TECHNO-ECONOMIC ASSESSMENT FOR COMPRESSED BIOGAS FROM PALM OIL MILL EFFLUENT FOR RURAL ELECTRIFICATION

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ABSTRACT

As one of the world's lead exporter of palm oil, Malaysia has generated a lot of waste from the production of palm oil. One of the highest produced waste is palm oil mill effluent (POME). POME can be utilized as fermentation media, fertilizer, and in generating biogas. Biogas is a mixture of gas consisting mainly of methane and carbon dioxide (CO_2). It can be used for cooking, vehicle fuel, and to generate power. Biogas generation helps cut reliance on the use of fossil fuels and has a great potential to generate power in rural areas that has no access to an electricity grid. The government has acted in solving the issue by installing solar panels to generate electricity. However, solar is an intermittent energy source. The virtual distribution of upgraded compressed biogas to generate power has attracted attention, especially for remote electrification due to the secure supply of biogas. However, this concept poses some issues concerning logistics due to the scattered spatial distribution of palm oil mills. Addressing these aspects requires techno-economic and comprehensive supply chain analyses. The main objective of this study is to design an integration of biogas compression and bottling system for rural electrification on the available biogas plant from POME. First, a preliminary study was performed to estimate the availability of excess biogas in the palm oil mill. Second was designing the integrated compressed biogas plant with and without CO_2 upgrading. Next, an analysis was conducted to identify the optimal pressure range for compressed biogas. The optimal pressure selected was 150 - 250 bar. Besides that, the economic and environmental analyses for compressed biogas production with and without CO_2 upgrading were executed to know which technology is profitable and eco-friendly. From the economic analysis results, it can be seen that the production of compressed biogas with upgrading has a higher profit compared to production without upgrading. Meanwhile, for environmental analysis, the compressor is the highest contributor to greenhouse gases (GHG) emissions. In addition, a case study on the application of compressed biogas was done at Rumah Dau, Sri Aman, Sarawak. This study presented the development of a framework for synthesizing biogenset for rural electrification. Biogenset is a generator that uses biogas as fuel. Currently, the rural electrification is supplied using a 129.6 kWp solar PV hybrid system model integrated with 2 sets of 58 kW diesel generators while biogenset with a capacity of 250 kW was proposed to replace the hybrid solar and diesel engine. The results of this study showed that biogenset is more economically attractive compared to the solar hybrid system. The biogenset has higher profit compared to the solar hybrid scheme which is RM 76,554 per year. However, biogenset has higher GHG emissions compared to the solar hybrid system but lower compared to diesel generator which is 44,283 kg CO_2 eq. The model of biogenset shows a promising strategy to be applied for rural electrification.

ABSTRAK

Sebagai salah satu pengeksport minyak sawit terkemuka di dunia, Malaysia telah menjanakan banyak sisa dari pengeluaran minyak sawit. Salah satu bahan buangan yang paling banyak dihasilkan adalah sisa cecair dari kilang kelapa sawit (POME). POME boleh digunakan sebagai media fermentasi, baja, dan penjanaan biogas. Biogas adalah campuran gas yang terdiri daripada metana dan karbon dioksida (CO_2). Biogas boleh digunakan sebagai bahan api untuk memasak, bahan api kenderaan, dan untuk penjanaan tenaga. Penjanaan biogas membantu mengurangkan kebergantungan pada bahan bakar fosil dan berpotensi untuk penjanaan tenaga di kawasan luar bandar yang tidak mempunyai akses elektrik. Kerajaan telah bertindak dalam menyelesaikan masalah tersebut dengan memasang panel solar untuk menjana elektrik. Tetapi, solar adalah sumber tenaga yang bersifat tidak tentu. Pengagihan biogas termampat yang dinaiktaraf secara maya telah menarik perhatian, terutamanya untuk pengelektrikan di kawasan terpencil kerana bekalan biogas yang terjamin. Namun demikian, konsep ini menimbulkan beberapa isu berkaitan logistik kerana kedudukan kilang kelapa sawit yang merata. Untuk menangani masalah ini, ia memerlukan analisis tekno-ekonomi dan rantaian bekalan komprehensif. Objektif utama kajian ini adalah untuk merekabentuk sistem pemampatan dan pembotolan biogas bersepadu untuk pengelektrikan di luar bandar pada loji biogas yang sedia ada dari POME. Pertama, kajian awal dilakukan untuk menganggarkan ketersediaan lebihan biogas di kilang kelapa sawit. Kedua adalah merekabentuk loji biogas termampat bersepadu dengan dan tanpa peningkatan CO_2. Selanjutnya, analisis dilakukan untuk mengetahui tekanan optimum bagi biogas termampat. Tekanan optimum yang dipilih ialah 150 - 250 bar. Selain itu, analisis ekonomi dan persekitaran untuk penghasilan biogas termampat dengan atau tanpa peningkatan CO_2 dilakukan untuk mengetahui teknologi mana yang lebih menguntungkan dan mesra alam. Dari hasil analisis ekonomi, pengeluaran biogas termampat dengan peningkatan mempunyai keuntungan yang lebih tinggi berbanding dengan pengeluaran tanpa peningkatan. Sementara itu, untuk analisis persekitaran, pemampat adalah penyumbang tertinggi pelepasan gas rumah hijau (GHG). Satu kajian kes mengenai penggunaan biogas termampat dilakukan di Rumah Dau, Sri Aman, Sarawak. Kajian ini membentangkan satu rangka kerja mengunakan *biogenset* untuk pengelektrikan di luar bandar. *Biogenset* adalah penjana yang mengunakan biogas sebagai bahan api. Pada masa ini, pengelektrikan di luar bandar dibekalkan menggunakan model sistem hibrid PV solar 129.6 kWp yang disatukan dengan 2 set penjana diesel 58 kW sementara *biogenset* dengan kapasiti 250 kW dicadangkan untuk menggantikan solar hibrid dan enjin diesel. Hasil kajian ini menunjukkan bahawa *biogenset* lebih menarik dari segi ekonomi berbanding sistem hibrid solar. *Biogenset* mempunyai keuntungan yang lebih tinggi berbanding dengan skim hibrid solar iaitu RM 76,554 setahun. Walau bagaimanapun, *biogenset* mempunyai pelepasan GHG yang lebih tinggi berbanding dengan sistem hibrid solar tetapi lebih rendah berbanding dengan penjana diesel iaitu 44,283 kg CO_2 eq. Model *biogenset* menunjukkan strategi yang memberangsangkan untuk digunakan sebagai pengelektrikan di luar bandar.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ABE	-	Acetone-Butanol-Ethanol
AD	-	Anaerobic Digestion
AF	-	Anaerobic Filtration
BOD	-	Biochemical Oxygen
CDM	-	Clean Development Mechanisms
CNG	-	Compressed Natural Gas
COD	-	Chemical Oxygen Demand
CPO	-	Crude Palm Oil
CSP	-	Concentrating Solar Thermal Power
CSTR	-	Continuous Stirred Tank Reactor
DOE	-	Department of Environment
EF	-	Emission Factor
EFB	-	Empty Fruit Bunches
EPPs	-	Entry Points Projects
FFB	-	Fresh Fruit Bunches
FiT	-	Feed-In-Tariff
FV	-	Future Value
GHG	-	Green House Gases
HRT	-	Hydraulic Retention Time
HRT	-	Hydraulic Retention Time
INDCs	-	Intended Nationally Determined Contributions
IRR	-	Internal Rate of Return
IRR	-	Interest Rate of Return
LCA	-	Life Cycle Analysis
LCI	-	Life Cycle Inventory Analysis
LCIA	-	Life Cycle Impact Assessment
LPG	-	Liquefied Petroleum Gas
NKEA	-	National Key Economic Areas
NPV	-	Net Present Value
NPV	-	Net Present Value

PFD	-	Process Flow Diagram
PFD	-	Process Flow Diagram
PHA	-	Polyhydroxyalkanoates
PKC	-	Palm Kernel Cake
PKS	-	Palm Kernel Shell
POME	-	Palm Oil Mill Effluent
PV	-	Photovoltaic
RE	-	Renewable Energy
RE	-	Renewable Energy
TNB	-	Tenaga National Berhad
UASB	-	Up-Flow Anaerobic Sludge Blanket
UASFF	-	Up-Flow Anaerobic Sludge Fixed Film
UNFCCC	-	United Nations Framework Convention on Climate Change
VFAs	-	Volatile Fatty Acids

LIST OF SYMBOLS

°C	-	Degree Celsius
ρ_{CH4}	-	Density of Methane
BHP	-	Brake Horsepower of Compressor
C_e	-	Electric Utility Cost of Compression
C_{Trans}	-	Transportation Cost
CH_4	-	Methane
CO_2	-	Carbon Dioxide
D	-	Travel Distance from Supply to Demand
E_{In}	-	Energy of Biogas Inlet
E_{Demand}	-	Energy Demand
E_{Truck}	-	Energy Per Truck
F	-	Coefficient of The Different Numbers of Stage Compression
H_2S	-	Hydrogen Sulfide
N	-	Number of Time Periods
N_{Trip}	-	Number of Trips Required
P	-	Absolute Pressure
P_D	-	Pressure Discharge After Compression
P_{In}	-	Suction Pressure
R	-	Absolute Temperature
R_C	-	Compression Ratio
T	-	Total Operating Days
v	-	Specific Volume
V_{In}	-	Biogas Inlet
V_D	-	Discharge Volume After Compression
X_D	-	Transportation Cost
X_e	-	Electric Tariff
Z	-	Compressibility Factor

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of the Problem

As the world's leading exporter of palm oil, Malaysia has exported more than 19.5 million tonnes of palm oil in 2018 and 5.8 million hectares of land have been spent on oil palm plantation (Ying and Ho, 2019). Sabah, Johor, Pahang, and Sarawak are the main contributors to oil palm (Environmental Technology Research Centre, 2014). Figure 1.1 shows the percentage of palm oil world exported from Malaysia.

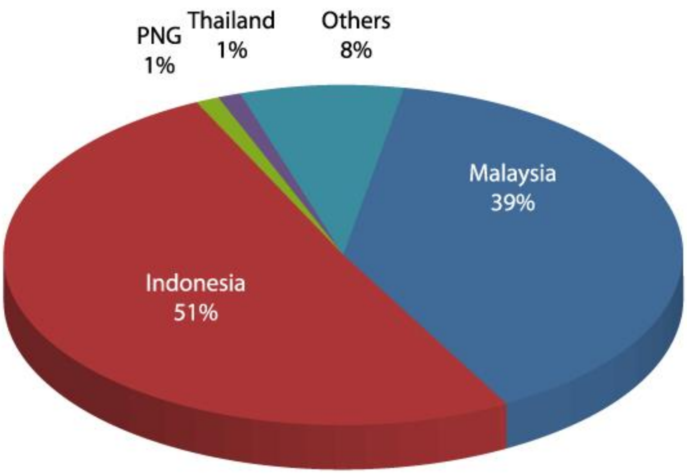

Figure 1.1 Percentage of World Palm Oil Exporter (Basiron, 2015)

The extractions of palm oil from palm fruits have generated around 70 million tonnes of waste such as empty fruit bunches (EFB) and palm oil mill effluent (POME) (Zafar, 2015a). POME is wastewater from the sterilization process, crude oil clarification process, and cracked mixture separation process (Sarawak Energy, 2013). It is a hot (temperature 60 - 80°C), acidic (pH 3.3 – 4.6), thick, brownish liquid with high biochemical oxygen (BOD) and chemical oxygen demand (COD) (Rahayu et al., 2015).

The water used is estimated at 5 – 7.5 tonnes to produce one tonne of crude palm oil (CPO), and more than 50% of water ends up as POME (Ahmad et al. 2003). The palm oil industry in Malaysia has produced about 58 million tonnes of POME annually. Without proper waste management, the huge quantity of POME will pollute waterways near the palm oil mills.

In order to control pollution, regulatory control over discharges from palm oil mills is instituted through Environmental Quality (Prescribed Premises) (Crude Palm Oil) Regulations, 1977 promulgated under the Environmental Quality Act, 1974 and enforced by the Department of Environment (DOE). The palm oil mills are required to comply with prescribed regulations including laws governing the discharge of mill effluent into waterway and land (Ahmad et al. 2003). Therefore, an effective treatment process must be implemented by all palm oil mills to achieve the standard requirements on effluent discharge constantly.

Anaerobic digestion is one of the preferable methods to treat POME. It is a biological process that occurred between microbes and organic waste (Rahayu et al., 2015). The product of this process is biogas. With the availability of POME in Malaysia, the production of biogas can reach 15 billion m^3 (Zafar, 2015b). Biogas is a mixture of methane (CH_4), carbon dioxide (CO_2), and a small amount of hydrogen sulfide (H_2S), moisture, and other gases (Wilkie, 2015). It has the potential to be used as fuel due to the energy released when undergoing the combustion process. Biogas can be used for cooking, vehicle fuel, and power generation.

In Malaysia, some palm oil mills already have biogas facilities. Some of the produced biogas will be injected into a gas engine to generate electricity, and then the generated electricity will be injected into the grid network while the excess biogas will be used at the mills or flared. Table 1.1 shows the excess amount of biogas available in Johor’s palm oil mills.

Table 1.1 Excess Amount of Biogas Available at Johor's Palm Oil Mills (Environmental Technology Research Centre, 2014)

Palm Oil Mill	POME Capacity (m^3/yr)	Electricity (MW)	Electricity Injected to Grid (MW)	Excess (MW)	Excess (m^3/yr)
Johore Labis Palm Oil Mill	216,000	1.44	1.25	0.19	285,326
Kilang Kelapa Sawit Serting	194,000	1.3	1.1	0.2	300,343

Regarding the generation of electricity, Malaysia is still highly dependent on non-renewable sources to generate electricity. To become a developed country, Malaysia is required to comply with all components of sustainability such as economy, environment, and society (Samsudin, Rahman and Wahid, 2016). In 2012, almost 80% of the resources for power generation are non-renewable resources like petroleum, natural gas, and coal.

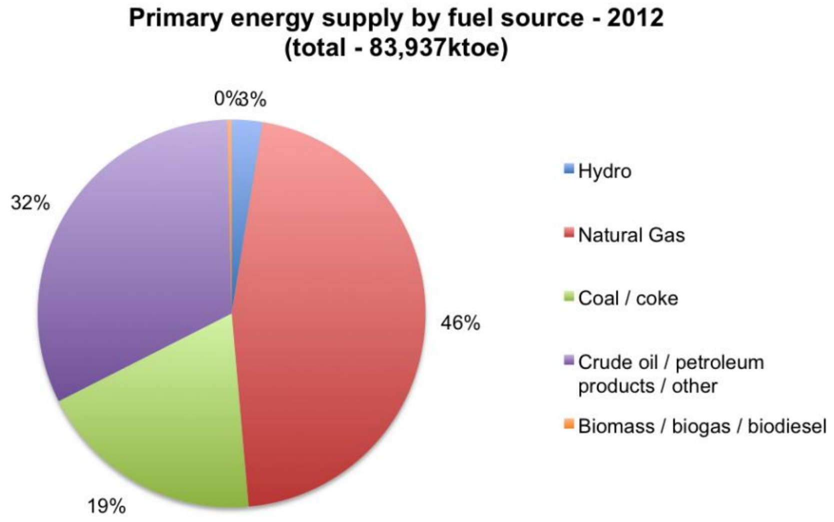

Figure 1.2 Malaysia's Primary Energy Consumption in 2012 (Roberts, 2015)

In addition, some parts of Malaysia still have no electricity access which is a vital utility that people need. Based on a report made by Shiun (2016), there are 1,919 villages with 41,100 households still having no 24 hours access to electricity in Sarawak. The government has done many efforts to solve this problem by installing solar panels and building micro-hydro dams (Sarawak Energy 2014). However, all those renewable energies (RE) are unstable energy and the progress of installing the RE takes time due to a lack of collaboration and partnership between government and public entities.

1.2 Problem Statement

Electricity is an essential need for sustainable economic development. Electricity supplied by the national electricity grid is not accessible in rural areas, therefore alternative energy supply is highly necessary for rural electrification. In Sarawak, around 10% of the rural population has no access to the 24 hours of electricity supply. Extension of grid electricity networks becomes uneconomical because of the geographic conditions of these areas and the low energy density electricity demand based on the population. Currently, off-grid solar photovoltaic (PV) is used to provide alternative power in rural areas due to the abundant solar energy resource in the region. However, solar energy is intermittent renewable energy (RE). Solar energy can only produce energy during the day time and the initial cost for installing the solar panels is expensive (Rinkesh, 2016). On the other hand, the biogas generation from palm oil mill effluent (POME) in the remote areas could be effectively exploited to provide an alternative source of energy for rural electrification. Currently, biogas from POME has mostly been used as fuel for on-site heating and power. Due to logistical issues between biogas resource availability and its demand, biogas compression in gas cylinders is proposed for easy transportation in the rural area. It is foreseen that the utilization of biogas could contribute significantly to the rural electrification that does not have access to electricity grids. The integration of the generation of biogas renewable power in remote and rural areas can supply the required power demand and mitigates emissions. This study presents the development of a framework for synthesizing a biogenset for rural electrification. An economic analysis will also be done to find out which RE is more profitable, either solar energy or biogas.

1.3 Objectives

The purpose of this study is to design an integration of biogas compression and bottling system for rural electrification on the available biogas plant from palm oil mill effluent. There are three objectives that need to be achieved in this research, which are:

1. To evaluate the availability of biogas and its excess of the palm oil mill.

2. To analyse the optimal operation condition by the inclusion of the compression unit in the existing biogas plant.

3. To perform economic and life cycle analysis on the production of compressed biogas.

1.4 Scope of the Study

The scopes of the study are stated as follow:

1. A method to estimate the availability of biogas and its excess.

    a) The availability of biogas is identified in Peninsular Malaysia, Sabah, and Sarawak.

    b) Data for the availability of excess biogas is collected from Kekayaan Palm Oil Mill, Paloh, Johor.

    c) The value of POME generated is collected from the mill while the rest of the physical properties such as the density of POME is extracted from the literature.

d) The boundary of the study includes the generation of POME to the cooling pond, flow through anaerobic treatment, and produce biogas and finally compressed it for easy transportation. It does not include the processing part of palm oil.

2. A method to analyse the optimal operation condition for compressed biogas.

a) The operation condition that has been analysed in this research is the pressure of compressed biogas. The other parameters are not significant for a compression unit.

3. Economic and life cycle analysis on the production of compressed biogas has been carried out for

a) Two scenarios are considered for economic analysis which are:

i. Compressed biogas with and without CO_2 purification.

ii. Comparison of economic evaluation for electrification using biogas and solar energy.

b) Rumah Dau Sri Aman, Sarawak case study is utilized to demonstrate the applicability of the compressed biogas for the whole supply chain.

c) Carbon footprint analysis has been performed to assess the emission of greenhouse gases (GHG) generated during the production of compressed biogas is calculated.

d) A comparison of GHG emissions between a biogenset and solar hybrid system is performed to identify environmentally-sound technology i.e. diesel vs compressed natural gas (CNG).

1.5 Significance of the Study

The importance of performing this research are:

1. To enable 24 hours of electricity access for the off-grid electricity area.

2. Compressed biogas can be one of the alternative fuels to generate electricity, especially for rural electrification.

3. Support the government's energy policy stated in the 10th Malaysia Plan which encouraging the use of renewable energy (RE) in anticipation of fossil fuel depletion.

4. The reduction of GHG emissions on the usage of biogenset will help in conserving the environment for future generations.

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