A STUDY ON TEMPERATURE CONTROL SYSTEM FOR BIOMASS GASIFICATION PROCESS

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The thermal chemical conversion process is used to change the biomass to the renewable energy source. The process is distinguished by different temperature. The main goal of this study was experimentally about the ability of the direct fired furnace in control the temperature of furnace and reactor. This studied by do the modification on the system to regulate and control the fuel input in order to know the required energy for the direct fired system. The minimum setting fuel flow rate is 18 L/min that produce 28.2KW energy. By limitation of flow meter, the maximum fuel flow rate was 22L/min that produced 34.47 KW of energy. But the setting of opening air damper is gave the effect the furnace and reactor temperature. The fuel flow rate constant at 22L/min but the opening air damper setting is changed to get the required temperature for desired process. 3.6 of opening air damper setting are used for torrefaction process and 0.6 is for pyrolysis process. For gasification process could not achieve because to many heat loss occur in this system. Based on the energy produced, the theoretical reactor temperature is calculated based on heat transfer equation for hollow cylinder. The comparison between theoretical and actual reactor temperature showed there is 13% of heat loss occurred.
ABSTRAK

Proses penukaran bahan kimia haba digunakan untuk menukar biojisim untuk sumber tenaga boleh diperbaharui. Proses ini dibeza oleh suhu yang berbeza. Matlamat utama kajian ini adalah eksperimen tentang keupayaan relau api langsung dalam kawalan suhu relau dan reaktor. Ini dikaji dengan melakukan pengubahsuaian pada sistem untuk mengawal selia dan mengawal input bahan api untuk mengetahui tenaga yang diperlukan untuk sistem api langsung. Kadar aliran bahan api tetapan minimum 18 L / min yang menghasilkan tenaga 28.2KW. Oleh had meter aliran, kadar aliran bahan api maksimum adalah 22L/min yang dihasilkan 34.47KW tenaga. Tetapi tetapan membuka peredam udara memberi kesan suhu relau dan reaktor. Kadar aliran bahan api malar pada 22L/min tetapi tetapan peredam udara pembukaan ditukar untuk mendapatkan suhu yang diperlukan bagi proses yang dikehendaki. 3.6 membuka tetapan peredam udara digunakan untuk proses torrefaction dan 0.6 adalah untuk proses pirolisis. Untuk proses gasifikasi tidak dapat mencapai kerana kehilangan haba banyak berlaku dalam sistem ini. Berdasarkan tenaga yang dihasilkan, suhu teori reaktor dikira berdasarkan persamaan pemindahan haba bagi silinder berongga. Perbandingan di antara suhu teori reaktor dan sebenar menunjukkan terdapat 13% daripada kehilangan haba berlaku.
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Abbreviation

\begin{itemize}
  \item \texttt{CO}_2 \quad \text{-} \quad \text{Carbon ioxide}
  \item \texttt{NO}_x \quad \text{-} \quad \text{Nitrogen oxide}
  \item \texttt{SO}_x \quad \text{-} \quad \text{Sulphur oxide}
  \item \texttt{EFB} \quad \text{-} \quad \text{Empty fruit bunch}
  \item \texttt{LPG} \quad \text{-} \quad \text{Liquefied petroleum gas}
  \item \texttt{^\circ C} \quad \text{-} \quad \text{Degree celcius}
  \item \texttt{CO} \quad \text{-} \quad \text{Carbon monoxide}
  \item \texttt{H}_2 \quad \text{-} \quad \text{Hydrogen}
  \item \texttt{O}_2 \quad \text{-} \quad \text{Oxygen}
  \item \texttt{C}_2\text{H}_6 \quad \text{-} \quad \text{Ethane}
  \item \texttt{H}_2\text{O} \quad \text{-} \quad \text{Water}
  \item \texttt{N}_2 \quad \text{-} \quad \text{Nitrogen}
  \item \texttt{C} \quad \text{-} \quad \text{Carbon}
  \item \texttt{AF} \quad \text{-} \quad \text{Air fuel}
\end{itemize}
### Parameters/Symbols

<table>
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<tr>
<td>$Q$</td>
<td>Heat transfer</td>
</tr>
<tr>
<td>$r_2$</td>
<td>Outside radius</td>
</tr>
<tr>
<td>$r_1$</td>
<td>Inside radius</td>
</tr>
<tr>
<td>$T_1$</td>
<td>Inside temperature</td>
</tr>
<tr>
<td>$T_2$</td>
<td>Outside temperature</td>
</tr>
<tr>
<td>$L$</td>
<td>Length</td>
</tr>
<tr>
<td>$k$</td>
<td>Thermal conductivity</td>
</tr>
<tr>
<td>$A$</td>
<td>Cross sectional area</td>
</tr>
<tr>
<td>$X_2-X_1$</td>
<td>Distance</td>
</tr>
<tr>
<td>$h$</td>
<td>Convective heat transfer coefficient</td>
</tr>
<tr>
<td>$T_w$</td>
<td>Temperature of solid surface</td>
</tr>
<tr>
<td>$T_f$</td>
<td>Average or bulk temperature of the fluid flowing past</td>
</tr>
<tr>
<td>$V$</td>
<td>Fuel flow rate</td>
</tr>
<tr>
<td>$CV$</td>
<td>Calorific value</td>
</tr>
<tr>
<td>$mm$</td>
<td>millimetre</td>
</tr>
<tr>
<td>$L/min$</td>
<td>litter/minute</td>
</tr>
<tr>
<td>$kW$</td>
<td>kilowatt</td>
</tr>
<tr>
<td>$m/s$</td>
<td>meter/second</td>
</tr>
<tr>
<td>$MJ/m^3$</td>
<td>mega joule/meter cubic</td>
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CHAPTER 1

INTRODUCTION

1.1) Background of Study

The energy demand highly increases in the world. Fossil fuels are the most common energy sources used in the world. It has been reported that over 80% of the energy consumption counts for fossil fuels. By Rapid development of technology and industrialization has faced mankind with two major concerns are Depletion of fossil energy resources and deterioration of the environment

Fossil fuels emit significant amount of pollutants such as CO$_2$, NO$_x$ and SO$_x$ into the atmosphere. Due to this situation, the world fossil fuel reservation decrease. Meanwhile, the cost of fossil fuel is globally increasing (Li K et al, 2009).

Besides, energy consumption has increased 17 fold in the last century and with the present rate of energy consumption, it is estimated that the world’s oil reservoir will be diminished by 2050 (Zainal et al., 2010). These issues may researches the alternative fuel resources which are renewable, sustainable and count for environmental friendly fuels. Among all of the renewable resources, biomass is the only renewable source that contains carbon which can be converted to solid, liquid and gaseous product through various conversion processes. Biomass energy contributed for 14–15% of total world energy consumption. Therefore, the exploitation and application of biomass energy are effective and necessary for relieving the pressures caused by environmental pollution and insufficient fossil fuel (Dangzhen et al., 2010). One of the promising technologies which utilize the biomass wastes is biomass gasification.
Malaysia is the largest producer of palm oil and it contributes about 47% of the world palm oil production (Mohammed et al., 2010). The consequences of this industry, they generate huge quantities of palm oil biomass including oil palm trunks, oil palm fronds, empty fruit bunch (EFB), shell and fibers. The Figure 1.1 shows the types of biomass produced from oil palm tree and the quantities produced per annum in million tonnes. This oil palm biomass has high potential to convert into renewable energy.

**Figure 1.1**: Types Of Oil Palm Biomass Produce in Malaysia In 2009 in MnT/year

Source: Mohammed et al., 2010

The previous study, researcher used electric as heating element to heat up the furnace for a gasification of biomass (Mohammed et al., 2011). The energy conversion of heat by electricity is 40% of efficiency which is not efficient (Jafar, 2008). In the real situation, the industries used the direct fired system such as the boiler in industries used the direct fired furnace to generate the heat to change the water to the steam. To expose the student for the real situation as in industries, University Malaysia Pahang researcher has built the gasification system that used direct fired as heating agent to heat up the
reactor inside the furnace. This system used the liquefied petroleum gas (LPG) as a fuel. This direct fired furnace more efficient compared to the electrical furnace.

Figure 1.2: Electrical Furnace on Fluidized Bed Reactor

Source: Mohammed et al., 2011

Figure 1.3: Schematic Diagram of Direct Fired System
1.1 Problem Statement

Based on the previous study, mostly researcher used the electrical furnace as medium to supply the heat for thermal chemical conversion process. The electrical furnace is easy to set, suitable for the small scale and more safety when run it in lab. By developing the direct fired gasification system, the heat distribution in furnace to the reactor is not the same as electrical furnace which can constantly and uniform in distribution of heat to the reactor. So this study is to see whether the temperature of direct fired furnace is can be control or not compared to the electrical furnace the temperature easy to control and set.

1.3) Objectives

Based on the problem statement, this research can be come out with two objectives which are:

a) To develop a system to regulate and control fuel input into the furnace.

b) To study the energy requirement to achieve the temperature for gasification of biomass material

1.4) Scope of Study

In this research, the experiment will be focused on the flow measurement system in fuel line before enter the gas burner, air damper setting and a study to control the temperature in the reactor by manipulating the fuel and air flow rate enter the gas burner to achieve the desired temperature for thermochemical process. By knowing the flow rate of the LPG use for the heating process in direct fired gasification system, the energy that produces to achieve the temperature can be determined. The scope of work includes:

a) Modify the system by installing the flow meter to the fuel line.

b) The liquefied petroleum gas (LPG) is used as a fuel

c) The empty fruit bunch use as a biomass material
d) Taking three differences fuel flow rate and 5 setting of opening air damper

e) The range experiment temperature is 320 °C – 700 °C.
LITERATURE REVIEW

2.1 Process of Thermal Conversion of Biomass

Thermochemical biomass conversion includes a number of possible roots to produce from the initial biomass feedstock useful fuels and chemicals. The bases of thermochemical conversion are the combustion, gasification, pyrolysis and liquefaction process, which include all chemical changes occurring when heat is applied to a material in the absence of oxygen. (Mohammed et al., 2011)

![Figure 2.1: Energy Production Processes Based On Biomass](image)

Source: Mohammed et al., 2011
Thermochemical conversion of woody biomass under restricted supply of oxidant is among the most promising non-nuclear forms of future energy. Besides utilizing a renewable energy sources, the technology also offers an eco-efficient and self- sustainable way of obtaining gaseous fuel usually called producer gas. It can be used in either premixed burners (dryers, kilns, furnaces or boilers) for thermal applications or in direct feeding of high efficiency internal combustion engines/gas turbines for mechanical applications (Damrtzis, 2010)

2.1.1 Torrefaction

Torrefaction or other word called mild pyrolysis is a thermal chemical process the conducted under inert atmosphere range and low heating rate at the temperature range between 200°C to 300°C. Torrefaction is currently being considered as a biomass feedstock pretreatment particularly for thermal conversion systems. During torrefaction various permanent gases and condensable, with high oxygen content, are formed mainly due to hemicellulose degradation. As a consequence the final solid product, so called torrefied biomass, will be composed mainly of cellulose and lignin and characterized by increased brittleness, hydrophobicity, microbial degradation resistance, and energy density (Kristoffer, 2006). Thus torrefaction can play a significant role in decreasing transportation and storage costs of biomass in the large quantities needed to sustain biofuels production. In addition, torrefaction may have positive effect on pyrolysis, gasification, and co-firing units operation by lowering power consumption and cost for biomass grinding, eliminating compounds responsible for high acidity of pyrolysis oil, and by increasing the uniformity of biomass feedstock. (Medic et al., 2012)

2.1.2 Pyrolysis

Pyrolysis is a process that converts biomass at temperatures around 450°C – 550°C in the absence of oxygen to liquid (bio-oil), gaseous, and solid (char) fractions. The use of catalysts or additives to improve the yield and quality of gas or liquid fuels from biomass is common. Extensive fundamental studies have been carried out to explore the wide range of conventional and unconventional catalysts. In the following section, state of the art technologies and developments concerning production,
upgrading, and utilization of bio oil, with a special focus on different catalysts, is introduced. Bio oil can be used in further conversion processes, such as efficient power generation gasification for syngas production and as an alternative fuel for vehicles (Long et al., 2012)

2.1.3 Gasification

Gasification rely on a chemical process which takes place at high temperatures, more than 700°C this is what distinguishes this process from any other thermochemical process, such the torrecfaction and pyrolysis process. The gasification process basically consists of two steps which pyrolysis and char conversion. The gasification process consists of the following stages (Zainal et al., 2010):

i. Drying. In this stage, the moisture content of the biomass is reduced. Typically, the moisture content of biomass ranges from 5% to 35%. Drying occurs at about 100–200°C with a reduction in the moisture content of the biomass of <5%.

ii. Devolatilisation (pyrolysis). This is essentially the thermal decomposition of the biomass in the absence of oxygen or air. In this process, the volatile matter in the biomass is reduced. This results in the release of hydrocarbon gases from the biomass, due to which the biomass is reduced to solid charcoal. The hydrocarbon gases can condense at a sufficiently low temperature to generate liquid tars.

iii. Oxidation. This is a reaction between solid carbonized biomass and oxygen in the air, resulting in formation of CO₂. Hydrogen present in the biomass is also oxidized to generate water. A large amount of heat is released with the oxidation of carbon and hydrogen. If oxygen is present in sub-stoichiometric quantities, partial oxidation of carbon may occur, resulting in the generation of carbon monoxide.

iv. Reduction. In the absence (or sub-stoichiometric presence) of oxygen, several reduction reactions occur in the 800°C–1000°C temperature range. These reactions are mostly endothermic.
Gasification reactivity studies usually focus on the reactivity of the char residue, since the volatile matter is rapidly released from the fuel and transferred to the gaseous environment. The properties and reactivity of chars are determined by several factors, including temperature, heating rate, pressure and residence time of the particles. Therefore, a clear understanding of char reactivity kinetics is a necessary requirement for the proper design of gasification reactors both from the point of view of process efficiency and environmental regulations (Fermoso et al., 2009). Various gasifying agents including air, steam, oxygen and steam, air and steam, O₂ and enriched air and oxygen, air and steam have been used in fluidized biomass gasification (Campoy et al., 2009).

The production of generator gas (producer gas) called gasification, is partial combustion of solid fuel (biomass) and takes place at temperatures of about 1000°C in reactor 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 combustible gases such as Carbon monoxide (CO), Hydrogen (H₂) and traces of Methane and non-useful products like tar and dust. The production of these gases is by reaction of water vapor and carbon dioxide through a glowing layer of charcoal. Thus the key to the gasifier design is to create conditions such that biomass is reduced to charcoal and charcoal is converted at suitable temperature to produce CO and H₂.

**Table 2.1: Summary of Thermal Chemical Process**

<table>
<thead>
<tr>
<th>Thermal Chemical Process</th>
<th>Temperature</th>
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<tr>
<td>Torrefaction</td>
<td>200 – 300 °C</td>
</tr>
<tr>
<td>Pyrolysis</td>
<td>450 -550 °C</td>
</tr>
<tr>
<td>Gasification</td>
<td>&gt;700 °C</td>
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</table>
2.2 Combustion

Combustion is the rapid chemical combination oxygen with certain elements. Although similar to oxidation, it occurs very much faster and requires a certain minimum temperature to initiate the reaction. This rapid chemical reaction can be controlled so that, in normal circumstances, it not explosive. For effective combustion the reacting elements must be mixed with the oxygen, maintained at a suitable temperature and given sufficient time to react. Hence the three T’s of combustion that are turbulence, temperature and time, which determine the success or otherwise of a combustion process. Combustion process release heat so generally, once ignition has been accomplished, the temperature is maintained at the suitable values. As combustion proceeds the concentration of the oxygen and the reacting elements decreases and continued turbulence is required to bring unreacted elements into contact with the oxygen. Adequate time is thus required form initial ignition to affect complete combustion (Eurotron, 2006).

2.2.1 Complete and incomplete combustion

The theoretical and actual combustion of fuel have three main different is that in a theoretical combustion process the process is complete, while in an actual combustion process is incomplete. A complete process means that all of the combustible components of a fuel are burned to completion as seen in the following example:

\[
C_2H_6 + \frac{9}{2}O_2 \rightarrow 2CO_2 + 3H_2O + O_2
\]

In an incomplete process the combustion products contain unburned fuel or component such as carbon, di-hydrogen, CO, and OH.

\[
C_2H_6 + 5O_2 \rightarrow 2CO_2 + 2H_2O + O_2 + 2OH
\]
2.2.2  Reason for incompleteness

There are many contributing reasons to why a combustion process becomes incomplete in an actual case. One of the easiest reasons to see is that a lack of oxygen leaves some of the fuel left unburned. But also incompleteness can be attributed to insufficient mixing in the combustion chamber due to the short time intervals in which these combustions are occurring. Another cause for incompleteness is because of a process called hydrogen bonding. Hydrogen bonding is a process in which chemical bonds form between molecules containing a hydrogen atom bonded to a strongly electronegative atom (an atom that attracts electrons). Because the electronegative atom pulls the electron from the hydrogen atom, the atoms form a very polar molecule, meaning one end is negatively charged and the other end is positively charged. Hydrogen bonds form between these molecules because the negative ends of the molecules are attracted to the positive ends of other molecules, and vice versa. In combustion process oxygen would be the electronegative atom since it needs 2 electrons to gain an octet in its outer electron orbit (Adams and Lee, 2001).

2.2.3  Stoichiometry

Stoichiometry is a basic theoretical analyzation process in which the assumption is made that the minimum amount of air is needed for the complete combustion of the fuel being analyzed, which is also known as theoretical air. When the assumption is made that the fuel is burned with theoretical air, it means that the process is complete or chemically correct and that there are no uncombined oxygen atoms present in the resultant gas.

Stoichiometry is one of the most widely used methods for determining the empirical formula of an unknown compound. Most widely used for compounds that contains carbon. In combustion analysis, an accurately known mass of a compound is burned in a stream of oxygen gas. All of the carbon in the sample is converted to carbon dioxide and all of the hydrogen is converted to water. The most important feature in this
analysis is that atoms of each element involved in the reaction are conserved (Adams and Lee, 2001).

i. Every carbon atom in the original sample ends up in a CO$_2$ molecule
ii. Every hydrogen atom in the original sample ends up in an H$_2$O molecule

2.2.4 Actual combustion process

In actual processes it is common to use an excess amount of oxygen in the process to increase the likely hood that all of the fuels in the combustion chamber combusts and yields a theoretical stoichiometric amount. The amount of air in excess is usually expressed as percent excess air or percent theoretical air; for example two hundred percent excess air is equal to three hundred percent of theoretical error.

2.2.5 Composition of air

Atmospheric air is composed of 78% nitrogen, 21% oxygen and 1% argon and trace amounts of carbon dioxide and other gases. In all practical application of combustion the oxygen is supplied as a constituent of atmospheric air and nitrogen passes through essentially unreacted. In effect the nitrogen dilutes both the oxygen and the combustion products and appears on both sides of the combustion equation. For carbon burning in air combustion equation in thus:

$$C + O_2 + 3.76N_2 = CO_2 + 3.76N_2$$

2.2.6 Excess air requirements

Stoichiometric combustion condition as describes above are an ideal situation difficult to achieve in practice. As the oxygen and fuel are consumed, the remaining reactants become more dilute and more time required for them to come into contact with one another. Even with good turbulence it is unlikely that the last remaining particles of fuel will react with the highly diluted oxygen remnants. The result is that a
certain amount of unreacted fuel oxygen will leave the combustion space (Kim et al., 2009).

To overcome this problem the quantity of air supplied is increased slightly above the theoretical air amount. During the last stage of combustion there will thus be significantly more oxygen in the combustion mixture so that the possibility of reaction with the last remaining particles of fuel is much enhanced. In this way virtually complete combustion can be ensured but some oxygen will pass though unreacted (Singer, 1991).

2.2.7 Effect of air ratio

The changes in the concentration of different species versus air ratio, with the short straight lines suggesting general trends rather than true linear relationships. The concentrations of CO₂ and H₂O would be expected to increase with increasing air ratio, while the concentrations of reducing species, such as CO, H₂ and CH₄, decrease. Therefore the improved carbon conversion at higher air ratios, the total fraction of combustible species decreases with increasing air ratio, since the increase in the inert nitrogen far exceeds the gains in wood-borne species (Li et al., 2004).

2.2.8 The impact of air fuel ratio to the temperature

According to the Catharina and Torsten, 2010, the increase of the gas flow obtained with the higher AF-ratio is stronger than effect on the gas composition in the studied gasifier load interval. The higher AF-ratio leads to the higher gasification temperature and thus better conversion.