PREDICTIVE MODELLING OF BIOGAS GENERATION FROM PALM OIL MILL EFFLUENT FOR THE WASTEWATER-ENERGY NEXUS

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A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Science (Energy Management)

School of Chemical and Energy Engineering
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AUGUST 2018

ACKNOWLEDGEMENT

In the name of Allah, the Most Beneficient, the Most Merciful

In the course of this project report completion, it has been a journey yet possible only with the continuous support and motivation that I have received.

I would like to express my utmost gratitude to my supervisor Prof. Ir. Dr. Haslenda Hashim for her endless guidance and encouragement. She has guided me in many aspects with her constant sharing of knowledge and has motivated me in many ways than one with her dedication and passion. She has been very patient and is always supportive of me, be it rain or shine. I would also like to thank her for providing me platforms and opportunities to get involved in projects which have given me such valuable experiences.

I would also like to greatly thank my lecturers as well as fellow colleagues in this study program who have always been supportive and aided me throughout this journey. My sincerest appreciation to all friends, near and far, who have continuously encouraged me in the hardest of days.

Last but not least, as words could not entirely justify the amount of gratitude I could express, I thank Ibu and Ayah as well as my siblings, Hazimah and Miza, for whose infallible belief has been my greatest pillar of strength. I would also like to further extend my appreciation to Ibu for her continuous encouragement and support, whose undoubted enthusiasm in the field of knowledge has always motivated me in pursuing my studies.

For all this and much more, I dedicate this work to my supervisor, lecturers, family and friends.

ABSTRACT

Palm oil mill effluent (POME) wastewater from crude palm oil production has seen to be a valuable waste resource for biogas recovery. Nonetheless, with only improvements on the wastewater treatment processes, there is lack of study on specifically identifying significant biogas-production parameters and its correlations that will further enhance biogas recovery. In addition, there is also absence of a study to further exploit these relations in predicting parametric inputs and outputs to be applied in an interwoven, closed-loop relation known as the wastewater-energy nexus. Thus, this study aims to establish the identification of significant physicochemical parameters of POME wastewater and determine its correlation strength towards biogas production. Regression relations are also established in predicting biogas generation based on the significant parameters of POME wastewater. In addition, predictive assessment on economic and environmental implications from the predicted biogas production is also carried out. Following the methodology of this study, a predictive modelling approach based on statistical analysis, specifically regression analysis, on study parameters are carried out to predict biogas yield. Validation of the regression models are carried out with comparison on modelled and observed data with deviations observed. The results demonstrated a high correlation between pH of anaerobic digestion, temperature, percentage of COD removal and FFA percentage in POME towards biogas production with correlation coefficients higher than 0.8.Furthermore, based on an illustrative scenario analysis carried out on the linear and multilinear regression models, with an input of FFA percentage at 3%, it was able to be predicted that as much as 909.76 m^3 of POME is needed to generate 34,489.70 m^3 of biogas. The energy generated is predicted to be 68,979.40 kWh. Possible mitigation of CO_{2eq} emissions were predicted at a value of 579,426.96. A Sankey diagram is presented to further demonstrate the application of the model on the wastewater-energy nexus in summarizing the system as a whole. This study is intended to be of significant importance to predict parametric control of POME on energy which in hand will deliver economic as well as environmental benefits.

ABSTRAK

Air sisa efluen kilang minyak sawit (POME) hasil daripada pengeluaran minyak sawit mentah dilihat sebagai satu sumber buangan bernilai bagi perolehan semula biogas. Namun begitu, dengan hanya penambahbaikan di dalam proses rawatan air sisa, terdapat kekurangan kajian bagi mengenalpasti secara khusus parameter produksi biogas yang signfikan dan korelasi yang akan selanjutnya meningkatkan perolehan semula biogas. Tambahan pula, terdapat juga kekurangan kajian yang dapat selanjutnya mengeksploitasi korelasi ini dalam meramal parameter input dan output untuk diaplikasi di dalam jalinan dan hubungan tertutup yang dikenali sebagai neksus air sisa-tenaga. Dengan itu, kajian ini bertujuan bagi mengesahkan pengenalpastian parameter fizikal dan kimia di dalam air sisa efluen kilang minyak sawit dan menentukan kekuatan korelasi parameter ini terhadap produksi biogas. Hubungan regresi juga dihasilkan dalam meramal produksi biogas melalui parameter signifikan di dalam air sisa POME. Di samping itu, penilaian ramalan terhadap implikasi ekonomi dan alam sekitar daripada ramalan produksi biogas juga telah dilakukan. Berteraskan metodologi kajian ini, pendekatan model ramalan yang berasaskan analisa statistik, secara khususnya analisa regresi terhadap parameter, telah dilakukan bagi meramalkan hasil biogas. Pengesahan terhadap model regresi dijalankan dengan perbandingan di antara data model dan data pemerhatian. Hasil kajian menunjukkan korelasi yang tinggi di antara pH pencernaan anaerobik, suhu, peratusan penyingkiran keperluan oksigen kimia (COD) dan peratusan asid lemak bebas (FFA) di dalam POME terhadap penghasilan biogas dengan pekali korelasi bernilai lebih tinggi daripada 0.8. Selain daripada itu, berdasarkan senario analisa ilustrasi yang dijalankan terhadap model regresi linear dan multilinear, dengan input peratusan FFA sebanyak 3%, telah dapat diramalkan bahawa sebanyak 909.76 m^3 POME diperlukan bagi penghasilan 34,489.70 m^3 biogas. Tenaga yang dapat dihasilkan diramalkan berjumlah sebanyak 68,979.40 kWh. Kemungkinan pengurangan pelepasan karbon dioksida diramalkan pada nilai 579,426.96. Rajah Sankey diperkenalkan bagi mendemonstrasi secara selanjutnya aplikasi model pada neksus air sisa-tenaga yang dapat merumuskan sistem secara keseluruhan. Kajian ini adalah sangat signifikan dan penting dalam meramalkan kontrol parameter POME terhadap tenaga yang akan dapat memberi kebaikan terhadap ekonomi dan alam sekitar.

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LIST OF SYMBOLS

%	-	Percentage
°C	-	Degree Celsius
µg	-	Microgram
B	-	Boron
C	-	Calcium
CH_4	-	Methane
CO_2	-	Carbon dioxide
$CO_{2\ eq}$	-	Carbon dioxide equivalent
Cu	-	Copper
Fe	-	Iron
g	-	Gram
H_2	-	Hydrogen
H_2O	-	Water
H_2S	-	Hydrogen sulphide
K	-	Potassium
kg	-	Kilogram
l	-	Litre
m^3	-	Cubic meter
mg	-	Milligram
Mg	-	Magnesium
Mn	-	Manganese
N_2	-	Nitrogen
NH_3	-	Ammonia
NH_3-N	-	Ammoniacal nitrogen
O_2	-	Oxygen

P	-	Phosphorus
r	-	Coefficient correlation
T.N.	-	Total nitrogen
Zn	-	Zinc

LIST OF ABBREVIATIONS

ANN	-	Artificial Neural Network
BOD	-	Biochemical oxygen demand
COD	-	Chemical oxygen demand
CPO	-	Crude palm oil
EF	-	Emission factor
EFB	-	Empty fruit bunch
FFA	-	Free fatty acid
FFB	-	Fresh fruit bunch
GHG	-	Greenhouse gas
kWh	-	Kilowatt hour
MT	-	Metric tonne
MW	-	Mega Watt
MIMO	-	Multiple input and multiple output
MSW	-	Municipal solid waste
OPF	-	Oil palm trunk
OPT	-	Oil palm frond
PKS	-	Palm kernel shell
POME	-	Palm oil mill effluent
PPF	-	Palm pressed fibre
R&D	-	Research and development
SDG	-	Sustainable development goals
SRT	-	Solid retention time
TCOD	-	Total chemical oxygen demand
TNB	-	Tenaga Nasional Berhad
VFA	-	Volatile fatty acid

CHAPTER 1

INTRODUCTION

1.1 Background of the Problem

Malaysia is one of the largest producers in the palm oil industry, accounting up to 39 percent of the world palm oil production, placing second after Indonesia. Palm oil exports are also carried out throughout the world with a total of 23,294,140 tonnes of palm oil being exported in 2016 (Malaysia Palm Oil Board, 2017). These large productions and exports are mainly contributed by the large areas of plantation whereby 4.49 million hectares of land throughout Malaysia has been utilized for palm oil cultivation. From these palm oil plantations, as much as 17.73 million tonnes of palm oil is produced (Malaysia Palm Oil Council Website, 2012). With the current global high demands for refined palm oil, it undoubtable that the palm oil industry has become one of the most marketable and important sectors in Malaysia.

Nonetheless, despite the promising market of palm oil which leads to increased production, it has consequently been seen that relatively large amounts of biomass waste are produced in this industry. The variation of wastes produced include solid wastes such as oil palm trunks (OPT), oil palm fronds (OPF), empty

fruit bunches (EFB), palm pressed fibres (PPF) as well as liquid waste such as palm oil mill effluent (POME). From these different types of waste, POME contributes to the largest portion of waste production with 53 million m^3 of POME being produced in Malaysia, annually (Lorestain, 2006). Other than its significantly large amount in the palm oil waste generation, POME is also one of the most harmful wastes for the environment when it is discharged without any form of treatment. It contains high amounts of suspended materials, oil and grease, ammoniacal nitrogen and have high COD and BOD levels.

With massive volumes of waste generated available in treating POME, various methods of treatment are carried out in order to reduce the negative effects of palm oil mill effluent wastewater accumulation. One of the most approachable methods is through the wastewater treatment using an anaerobic bioreactor. Consequently, this digestion not only reduces the amount of unwanted compounds in the wastewater but also allows tapping of biogas, specifically methane gas, CH_4, a great form of renewable energy.

Hence, through this general observation, a specific study is carried out in order to identify the significant factors that will significantly affect biogas-production parameters. Ultimately, the prediction in regards to the amount of biogas and energy that can be produced is able to be carried out. The factors that are potentially to be studied include amount of POME generation as well as operating conditions such as amount of COD removal, temperature, pH and other additional factors. Maximization of biogas production based on the ability to predict and control the physicochemical parameters will in hand increase energy or electricity production. Energy that will be produced can be utilized in the gas engine of the boiler for energy generation of the palm oil mill processes which ultimately discharges POME once again. The process is reiterated to utilize POME wastewater again to obtain energy. This further generates a closed loop-cycle correlation or known as the wastewater-energy nexus by which water is represented by the POME wastewater while energy is equivalent to the biogas production as a form of energy. The economic and environmental implications of the predictive modelling approach

is additionally observed in order to gauge the significance of the nexus to the palm oil mill industry and environment. Additionally, recommendations for improvement in the predictive modelling approach will also be proposed in order to fully optimize the potential of biogas production from POME biogas through parametric control.

1.2 Statement of the Problem

Large amounts of POME wastewater is produced from the crude palm oil (CPO) extraction process. The wastewater, if discharged into marine and freshwater ecosystems without proper treatment will extensively alter aquatic biodiversity. This eventually leads to adverse effects to the human population as a whole. With various research as of the current moment, proper treatment of the palm oil mill effluent wastewater is able to be conducted and one of the approaches is through anaerobic digestion and further sludge treatment. Low costs of biogas recovery are possible by this method of treatment.

Apart from the various specific processes available that are used to recover biogas, it is significantly important to identify the significant parameters that are able to control biogas production. Despite having general ideas in regards to the factors that affect biogas generation, it is yet undetermined of the strength of each factor towards the production of biogas. As of current, there is lack of study in regards to this matter that cover the multiple parameters and correlations of the biogas-production parameters in optimizing biogas and energy production have not been clearly established. These relations are required in contributing towards the prediction of the outputs of the significantly important water-energy nexus. In relation to that, there is also absence of further analysis on the possible impacts towards the economy and environment based on the ability to predict biogas production through parametric relations.

1.3 Objectives of the Study

The study was conducted in order to achieve the following objectives:

1. To study the significant physicochemical parameters that affect biogas production of palm oil mill effluent (POME) wastewater as well as determining its strength of correlation.
2. To construct linear and multilinear regression relations of physicochemical parameters in predicting biogas generation from palm oil mill effluent (POME) wastewater for the wastewater-energy nexus.
3. To analyse the predictive economic and environmental implications of biogas generation from palm oil mill effluent (POME) wastewater.

The developed predictive approach were then demonstrated on an illustrative set of conditions of the physicochemical properties in POME wastewater.

1.4 Scope of the Study

In order to achieve the objectives of the study, the scope of the work is defined as follows:

1. State-of-the-art review on past studies and literature in better understanding the various factors and parameters of the study which include, COD, pH, FFA, temperature as well as review of predictive modelling approaches and the network of wastewater-energy nexus.

2. Data collection of the POME wastewater quality based on various parameters, amount of biogas generation and amount of energy generation at a daily basis from current and historical data.
3. Statistical analysis based on regression in further comprehension of POME physicochemical parameters that affect biogas generation as well as result validation based on a model test on additional sets of data.
4. Scenario analysis of economic implications of the predictive biogas and energy generation for the wastewater-energy nexus and environmental implications with emphasis on possible mitigation of GHG emissions which are avoidance of CO_2 emissions towards the environment.

1.5 Significance of the Study

This study is crucial in understanding the significant physicochemical parameters in palm oil mill effluent wastewater that will ultimately affect biogas production. Identification of the strength of each influential parameter as well as establishment of its correlations also contribute to the prediction of biogas and energy generation. This will indirectly help the palm oil mill industry to understand the behavioural pattern in controlling biogas generation. Application of the predicted outputs from this study on the wastewater-energy nexus establishes a visual network that can be seen clearly through the aid of a Sankey diagram. Economic savings and revenues can also be predicted through this study such that the energy which can be sold to the National Grid as well as the savings from internal energy usage can be calculated easily. Environmental concerns in regards to possible reduction of carbon dioxide emissions predicted from the study is also valuable information for the industry. All in all, the approach used in this study could become a guideline in future studies to better optimize and model such parametric relations in maximizing biogas generation from POME wastewater.

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