

EFFECT OF PARTICLE SIZE AND FUEL TYPE ON SOLID WASTE  
COMBUSTION

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"I hereby to declare that the work is my own except for summaries and quotations  
which have been duly acknowledged"

Signature : .....

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## ABSTRACT

In today's high energy demand world, power generation makes important role day by days. There are many different kind of power generation system available for instance biomass, solar, nuclear, wind and conventional energy. Biomass or also known solid waste is widely used in the industries nowadays. The biomass is not only using as a fuel for the combustion but it have a potential to gain an energy to become a new alternative source of energy. The important aim for this project is to analyse the temperature distribution and product gases from the gasification process releases and also effect of particle size and fuel type. There are two important element influences the combustion rate for the solid waste which is fuel size and fuel type. Then analysis the efficiency combustion and the product released from the combustion. The scopes of this project to run experimental work on solid waste by varying the fuel type, and fuel size. The experiment was conduct to know the product released from the gasifier stack. Based on the results the various particle size and fuel type will effect on solid waste combustion. The half size and a wood show the highest temperature and the shortest burning time and also the oxygen  $O_2$  emission is lower compare with other sample. The gas emission of  $O_2$  and  $CO_2$  is inversely in graph gas emission. This is because of the particle size, moisture and ash content on fuel type.

## ABSTRAK

Dalam permintaan tinggi tenaga pada dunia hari ini ,penjanaan kuasa menjadi sesuatu yang penting dari hari ke hari.terdapat pelbagai jenis penjanaan kuasa yang wujud seperti biojisim, solar,nuklear, angin dan tenaga konvensional. Biojisim ataupun dikenali sisa pepejal digunakan secara meluas di dalam industri. Sisa pepejal bukan sahaja digunakan sebagai bahan bakar tetapi ia juga mempunyai potensi untuk menjadi salah satu sumber tenaga baru.Matlamat utama di dalam projek ini untuk mengkaji taburan suhu dan hasil gas yang terbebas daripada proses gasifikasi dan kesan penggunaan bahan api yang berbeza dan saiz. Terdapat dua elemen penting yang mempengaruhi kadar pembakaran iaitu bahan api yang berbeza dan saiz yang berbeza. Kemudian analisa kecekapan pembakaran dan pembebasan produk dari pembakaran.Skop projek ini adalah menjalankan eksperimen menggunakan sisa pepejal dengan mengambil kira sisa pepejal yang digunakan, kandungan kelembapan dan kadar halaju. Eksperimen perlu dilakukan untuk mengetahui hasil yang terbebas dari serombong pengas.Berdasarkan pada keputusan kepelbagaian saiz dan jenis bahan bakar akan member kesan kepada pembakaran sisa pepejal. Setengah saiz daripada saiz sebenar dan kayu menunjukkan suhu tertinggi dan masa pembakaran yang paling cepat dan juga pembebasan oksigen O<sub>2</sub> rendah berbanding sampel lain.Pembebasan gas O<sub>2</sub> dan CO<sub>2</sub> adalah bertentangan satu sama lain di dalam graf pembebasan gas.Ini disebabkan oleh saiz sampel,kandungan kelembapan dan kandungan habuk di dalam bahan bakar.

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## CHAPTER 1

### INTRODUCTION

#### 1.1 Project Overview

Biomass heating systems refers to the various methods used to generate heat from biomass. The systems fall under the categories of direct combustion, gasification, combined heat and power (CHP), anaerobic and aerobic digestion. The use of biomass in heating systems is beneficial because it uses agricultural, forest, urban and industrial residues and waste to produce heat and electricity with a very limited effect on the environment. This type of energy production has a very limited effect on the environment because the carbon in biomass is part of the natural carbon cycle, while the carbon in fossil fuels is not, and adds carbon to the environment when burned for fuel. Historically, before the use of fossil fuels in significant quantities, biomass in the form of wood fuel provided most of humanity's heating, as well as providing our first renewable energy resource.

The production of generator gas (producer gas) called gasification, is partial combustion of solid fuel (biomass) and takes place at temperatures of about 10000C. The reactor is called a gasifier. The combustion products from complete combustion of biomass generally contain nitrogen, water vapor, carbon dioxide and surplus of oxygen. However in gasification where there is a surplus of solid fuel (incomplete combustion) the products of combustion are combustible gases like Carbon monoxide (CO), Hydrogen (H<sub>2</sub>) and traces of Methane and no useful products like tar and dust. Gasification is a very efficient method for extracting energy from much

different type of organic materials. In this research the work will emphasize on the gasification of solid waste that consists coconut shell, food waste and wood waste. These solid wastes are usually left to decompose naturally in the dumpsites. If this solid waste is burnt with the right method, it has potential to generate electricity. This will become an alternative for energy source not only for reduce the solid waste.

In this project research, solid waste that consist coconut shell, wood and food waste is burned inside the gasifier. The rate of combustion is related to the turbulence that consists inside the gasifier. There is little condition that related to the turbulent which are the size of the fuel and the type of fuel that taken for the combustion. The size of the fuel will influence the rate of the combustion, with the smaller size of the fuel size will increase the combustion rate compare with the biggest size. The smaller size may occur the surface area for combustion is higher than the surface area for the biggest size. For the various fuel type, it depend on the content of the fuel, that consist The high moisture and ash contents in biomass fuels can cause ignition and combustion problems. The melting point of the dissolved ash can also is low which causes fouling and slagging problems. Because of the lower heating values of biomass accompanied by flame stability problems.

## **1.2 Objective**

The main objective in this project PSM is:

To investigate experimentally the effect of fuel particle and fuel type on combustion process.

### **1.3 Work Scope**

Scope of work in this PSM research includes:

1. To run experimental work on solid waste by varying the:
  - a. Fuel type: coconut shell, wood and food waste
  - b. Fuel size: Initial size, half and quarter of initial size.
2. Analyse temperature distribution and product gases released
3. Analyse the effect of the different size and fuel type on solid waste combustion

### **1.4 Problem Statement**

No extensive work on the gasifier through experimental or simulation work. Hence, this project is done for analyze the performance of the gasifier with the various fuel type and the suitable fuel size to get the complete combustion. This project also study the emission released from the combustion of solid waste of the gasifier stack to analyze the product gases released.

### **1.5 Significant of Study**

In this research, the main equipment that will be use is an updraft gasifier. The updraft gasifier operated with the air that flow all the way through in it start from the bottom to the top of it where all the combustible gases will come out. The rate of combustion of the gasifier is mainly affect by the turbulence in it which involves the fuel type and the size of fuel in the solid waste. These two conditions are very important because it related to the reaction mechanism of the gases and the product of gases that will occur. That efficiency of the combustion can be determined. Hence, the performance of the gasifier can be identified.

## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 Introduction

Biomass refers to organic materials that stem from plants. It stores energy from sunlight by photosynthesis in bonds of carbon, hydrogen and oxygen molecules. It is characterized into four main types: woody plants, herbaceous plants/grasses, aquatic plants and manures. Biomass is presently estimated to contribute of the order 10–14% of the world's energy supply. The sources of biomass are specially grown energy crops, agricultural wastes, forestry residues and the organic fraction of municipal wastes. Its energy is converted to heat, power or chemical feedstock mainly by thermo-chemical conversion.

Combustion is a widely used technology for energy conversion of biomass. Most biomass consumed at the present time is burned in fixed or moving beds. A fixed bed has two basic configurations depending on the flow direction of air and fuel: co-current and counter-current, while a moving bed on a grate is counter-current. However, the fixed bed has an analogy with the moving bed since the time elapsed in a fixed bed can be transformed into the location on the grate in the moving bed corresponding to the fuel residence time. Thus, the combustion characteristics and process rates in the fixed bed can be applied to the moving bed. This study is for a counter-current bed which is more commonly applied.

Combustion of solid fuel in a fixed bed involves complicated heat and mass transfer along with various chemical reactions. Conductive, convective and radiative



heat transfer takes place (a) between solid phases and (b) between solid and gas within the bed, and (c) between the bed, the walls and the flame above the bed. The composition changes include drying, pyrolysis and char gasification of the solid fuel, and the reactions of volatile gases with air. Once the fuel is ignited by an external heat source (usually by radiation from above the bed), the ignition front propagates into the bed. The heat generated by gaseous reactions and char oxidation at the ignition front transfers downwards to dry and heat up the fresh particles below. Since the heterogeneous char oxidation is relatively slow and oxygen is consumed first by the volatile gases from the particles, carbonised particles remain above the ignition front. Therefore, the drying, pyrolysis, char oxidation and ash zones appear sequentially from the bottom to the top of the bed during the ignition propagation, although these processes occur simultaneously for large fuel particles. Once the ignition front reaches the bed bottom, only the oxidation of the remaining char takes place.

Two process rates are often used to quantify the progress of combustion in fixed beds. The ignition front speed, which is also referred as flame front speed or reaction front velocity, is based on the temperature history within the bed. The burning rate is a mass loss rate of the bed per unit area and unit time.

The fuel properties and process conditions affect the combustion characteristics, altering the heat generation, heat transfer and reaction rates in a complicated manner. The air flow rate is the key process parameter that determines the amount of oxygen available and convective heat transfer. The process rates are classified into three successive regimes depending on the air flow rate: Oxygen-limited, reaction-limited and extinction by convection regimes. When the air flow rate is small, the propagation of the ignition front is controlled by the amount of oxygen and the process rates are linearly proportional to the air flow rate. In the reaction-limited regime, the process rates are limited by the reaction rate of the fuel. As the air supply increases further, the convective cooling of particles around the ignition front slows down the process and finally causes

extinction of the flame. Gort also presented similar classification: partial gasification, complete gasification and combustion regimes.

Biomass has a wide range of variety in physical properties, which significantly change the process rates and detailed phenomena. More fundamental studies are required to understand the combustion characteristics of different biomass materials. One important aspect in the fuel properties is pelletisation that is used because many raw biomass materials, especially grass, straw and sawdust, have a very low bulk density (usually less than  $150 \text{ kg/m}^3$ ), which require high cost for storage, transportation and handling. Pelletisation significantly densifies biomass to over  $600 \text{ kg/m}^3$ , which is essential for biomass to compete with other sources of energy.

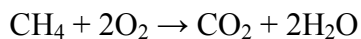
The ash composition is a major concern in biomass combustion. The high presence of alkali metals in biomass may cause slagging, fouling and ash agglomeration. The primary sources of these problems are: the reaction of alkali with silica to form alkali silicates that melt or soften at low temperatures (can be lower than  $700 \text{ }^\circ\text{C}$ , depending on the composition), and the reaction of alkali with sulphur to form alkali sulphates on heat transfer surfaces . Investigating the elemental composition of ash is important in order to identify possible operational problems in the actual application.

## **2.2 Combustion**

Combustion or burning is a complex sequence of exothermic chemical reactions between a fuel usually a hydrocarbon and an oxidant accompanied by the production of heat or both heat and light in the form of either a glow or flames, appearance of light flickering.

Direct combustion by atmospheric oxygen is a reaction mediated by radical intermediates. The conditions for radical production are naturally produced by thermal runaway, where the heat generated by combustion is necessary to maintain the high temperature necessary for radical production.

In a complete combustion reaction, a compound reacts with an oxidizing element, such as oxygen or fluorine, and the products are compounds of each element in the fuel with the oxidizing element. For example:



A simpler example can be seen in the combustion of hydrogen and oxygen, which is a commonly used reaction in rocket engines:



### 2.2.1 Types

There are 5 types of combustion:

1. Rapid
2. Slow
3. Complete
4. Turbulent
5. Incomplete

#### 2.2.1.1 Rapid

Rapid combustion is a form of combustion in large amounts of heat and light energy are released. Rapid combustion usually used for machinery. In rapid combustion it also has the large quantity of gas that can creates excess pressure that can produce a loud noise like an explosion.

### **2.2.1.2 Slow**

In slow combustion the combustion that happen in low temperature like in cellular respiration.

### **2.2.1.3 Complete**

In complete combustion the reactant will burn in oxygen that producing a limited number of product. When a hydrocarbon burns in oxygen, the reaction will only yield carbon dioxide and water. When a hydrocarbon or any fuel burns in air, the combustion products will also include nitrogen. When elements such as carbon, nitrogen, sulfur, and iron are burned, they will yield the most common oxides. Carbon will yield carbon dioxide. Nitrogen will yield nitrogen dioxide. It should be noted that complete combustion is almost impossible to achieve. In reality, as actual combustion reactions come to equilibrium.

### **2.2.1.4 Turbulent**

In the turbulent combustion it generates by turbulent flows. Turbulent combustion usually used in industries like gas turbines and gasoline engines. The turbulent combustion is suitable used in industries because the turbulence helps in mixing process between the fuel and oxidizer.

### **2.2.1.5 Incomplete**

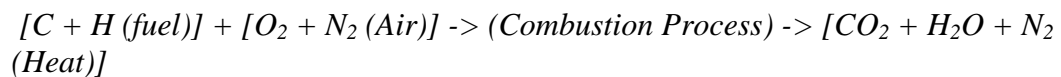
In the incomplete combustion that the combustion doesn't has enough oxygen to allow the fuel to react completely to produce carbon dioxide and water.

### 2.3 Stoichiometric Combustion

Stoichiometric combustion are also known as theoretical combustion. This is the ideal combustion process of a completely burned fuel, where all the carbon ( C ) converted to ( CO<sub>2</sub> ),all hydrogen( H) to water (H<sub>2</sub>O) and all sulphur to sulphur dioxide ( SO<sub>2</sub> ).during which a fuel is burned completely. A complete combustion is a process which burns all the carbon (C) to (CO<sub>2</sub>), all hydrogen (H) to (H<sub>2</sub>O) and all sulfur (S) to (SO<sub>2</sub>). If there are unburned components in the exhaust gas such as C, H<sub>2</sub>, CO the combustion process is uncompleted so it not calls a stoichiometric combustion.

The stoichiometric ratio is also known as ideal fuel ratio, whereby it required the correct chemical mixing proportion. The stoichiometric air-fuel ratio needed to be identified first in order to determine the percent excess air or excess fuel at combustion systems operations.

#### Chemical Reaction



Where:

*C = Carbon*

*H = Hydrogen*

*O = Oxygen*

*N = Nitrogen*

### 2.4 Gasification

Gasification is the conversion of biomass to a gaseous fuel by heating in a gasification medium such as air, oxygen or steam. Unlike combustion where oxidation is substantially complete in one process, gasification converts the intrinsic chemical energy of the carbon in the biomass into a combustible gas in two stages.

The gas produced can be standardised in its quality and is easier and more versatile to use than the original biomass example it be used to power gas engines and gas turbines, or used as a chemical feedstock to produce liquid fuels.

Strictly, gasification includes both biochemical and thermochemical processes, the former involving micro-organisms at ambient temperature under anaerobic conditions example anaerobic digestion, while the latter uses air, oxygen or steam at temperatures  $>800\text{ }^{\circ}\text{C}$ .

#### 2.4.1 Four steps of level in gasification process:

- i. Hearth zone (Oxidation),
- ii. Reduction zone,
- iii. Distillation zone (Pyrolysis)
- iv. Drying zone

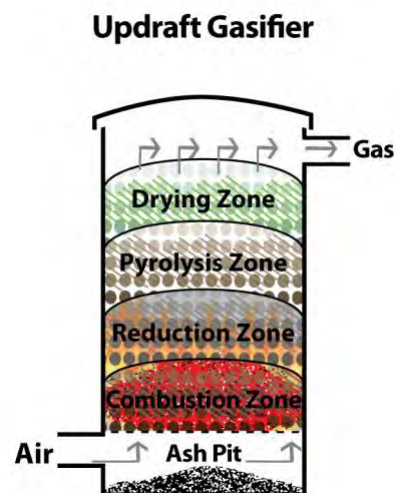
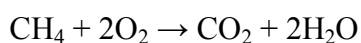


Figure 2.1: Four Zone Process in Updraft-Gasifier

(Resource: Skov, N. A.1974)

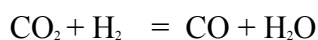
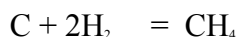
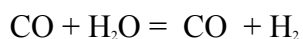
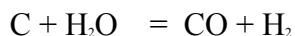
#### 2.4.1.1 Hearth zone (Oxidation)

Hearth zone or oxidation zone also known as combustion zone which the combustible substance of a solid fuel is usually composed elements of carbon, oxygen and hydrogen. A complete combustion normally carbon dioxide will be produce from the carbon in the fuel and water will be produce from the hydrogen (steam). The combustion reaction is a complex sequence of exothermic chemical reactions between a fuel (usually a hydrocarbon) and an oxidant accompanied by the production of heat. The reactions are:



#### 2.4.1.2 Reduction zone

The activated carbon reacts with water vapour and carbon dioxide to form combustible gases such as hydrogen and carbon oxide. The reduction (or gasification) process is carried out in the temperature ranging up to about 1100°C.



#### 2.4.1.3 Distillation zone (Pyrolysis)

Volatile gases are released from the dry biomass at temperatures ranging up to about 700°C. These gases are non-condensable vapours (e.g. methane, carbon-monoxide) and condensable vapours (various tar compounds) and the residuum from this process will be mainly activated carbon.

#### **2.4.1.4 Drying zone**

Free moisture and cell-bound water are removed from the biomass by evaporation. These processes should ideally take place at a temperature of up to about 160°C using waste heat from the conversion process

#### **2.5.1 Gasifier**

The production of generator gas (producer gas) called gasification, is partial combustion of solid fuel (biomass) and takes place at temperature of about 1000 °C. The reactor is called a gasifier. The combustion products from complete combustion of biomass generally contain nitrogen, water vapor, carbon dioxide and surplus of oxygen. However, in gasification where there is a surplus of solid fuel (incomplete combustion) the products of combustion are combustible gas like carbon monoxide, hydrogen and traces of methane and non useful products like tar and dust. The production of these gases is by reaction of water vapour and carbon dioxide through a glowing layer of charcoal. Thus the key to gasifier design is to create conditions such that biomass is reduced to charcoal and, charcoal is converted at suitable temperature to produce CO and H<sub>2</sub>. (Skov et al., 1974).

There are few types of gasifier:

- i. Updraft gasifier;
- ii. Downdraft gasifier and;
- iii. Crossdraft gasifier

#### **2.5.1 Updraft Gasifier**

In the updraft gasifier the feed is introduced at the top and the air at the bottom of the unit via a grate .Immediately above the grate the solid char (the