BIOGAS PRODUCTION FROM ANAEROBIC CO-DIGESTION OF COW DUNG AND LIGNOCELLULOSIC WASTES

BY

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ABSTRACT

A series of study on biogas potential test and the effect of organic loading rate (OLR) and NaOH pretreatment concentration from the co-digestion of cow dung (CD) with corn husk (CH), palm oil leaf (POL), and grass-cutting (Gr) was conducted. Biogas potential test observation was performed with feeding rate of organic dry matter set to 238 g volatile solid (VS)/day^{-1} (FR_{BPT-1}), 476 g VS/day^{-1} (FR_{BPT-2}), and 714 g VS/day^{-1} (FR_{BPT-3}). The co-substrates (CH, POL, and GR) were soaked with NaOH solution at 3 days (NT_3) for FR_{BPT-1}, 4 days (NT_4) for FR_{BPT-2}, and 5 days (NT_5) for FR_{BPT-3}. The result showed that CH has the highest yield of biogas for all three set of parameters at 2.27, 1.51, and 2.06 L biogas/Kg VS.day^{-1} on FR_{BPT-1}/NT_3, FR_{BPT-2}/NT_4, and FR_{BPT-3}/NT_5, respectively. A subsequent study on the optimization with the same variables was conducted, by Face-Centered Central Composite Design (CCF) as the experimental design. OLR was set at 25, 35, and 45 g VS/L.day^{-1} per digester, denoted as FR1, FR2, and FR3, respectively. The pretreatment concentration of NaOH was given at 25, 35, and 45%, denoted as N1, N2, and N3, respectively. The maximum yield obtained was 8.98 L biogas/kg VS.day^{-1} with 45 g VS/L.day^{-1} of OLR and 25.0% application of NaOH pretreatment concentration. While the maximum methane content observed was 68.8% by volume, obtained at 45.0 g VS/L.day^{-1} OLR and 45.0% NaOH pretreatment concentration.

ملخص البحث

تم إجراء سلسلةٍ من الدراسات لاختبار إمكانية إنتاج الغاز الحيوي وتأثير معدّل تحميل المادة العضوية (OLR) وتركيز محلول هيدروكسيد الصوديوم المستخدم في معالجة روث البقر(CD) مع كلٍّ من قشر الذرة (CH) ، ورق زيت النخيل (POL) وكذلك قطع العشب (Gr) كموادٍ مساعدة في عملية الهضم. تمت مراقبة عملية التخمّر عند تحميل المادة العضوية بمعدل 238 (FR_{BPT-1}) ، 476 (FR_{BPT-2}) وَ 714 (FR_{BPT-3}) جم من المادة الصلبة المتطايرة لكلٍّ لتر في اليوم. تم نقع المواد المساعدة للهضم (CH, POL, GR) في محلول هيدروكسيد الصوديوم لفترات متفاوتة: 3، 4، 5 أيام لكل من FR_{BPT-1}، FR_{BPT-2} وَ FR_{BPT-3} على التوالي. أظهرت النتائج أن قشر الذرة كان له أكبر عائد من الغاز الحيوي لكل المتغيرات التي تم اختبارها كالتالي: 2.27، 1.51 وَ 2.06 لتر غاز حيوي لكل كجم صلب متطاير في اليوم عند المعالجة بهيدروكسيد الصوديوم لمدة 3،4،5 ساعات على التوالي. وقد تم لاحقاً إجراء دراسة على أثر تحميل المادة العضوية وتركيز محلول هيدروكسيد الصوديوم على معالجة قشر الذرة باستعمال تصميم المجمع المركزي Centered Central Composite Design تحتCCF لتصميم التجارب. تم تحديد تحميل المادة العضوية عند ثلاث متغيرات وهي: 25.0، 35.0 وَ 45.0 جم مادة صلبة متطايرة لكلّ لتر في اليوم لكل وعاء هضم، وتركيز محلول هيدروكسيد الصوديوم للمعالجة 25.0 ، 35.0، 45.0 % على التوالي. تم الحصول على أقصى عائد من الغاز (8.98) لتر لكلّ كجم في اليوم عند استخدام 45.0 جم من المادة الصلبة المتطايرة وتركيز 25% من محلول هيدروكسيد الصوديوم، في حين أن أعلى محتوى من الميثان تمت ملاحظته 68.8% حجماً، تم الحصول عليه عند استخدام 45.0 جم مادة صلبة متطايرة لكلّ لتر في اليوم وتركيز 45.0 % من محلول هيدروكسيد الصوديوم.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion; it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Biotechnology Engineering.

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DECLARATION

I hereby declare that this thesis is the result of my own investigation, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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For the best of times, and the epoch of belief.

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LIST OF ABBREVIATIONS

°C	Degree celcius
2FI	Two Factors Interaction
AEBIOM	*Association Européenne pour la Biomasse* (The European Biomass Association)
ANOVA	Analysis of Variance
BOD	Biochemical Oxygen Demand
Btu	British Thermal Unit
CCD	Central Composite Design
CCF	Face-centered Central Composite Design
cells/mL	Cells per millilitre
COD	Chemical Oxygen Demand
CSTR	Continuously Stirred Tank Reactor
d	Day (Time Unit)
DM	Dry Matter
EBA	European Biogas Association
EIA	United States Energy Information Administration
EISA	Energy Independence and Security Act
EPA	United States Environmental Protection Agency
EU or EU-17	European Union
g/dm^3	Gram per cubic decimetre
h	Hour (Time Unit)
HRT	Hydraulic Retention Time
$kg\ kmol^{-1}$	Kilogram per kilomole
$kg\ m^{-3}$	Kilogram per cubic metre
kHz	KiloHertz
$kWh\ m^{-3}$	Kilowatt-hour per cubic metre
L/day	Litre per day
m^3	Cubic metre
mm	Millimetre
ODM	Organic Dry Matter
OECD	Organization for Economic Cooperation and Development
OLR	Organic Loading Rate
OTS	Organic Total Solids
ppm	Part per million
PVC	Poly Vinyl Chloride

rpm	Rotation per minute
TS	Total Solid
VFA	Volatile Fatty Acid
VS	Volatile Solid
VSS	Volatile Suspended Solid

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Energy scarcity is a very important issue that will take the centre stage in the next several decades. Several forecasts from governments, companies, and related agencies show and update the status of the world energy demand and its availability from time to time. A projection of The United States Energy Information Administration (EIA) (2013) stated that the increase in global energy demand from 2010 to 2040 occurs with the increases from 524 quadrillion British thermal unit (Btu) in 2010 to 820 quadrillion Btu in 2040, a 30-year increase of 56 percent. This value increases by time as the demand and consumption arise faster than its production.

Different energy consumption behaviour occurs between the developed nations and the developing nations, where the former for the most part already more mature in the energy consumption. In contrast, the developing nations with the strong economic growth and expanding population contributes to 85 percent of the increase in global energy demand (EIA, 2013). This makes the future energy growth is driven by the developing countries. However, it is not followed by the improved growth of energy production that the problem on the energy scarcity arises. Given the impact, it is crucial for all of the stakeholders to consider other alternatives which are sustainable and affordable to substitute the main energy source of the world.

Increased generation of wastes, on the other hand, emerge as another important issue for the environment. Organic wastes in the form of biomass residues collected from the municipal and agricultural sectors can reach an outstanding amount in the worldwide scale. As the centre of upstream food sources, the agricultural sector sustains its production continuity. Thus the emissions and pollutions level from the agricultural sector alone is rising steadily over time.

Agricultural wastes in the form of biomass residues are viable alternative source of energy. The residues in the form of lignocellulosic materials are abundant in this sector, and considered as the most suitable feedstock for the future energy production. Through the process of anaerobic fermentation, it is possible to convert the biomass to harvest energy in the form of biogas. Biogas in the agricultural basis has been contributing to the global renewable energy generation and it has been evaluated at the industrial scale worldwide with its significant contribution at the preservation of natural sources and the environmental protection.

The benefits of biogas cover the aspect of energy security, environment, and economics. The increase of energy security is included as its production requirement offsets non-renewable fossil fuel energy sources by the utilisation of biomass residues. Fewer emissions and cleaner environment are also improved as biogas utilization prevents methane release in the atmosphere and its make use of biomass residues through anaerobic digestion process. Likewise, the economics is affected as the biogas production creates jobs and benefits local economies.

Biogas has a great potential in terms of energy production. The European Biomass Association (AEBIOM) estimates that the European production of biomass based energy can be increased from 72 million tonnes in 2004 to 220 million tonnes in 2020 (Al Seadi et al., 2008). Moreover, the largest potential lies in biomass originating from agricultural sector. With this great potential to be explored, biogas has been adapted well to daily applications. In Malaysia, the government has identified biomass as one of the potential renewable energy. Malaysia produces at least 168 million tonnes of biomass, including timber and oil palm waste, rice husks, coconut trunk fibres, municipal waste and sugar cane waste annually. In a conversion, Malaysia has more than 2400 MW of biomass and 410 MW of biogas potential, out of which only 773MW has been harnessed until 2011 (Zafar, 2014).

The direct application of biogas, with no other processes on post-fermentation, is to generate heat. In India, the implementation of simple biogas technology can provide a renewable energy source to provide heat, with the potential to reduce pressure on forest, soil and the ecosystems (Agoramoorthy & Hsu, 2008). The upgraded biogas can be used for electricity generation as well as vehicle fuel. Germany, as one of the advanced country in biogas production and utilization, has currently more than 7,300 biogas plants, with an installed electrical capacity of about 3 GW in operation (Hahn et al., 2014). In a larger part, European Biogas Association stated that as 2012 Europe has already over 13,800 biogas plants and more than 7,400 MW of installed capacity (EBA, 2013). The advanced application of biogas for vehicle fuel can be found in Sweden. Forssberg (2010) reported that in Stockholm, the world's first biogas ambulance was brought into operation in June 2009, and 90 buses in the inner city run on biogas from the *Henriksdal* wastewater treatment plant. It is possible to use biogas for heating or for electricity generation in Sweden, but the most environmentally efficient way is to use biogas as a vehicle fuel instead of fossil fuel like diesel or petrol.

Although with less advanced technology, the biogas production through anaerobic digestion in the developing countries is also gaining importance. A study conducted in Ghana, a country which depends heavily on wood as a source of fuel contributing about 72 percent of the primary energy supply, revealed having the technical potential of constructing about 278,000 biogas plants, which only a little over 100 biogas plants has so far been established (Arthur et al., 2011). In Malaysia, the utilization of biogas may not be the main concern for the provision of the alternative energy source. However, several attempts have been conducted. Retrieved from Waste Management World (WMW), *Camco International* was issued to build its biogas facility by utilising palm oil waste at Palong, Pahang State (WMW, 2012). Another project was conducted in the utilization of pig farm residues at Sarawak State where the biogas plant itself is only part of the total project. The construction of the plant was expected to be finished in the course of the summer of 2013 (NIRAS, 2014).

Over all the advantages and the potential of biogas that could be modelled, the main benefit lays on the production of methane as the alternative of renewable energy source. In terms of the environmental impact, biogas reduces the emissions from the untreated biomass residues to the atmosphere. As a matter of fact, the biogas production converts these biomass residues and reducing its amount by producing energy and eco-friendly natural by-products.

1.2 PROBLEM STATEMENT

Anaerobic digestion is the conversion process of organic materials, called substrates or feedstock, to produce biogas in the absence of oxygen. This biological process is strongly dependent on the environmental conditions and the characteristic of substrates. Afterwards it is found that mixing organic substrates, which commonly known as co-digestion, may give a synergistic effect that can result in the higher production rate of the biogas (Deublein & Steinhauser, 2011).

Organic loading rate (OLR) is an important parameter in a continuous co-digestion process, indicating how many kilograms of organic dry solids are loaded per m^3 of digester volume and unit of time. It depends on the characteristic of the substrates and very important for the microorganisms inside the digester. A higher OLR may increase the biogas production. However, an exaggerated one will result in the microorganisms stress and rather lead to the fermentation washout.

Lignocellulosic biomass which commonly generated from the agricultural and forestry sectors is abundant in quantities. Corn husk, palm oil leaf, and grass-cuttings are some of the example of this residue. Despite the quantities, it requires a particular pretreatment prior to its usage as a substrate for the microorganisms. This is due to the nature of the materials which is eminence to resist against physical and biological measures. Without a pretreatment step, the digestibility quality is not typically high enough for a biogas production process. The most widely used pretreatment technique involves the utilization of alkaline chemicals. Alkaline pretreatment by using sodium hydroxide (NaOH) has been extensively used as one of the economical way to increase the digestibility of lignocellulosic substrates by the microorganisms. A proper control must be carefully taken in order to increase the digestibility while maintaining the allowable pH for the microorganisms in the fermentation.

The biogas production can be considered as the final result of the fermentation performance which is affected by the synergy of complex fermentation settings. Consequently, this makes the appropriate combination of the optimum OLR and substrates pretreatment may provide a high production of biogas, as it would increase the concentration of the biomass in the right quantity. However, this type of combination processes cannot be univocally defined for all fermentation processes, but rather to be investigated for each specific substrate, and at specific operating conditions.

1.3 OBJECTIVES

The research was initiated on the aims of both energy production in the form of biogas, and the understanding of biomass residues pretreatment. The specific objectives are to:

1. Investigate the potential of biogas production from the co-digestion of cow dung and lignocellulosic biomass resources of corn husk, palm oil leaves, and grass cuttings.
2. Determine the optimum concentration of NaOH for the pretreatment process of corn husk.
3. Determine the optimum organic loading rate (OLR) for the co-digestion of corn husk and cow dung in an anaerobic fermentation.

1.4 RESEARCH SCOPE

The research was initiated by investigating the capability of lignocellulosic biomass to produce biogas in anaerobic co-digestion fermentation with cow dung. Biogas production rate which is embodied in terms of yield, and the concentration of methane contained in the biogas produced, were used as a hint of the anaerobic fermentation efficacy in producing biogas. A further step on the research was emphasized on the alkaline pretreatment of corn husk with NaOH to produce biogas. The different OLR on the operating conditions leading to optimum result for the quantity and quality of biogas was explored as well.

The biogas volumetric production was determined from the volume of gas produced per time in certain working volume of digester. Its quality was assessed in term of methane and impurities gas percentages contained from the biogas produced under different configurations of co-substrate pretreatment and OLR. Optimization scenarios are provided for the anaerobic co-digestion of corn husk; accounting the two independent variables and some of the main generated responses. However, further step on the downstream processing of the biogas was not included in the research.

1.5 RESEARCH BENEFITS

The information gained from the experimental results contributes to the knowledge on the utilization of lignocellulosic biomass for the biogas production scenarios. On the particular part of the corn husk utilization in more specific operating parameters, a better insight to the effect of OLR and NaOH co-substrate pretreatment is provided.

In terms of technical and economical operations, the OLR provides the data as a part of the search for the optimum operating conditions. The optimum condition generated can be used as the benchmark for a similar configuration of another anaerobic digestion process. This aspect is important, due to the situation where a feeding action may affect the technical operation costs of the related plant.

The optimum concentration of NaOH in the pretreatment of corn husk can lay the foundation for further exploration to improve the related parameter for a better quantity and quality of the biogas produced. This is expected to efficiently work for similar co-substrates for the biogas production.

All the information gathered are believed to be beneficial for the current knowledge of renewable energy, as well as the industrial actors who implement it in the actual situation.

1.6 THESIS OUTLINE

This thesis is organized into five chapters with several appendices. Chapter One covers the introduction to the research, including the background information, problem statement, objectives, scope, and the benefits of the research. Chapter Two reviews the available literatures in the area of biogas substrates, formation, and process engineering. Introduction to the renewable energy overview and the biogas potential will be mentioned at the beginning of the chapter. Emphasizes are given to the pretreatment of lignocellulosic co-substrate, OLR, and co-digestion process. Chapter Three described the detailed methodology of the study which covers materials, experimental methods, and analytical procedures. Chapter Four presents the experimental results and their extensive discussions. Conclusion and recommendations are discussed in Chapter Five.