time. Biogas production may be affected by several factors such as OLR, influent VFA and substrate feeding. It was shown that OLR and VFA had negative correlation with biogas production. Substrate feeding contributed to higher biogas production at day time. Methane emission for the digester was found at 490.3 kg/day with methane concentration ranging from 58.7 to 68.5%.

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Persian Abstract

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چکیده

امروزه بیوگاز آزاد منتشر شده در کارخانه های روغن پالم با وجود اینکه در گرم شدن کره زمین به رسمیت شناخته شده است، به عنوان منبع انرژی دست نخورده مورد توجه می‌باشد. تاکنون، بسیاری از کارخانه‌های تولید روغن پالم هنوز با سیستم‌های هضم بی‌هوازی عمل می‌کنند که ممکن است صنعت بیوگاز را برای زندگی تشویق نمی‌کند. این مطالعه تولید بیوگاز را بین روز و شب تحت شرایط عملیاتی موجود در کارخانه در تصفیه پساب (ETP) بررسی کرده است. بیوگاز در طول روز شصت و دو درصد در مقایسه با سی و هشت درصد در طول شب با مجموع انتشار متان چهار صد و نود کیلوگرم در روز بوده است. غلظت متان ثبت شده در مخزن هضم کننده از پنجاه هشت و نیم تا شصت هشت و نیم درصد متغیر بوده است. ارتباط بین عوامل مختلف که ممکن است تولید بیوگاز را تحت تاثیر قرار دهد، مورد بررسی قرار گرفت. این یافته نشان می‌دهد که خوراک مغذی مهمترین عاملی است که می‌تواند منجر به تولید بیوگاز بیشتر در طول روز شود.