POME Biogas Capture, Upgrading and Utilization

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ABSTRACT

A complete-mix flow-through, closed-tank anaerobic digester system for the generation and capture of methane for palm oil mill effluent (POME), which has been in continuous operation for over 20 years is described. The system was designed for a POME flow of 400 m^3 day^{-1}, including the juice from the pressing of empty fruit bunches, and a hydraulic retention time of 18 days. With COD loading in the range of 2.6-3.5 kg m^{-3} day^{-1}, biogas yield of about 11 000 m^3 day^{-1} and a relatively consistent composition of 62.5% CH_4, 37% CO_2 and 1500 - 3000 ppmv H_2S has been maintained throughout the operation of the system. The biogas generated has practically been fully utilized as a boiler fuel for an oil refinery within the industrial complex. This paper also discusses the prospects of new technologies for the upgrading of POME biogas to the equivalent quality as compressed natural gas for vehicle use. Through the development of the new dimensions in POME biogas utilization and support from CDM carbon assets creation, it is anticipated that significant reductions in greenhouse gas emissions in the palm oil mill sector will be realized.

INTRODUCTION

There have been keen interests in the capture of POME biogas recently because of the vast methane recovery potential. It can serve as a clean renewable gaseous fuel instead of being a hazardous greenhouse gas and its utilization as a renewable energy is well-recognized by the Clean Development Mechanism (CDM) under the Kyoto Protocol as Certified Emission Reduction (CER) credits.

Gross methane recovery potential can be estimated based on the annual crude palm oil (CPO) production. With CPO production of 13.976 million tonnes reported for Malaysia for 2004 (MPOB Statistics, 2005), palm oil mill effluent (POME) is estimated to be 41.9 million tonnes. This can give a total COD loading of 2.095 million tonnes resulting in 524 000 t of methane recovery according to IPCC Guidelines (1996a,b).

In terms of greenhouse gas emission reduction, the capture of POME biogas could thus contribute to a potential CER credits of 11 million tonnes of CO_2-equivalent per annum, based on the Global Warming Potential for methane that is 21 times that of CO_2.

This article briefly reviews the common POME treatment methods adopted by most of the palm oil mills. The experience in the design and operations of a complete-mix flow-through, closed-tank anaerobic digester system of Keck Seng (Malaysia) Berhad, for the generation and capture of POME biogas is highlighted. Keck Seng's system has been in continuous operation maintaining an optimum methane output for over 20 years. The article also discusses the prospects of new technologies for upgrading of POME biogas to the equivalent quality as compressed natural gas (CNG) for use as transport fuel.

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COMMON POME TREATMENT SYSTEMS

Ponding Digestion System

With the rapid growth of the palm oil industry since the 1960s, active research and development work on the treatment methodologies for POME have been carried out. The introduction of the Environmental Quality Act 1974 has been a catalyst to these efforts and significant successes have been achieved in reducing the very high BOD and COD in raw POME to meet the regulatory standards in the 1980s. This has then contributed to significant improvement in water quality of rivers in the country receiving treated effluent from the industry.

The very high level of organic matters in POME requires the adoption of anaerobic digestion as the primary treatment process. The anaerobic process offers important advantages by converting the bulk of the wastes to biogas, with little input of external energy, and the generation of relatively low quantity of biosolids. Surveys conducted by the Malaysian Palm Oil Board (MPOB), previously known as Palm Oil Research Institute of Malaysia (PORIM) (Ma *et al.*, 1993), have shown that most of the palm oil mills (more than 85%) have adopted the most practical pond system, involving anaerobic digestion, for the treatment of POME.

In the pond digestion system approach, raw POME is allowed to go through a cooling/de-oiling tank/pond (one-day hydraulic retention time or HRT), acidification pond (two or four days HRT) before feeding to anaerobic ponds of 5 - 7 m depth (30 - 45 days HRT). The anaerobic process in deep ponds breakdown a high proportion of the organic matter into methane, CO_2 and small amount of hydrogen sulphide. Methane generated is normally uncontrolled and escape directly to the atmosphere. The treated effluent is further subjected to an aerobic or facultative treatment in shallow ponds (1.5 m) in order to meet the required discharge standards.

Open Tank Digester System

As an alternative, some mills (5% - 10%) have opted to build open-top tanks instead of ponds for the anaerobic digestion process due to land limitations. Tank digesters have been built with about 20 days HRT. Similar to the ponding system, mixing is limited as this is effected mainly by the biogas generated, and the influent and effluent flows. Biogas generated is uncontrolled as in the case of ponding system and it escapes directly to the atmosphere. The tank approach facilitates easier removal of solids build-up at the bottom on a regular basis, thus, maintaining the desired treatment efficiency. The digested effluent is further treated by the aerobic or facultative ponds or extended aeration system with approximately 20 days HRT. The effluent from the anaerobic digesters may also be diverted for land application.

POME BIOGAS CAPTURE BY CLOSED-TANK ANAEROBIC DIGESTER SYSTEM

A few attempts to employ closed-tank anaerobic digester method for POME treatment have been reported (Quah and Gilles, 1981; Chua and Gian, 1986). The biogas generated is captured and directed to flaring or used as a boiler fuel or for power generation. The treated effluent from the anaerobic digesters may be discharged for land application or further treated by aerobic/facultative or extended aeration system to meet the effluent discharge standard of the Department of Environment. The closed-tank anaerobic digester system with biogas capture of Keck Seng (Malaysia) Berhad at Masai, Johor appears to be the only one, which has been in its continuous operation since early 1980s.

Keck Seng's complete-mixed, closed-tank anaerobic digester system built in 1984 is a continuous flow stirred tank reactor (CSTR). The system design and experience gained in operations and performance of Keck Seng's CSTR system is briefly presented below.

POME Pre-treatment and Raw POME Characteristics

Prior to feeding to the anaerobic digester tanks, raw POME is allowed to go through a de-oiling step for one-day, followed by cooling and acidification processes in two ponds with a total retention time of approximately five days. The pre-treatment, which also provides a certain degree of equalization is essential for optimum performance of the digester system. The pre-treatment allows the settling and removal of oil residue mixed with fibre sludge, mainly in the form of scum. Hydrolysis and acidification takes place to ensure compatibility with the anaerobic digestion process. Raw POME from the pre-treatment pond is pumped to an SS Feeding Tank in the anaerobic digester tank farm and uniformly fed to the CSTR tanks via a distribution system.

Biogas generation is dependent on the characteristic of the POME input characteristics. Raw POME after the pre-treatment, prior to feeding to the anaerobic digester tanks, has been found within the range of 25 000 - 35 000 mg $litre^{-1}$ and 45 000 - 70 000 mg $litre^{-1}$, for BOD and COD, respectively. The design flow takes into consideration the increase in the flow, BOD and COD levels in raw POME with the addition of juice from the pressing of empty fruit bunches (EFB), as compared to the normal range of BOD and COD levels reported for raw POME (Ma *et al.*, 1993).

Digester Design

The design and configuration of Keck Seng's anaerobic digester system is illustrated in *Figure 1*. An influent raw POME flow of 400 m^3 day^{-1} is typical of a 30 t FFB per hour mill, which also receives the EFB juice.

The anaerobic digester system comprises two units of floating roof and one unit of fixed roof tanks of 2500 m^3 each. Total anaerobic digester capacity is 7500 m^3 providing approximately 18 days of HRT for the POME. Each of these tanks is equipped with a mechanical cum gas-lifting dual function mixing system.

A sludge sedimentation tank (approximately one-day HRT) is also incorporated to provide sludge return for the enhancement of the sludge level in the digester tanks.

The floating roof digester tanks provide a cost-effective means for gas-holding and for flow balancing. The slightly pressurized biogas, resulting from the roof weight, is led through the biogas piping system and piped directly for use in the boilers. The piping system is connected to a gas flaring system with the necessary safety equipment and features for protection against explosion or fire risks.

Digested POME

For controlled anaerobic tank digester method with mixing, the gross treatment efficiency has been estimated to be in the range of 90% – 95% in terms of BOD removal (Yeoh and Chong, 1985). Corresponding COD treatment efficiency was estimated in the range of 80% – 90%.

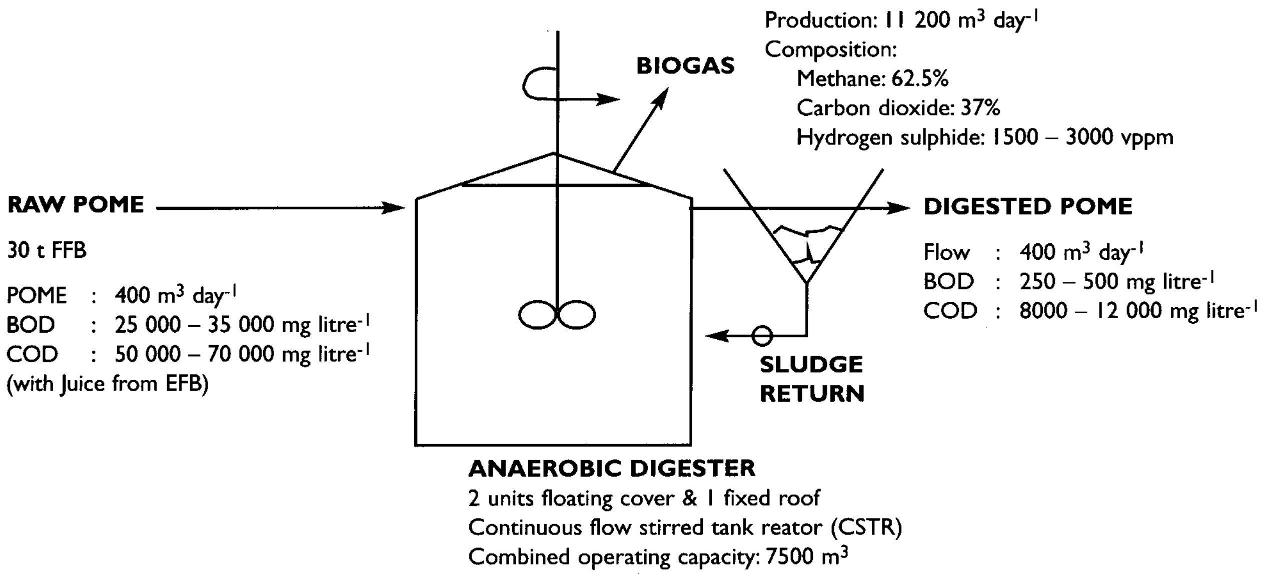

Figure 1. Specifications and performance of KS anaerobic digester system.

The data reported by Ma *et al.* (1993) in a survey of 17 palm oil mills show that the overall treatment efficiency for BOD and COD removal combining anaerobic digestion and aerobic or facultative treatment for both the ponding and tank systems was very high (>99% for BOD and ~97.5% for COD). Data from Ma *et al.* (1993) on BOD and COD removal for open tank digestion followed by land application show removal rates during the anaerobic digestion process at 97.7% for BOD (from 22 380 mg litre^{-1} to 513 mg litre^{-1}) and ~93% for COD (from 63 800 mg litre^{-1} to 4550 mg litre^{-1}).

For Keck Seng's closed-tank CSTR system, the total COD in the effluent from the anaerobic digester was found in the range of 8000-12 000 mg litre^{-1} range, and a range of 2000 - 3000 mg litre^{-1} in COD if suspended solids were excluded. The practical COD removal efficiency has been found in the range of 80% - 85%. It is estimated that the anaerobic sludge wasted and non-biodegradable COD solids account for approximately 10% of the balance. Residue of digestible COD is estimated to be less than 5% in the effluent discharged from the anaerobic tanks.

Biogas Characteristics and Yield

Biogas production has been estimated at 28.3 m^3 of POME digested as reported by Quah and Gilles (1981) where the methane content was found to be in the range of 54% – 70% volume (average: 64% volume), CO_2 of 31% – 46% volume (average: 36% volume) and traces of hydrogen sulphide from 670 – 2500 vppm.

The volume of the daily biogas output varies significantly with changes in the loading of raw effluent to the digester. The daily biogas output efficiency of Keck Seng's biogas plant was comparable to that reported by Quah and Gilles (1981), estimated at 11 200 m^3 day^{-1} at an average input of COD in raw POME of 53 000 mg litre^{-1}. The biogas composition, however, has been maintained at fairly constant level with CH_4 at approximately 62.5% volume and CO_2 at approximately 37% volume, by carefully regulated and continuous operations of the system.

The energy rate equivalent of the biogas output converts to approximately 220 000 MJ day^{-1}. The total methane captured and utilized as boiler fuel has been estimated to be 1407 yr^{-1}. In terms of GHG emission avoided, this quantity converts to 29 547 t CO_2-e yr^{-1}.

UTILIZATION OF BIOGAS CAPTURED

Due to the abundant and excess biomass energy sources available in all palm oil mills, the capture of biogas from POME treatment as a fuel has rarely been taken into serious consideration. The exceptions are for those mills, such as Keck Seng, which are located within a palm oil processing industrial complex. Biomass resources generated in the mill, including biogas from POME treatment, are fully utilized to meet the large demand for steam and electricity of the palm oil refinery.

Biogas can be used for all applications in place of natural gas, since the common major component is methane. These include: heating (as boiler fuel, for kitchen stove), stationary engines (CHP), vehicle fuel and natural gas or town gas grid.

In Keck Seng, a total of about 1400 t of methane is captured and utilized as boiler fuel annually. The estimated savings from biogas usage in terms of displacement of diesel (4000 litres day^{-1} @RM 1.65 litre^{-1}) and medium fuel oil (2500 litres day^{-1} @ RM 1 litre^{-1}) for the refinery amount to a total of about RM 2.73 million at current rates.

The barriers to finding suitable utilization of the biogas capture with a value comparable to fossil fuel in most palm oil mills, other than the availability of abundant and excess biomass energy resources as mentioned above are due to:

- transportability and off-site utilization of biogas is limited as it is not practical to liquify methane, the major component in biogas, by conventional and economical means;

- relatively high investment cost is involved in the utilization of biogas for power generation in the range of a few hundred kW to 2-3 MW, expected from the medium to large capacity mills, as stand alone system for grid connection; and

- combined treatment of POME from a few mills to enhance the economic scale of the biogas output is also impossible as it would involve high POME transport costs.

TECHNOLOGIES FOR BIOGAS UPGRADING AND UTILIZATION AS TRANSPORTATION FUEL

A direct approach to overcome the barriers in the utilization of biogas is to develop new technologies to enhance the value and accessibility of the biogas captured. Recent development in the European Union and other countries has shown that upgrading of biogas for use as transportation fuel is viable. Refined biogas can readily fit into localized programme for displacement of conventional transportation fuel.

Upgrading of biogas is for the removal of the unwanted gaseous components, depending on the requirements of the type of applications, as shown in *Table 1*. Biogas has to be upgraded to a quality comparable to that of compressed natural gas (CNG) in order to be used in normal vehicles, which have been modified to use

TABLE 1. REQUIREMENTS TO REMOVE GASEOUS COMPONENTS FROM BIOGAS

Application	H_2S	CO_2	H_2O
Gas heater (boiler)	< 1000 ppm	No	No
Kitchen stove	Yes	No	No
Stationary engine (CHP)	< 1000 ppm	No	No condensation
Vehicle fuel	Yes	Yes	Yes
Natural gas grid	Yes	Yes	Yes

Source: *Biogas Upgrading and Utilization, IEA Bioenergy Document, Task 24: Energy from Biologica Conversion of Organic Wastes (2001).

CNG. Basically, the basic product gas quality required is as follows: CH_4 content (volume): > 97%; CO_2 content (volume): < 3%; H_2S: < 10 vppm; and water content: < 32 mg Nm³.

The common technologies available for biogas upgrading include: water scrubbing, polyethylene glycol scrubbing, pressure swing adsorption (PSA) using molecular sieves, and membrane separation. Schematic diagrams of a gas refinery plant employing the water scrubber technology (*Figure 1*), connected direct to a refuelling station are as shown in (*Figures 2* and 3). Crude biogas is compressed to 8 - 12 bar and fed to the water scrubber absorption column where carbon dioxide and hydrogen sulphide

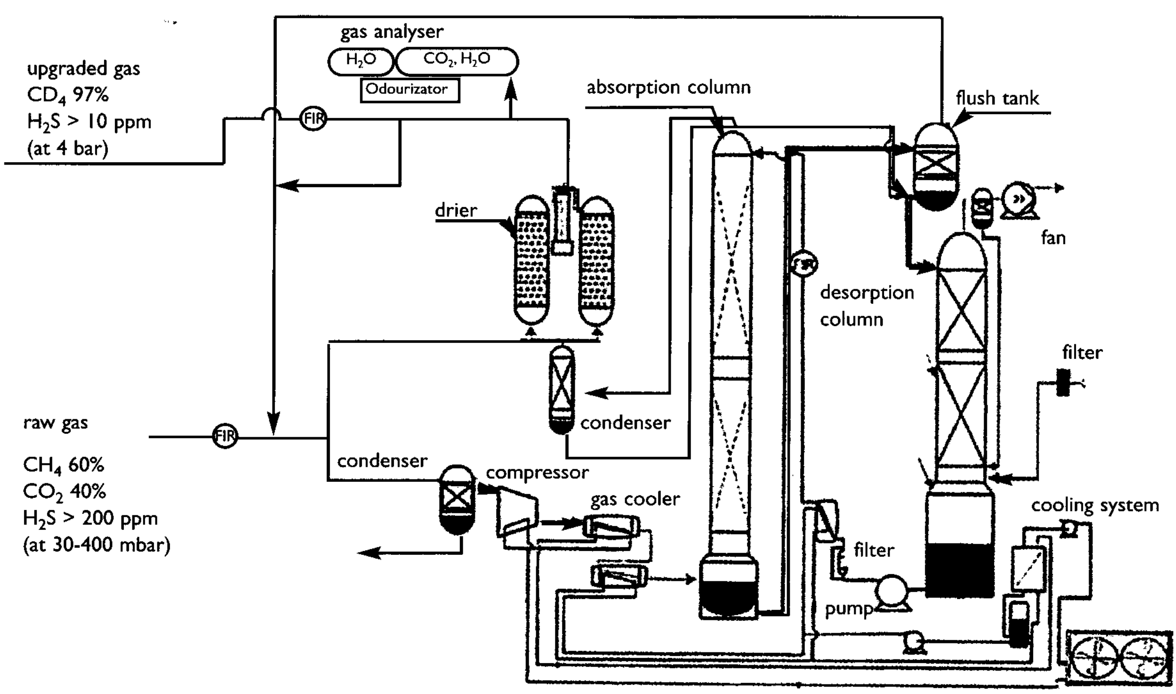

Figure 2. Biogas refinery flow diagram.

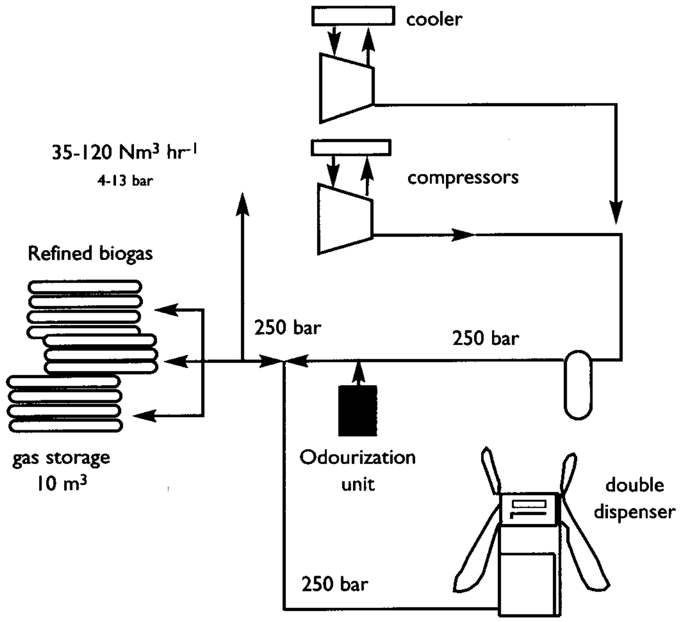

Figure 3. Refuelling station flow diagram.

are removed by absorption in water. The exit gas is dried in an adsorption dryer that operates with zeolites as the adsorbing agent. Water is recycled in a stripper or desorption column. Refined biogas is compressed to 250 bar, odourized and stored in a refuelling station for refuelling to vehicles.

The upgrading cost depends on the plant size. For bigger plants of 300 m^3 hr^{-1} or higher, upgrading costs around 1 – 1.5 $ckWhr^{-1}$ have been reported for systems installed in Sweden (Jonsson, 2004).

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CONCLUSION

The design and operations of the closed-tank CSTR system of Keck Seng has proven to be highly reliable and efficient for POME biogas generation and capture. The direct use of the biogas captured as a boiler fuel has contributed to significant return in terms of fuel displacement. The biogas capture also has resulted in substantial GHG emission reductions, estimated at about 30 000 t CO_2-e per annum for a 30 t FFB capacity mill. It is anticipated that recent developments in technologies for biogas upgrading will open up wider applications and higher value-added utilization of upgraded biogas.

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