Synthesis of Integrated Biomass Fermenter – Digester for Fuel Production

by

Izatul Husna Binti Zakaria

Dissertation submitted in Partial Fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Chemical Engineering)

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Chemical Engineering Programme
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Approved:

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TRONOH, PERAK

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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IZATUL HUSNA BINTI ZAKARIA

ABSTRACT

Due to the diminishing fossil fuel reserves, alternatives energy sources need to be renewable, sustainable, efficient, cost effective and safe. Biomass has huge potential to generate renewable fuel oil replacing fossil fuel in our country. There are many options of process technologies to produce biofuel such as Pyrolysis and Fermentation. The objectives of this study to synthesis a conceptual integrated process for the production of renewable fuel.

This study covers the feedstock, production, enzyme, chemical process, material energy balance and simulation to produce fuel from a fermenter and an anaerobic digester plant. The processes involve feed pre-treatment, reaction part and product recovery. The data will be used or to synthesize a conceptual integrated process for fuel production.

Basis of 1 kilogram biomass in batch reactor produces 60.2% gases which include methane, CO2 and traces gases. Fermenter digester produces 41.6% liquid and solid those contain liquid ethanol and sludge. 12.9% and 9.1% fuel production resulted from anaerobic digestion and fermentation process. Heat capacity and kinetic energy used for anaerobic digester are 32.5 kJ and 0.05 J respective values. Kinetic energy value is too small and can be neglected. Heat capacity and kinetic energy used for fermentation are 32.1 kJ and 172.0 J respective values. The process energy efficiency for digester and fermenter are 32.5 kJ/kg biomass and 32.1 kJ/kg biomass. Both bioprocess give high percentage of energy produce.

Integrated biomass fermenter digester resulted in 338% Methane gas produce and 23% Ethanol liquid. Sludge produce from the integrated plant will be further distillate to obtain ethanol liquid. Economic potential using Deterministic approach evaluation shows that this project investment assures profit.

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LIST OF ABBREVIATIONS

AD	Anaerobic Digestion
ASBR	Anaerobic Sequencing Batch Reactor
CSTR	Continuous Flow Stirred Tank Reactors
HRT	Hydraulic Retention Time
TCOD	Total Chemical Oxygen Demand
ADP	Adenosine diphosphate
ATP	Adenosine-5'-triphosphate
NAD+	Nicotinamide adenine dinucleotide
BMP	Biochemical Methane Potential
Is	Specific Investment
PI	Profitability Index

CHAPTER 1

INTRODUCTION

1.0INTRODUCTION

1.1 Background of Study

The world today is facing an alarming growth of energy demands on the back of depleting non renewable energy resources while the oil consumption is large. China spectacular economy growth has imposed serious pressure on the global demand for oil.

More over continuing crises in the Middle East could lead to uncontrolled speculation in the stock commodity market has create an energy security issue that has seen the oil prices surpassing the 100 dollars per barrel in mark early 2007. (Sa'nchez, Cardona,2007)

World will face economy crisis if the fossil oil demand and price getting higher. In addition the intensive utilization of fossil fuels has led to the increase in the generating of polluting gases released in the atmosphere. Atmospheric pollution is the major causes for the change in global climate.

Historically due to high feedstock prices, primarily corn in USA and communication from other products for its gasoline uses, the economics of the production of this renewable fuel such as ethanol have been marginal. Improvements of the fuel ethanol production process resulting in even 2-5 %reduction per gallon could significantly increase it demand.

Plantation waste biomass has the potential to generate fuel fire replacing fossil fuel with sustainable fuel originally from plant matter creates a cleaner and renewable energy alternative. The most important benefit with biomass fuel is that it relies on a renewable resource. Biomass fuel production plants must be sited near a reliable source.

Realizing that biofuel production is more economical compared to fossil fuel, many companies in the world come out with initiatives to generate biomass power. Biomass power systems can be referred to as carbon dioxide or green house gas neutral. This is because the plant material absorbs as much carbon dioxide during its life as is released when burned to produce electricity.

1.1.1 Anaerobic Digestion

Anaerobic Digestion (AD) is a biological process that happens naturally when bacteria breaks down organic matter in environments with little or no oxygen. It is effectively a controlled and enclosed version of the anaerobic breakdown of organic waste in landfill which releases methane. Almost any organic material can be processed with AD, including waste paper and cardboard (which is of too low a grade to recycle, e.g. because of food contamination), grass clippings, leftover food, industrial effluents, sewage and animal waste.

AD produces a biogas made up of around 60 per cent methane and 40 per cent carbon dioxide (CO2). This can be burnt to generate heat or electricity or can be used as a vehicle fuel. If used to generate electricity the biogas needs to be scrubbed. It can then power the AD process or be added to the national grid and heat for homes.

As well as biogas, AD produces a solid and liquid residue called digestate which can be used as a soil conditioner to fertilise land. The amount of biogas and the quality of digestates obtained will vary according to the feedstock used.

More gas will be produced if the feedstock is purescible, which means it is more liable to decompose. Sewage and manure yield less biogas as the animal which produced it has already taken out some of the energy content.

In UK, AD has until recently been limited to small on-farm digesters. However AD is widely used across Europe. Denmark has a number of farm co-operative AD plants which produce electricity and district heating for local villages, biogas plants have been built in Sweden to produce vehicle fuel for fleets of town buses and Germany and Austria have several thousand on-farm digesters treating mixtures of manure, energy crops and restaurant waste, with the biogas used to produce electricity.

AD is also widespread in other parts of the world. India and Thailand have several thousand mostly small scale plants. In developing countries, simple home and farm-based AD systems offer the potential for cheap, low cost energy from biogas. When treating municipal waste, AD can be used to process specific source separated waste streams such as separately collected food waste. The digestate will be uncontaminated so can be used as a soil improver. To minimize the waste impact has on the climate, compostable and recyclable material should be separated at source for treatment or reprocessing, using AD where suitable.

1.1.2 Fermentation

Fermentation is generally the conversion of a carbohydrate such as sugar into an acid or an alcohol. More specifically, fermentation can refer to the use of yeast to change sugar into alcohol or the use of bacteria to create lactic acid in certain foods. Fermentation occurs naturally in many different foods given the right condition. Same type of Anaerobic Digestion feed can be used for Fermentation process. Both process used sugar such as glucose that contain in biomass to form biofuel. Fermentation use glycolysis reaction to break the molecule of glucose in pyuvate and yeast to produced ethanol. Otherwise, anaerobic digestion uses bacteria to hydrolyze the sugar and produce methane.

Ethanol (ethyl alcohol, C_2H_5OH) is a liquid biofuel which can be produced from several different biomass feedstock and conversion technologies. Ethanol is an attractive alternative fuel because it is a renewable bio-based resource and it is oxygenated thereby provides the potential to reduce particulate emissions in compression ignition engines (Hansen, et al., 2005).

As demand for the limited global supply of non-renewable energy resources increases, the price of oil and natural gas keep increasing. As a result, production of ethanol by fermentation from renewable carbohydrate materials for use as an alternative liquid fuel has been attracting worldwide interest. There is a growing interest to find alternative bioresources apart from sugarcane, beet molasses and starchy crops like cassava, sweet potato and sweet sorghum for ethanol production. Further, considerable interest has been shown in using these agricultural crops and their products for ethanol production using solid-state fermentation.

1.2 Problem Statement

World faces the progressive depletion of its energetic resources mainly based on non renewable fuels. Biomass has huge potential to generate renewable fuel oil replacing fossil fuel in our country. Current process technologies producing biofuel such as pyrolysis, destructive distillation and hydrogenation need high cost for plant operations and complex. Process synthesis by laboratory scale and pilot plant stages have been carried out to solve current problem related to biomass processes. Integrated biological approach process can be applied to enhance the bio fuel product recovery.

1.3 Hypothesis

AD and Fermentation applied low technology process which result in low operating cost. There are similarities between AD and Fermentation methods such as type of feed, anaerobic condition and operating parameter so that both methods can be integrate in a plant to enhance methane and ethanol production. Further research will be conducted to develop the plant operation performance.

1.4 Objective

This research focused on simulates fuel production by integrated biomass fermenter digester. Created database of available biomass fermenter and digester process technologies used to determine the optimal flowsheet for integrated fermentation on processing biomass production.

1.5 Scope of Study

The study cover on the feedstocks, productions, enzymes, chemical processes, material and energy balances used for fermenter and anaerobic digester system. Further research will be carried out to integrate both process and optimizing the plant

CHAPTER 2

LITERATURE REVIEW

2.1 Anaerobic Digestion

Anaerobic digestion is the process of decomposition of organic matter by a microbial consortium in an oxygen-free environment. It is a process found in many naturally occurring anoxic environment including watercourses, sediments, waterlogged soils and the mammalian gut. It can also be applied to a wide range of feedstock including industrial and municipal waste waters, agricultural, municipal, food industry waste and plant residues (Ward, 2007)

The production of biogas through anaerobic digestion offers significant advantages over other form of waste treatment including firstly less biomass sludge is produces in comparison to aerobic treatment technologist. Secondly, successful in treating wet wastes of less than 40% dry matter. Thirdly, cause more effective pathogen removal. This is especially true for multi stage digesters or if a pasteurization step is included in the process. Fourthly, minimal odor emissions as 99% of volatile compounds are oxidative decomposed upon combustion as example hydrogen sulfide transform into sulfur dioxide. Fifthly, high degree of compliance with many national waste strategies implemented to reduce the amount of biodegradable waste entering landfill. Finally, the slurry produced (digested) is an improved fertilizer in terms of both its availability to plants and its archeology. Finally, a source of carbon neutral energy is produced in the form of biogas.

Anaerobic digestion provides a viable alternative to landfill for category 3 wastes. Include food industry wastes, domestic wastes and abattoir wastes. Once produced, biogass is generally composed of 48-65% methane, 36-41% carbon dioxide, up to 17% nitrogen, <1% oxygen, 32-169 ppm hydrogen sulphide and traces of other gases (J.Ward, 2007). Both carbon dioxide and methane are potent greenhouse gases and possibly 18% of global warming is thought to be caused by methane emissions.

Carbon dioxide released through natural mineralization is considered neutral in greenhouse gas terms as it is part of the carbon cycle. Controlled anaerobic digestion of organic material is therefore environmentally beneficial in two ways. First by containing the decomposition process in a sealed environment, potentially damaging methane is prevented from entering the atmosphere and subsequent burning of the gas will release carbon neutral carbon dioxide back to the carbon cycle. Second, the energy gained from combustion of methane will displace fossil fuels reducing the production of carbon dioxide that is not part of the recent carbon cycle.

2.1.1 Biological and Chemical Stages of Anaerobic Digestion

In most cases biomass is made up of large organic polymers. In order for the bacteria in anaerobic digesters to access the energy potential of the material, these chains must first be broken down into their smaller constituent parts.

First stage in anaerobic digestion is hydrolysis. Hydrolysis is a process of breaking chains of high molecular weight polymeric components and dissolving the smaller molecule into solution. Through hydrolysis the complex organic molecules are broken into simple sugars, amino acids and fatty acids. Acetate and hydrogen produced in the first stages can be used directly by methanogens.

Anaerobic sequencing batch reactor (ASBR) and continuous-flow stirred tank reactors (CSTR) for investigate for the digestion of thermally hydrolyzed sewage sludge. Experiments were evaluated with an equivalent loading rate of 2.71 kg COD/m3 day at 20-day hydraulic retention time (HRT) and 5.42 kg COD/m3 day at 10-day HRT.

The average total chemical oxygen demand (TCOD) removals of the ASBR at the 20-day and 10-day HRT were 67.71% and 61.66%, respectively. These were 12.38% and 27.92% higher than those obtained by CSTR. As a result, the average daily gas production of ASBR was 15% higher than that of the CSTR at 20-day HRT, and 31% higher than that of the CSTR at 10-day HRT.

Solids in thermally hydrolyzed sludge accumulated within ASBR were able to reach a high steady state with solid content of 65–80 g/L. This resulted in a relatively high solid retention time (SRT) of 34–40 days in the ASBR at 10-day HRT. The evolution of the gas production, soluble chemical oxygen demand (SCOD) and volatile fatty acids (VFAs) in an operation cycle of ASBR also showed that the ASBR was steady and feasible for the treatment of thermally hydrolyzed sludge. (Wang, 2008)

The biological process of acedogenesis is where further breakdown of the remaining components by acidogenic bacteria is which also known as fermentative bacteria. Here, VFA'S are created along with ammonia, carbon dioxide and hydrogen sulfide as well as other by-products. The process of acedogenesis is similar to the way that milk sours. The third stage anaerobic digestion is acetogenesis. Here simple molecules created through the acidogenesis phase are further digested by acetogens to produce largely acetic acid as well as Carbon Dioxide and Hydrogen.

The terminal stage of naerobic digestion is the biological process of methanogenesis. Here methanogens utilize the intermediate products of the preceding stages and convert them into methane, carbon dioxide and water. This component that makes up the majority of the biogas emitted from the system. Methanogenesis is sensitive to both high and low PHs and occurs between pH 6.5 and pH 8. The remaining, non digestible material which the microbes cannot feed upon along with any dead bacterial remains constitutes the digested (Kasozi, 2008). A simplified generic chemical equation for the overall process outlined above is as follows:

$$C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4$$

2.2 Fermentation

Ethanol fermentation is the biological process by which sugars such as glucose, fructose and sucrose are converted into cellular energy and thereby producing ethanol and carbon dioxide as methabolic waste products. The most widely used sugar for ethanol fermentation is blackstrap molasses which contains about 35-40wt% sucrose, 15-20 wt% invert sugars such as glucose and fructose, and 28-35 wt% of non-sugar solid. Black strap (syrap) is collected as a by product of cane sugar manufacturer. The molasses is dilute to a mash containing about 10-20 wt% sugar.

An experiment was conducted for mash feed. After the pH of the mash is adjusted to about 4-5 with mineral acid it is inoculated with yeast and the fermentation is carry out non-aseptacally at 20 Celsius until 32 Celsius for about 1-3 days. The fermented product which typically contains around 6-10 wt% ethanol, is then set to the product recovery in purification section of the plant. (Bada, 2009).

In Japan, to effectively utilize the cassava pulp, an attempt was made to convert its components to ethanol using a sake-brewing yeast displaying glucoamylase on the cell surface. Saccharomyces cerevisiae Kyokai no. 7 (strain K7) displaying Rhizopus oryzae glucoamylase, designated strain K7G, was constructed using the C-terminal-half region of a-agglutinin.

A sample of cassava pulp was pretreated with a hydrothermal reaction (140 Celsius for 1 hour), followed by treatment with a Trichoderma reesei cellulase to hydrolyze the cellulose in the sample. The K7G strain fermented starch and glucose in pretreated samples without addition of amylolytic enzymes, and produced ethanol in 91% and 80% of theoretical yield from 5% and 10% cassava pulp, respectively (Kosugi, 2008).

All potable alcohol and most fermentation industrial alcohol is currently made principle from grains. Fermentation of starch from grain is somewhat more complex than fermentation of sugars because starch must first be converted to sugar and then to ethanol. Starch is converted enzymatically to glucose either by diastase presents in sprouting grain or by fungal amylase. The resulting dextrose fermented to ethanol with the aid of yeast producing CO_2 as co-product. Another co-product of unfermented starch, fiber, protein and ash known as distillers grain is also produces as high protein cattle feed.

Each step in the progress of the conversion of cellulose to ethanol proceeded with 100% yield. Almost two thirds of the mass will disappear during the sequence, mostly as carbon dioxide, in the fermentation of glucose into ethanol and carbon dioxide. Carbon dioxide release to air leads to environmental problem.

Another problem is that the aqueous acid used to hydrolyze the cellulose in wood to glucose and other simple sugars destroy much of the sugars in the process. This kind of problem cause many companies use high technology to produce biofuel. On going study will solve the problems as fermentation method cheaper and low technology needed.

2.2.1 Chemical Process

The chemical equation below summarizes ethanol fermentation in which one hexose molecule is converted into two ethanol molecules and two carbon dioxide molecules:

$$C_6H_{12}O_6 \longrightarrow 2\ C_2H_5OH + 2\ CO_2$$

The process begins with a molecule of glucose being broken down by the process of glycolysis into pyruvate:

$$C_6H_{12}O_6 \longrightarrow 2\ CH_3COCOOH + 2\ H^+$$

This reaction is accompanied by the reduction of two molecules of NAD^+ to NADH and a net of two ADP molecules to two ATP plus the two water molecules. Pyruvate is then converted to acetaldehyde and carbon dioxide.

The acetaldehyde is subsequently reduced to ethanol by the NADH from the previous glycolysis, which is returned to NAD+.

$CH_3COCOOH + H^+ \rightarrow CH_3CHO + CO_2$

$CH_3CHO + NADH \rightarrow C_2H_5OH + NAD^+$

Yeast will perform the above two reactions only if oxygen is excluded from the environment. Otherwise yeast will oxidize pyruvate completely to carbon dioxide and water.

2.3 Feed Stocks

As demand for the limited global supply of non-renewable energy resources increases, the price of oil and natural gas keep increasing. As a result, production of ethanol by fermentation from renewable carbohydrate materials for use as an alternative liquid fuel has been attracting worldwide interest. There is a growing interest to find alternative bioresources apart from sugarcane/beet molasses and starchy crops like cassava, sweet potato and sweet sorghum for ethanol production. (Sujit, et, al., 2008).

The direct comparison of biogas production from different feedstock is difficult as performance data for specific types are often produces under a wide variety of experimental conditions such as mixing regime, temperature, total solids, volatile solids and hydraulic retention time. Consequently, it is better to compare feedstocks by their ultimate methane yield, determine by the biochemical methane potential (BMP) assay.

2.3.1 Biomass

Biomass is a promising feedstock for anaerobic digestion. Grasses including straws from wheat, rice, and sorghum are a plentiful supply of biomass much of which is a waste product of food production. Ultimate methane yield values are typically high from these feedstocks, although the high proportion of recalcitrant materials often requires pretreatments to fully realize the potential yield (Ward, 2007). Methane yield biomass variety as shown below:

Table 2.1: Vary in methane yield for different biomass feedstock

Feedstock	Methane yield (cubic meter/1kg volatile solids)
Winter rye	0.36
Oilseed rape	0.42
Faba bean straw	0.441
Winter wheat straw	0.189
Sugar beet leaves	0.210

2.3.2 Fruit and Vegetable Wastes

Fruit and vegetables wastes tend to have low total solids and high volatile solids and are easily degraded to an anaerobic digester. The rapid hydrolysis of these feedstocks may lead to acidification of a digester and the consequent inhibition of methanogenesis.

It was discovered in the late 1970s and early 1980s that many carbohydrate rich feed stocks were found to require either co digestion with other feedstocks or addition of alkaline buffed to ensure stable performance.

2.3.3 Manures

Manures are plentiful source of organic material for use as feedstock in anaerobic digesters. In England and wales alone approximately 67 million tones are collected annually. Using manures for biogas production also reduces the volume of greenhouse gasses normally released during storage. Some BMP assay results for manure that the methane potential varies widely between livestock types.

Factors which contribute to the methane potential of manures are the species, breed, and growth stage of the animals, feed amount, type of bedding and also any degradation processes which may take place during storage.

2.4 Energy

Anaerobic digester converts the energy stired in organic materials present in biomass into biogas. Biogas can be feed directly into a gas fired combustion turbine. The type of turbine most often used for small scale electricity production is the microturbine. Combustion of biogas convert the energy stored in the bonds of the molecules of the methane contained in the biogas into mechanical energy as it spins a turbine.

The mechanical energy produced by biogas combustion in an engine or microturbine spins a turbine that produces a stream of electrons or electricity. As a fuel, biogass compose of 65% methane yields about 1066 Btu per cubic foot. Often used when designing systems for the anaerobic digestion of biomass these energy estimates can predict the amount of power production per biomass (Barker, 2001)

Fermentation converts the energy stored in the organic materials present in biomass into ethanol while ethanol can be used directly as fuel. It is commonly blended with gasoline. Some amount of energy needed to produce amount of energy from digester and fermentation process.

Several different forms of energy including in the process, but not limited to, are kinetic, potential, thermal, gravitational, sound energy, light energy, elastic, electromagnetic, chemical, nuclear and mass have been defined to explain all known natural phenomena.

Most of energy used for anaerobic digestion and fermentation process are thermal and kinetic energy. Thermal energy is form of energy that manifests itself as an increase of temperature. It is also the sum of sensible heat and latent heat Kinetic energy is the extra energy which it possesses due to its motion. It is defined as the work needed to accelerate a body of a given mass from rest to its current velocity.

2.4.1 Temperature

There are two conventional operational temperature levels for the processes. The first is mesophilic which takes place optimally around 37- 40 Celsius or at ambient temperature around 20-45 Celsius. In this process, mesophiles are the primary microorganism present. The other temperature level is thermophilie which take place optimally around 50-52 Celsius. The temperature can be up to 70 Celsius. Thermophilcs are the primary microorganisms present in this process (Charles, 2009).

There are greater numbers of species of mesophiles than thermophiles. These bacteria are also more tolerant to change in environmental conditions than thermophiles. Mesophilic system is therefore considered to be more stable than thermophilic digestion systems. Thermophilic digestion systems are considered to be less stable, however the increased temperature facilitate faster reaction rates and hence faster gas yields. Operation at higher temperature facilitates grater sterilization of the end digestate.

A drawback of operating at thermophilic temperature is that more heat is required to achieve the correct operations temperature. This increase in energy may not be outweighed by the increase in the outputs of biogas from the systems. It is therefore important to consider an energy balance for these systems (Song, et.al, 2004).

2.4.2 Specific Heat

Specific heat is the measure of the heat energy required to increase the temperature of a unit quantity of a substance by a certain temperature interval. The term originated primarily through the work of Scottish physicist Joseph Black who conducted various heat measurements and used the phrase "capacity of heat" (Media group, 2009).

A substance with high specific heat capacity subsequently requires more energy to cause an increase in its temperature. The specific heat of virtually any substance can be measured including chemical elements, compounds, alloys, solutions and composites.

The equation relating heat energy to specific heat capacity, where the unit quantity is in terms of mass is:

$$\Delta Q = mc\,\Delta T$$

Where ΔQ is the heat energy put into or taken out of the biomass, m is the mass of the biomass, c is the specific heat capacity and ΔT is the temperature differential. Heat capacity is usually expressed in units of JK-1. For instance, one could write that the gasoline in a 55-gallon drum has an average heat capacity of 347 kJ/K.

2.5 Process Design

Biorefineries for production of several products and by-products such as biofuels, heat and electricity have been in focus in the recent years. In a biorefinery, biomass can be converted to useful biomaterials and energy carriers in an integrated manner and thereby it can maximize the economic value of the biomass used while reducing the waste streams produced (Thomsen, 2005).

Development of multiple biofuels based biorefinery from lignocellulose is seen as an important possibility to increase the efficiency for materials and energy, and reduce the costs of biomass options to mitigate GHG emissions (Sheehan et al., 2003).

Mass flow in the studied biorefinery concept was calculated based on the amount of sugars and their conversion to different products. Pretreatment often results in loss of dry matter due to formation of gasses like CO2 and acetic acid at high temperature. To prevent this happen, loss of dry matter go along with water as biomass is washed with water in order to remove the inhibitory materials and other water-soluble hemicellulose produced during thermal hydrolysis (Prasad et al., 2009).

Many current pretreatment methods such as dilute acid, ammonia fiber explosion, ammonia recycle percolation, hot water, and lime pretreatment have limitations such as capital-intensiveness, the tendency to form inhibitors, as well as low yields.

Studies have been done to establish a pretreatment concept, using acidic and alkaline electrolyzed water to treat biomass was explored. Electrolyzed water is a technique first developed in Japan in the 1990's. The acidic water from the anode of an electrolysis chamber normally has a pH of °Ü 2.7 and an oxidation reduction potential (ORP) of > 1,100 mV. The water produced from the cathode side has a pH of > 11.4 and ORP of < -795 mV. Because of its high hydrogen ion concentration, the acidic electrolyzed water could be used as an environmentally friendly alternative to the sulfuric acid.

Likewise, the alkaline electrolyzed water would play the role of the bases used in alkali pretreatments. For defractionating carbohydrate components in biomass, a combined treatment of acidic and alkaline electrolyzed water was tested. The two-stage percolation had enhanced the yields of total sugars and improved the digestibility of biomass (Wang, 2005).

2.6 Process Economics and Cost Estimation

The design of biomass power plants is traditionally performed by using a deterministic approach. The deterministic model takes into account energetic, local and social factors to maximize the plant economic profit. When dealing with renewable energy applications, which involve unpredictable factors a major influence, has recently been recognized as an important factor. In order to take into account the stochastic nature of uncertainty, probabilistic approaches have been widely applied to electric power system design and management (Anders, 1990).

Astochastic approach relates the plant economic index to the technological design. The stochastic approach extends from the deterministic approach characterizes the uncertainty which concern the model by introducing random variables and probability functions. (Fiala, Pellizzi, and Riva, 1997).

Deterministic approach to biomass plant design is based on an analytical model, which involves geographical and social factors often difficult to characterize. An optimal design has been proposed, aimed at maximizing the profitability index, PI as function of plant operation area and specific investment, Is.

Many papers have successfully applied the probability methodology to account for the stochastic uncertainties in power system applications. This research has already attained a significant level of theoretical maturity, and is currently in a stage of emerging development (Anders, 1990). While the deterministic approach assumes the exact knowledge of the model input data, the probabilistic approach recognizes the effect of randomness in data.

Compared to the deterministic methods, the probabilistic approach can offer a more accurate result as well as more information, such as expected values and variances. In fact, the conventional deterministic methods show only snap-shots of certain conditions, and they are unable to evaluate every possible combination of design.

CHAPTER 3

METHODOLOGY

3.1 METHODOLOGY

Figure 3.1 shows the overall methods applied in this project. This chapter divided into three main parts. The first part is research and study stage. Data base created stage contains identify source of data, create MEB data and analyze fuel potential recovery. The data base will be used to provide the basis to make flowsheeting for separate processes, synthesis integrated fermenter-digester process and optimize the established integrated process flowsheeting.

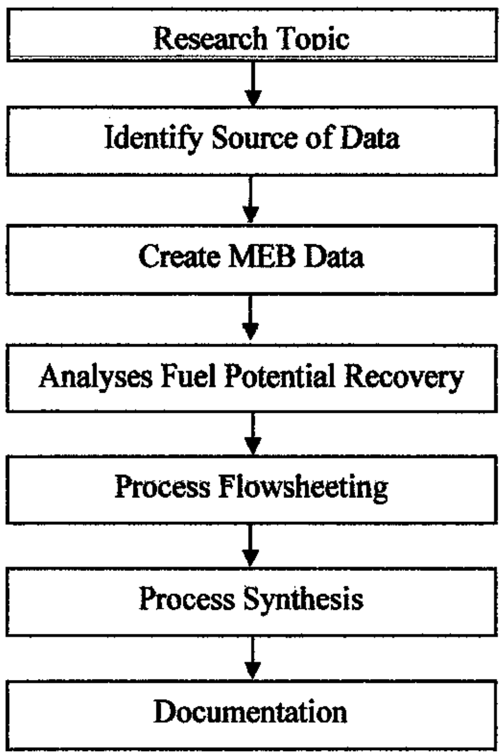

Figure 3.1: Methods involved in the project

3.1 Research and Study

Research element is to synthesis a conceptual integrated process for the production of renewable fuel. Process involve are anaerobic digester and fermenter. Huge knowledge and strong understanding of anaerobic digestion and fermentation process is important base in the project continuity. Criteria of study is to gather history of the process until current research so that information such as type of feed inlet, operation and separation process can be understand. Source for this study are journals, articles, books and website.

3.2 Create Database

Research and analysis of related literature on anaerobic digestion and fermentation are performed to create database of process technologies. Data needed are amount of material input, amount of material outputs, energy used and energy produce. Average value taken will be use as the final database which used for reaction material and energy balance. Data gather from current literature source and further analysis on the result has been done to identify the project relevancy.

3.3 Process Synthesis

Study and establish the flowsheet for integrated AD and Fermentation processes. Then synthesis fuel production from the integrated process. The production can be separated into three sections that are biomass pretreatment, reaction stage and product recovery. From integrated process material balance calculation, amount of fuel obtain can be estimate. Basis database created provide the basis for rigorous simulation. Future study is suggested to use simulation software such as Hysis in optimizing the production and operating condition of the plant. Percentage of fuel produce, flowsheet design, material used and other aspect was being compared with current industry.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Mass Flow

4.1.1 Anaerobic Digestion

Table 4.1 shows the data gathering for Anaerobic Digestion (AD) process. Different application of technology give varies value of product in Anaerobic Digestion and fermentation. Study on related journals with different biomass and technology had been done to identify feed and yield design basis value as show in table 4.2 and table 4.3. Basis 1 kg of biomass is use in this study. Data analysis for Anaerobic Digestion process conducted shown in table 4.4.

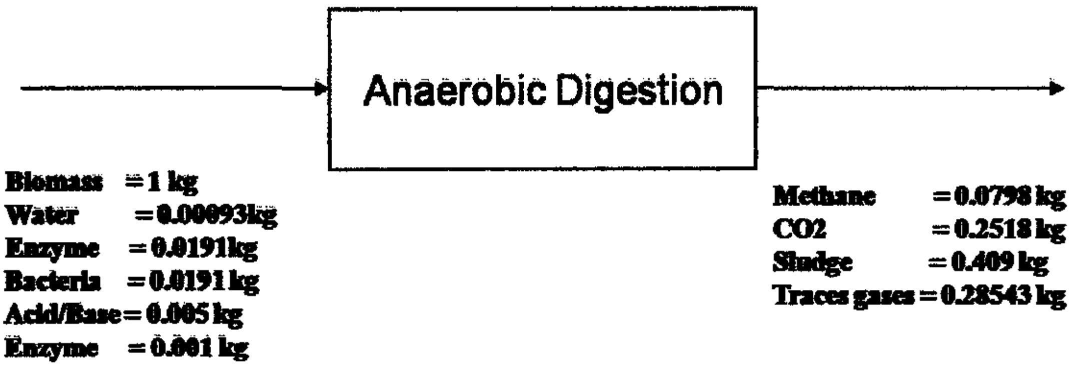

Figure 4.1: Anaerobic Digestion feed and yield design basis value

Figure 4.1 illustrated the design basis for Anaerobic Digestion mass flow. Inputs are 1 kg biomass, 9.3×10^{-4} kg enzyme, 5×10^{-3} kg base and 1×10^{-3} kg enzyme otherwise the outputs are 7.89×10^{-2} kg methane, 2.5×10^{-1} kg carbon dioxide, 4.1×10^{-1} kg sludge and 2.9×10^{-1} of traces gas. Traces gas mainly included hydrogen, oxygen and hydrogen sulfide.

Table 4.5: Data gathering for Fermentation feed and yield value

Reference	1		2	3	4	5	6	7	8
Biomass	1	1	1	1	1	1	1	1	1
Water	-	-	-	-	-	-	-	$9.3x10^{-4}$	-
Enzyme	-	-	$1x10^{-3}$	-	-	-	-	-	-
Bacteria	$3x10^{-5}$	$3x10^{-5}$	-	-	-	$6.9x10^{-2}$	$4.5x10^{-2}$	$4x10^{-4}$	$4x10^{-5}$
Acid/Base	-	-	$1.62x10^{-3}$	$9.1x10^{-3}$	-	$4.0x10^{-3}$	-	-	-
Methane	$1.34x10^{-3}$	$6.8x10^{-2}$	$9x10^{-4}$	$1.3x10^{-2}$	$3.92x10^{-2}$	$2.9x10^{-2}$	$6.7x10^{-2}$	$2.6x10^{-2}$	$3.4x10^{-1}$
CO2	$8.1x10^{-1}$	$4.1x10^{-2}$	$2.3x10^{-3}$	$3.4x10^{-2}$	$1.08x10^{-1}$	$7.8x10^{-2}$	$1.84x10^{2}$	$6.6x10^{-2}$	$9.43x10^{-1}$
Traces Gas	2.15 m^3	1.087m^3	-	0.0125m^3	-	0.0925m^3	31kg	0.01m^3	0.0001kg
Sludge	-	-	-	-	-	-	$7.18x10^{-1}$	-	$1.0x10^{-1}$

Table 4.2: Design basis for Anaerobic Digestion feed

Feed	Range	Design Basis
Water(kg)	0 - $9.3x10^{-4}$	9.3010^{-4}
Enzyme(kg)	0 - $1x10^{-3}$	$1.00x10^{-3}$
Bacteria(kg)	$3x10^{-5}$ - $6.9x10^{-2}$	$1.91x10^{-2}$
Acid/Base(kg)	$1.62x10^{-3}$- $9.1x10^{-3}$	$5.00x10^{-3}$

Table 4.3: Design Basis for Anaerobic Digestion effluent

Yield	Range	Design Basis
Methane (kg)	$9.00\ x10^{-4}$ - $3.40x10^{-1}$	$7.89x10^{-2}$
CO2(kg)	$9.43x10^{-1}$- $2.3x10^{-3}$	$2.25x10^{-1}$
Traces Gas(kg)	$1.00x10^{-4}$– 31.00	$2.85x10^{-1}$
Sludge(kg)	$1.00\ x10^{-2}$ - $7.18x10^{-2}$	$4.10x10^{-1}$

1 kg of biomass feed used as basis. From the input and output value, percentage amount of fuel production can be analyze. Table 4.4 shows the weight percentage of AD effluent composition. AD process produces 60.16 % of gases phase and 39.84 % of sludge. Result analyse show 12.93% methane fuel production from the process effluent.

Table 4.4: Weight percentage and phase of Anaerobic Digestion effluent

	Output	Wt%	Phase
Input: 1 kg biomass	Methane	7.80	Gas
	CO2	24.54	Gas
	Sludge	39.86	Liquid/Solid
	Traces Gas	27.82	Gas

4.1.2 Fermentation

Table 4.5 shows the data gathering for Fermentation process feed and yield value from eight different journals which use different type of biomass and methods. But the reactor used in the journals referred is batch reactor to ensure the accuracy of the data gather. Table 4.6 and table 4.7 show the design basis taken for Fermentation feed and effluent.

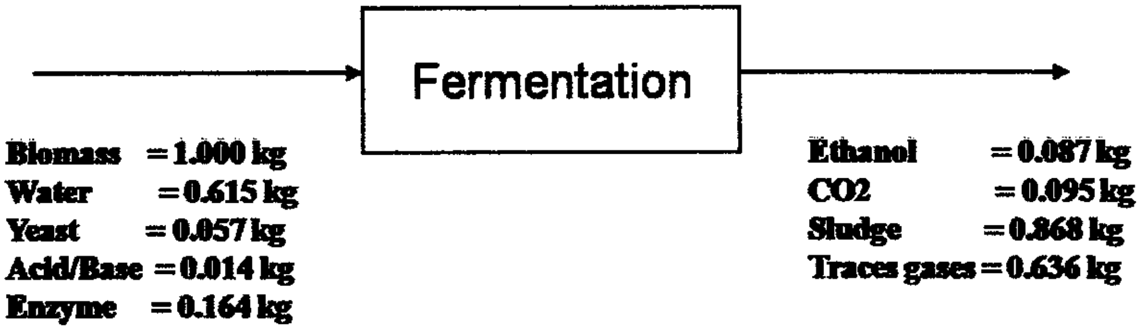

Figure 4.2: Fermentation digester feed and yield design basis value

Figure 4.2 illustrated the design basis value for fermentation process inlet and outlet. Basis 1 kg of biomass is used in the process. Others material inlet are 0.615 kg of water, 0.057 kg of yeast, 0.014 kg for acid/base and 0.164 kg for enzyme such as hydrolyze enzyme use in the early stage of Fermentation process. Minerals also commonly used in both process such as $(NH_4)_2SO_4$, KH_2PO_4, NH_4NO_3, $MgSO_4$ ($7H_2O$) and reducing agent H_2SO_3. Fermentation process aim is producing ethanol fuel. Other components produces are CO_2, sludge and traces gases. Ethanol produces in liquid phase. Sludge produce can be further treated to produce more ethanol fuel.

Table 4.5: Data gathering for Fermentation feed and yield value

Reference	1		2	3	4	5	6	7	8
Biomass	1	1	1	1	1	1	1	1	1
Water	-	$6x10^{-1}$	-	-	-	$3.95x10^{-1}$	-	-	$8.5x10^{-1}$
Yeast	$4.0x10^{-2}$	$2x10^{-3}$	$5.1x10^{-2}$	$8.6x10^{-2}$	$1.19x10^{-1}$	$1.0x10^{-1}$	$5.0x10^{-2}$	$1.0x10^{-2}$	$5.1x10^{-1}$
Acid/Base	-	-	-	$3.63x10^{-2}$	-	$5.0x10^{-3}$	-	$2.89x10^{-6}$	-
Enzyme	-	$2.64x10^{-3}$	$2.65x10^{-2}$	$8.75x10^{-2}$	$3.0x10^{-3}$	$8.66x10^{-1}$	-	$1.75x10^{-3}$	$3.0x10^{-5}$
Ethanol	$2.41x10^{-2}$	$1.54x10^{-3}$	$1.81x10^{-2}$	$7.65x10^{-2}$	$9.95x10^{-2}$	$3.9x10^{-1}$	$1.3x10^{-4}$	$2.89x10^{-2}$	$7.9x10^{-3}$
CO2	$2.3x10^{-2}$	$1.47x10^{-1}$	$17.3x10^{-2}$	$7.3x10^{-2}$	$9.5x10^{-2}$	$3.72x10^{-1}$	$1.22x10^{-4}$	$2.79x10^{-2}$	$7.55x10^{-3}$
Sludge	-	-	-	-	-	$7.37x10^{-1}$	$9.99x10^{-1}$	-	-

Table 4.6: Design basis for Fermenter Digester feed

Feed	Range	Design Basis
Water(kg)	$3.95x10^{-1}$ - $8.5x10^{-1}$	$6.15x10^{-1}$
Yeast(kg)	2.00x10-3 - $5.1x10^{-1}$	$5.73x10^{-2}$
Acid/Base(kg)	2.89x10-6 - $3.63x10^{-2}$	$1.38x10^{-2}$
Enzyme(kg)	3.00x10-5 - $8.66x10^{-1}$	$1.64x10^{-1}$

Table 4.7: Design basis for Fermenter Digester effluent

Yield	Range	Design Basis
Ethanol(kg)	$1.30x10^{-4}$ - $3.9x10^{-1}$	$8.70x10^{-2}$
CO2(kg)	$1.22x10^{-4}$ - $3.72x10^{-1}$	$9.50x10^{-2}$
Traces Gas(kg)	-	$6.36x10^{-1}$
Sludge(kg)	$7.37x10^{-1}$ - $9.99x10^{-1}$	$8.68x10^{-1}$

Further analyse on the Fermentation process effluent was conducted to identify the percentage of ethanol fuel obtain. Table 4.8 show the phase and weight percentage of the effluent. Fermentation process yield larger amount of sludge phase compare to AD effluent. Fermentation produces 58.43% of gases phase and 41.57% of sludge. The sludge can be further distillate to gain more ethanol. The process manages to get 9.10% of ethanol fuel.

Table 4.8: Weight percentage of Fermenter Digester effluent

	Output	Wt%	Phase
Input: 1 kg biomass	Ethanol	5.16	Liquid
	CO2	5.63	Gas
	Traces Gas	37.72	Gas
	Sludge	51.48	Liquid/Solid

4.2 Energy

Study on related journals with comparable biomass and technology had been done to identify average energy used in fermentation and digester processes. Two most of important energy involve are thermal energy and kinetic energy. Thermal energy produces amount of heat supply for the operation to be conducted. Motor rotations for input blender produce kinetic energy. Table 4.10 show the average of temperature different and motor rotating velocity of anaerobic digester.

Table 4.11 show the average of temperature different and motor rotating velocity of fermenter digester. The rotational force or angular force which causes change in rotational motion is typically expressed in Newton meters. A torque of 1 Newton-meter applied on 1 Radian requires exactly 1 Newton meter which equal to 1 Joule of energy. Below are the properties of ethanol and methane used in the energy calculation:

Table 4.9: Methane and ethanol properties

Properties	Methane	Ethanol
Molecule Weight (kg/kmol)	16.04	46.07
Density (kg/m3)	0.716	788
Energy Content (kW. hr)	0.3124	6.556

Assume that motor radius for batch reactor is $7.62\text{x}10^{-2}$ m and specific heat for glucose is 115 J/K. Table 4.12 shows the calculation of energy consumption for anaerobic digester and fermentation processes. Substance's specific heat capacity is a publish value and the object's quantity is subject to such a sizable relative uncertainty that is renders this detail moot. Heat capacity and kinetic energy used are 32.53 kJ and 0.053 J. Calculation done discovered that kinetic energy value on both processes are too small and can be neglected. Table 4.13 shows the calculation of energy produce for anaerobic digestion and fermentation processes. Heat capacity and kinetic energy used are 32.10 kJ and 0.172 kJ. The process energy efficiency for AD and fermentation are 32.5 kJ and 32.10 kJ using basis 1 kg feed of biomass.

Table 4.10: Anaerobic Digestion energy data gathering

Reference	1	2	3	4	5	6
Method	Mixed batch reactor	Stage Leach Reactor	Batch Reactor	Batch Reactor	Single Stage Continuous Reactor	Batch Reactor
Feed Temperature	27	27	27	27	27	27
Operating temperature	35	35	38	35	42	37
Motor	50	-	-	30	-	-

Table 4.11: Fermentation Digestion energy data gathering

Reference	1	2	3	4	5	6	7	8
Method	Batch Reactor	Jar Fermenter	Packed Column Bioreactor	Jar Fermenter	Erlenmeyer Flusk	500ml Fleaker	250 ml Flusk	Tower Type Reactor
Feed Temperature	27	27	27	27	27	27	27	27
Operating temperature	32	35	28	32	30	35	37	35
Motor	-	300	-	-	100	130	-	-

Table 4.12: Energy consumption by Digester and Fermentation process

	Anaerobic Digestion	**Fermenter Digester**
M (kg)	1.03	1.69
Cp (Kj/K.g)	1.12×10^{-1}	6.82×10^{-2}
ΔT (K)	283.15	279.15
ΔQ (Kj)	32.537	32.1
W (rad/s)	4.192	186
I (kg.m^2)	1.05×10^{-1}	1.00×10^{-2}
r(m)	7.62×10^{-2}	7.62×10^{-2}
Kinetic energy (j)	5.27×10^{-2}	172
Etotal (kW/h)	9.00×10^{-3}	8.96×10^{-3}

Table 4.13: Energy produce by Digester and Fermentation process

Anaerobic Digestion	Fermentation
Methane: Basis of 1 kg biomass 1 m3 producing 11.04 kW/h energy Methane produce is 7.98×10^{-2} kg Methane produce in volume is 0.11 m^3 Energy produce is 1.23 kW.h	Ethanol: Basis of 1 kg biomass 1 L producing 23.60 Mj energy Ethanol produce is 8.7×10^{-2} kg Ethanol produce in volume is 0.11 L Energy produce is 0.721 kW.h

4.3 Process Flowsheeting

Data base created for AD and Fermentation processes previously had been use to design an AD and Fermentation process flowsheeting. Figure 4.3 shows the main sections involve in AD process. The main sections are pretreatment, digester and product recovery. AD process commonly used inoculums for biomass pretreatment before flow into reactor. Bacteria, acid and water added into the digested process to help the biological process.

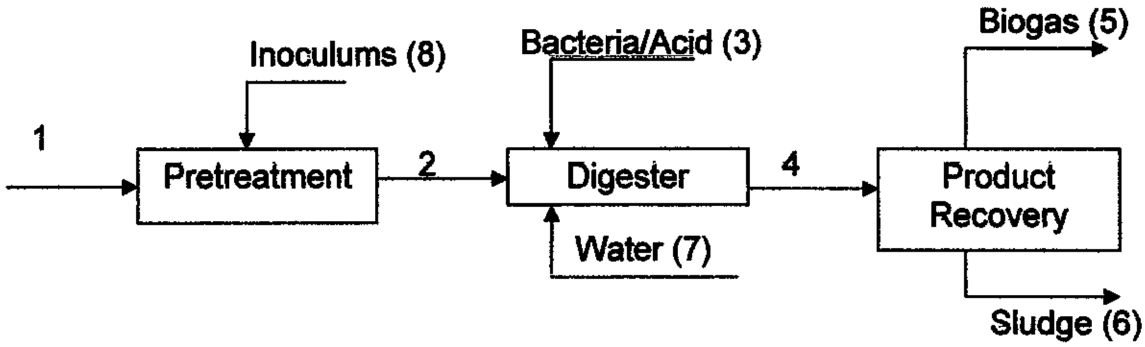

Figure 4.3: Anaerobic Digester process flowsheeting

The parameters and composition of AD flowsheeting shows in table 4.14. The table indicates flowrate, temperature and weight percentage of composition for each stream involve. Operating pressure is at ambient pressure, 101.3 kpa.

Table 4.14: Anaerobic Digester process flowsheeting

Stream	1	2	3	4	5	6	7	8
Flowrate (kg/h)	100	100	0.04	102.6	61.7	40.9	2.56	-
Temp (°C)	33	40	27	37	37	37	85	55
Composition (Wt %)								
Biomass	1.0	1.0	-	-	-	-	-	-
Water	-	-	-	0.000	-	-	1.0	-
Methane	-	-	-	0.067	0.24	-	-	-
CO2	-	-	-	0.184	0.65	-	-	-
Traces Gas	-	-	-	0.031	0.11	-	-	-
Sludge	-	-	-	0.718	-	1.0	-	-
Bacteria/Acid	-	-	1.0	0.000	-	-	-	-
Inoculums	-	-	-	0.000	-	-	-	1.0

Figure 4.4 shows Fermentation process flowsheet consist of three main sections that are pretreatment, Fermentation and product recovery. Pretreatment process use enzyme and water to hydrolyze the biomass inlet.

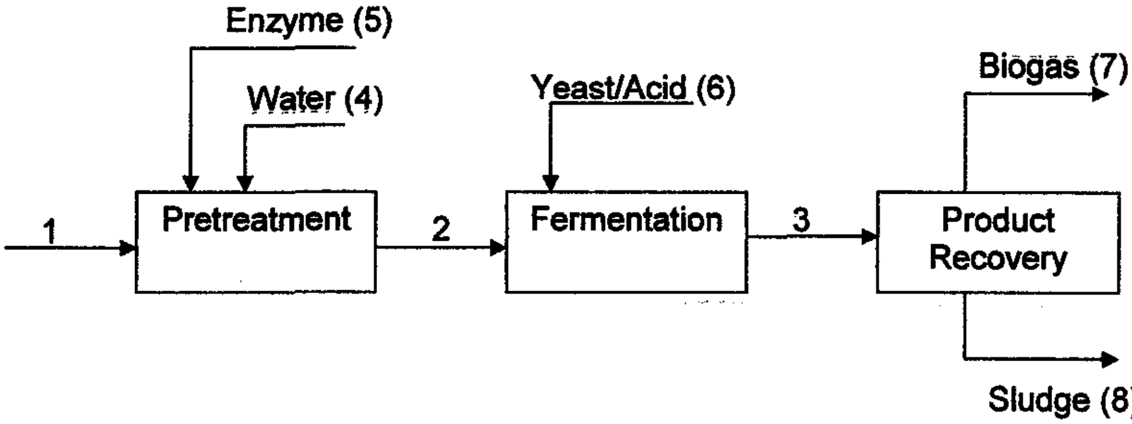

Figure 4.4: Fermentation process flowsheeting

From data finding, flowrate, temperature and weight percentage composition for each stream in the flowsheeting was calculated and shows in table 4.15. Operating pressure is at ambient pressure, 101.3 kpa.

Table 4.15: Fermenter Digester mass flow

Stream	1	2	3	4	5	6	7	8
Flowrate(kg/h)	100	250	257	400	40	7	161	96
Temp (°C)	27	180	33	28	28	30	30	30
Composition (Wt%)								
Biomass	1.00	0.62	0.90	-	-	-	-	-
Water	-	0.38	0.10	1.00	-	-	-	-
Enzyme/Acid	-	0.00	0.00	-	1.00	-	-	-
Yeast	-	0.00	0.00	-	-	1.00	-	-
Biogas	-	0.00	0.00	-	-	-	1.00	-
Sludge	-	0.00	0.00	-	-	-	-	1.00

The needs to synthesis integrated process are to discover the maximum fuel production and get the higher profitability. Figure 4.5 shows the synthesis of integrated biomass fermenter-digester flowsheet. Material balance had been conducted using 100 kg/hr of biomass as basis feed in into pretreatment process.

Hydrothermal pretreatment uses large amount of water to process the solid phase biomass. Heat use during pretreatment cause losses of biomass through steam explosion up to 20% (Bjerre and Schmidt, 1997). Pretreatment often results in loss of dry matter. This can be due to formation of gasses like CO2 and acetic acid at high temperature or loss of dry matter along with water as biomass is washed with water in order to remove the inhibitory materials and other water-soluble hemicellulose produced during thermal hydrolysis. So that pretreatment effluent is 432kg/hr instead of 540kg/hr.

Pretreatment effluent contained 75% of dry matter transferred to the solid fraction and 25% in liquid fraction also known as hydrolysate (Kaparaju, et, al., 2009). 75% of the dry matter was transferred to the solid fraction containing fibers mainly cellulose and, lignin which can be further used for fermentation. The high dry matter content in the solids fraction would give sugar and ethanol concentration above 8% and 4% w/w, respectively during the enzymatic hydrolysis and fermentation (Larsen, et, al., 2008).

Significant reduction of the distillation costs could be thereby achieved when the ethanol from fermentation broth is above 4% (w/w) (Zacchi and Axelsson, 1989). Hydrolysate contains xylose as the main of sugars which could be converted to methane in the anaerobic digestion. Glucose was also found in the hydrolysate but at a very low concentration. The low glucose concentration in hydrolysate was probably due to its crystalline and thermally stable structure.

Result from the integrated process of 100 kg/hr biomass achieved to produce 338 kg/hr of methane gas fuel and 23.63 kg/hr of ethanol. Typical biogass composition contain 40% - 75% of methane gas and 25% - 55% of Carbon Dioxide gas (Buswell and Boyle,2009). Sludge from fermentation process has to go through ethanol distillation or extraction process to obtain more ethanol. Stillage is the residue obtained after distillation of the ethanol fermentation broth.

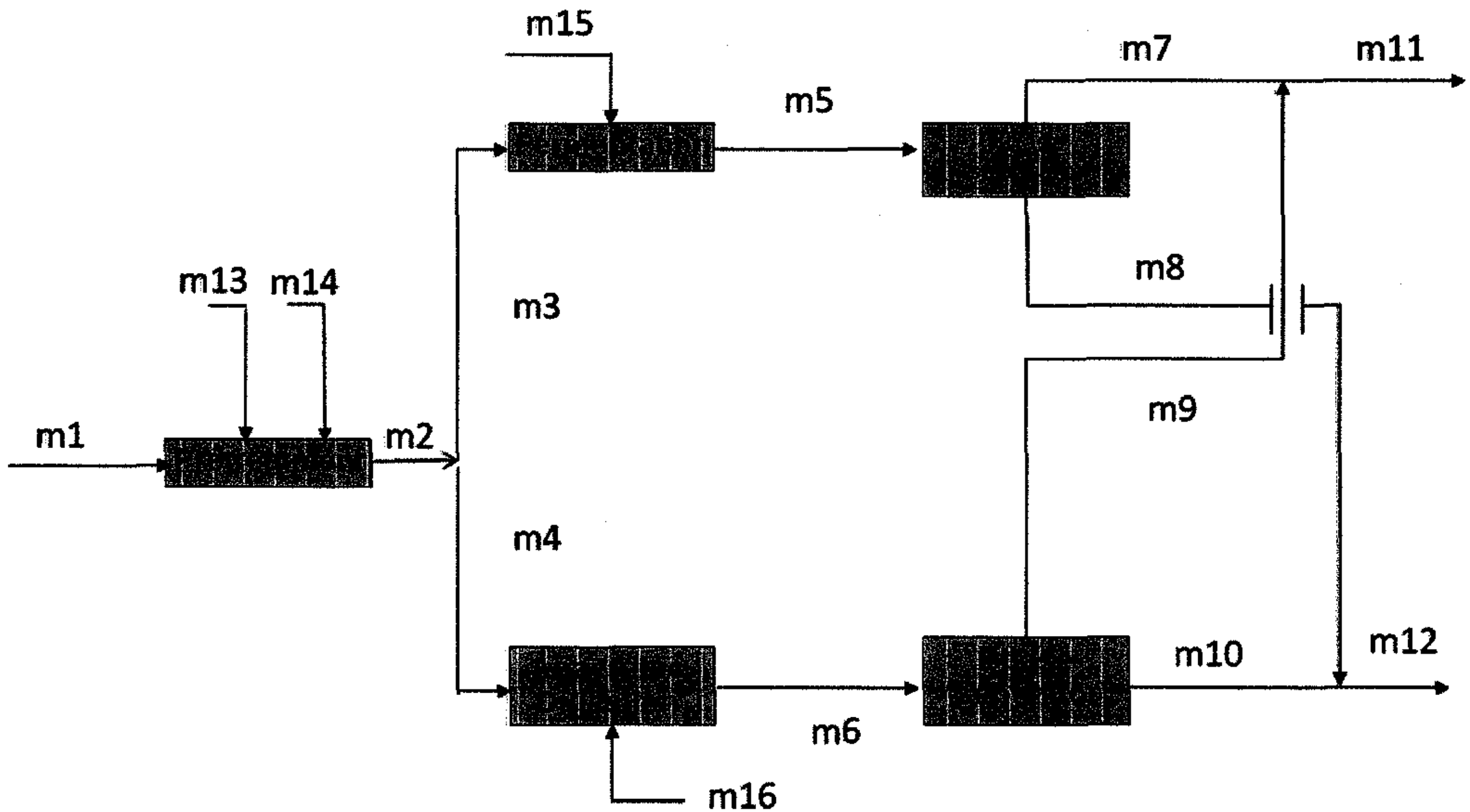

Figure 4.5: Basis flowsheeting of integrated biomass Fermenter-Digester process

Material balance calculation had been carrying out for the integrated flowsheeting. Table 4.16 show the mass flow rate for each stream in the integrated process. The material balance calculation used 100 kg/hr of biomass feed as basis.

Table 4.16: Streams flowrate

Stream	Material	Flowrate (kg/hr)
1	Biomass inlet	100.00
2	Pretreatment outlet	540.00
3	Solid fraction	324.00
4	Liquid fraction	108.00
5	Fermentation effluent	346.68
6	AD effluent	108.04
7	Biogass (Fermentation)	521.60
8	Sludge (Fermentation)	311.00
9	Biogass (AD)	66.60
10	Sludge (AD)	44.20
11	Biogass	588.20
12	Sludge	355.20
13	Water inlet	400.00
14	Enzyme/Acid	40.00
15	Yeast	22.68
16	Bacteria	0.043

The aim of integrated process is to enhance bio fuel recovery through combination of biological approaches. Further analysis on the weight percentage of product recovery is conducted. Table 4.17 shows the typical biogas composition. The methane fuel recovery for integrated biomass process is 57.5 % compare to AD process is 12.93%. Table 4.18 shows the typical sludge composition. Ethanol fuel percentage recovery is lower because further sludge distillation needed to recover more ethanol fuel.

Table 4.17: Typical biogas composition

Biogas Composition	Range (%)	Design Basis (%)	Mass Produce (kg/hr)
Methane, CH_4	40-75	57.5	338.22
Carbon Dioxide, CO_2	25-55	40.0	235.28
Nitrogen, N_2	0-5	2.5	14.71
Hydrogen, H_2	0-1	0.5	2.94
Hydrogen Sulfide, H_2S	0-3	1.5	8.82
Ammonia, NH_3	0-1	0.5	2.94
Oxygen and Carbon Monoxide, CO	13-20	16.5	97.05

Table 4.18: Typical sludge composition

Sludge composition	Wt %	Mass Produce (kg/hr)
Ethanol	6.37	22.63
Water, solid components	93.63	332.57

CHAPTER 5

CONCLUSION AND FUTURE WORK

5.1 Conclusion

The aim to simulate fuel production by integrated biological biomass process is achieved. The result show integrated fermenter digester process for methane and ethanol production can be achieved using database of available biomass fermenter and digester process technologies. The integrated flowsheet resulting 338 kg/hr methane and 23 kg/hr ethanol production with 100 kg/hr basis of biomass. Production of methane fuel increasing with integrated process. Sludge produce from the process can be further distillate to produce high concentration of ethanol. Further studies are needed to optimize the flowsheet for fuel production simulation and find out the comparative economics production.

5.2 Future Work

5.2.1 Process Optimization

Further studies are needed to optimize the flowsheet for fuel production. Optimal flowsheet for integrated fermentation on processing biomass production can be determine using simulation program such as Hysis and Icon using data base created in this research. Design of flowsheet which including recycle and purification system must be improves to enhance the quantity and quality of production.

5.2.2 Economic Potential

Basic calculation for the integrated biomass plant had been done to identify the profitability of the research. Result from Deterministic Approach calculation (refer to appendix 1) proved the research profitability. Detail study on the economic evaluation must be done to enhance the biomass plant productivity. This paper successfully carried out the material and energy calculation for individual process and material balance for integrated process. Further detail study on the energy consumes and produces from integrated process needed for plant profitability study.

REFERENCE

[1] A. Lehtomaki, 2007, Anaerobic Digestion of grass silage in batch lead bed processes for methane production," *Journal of Bioresource Technology* **99 (8):** 3267 – 3278

[2] Anneli P. and Mette H. Thomsen, 2007,"Potential bioethanol and biogas production using lignocellulosic biomass from winter rye, iol seed rape and fabe been," *Journal of Biomass and Bioenergy* **31 (5):** 812 – 819

[3] Boubaker F. and Ridha Ben Cheik, 2007, "Optimisation of the mesophilic anaerobic co-digestion of olive mill waste water with olive mild solid waste in a batch digester," *Journal of Desalination* **228 (7):** 159 – 167

[4] Badal C. Saha, Michael A. Cotta, 2008,"Lime pretreatment, enzymatic saccharification and fermentation of rice hulls to ethanol," *Journal of Biomass and Bioenergy* **32 (7):** 971 – 977

[5] Demiral and P. Scherer, 2007, "Production of methane from sugar beet silage without manure addition by a single stage anaerobic digestion process," *Journal of Biomass and Bioenergy* **32 (3):** 203-209

[6] Dennis J. O'Brien and Loried H. Rothl, 1999, "Ethanol production by continuous fermentation –pervaporation: a pleminary economic analysis," *Journal of Membrane science* **166 (8):** 105 – 111

[7] F. Raposo, C. J. Banks, I. Siegert, 2006, "Influent of inoculums to substrate ration on the biochemical methane potential of maize in batch tests," *Journal of Process Biochemistry* **41 (6):** 1444 – 1450

[8] G. D. Najafpour, A.A.L Zinatizadeh et. Al, 2008, "High rate anaerobic digestion of palm oil mill effluent in an upflow anaerobic sludge fixed film bioreactor," *Journal of Process Biochemistry* **41 (6):**370 - 379

[9] Hilkiah Ogoni and M. J. Ayotamuno, 2007, "Design of anaerobic digester of agriculture resources," *Journal of Applied Energy* **85 (6):** 430 – 438

[10] Jianling Yu and Tianwei Tan, 2008, "Ethanol production by solid state fermentation of sweet sorghum using thermotolerant yeast strain," Journal of Fuel Processing Technology

[11] Jeong Sikkim, 2002, "Effect of various pretreatment for enhanced anaerobic digestion with waste activate sludge," *International journal of Bioscience and Bioengineering* **95 (3):** 271 – 275

[12] Mirbella Caceres-Farfan et. Al, 2008,"Ethanol production from Henequen (Agave fourcroydes Lem) juice and molasses by a mixture of two yeasts," *Journal of Bioresource Technology* **99 (17):** 9036 – 9039

[13] M. Fiala, G. Pellizzi, G. Riva, 1997, " A model for the optimal dimensioning of biomass-fuelled electric power plants," *J. Agric. Eng. Res.* **67 (97)** 17–25

[14] Maritza, M.C, Zohrab S. and Adrian H., 2008, "Anaerobic digestion of municipal solid waste and agricultural waste and the effect of co-digestion with dairy cow manure," *Journal of Bioresource Technology* **99(17):** 8288 – 8293

[15] O'scar J. Sa'nchez et. Al, 2007, "Trends in biotechnological production of fuel ethanol from different feedstocks," *Journal of Biomass and Bioenergy* **32 (7):** 971-977

[16] P. E. Poh and M. F. Chong, 2008, "Development of anaerobic digestion methods for palm oil mill effluent (POME) treatment," *Journal of Bioresource Technology*

[17] Paula F. Siqueira, Susan G. Karpa and Julio C. Carvalho, 2008, "Production of bio-ethanol from soybean molasses by Saccharomyces cerevisiae at laboratory, pilot and industrial scales," *Journal of Bioresourse Technology* **99 (17):** 8156 – 8163

[18] Prasad Kaparaju, 2009, "Bioethanol, biohydrogen and biogas production from wheat straw in a biorefinery concept," *Journal of Bioresourse Technology* **100 (9):** 2562–2568

[19] Savitree Limtong et. Al, 2007, "Production of fuel ethanol at high temperature from sugar cane juice by a newly isolated Kluyveromyces marxianus," *Journal of Bioresource Technology* **98 (2):** 3367 – 3374

[20] Serpil Ozmihci and Fikret kargi, 2008, "Ethanol production from cheese whey powder solution in a packed column bioreactor at different hydraulic residence times," *Journal of Biochemical Engineering* **42 (8):** 180-185

[21] S. D. Probet, 2007, "Biomass and bioenergy enhancement of methane production from barley waste," Journal of Bioresource Technology 38 (4): 7554 – 7559

[22] Thiam Leng Chew and Subhash Bhatia, 2007, " Catalytic processes towards the production of biofuels in a palm oil and oil palm biomass based biorefinary," *Journal of Bioresource Technology* **80 (15):** 4012 – 4018

[23] T. D Hages and H.R Isaacson, 2004, "In situ methane enrichment anaerobic digestion," *International journal Biotechnology and Bioengineering* **35 (1):** 73 – 86

[24]W. Charles, 2009, "Effect of pre-aeration and inoculum on the start-up of batch thermophilic anaerobic digestion of municipal solid waste" *Journal of Bioresource Technology* **100 (9):** 2329–2335

[25] Yue-Qin Tang et. Al, 2008, "Ethanol production from kitchen waste using the f;occulating yeast Saccharomyces cerevisiae strain KF-7" *Journal of Biomass and bioenergy* **40 (2):** 104-111

[25] Yue-Qin Tang et. Al, 2008, "Ethanol production from acid hydrolysate of wood biomass using the flocculating yeast Saccharomyces cereviviae strain KF-7," *Journal of Process Biochemistry* **41 (7):** 909 – 914

[26] Bin Wang, 2 November 2005
<http://aiche.confex.com/aiche/2005/techprogram/P26282.HTM>)

[27] James C. Barker, 14 March 2001
<http://www.bae.ncsu.edu/programs/extension/publicat/wqwm/ebae071_80.html>

[28] John Kasozi, 2 January 2008,<http://www.anaerobic-digestion.com/>

[29] Media group, 27 January 2009< http://en.citizendium.org/wiki/Joseph_Black>

[30] Saha Bada, 17, February 2009
<http://www.ars.usda.gov/research/projects/projects.htm?ACCN_NO=405366&showpars=true&fy=2004>

[31] V. P. Puri, 24 May 1993
<http://www3.interscience.wiley.com/journal/107620636/abstract?CRETRY=1&SRETRY>

[32] G.J. Anders, Probability Concepts in Electric Power Systems, Wiley-Interscience, 1990

[33] H. Scott Fogler, 2006, Elements of Chemical Reaction Engineering, U.S, Pearson International

[34] A. Cano, F. Jurado,2006 "Optimum location of biomass-fuelled gas turbines in an electric system, in." *IEEE Power Engineering Society General Meeting 2006,* 18–22 June, 2006, p. 6

APPENDIX A

ECONOMIC EVALUATION

Revenue

Table 1: Revenue in term of fuel energy

Basis	1 t/hr of Biomass
Biomass produce	3380 kg/hr methane gas
Methane produce in volume	4714.09 m^3 /hr of methane gas
Energy produce	52044 kW.hr
Latest energy tariff by TNB	RM 10.70 for every 300 kW used
Revenue	RM 15 million/year

Table 2: Revenue in term of fuel energy

Current Methane fuel market price is	RM 12/1000 ft^3
Revenue	RM 16 million/year

Cost of production

1. Cost of purchase (Biomass) = RM 0

2. Cost of transport, Ct = RM 3.70 x 10-3 million/year

   Ct = 2/3 * 3.142 * Biomass density * Cts * $(R)^3$

   Cts = Specific transport cost (/t.km) = 50

   Assume plant area is 90 000 m^2

   R = Production radius (km) area = 0.17

   Biomass density, t/km2.year = 717

3. Cost of labour, Cw = RM 1.2 million/year

$Cw = Cws * Na$

Cws = Specific labour cost = 1000

Na = Number of employees = 100

4. Maintanance Cost, Cr = RM 0.3 million/year

$Cr = I\ Kr$

*Assumption

I = Amount of total investment, = RM 10 million/year

Kr = Coefficient factor of maintenance = 0.03

Cash Flow, CF = IN - OUT = RM 14.60742 million/year

Net present value:

NPV = CF fa – I = 11.91113449

fa, is a function of the assumed discount rate and plant useful life, Vu.
Only when NPV is greater than zero, the investment assures profit;

Discount rate, I = 15 %

Plant life, Vu = 10 year

APPENDIX B

FYP MILESTONE

No	Detail/ Month	1	2	3	4	5	6	7	8	9	10	11	12
	Find out the project objectives												
	Research topic												
	Gather information and data												
	Submission progress report 1												
	Economic potential analysis												
	Synthesis of fuel production												
	Submission progress report 2												
	MEB calculation												
	Determine individual process flowsheet for AD and Fermenter processes												
	Submission progress report 3												
	• Establish flowsheet for integrated process and the material balance • Study on the integration effect on the material, enzyme and etc.												
	Submission of progress report 4												
	Pre-EDX Poster Exhibition / Seminar												
	Submission Final Report (Dissertation draft)												
	Final Oral Presentation												
	Submission of hardbound copies												

Suggested milestone   Process