# AN OPTIMIZATION OF CARBONIZED EMPTY FRUIT BUNCH BRIQUETTES AND BIOMASS PRODUCER GAS QUALITY CHARACTERISTICS USING RESPONSE SURFACE METHOD (RSM)


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## LIST OF SYMBOLS

| | |
|---|---|
| °C | Degree Celcius |
| $H_2$ | Hydrogen |
| $O_2$ | Oxygen |
| $N_2$ | Nitrogen |
| CO | Carbon monoxide |
| $CH_4$ | Methane |
| $CO_2$ | Carbon dioxide |

# LIST OF ABBREVIATIONS

| | |
|---|---|
| EFB | Empty Fruit Bunches |
| RSM | Response Surface Methodology |
| BPG | Biomass Producer GAs |
| GC | Gas Chromatography |
| HHV | High Heating Value |
| USM | Universiti Sains Malaysia |
| OBM | Organic Binder Mixture |
| IOBM | Inorganic Binder Mixture |

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# ABSTRAK

Isu global pengurangan bahan bakar fosil telah mendorong Malaysia untuk mencari sumber tenaga alternatif yang boleh diperbaharui dan juga ekonomi, menjadikan briket biomas sebagai salah satu pilihan terbaik untuk mengurangkan penipisan ini. Sebenarnya, Tandan Buah Kosong (EFB) adalah salah satu sisa pertanian yang paling biasa di Malaysia, dan briketnya berpotensi untuk digunakan sebagai bahan bakar gas alternatif. Namun, dalam mengembangkan briket biomas dari EFB, proses pra-rawatan diperlukan kerana mempunyai beberapa ciri yang tidak diinginkan yang membatasi kualitinya sebagai sumber bahan bakar yang baik. Dalam kajian ini, komposisi pengikat (organik dan bukan organik) dan air dianalisis untuk mencari campuran briket EFB terbaik selepas pra-rawatan. Pati tapioka digunakan sebagai pengikat organik dalam karya ini, sedangkan kalsium hidroksida Ca (OH) 2 digunakan sebagai pengikat anorganik. Selanjutnya, analisis proksimat, analisis fizikal, dan nilai kalori digunakan untuk menentukan sifat campuran pengikat yang berbeza pada briket EFB. Hasilnya pada awalnya dibandingkan dari segi jenis pengikat yang digunakan untuk menentukan kualiti terbaik dari briket EFB. Kerana mempunyai analisis fisiokimia dan fizikal yang sederhana, hasilnya menunjukkan bahawa briket Campuran 2 mempunyai pencampuran EFB terbaik. Berbanding dengan bukan organik, ia mempunyai karbon tetap kurang tetapi juga kurang abu. Kurang abu bermaksud kesan negatif yang lebih kecil terhadap alam sekitar dan masalah dengan peralatan yang lebih sedikit. Selain itu, HHV briket OBMixture 2 adalah sederhana pada 22.10 MJ / kg, tetapi tidak ada perbezaan yang signifikan antara ia dan campuran lain. Kualiti optimum kemudian disiasat lebih jauh menggunakan alat statistik dan matematik, seperti RSM. Faktor dan tindak balas terbaik telah dikenal pasti, dan ia akan digunakan dalam kajian seterusnya. Secara keseluruhan, didapati bahawa campuran EFB berkarbonat, pengikat, dan air yang optimum dapat meningkatkan kualiti briket EFB dan menghasilkan gas pengeluar biomas yang optimum.

# ABSTRACT

The global issue of fossil fuel depletion has prompted Malaysia to look for alternate sources of energy that are both renewable and economical, making biomass briquettes one of the best options for mitigating this depletion. In fact, Empty Fruit Bunch (EFB) is one of the most common agricultural wastes in Malaysia, and its briquettes have the potential to be used as an alternative gaseous fuel. However, in developing biomass briquette from EFB, a pre-treatment process is required since it possesses several unwanted characteristics that limits its quality as a good source of fuel. In this study, the composition of binder (organic and inorganic) and water was analyzed to find the best mix of EFB briquettes after pre-treatment. Tapioca starch was used as an organic binder in this work, whereas calcium hydroxide Ca(OH)2 was used as an inorganic binder. Furthermore, proximate analysis, physical analysis, and calorific values were used to determine the properties of different binder mixtures on EFB briquettes. The results were initially compared in terms of the type of binders used to determine the best qualities of EFB briquettes. Because it has a moderate physiochemical and physical analysis, the results show that Mixture 2 briquettes have the best EFB blending. In comparison to inorganic, it has less fixed carbon but also less ash. Less ash means fewer negative effects on the environment and fewer issues with the equipment. Besides, the HHV of OBMixture 2 briquettes is moderate at 22.10 MJ/kg, but there is no significant difference between it and other mixtures. The optimal qualities are then investigated further using statistical and mathematical tools, such as RSM. The best factor and response were identified, and they will be used in the next study. Overall, it was discovered that the optimal mix of carbonized EFB, binder, and water can increase the quality of EFB briquettes and lead to optimal biomass producer gas.

# CHAPTER 1

# INTRODUCTION

## 1.1 An Overview of Biomass Briquette

Malaysia has faced challenges in sustaining fossil fuels produced from natural gas and coal in energy generation [1]. During the period of 1990 to 2016, more than 90% of electricity generated for Peninsular Malaysia was obtained from fossil fuel [2]. And in recent years, the global issue of fossil fuel depletion has triggered Malaysia to explore alternative source of fuel which is renewable and affordable. In order to overcome this situation, The Malaysia National Biomass target is aimed to achieve 800 MW installed capacity from the utilization of biomass by 2020[3]. And by 2030, their target for biomass to energy production is reaching is to reach 1,340 MW [4]. In view of this scenario, Biomass can potentially become a primary source of renewable carbon that can be utilized as a feedstock for biofuels production in order to achieve energy independence [5]. There are various kind of biomass resources available in this country and the biomass materials can be utilized as a source of fuel in various forms that includes pellet and briquette.

The process of Biomass briquetting is a mechanical process that involves the compacting of biomass residue into a uniform solid fuel. In most cases, biomass residue such as from agricultural wastes can be is used to produce biomass briquettes since Malaysia has the advantage of is blessed with high harvesting activities of the agricultural crops and thus producing high agricultural wastes. a lot of agricultural waste also produced. Empty Fruit Bunch (EFB) is one of the major agricultural wastes produced in Malaysia. The amount of the EFB is technically increasing as the increasing with the increase of Malaysia oil palm plantation area from 5.74 million hectares in 2016 to 5.81 million hectares in 2017[6].

However, in developing biomass briquette from EFB, a pre-treatment process is required since it possesses several unwanted characteristics that limits its quality as a good source of fuel. to become a source of energy supplied. The unwanted characteristics that includes such as its bulky in nature, fibrous, high moisture and alkali content of palm oil wastes will require the pre-treatment process and processing in order to increase its conversion efficiencies [1]. At the same time, this pre-treatment can increase the quality of briquette, especially on its physical factor and thermochemical factor characteristics. Biomass briquette was is commonly used as a source of fuel in industries that deal with steam boiler operation and gas production. for industrial purpose such as for boiler operation and gas production.

## 1.2 Research Background

Empty Fruit Bunch (EFB) is part of agricultural wastes from oil palm mill that can be treated and converted into useful energy resource. For that, EFB requires a pre-treatment process before it can be briquetted with special formulation of EFB, water and binder in order to convert it into useful solid fuel. The function of pre-treatment process is to improve both chemical and physical properties of EFB. In the previous study, EFB was pre-treated (torrefied), mixed with water and binder before briquetting. Characteristics study was done on the blended EFB with water and binder at different compositions as well as at different types of binders including both organic and inorganic binders. In addition, their finding of this study showed that physicochemical and combustion properties of the carbonized EFB briquette blended with starch mixture would influence by the type and portion of binder in order to produce good densified solid fuels as a source of energy [4].

Furthermore, several input and output parameters have been identified as critical parameters in producing good quality EFB briquettes and Biomass Producer Gas (BPG) for IC engine application. The critical parameters can be divided into two terms which is briquette production and gasification. For briquette production, the critical parameters are mixing ratio (raw material and binder), carbonization treatment (heating time) and carbonized temperature. Meanwhile, for gasification, the parameters are airflow and heating temperature.

In this study, further characterization process is needed to validate the significance of those parameters to the quality characteristics improvement of EFB briquettes and BPG production from the downdraft gasifier. Gasification process is better than direct burning in the boiler due to its environmentally friendly method. The yields of end products of gasification are dependent on several parameters which include temperature, biomass species, particle size, equivalence ratio and reactor configuration, as well as extraneous addition of catalysts [5]. When air is used as the oxidant, the gaseous product is usually called producer gas, and when oxygen or steam is used, the product is termed synthesis gas (syngas) [7]. The optimization of biomass producer gas is lacking in current researchers. Hence, this study also will be focusing on the quality of gas.

### 1.3 Problem Statement

The combustion of fossil fuels gives bad effects on public health and environment such as climate change and releases pollutants that lead to early death, heart attacks and respiratory disorders[8]. In addition, the depletion of fossil fuel has contributed to an increase of oil price and the negative impact to the environment from the long term application of fossil fuel via combustion needs to be mitigated and also any energy-related commodities will increase. Therefore, many researchers have studied the potential application of alternative and renewable fuels such as biomass in power production. Because of this, studies dealing with the use, characterization and study of biomass resources as alternative liquid fuels for the application of IC engines have recently increased.

Nevertheless, not all of them deal with the possible use of biomass producer gas (BPG) as dual fuel in the IC engine and not many have done the research on the optimization of biomass producer gas. Besides, the biomass use in this continuous study is Empty Fruit Bunches(EFB) which is known as most problematic biomass due to its fibrous structure thus producing briquettes from EFB facing several challenges such as poor grind ability, high moisture content and low energy density even though, EFB offers high quantity and has great potential as a cost-effective feedstock for producing briquette[9]. Next, the selection of best binder between inorganic and organic are lacking among the researchers. As pre-assumption an organic binder will contribute for a better EFB briquettes compared to inorganic binder in terms of physiochemical properties and physical analysis. On the other hand, a preliminary combustion characteristics study of BPG in CVCC has been conducted but it requires further study to validate the preliminary result.

Furthermore, the study of a comprehensive characteristic of EFB briquettes and BPG via parametric study (RSM) has not yet been performed. Using RSM, proper Design of Experiment (DOE) method will be achieved, thus improve the accuracy and the lead time of obtaining the optimized data In this project, to determine the optimize biomass producer gas, further investigations are required to get the condition for best quality of gas production through downdraft gasification process and using optimize briquettes based on response surface methodology (RSM). In addition, further study on the best binder that will give good quality briquette production are required.

## 1.4 Objectives

These are the objectives of this study:

1. To characterize the compositions of binder (organic and inorganic), water and EFB for the optimum blend of EFB briquettes production after pre-treatment process.
2. To perform characteristics study on the effects of organic and inorganic binders, composition of empty fruit bunch (EFB), water and binder to the quality of EFB briquettes and biomass producer gas (BPG) using statistical and mathematical techniques which is response surface methodology (RSM).

## 1.5 Scope of project

This project is the continuation of the 2019 project of the previous final year where the previous student did characteristics study on the blended EFB with water and binder at different compositions as well as at different types of binders including both organic and inorganic binders. In this project, the optimization of biomass producer gas from biomass briquettes will be done experimentally using downdraft gasifier and further analyzed using gas chromatograhpy (GC). In addition, the preliminary result of preliminary combustion characteristics will be validated and a comprehensive characteristics study of EFB briquettes and BPG via response surface methodology (RSM) will be performed.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Thermochemical process

### 2.1.1 Slow pyrolysis

Biomass pyrolysis is a promising renewable sustainable source of fuels and petrochemical substitutes[10]. The categories of pyrolysis are divided into three which are slow pyrolysis, flash pyrolysis and fast pyrolysis. Fast pyrolysis involves heating biomass residues at a high temperature with a high heating rate in the absence of oxygen. The flash pyrolysis technique involves rapid devolatilization in an inert atmosphere with a high heating rate and pyrolysis temperatures between 450 and 1000°C. Low temperature and low heating rates are used in slow pyrolysis.

However, this study only focusing on the slow pyrolysis which is torrefaction. Torrefaction involves the heating of biomass in the absence of oxygen to a temperature of typically 200 to 400°C and the structure of the biomass changes in such a way, that the material becomes brittle, and more hydrophobic. The study about slow pyrolysis stated that carbonization treatment is one of the thermochemical processes where it is classified as slow pyrolysis methods which will produce about 33% of char[11].

In this study, the critical review has been done on the essential features of carbonization. It is a process in which a biomass is heated in an atmosphere free of oxygen or limited by oxygen. The range of temperature is 200-400℃ and it was found that the briquette properties increase within that range due to the decomposition of lignin. Few analysis is done in order to study the effect of carbonization of EFB briquetted blended with a binder and it eventually shows that physiochemical and combustion properties were influenced by those selections of mixture. In this research also, the data produce can assist as reference to produce a biofuel commodity of the second generation which is producer gas via a gasification process.

The study shows that carbonized EFB increase the carbon content and decreasing the oxygen content. As referred to Table 3, carbonized briquette TS2 released the highest carbon content and lowest oxygen content compared to carbonized briquette prepared from others starch mixture and it shows the effect of carbonization treatment and binder on carbon, hydrogen, nitrogen, oxygen and sulphur of briquette[9]. TS2 showed the highest HHV which make it possible to produce high quality gas. Production of gas will be done by using gasification process.

| Treatment | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Raw** | **TS1** | **TS2** | **TS3** | **CS1** | **CS2** | **CS3** |
| C | 54.1 | 60.27 | 62.031 | 59.337 | 59.097 | 59.042 | 58.669 |
| H | 5.85 | 4.0335 | 3.9531 | 3.7169 | 3.9893 | 3.9385 | 4.2611 |
| analysis N | 0.58 | 0.6353 | 0.672 | 0.6002 | 0.5847 | 0.8757 | 0.8846 |
| | | | | | | | |
| (%) O (diff) 36.5 | | 34.9869 | 33.281 | 36.2868 | 36.2576 | 36.052 | 5 |
| S 0.09 | | 0.0728 | 0.0629 | 0.0591 | 0.0714 | 0.0918 | 0.0828 |
| High Heating Value 17.66 | | 22.29 | 23.62 | 23.46 | 19.31 | 20.66 | 19.27 |

Table 2.1 Effect of carbonization treatment and binder on carbon, hydrogen, nitrogen, oxygen and sulphur of briquette[9].

### 2.1.2 Downdraft Gasification

The typical setup used for gasification, operating at temperatures around 1000°C, was the fixed bed gasifier. There are three main types of fixed bed gasifiers which are updraft, downdraft and cross-draft gasifiers. In this project, downdraft gasifier will be used. The fundamental benefit of a downdraft gasifier is that the producer gas contains less tar and has a higher car conversation. The lower tar content is due to the gas passing through a hot zone (the combustion zone), which allows the tars generated during the gasification process to break[12] . A low tar concentration is a critical criterion for using biomass producer gas as a dual fuel with diesel or gasoline in an internal combustion engine.

The other gasifier, on the other hand, is not chosen as their rationale. Updraft, for example, has drawbacks in large-scale tar production. Meanwhile, cross-draft gasifier drawbacks such as high exit gas temperature, low CO2 reduction, and high gas velocity are the result of the design, and unlike downdraft and updraft gasifiers, cross-draft gasifiers have separate ash bin, fire, and reduction zones. The downdraft gasifier has the same mechanical configuration as the updraft gasifier except that the oxidant and product gases flow down the reactor, in the same direction as the biomass[13].

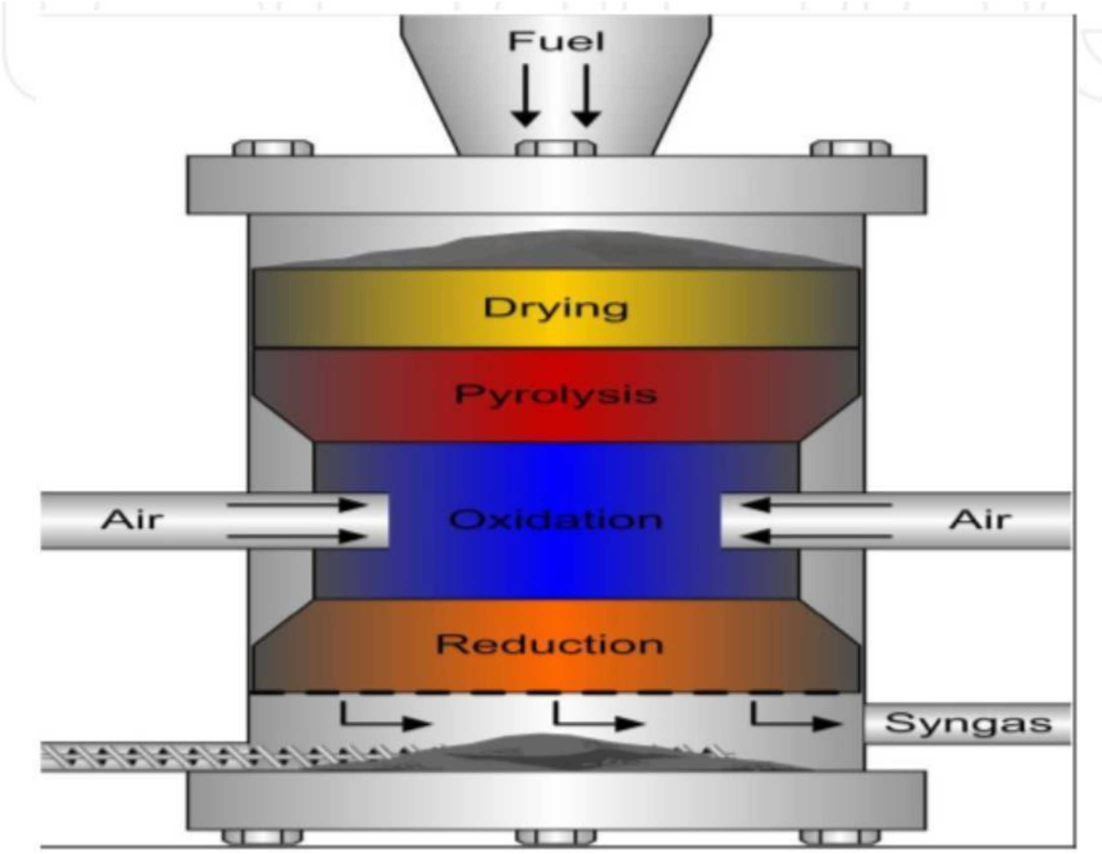


Figure 2.1 A downdraft gasifier[13].

In other research regarding gasification, the study is focusing on the effectiveness of gasification in downdraft gasifier depend upon the calorific value of biomass, size and its other chemical properties. Some of combustible gas were found during the gasification such as H2, CO, CH4 and CO2. The result analysis of producer gas compositions, thermal efficiency of briquetting and the calorific value is critically reviewed in this research. These elements are needed in order to know and improve it and to consider in the next research, especially for biomass producer gas. In addition, the usage of the downdraft gasifier method is highly given the various of problem-solver related to environment in terms of quality, smoke reduction, higher thermal efficiency and tar content.

## 2.2 Response Surface Methodology (RSM)

The response surface methodology (RSM) is a commonly used mathematical and statistical method for modelling and analysing a process in which the response of interest is influenced by a number of variables, with the goal of optimising the response

[14]. To define the relationship between variables, RSM helps to decide the best experimental design. The methodology of the response surface consisted of many techniques for designing the experimental procedures and one of them is central composite design (CCD). CCD-based optimization may screen a wide variety of factors as well as the role of each factor, and it can also analyse a single variable or the cumulative influence of the variables on the answer[15].

Optimization by RSM method involves three major steps; these are firstly statistically designed experiments, secondly, estimate the coefficients in a mathematical model and finally predicting the response and checking the adequacy of the model within the setup of the experiment[16]. The parametric study on the effects of critical parameters to the improved quality EFB briquettes and BPG can be done by RSM. In this study, five independent variables were chosen for the statistical experiment design as shown in Table 2.2.

Table 2.2 Critical parameters to improved quality EFB briquettes and BPG

| | |
|---|---|
| **Briquette production** | Mixing ratio (raw material and binder) |
| | Carbonization treatment (heating time) |
| | Carbonized temperature |
| **Gasification** | Air flow rate |
| | Heating temperature |

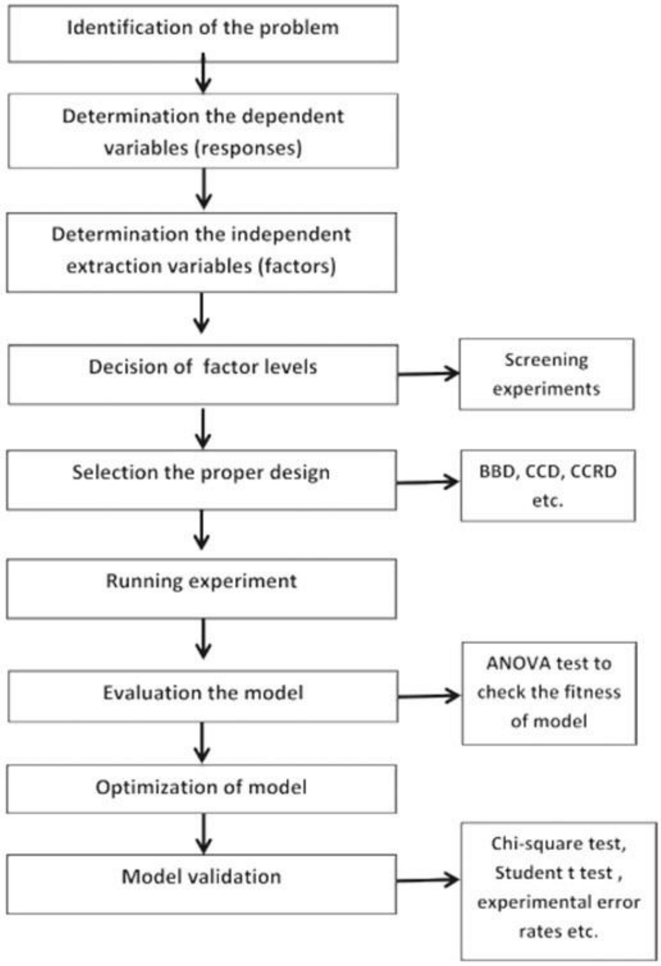


Figure 2.2 Flowchart step for response surface methodology[14].

# CHAPTER 3

# METHODOLOGY

## 3.1 Overview

The methodology, apparatus, materials, and complete experimental setup used throughout this work will be discussed in this chapter. It begins with doing RSM using Design Expert to produce a set of data to run the experiments. Next, the progress continues with researching the critical parameters in producing good quality EFB briquettes in journals, papers, websites, or publications. Then, in the Nibong Tebal area, look for EFB samples at the nearest palm mill. The sample was then taken to the School of Mechanical Engineering Bio Lab for pre-treatment before being briquetted with an unique EFB formulation.

Few analyses have been conducted to analyse the briquette with special formulation. The physicochemical and combustion parameters of each of the briquettes were determined by proximate and high heating value (HHV) analyses. Proximate analysis is the amount of volatile matter (VM), fixed carbon (FC), moisture content (MC), and ash content of the briquettes. The analysis were measured using a Perkin Elmer Pyris 1 Thermogravimetric Analyzer (TGA) according to ASTM standard methodology. The Nenken 1013-B bomb calorimeter was used to determine the HHV.

### 3.2 Workflow of the project

The overall activities of this project throughout this process research are depicted in Figure 3.1 flow diagram.

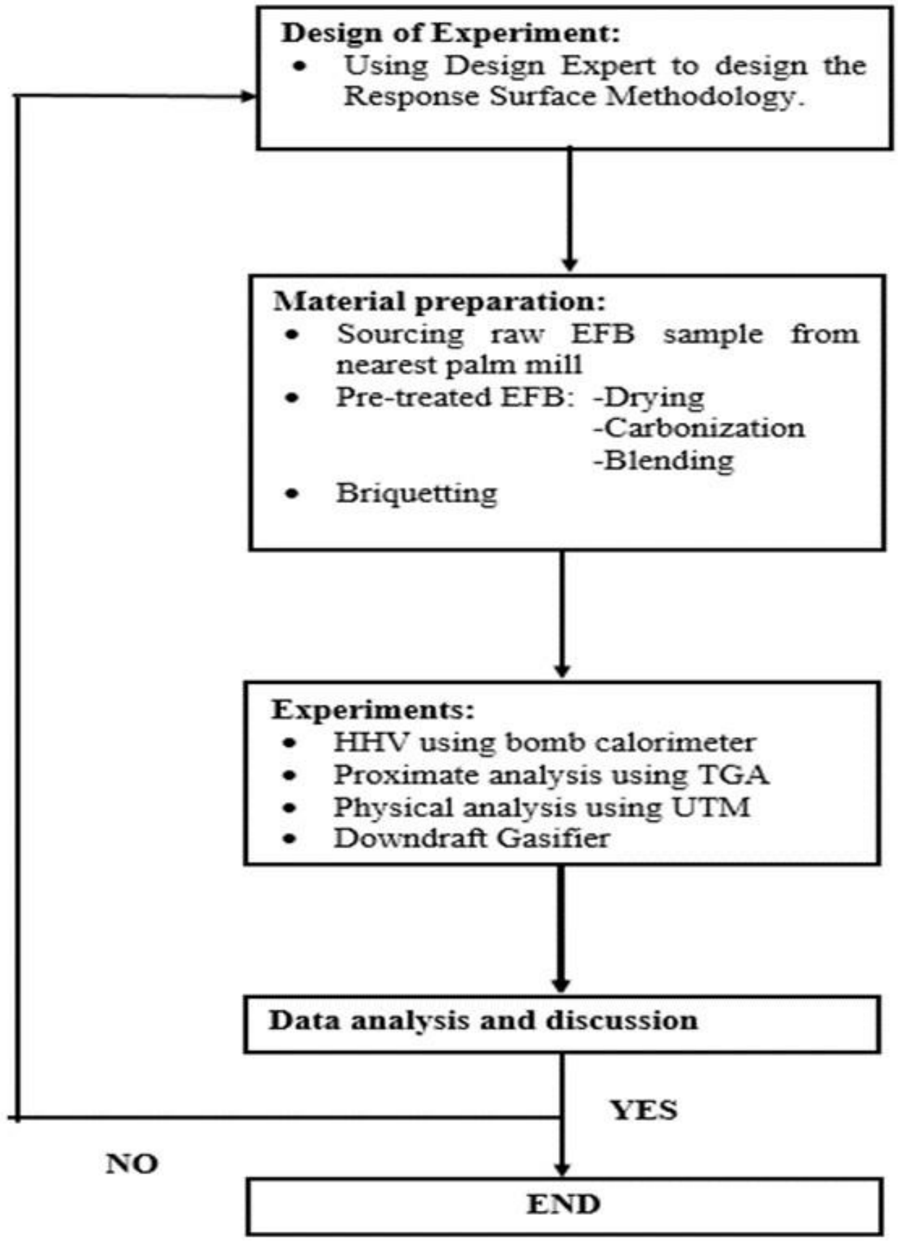


Figure 3.1 Workflow of the project