DEVELOPMENT AND CHARACTERISATION OF CONTINUOUS FAST PYROLYSIS OF OIL PALM SHELL FOR BIO-OIL PRODUCTION

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ABSTRACT

Fast pyrolysis of biomass is the most promising technology of converting solid biomass to liquid bio-oil as a renewable substitution of fossil resources in fuel and chemical feedstocks applications. Malaysia with abundant biomass resources especially from palm oil milling industry provides an ideal platform for the development of this thermal conversion technology. This study was aimed of developing a 6.0 kg/h pilot scale continuous fast pyrolysis system with oil palm shell (OPS) as the main feedstock. A two-stage fluidised bed reactor was designed based on the fluidisation technology with silica sand as the heat carrier to achieve rapid heat transfer required for the reaction. The amount of silica sand required was determined with the experimental study on cold-flow hydrodynamics and heat transfer performances. This reactor can be rapidly heated up from room temperatures to experimental conditions up to 500 ^{o}C within 15 minutes. The experimental study of OPS fast pyrolysis showed that the reaction temperature was the most dominant parameter to influence the process sustainability and bio-oil yields. Smooth process and substantial bio-oil yields could be achieved for the experiments carried out with the reaction temperature within 370 ^{o}C to 490 ^{o}C. Lower reaction temperature will result in inadequate heat to crack the biomass component while the higher reaction temperature will promote secondary reaction to produce more non-condensable gas than bio-oil. The maximum bio-oils yield up to 43.3 wt% was recorded at the reaction temperature of 430 ^{o}C by using moderate particle sizes within 212-600 µm in dry basis. The bio-oil produced was dark brown mobile liquid with the physical properties similar to heavy oil. From the analysis of Gas Chromatography - Mass Spectrometry (GCMS), the OPS bio-oil comprising mainly phenolic compounds, carboxylic acids and aldehydes. The bio-oil can be used for the manufacturing of phenolic resin or further upgraded for liquid fuel production. The development of fast pyrolysis system for oil palm solid wastes exhibits great potential to bring positive impact to Malaysia palm oil industry as it can broaden the industry's products spectrum and generate revenue from these wastes.

ABSTRAK

Pirolisis pantas biojisim merupakan teknologi paling berpotensi untuk menukar biojisim pepejal kepada bahan minyak-bio sebagai penggantian bahan pembaharuan sumber fosil dalam penghasilan bahan api cecair dan bahan mentah kimia. Malaysia yang kaya dengan sumber biojisim terutamanya daripada industri pemprosesan kelapa sawit telah memberi satu peluang untuk pembangunan teknologi ini. Kajian ini menfokuskan pembangunan sebuah sistem pirolisis pantas berterusan skala pandu berkadar 6.0 kg/jam dengan menggunakan tempurung kelapa sawit (OPS) sebagai bahan mentah utama. Sebuah reaktor dua peringkat lapisan terbendalir telah direkabentuk berdasarkan teknologi terbendalir dengan mempergunakan pasir silika sebagai bahan pembawa haba untuk mewujudkan kesan pemindahan haba yang cekap. Kandungan pasir silika yang diperlukan dalam reaktor ini telah ditentukan melalui kajian ujikaji hidrodinamik dan kajian prestasi pemindahan haba. Reaktor ini boleh dipanaskan daripada suhu bilik ke suhu tindak balas setinggi 500 ^{o}C dengan pantas iaitu dalam 15 minit sahaja. Daripada kajian ujikaji pirolisis pantas yang telah dijalankan, suhu tindak balas telah dikenalpasti sebagai parameter yang utama mempengaruhi kestabilan proses dan kadar penghasilan minyak-bio. Proses yang lancar dan kadar penghasilan minyak-bio yang memuaskan boleh dicapai pada suhu tindak balas daripada 370 ^{o}C kepada 490 ^{o}C. Suhu tindak balas yang terlalu rendah akan mengakibatkan kekurangan haba yang diperlukan untuk meleraikan komponen-komponen biojisim, manakala suhu tindak balas yang terlalu tinggi akan mempercepatkan tindak balas sekunder dan mengakibatkan prnghasilan lebih banyak gas-tidak-terpeluwap daripada minyak-bio. Penghasilan minyak-bio paling tinggi sebanyak 43.3 wt% yang telah dicapai pada suhu tindak balas 430 ^{o}C dengan menggunakan tempurung kelapa sawit yang telah dikeringkan dan dikisarkan kepada partikel sederhana halus di antara 212 μm dan 600 μm. Minyak-bio yang dihasilkan berwarna coklat tua dan bersifat fizikal yang serupa dengan minyak berat petroleum. Daripada analisa GCMS, minyak-bio tempurung kelapa sawit merupakan cecair yang bernilai dimana ia mempunyai komposisi bahan kimia seperti fenol, asid karboxylic dan aldehydes. Minyak-bio ini boleh digunakan untuk penghasilan resin fenol atau bahan api cecair setelah diproses lanjut. Pembangunan pirolisis pantas menunjukkan potensi besar untuk membawa kesan positif ke atas industri kelapa sawit Malaysia dimana ia akan menambahkan produks kepada industri ini dan juga menghasilkan keuntungan daripada bahan buangan ini.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The challenge to overcome the depletion of fossil fuels especially the petroleum based fuels is the critical issue of this century. Petroleum fuels have been regarded as a key component in the crucial energy and natural resources sector which drives the economic progress. Almost the entire modern human activities rely heavily on this physical resource. In addition to transportation and power generation, mass quantities of petroleum and petroleum derived chemicals are required for manufacturing, food processing, medicine and all other industries, as raw materials and fuels. Nature may have been generous to human but the size of these physical mineral resources is finite. All the reservoirs that exist in this planet will be recovered sooner or later (Mabro, 2003). Although International Energy Agency (IEA, 2004) reported that the Earth's petroleum resources are more than adequate to meet demand until 2030 and well beyond, they also pointed out that there would be uncertainties about how much it will cost to extract them and deliver them to consumers. In another word, oil reserves are not actually running out, but it will become more difficult and expensive to recover without significant breakthrough in extraction technology or discovery of new oil fields.

In this context, the balance of oil supply and demand has been extremely tight, even without actual disruptions, possible threats to supply from war of Lebanon, rising tensions over Iran's nuclear program to the civil wars in Nigeria's Delta region – were enough to push the oil prices above US 78 per barrel. Although it was later reduced to US 50-US 55, the energy cost is still doubled the OPEC price band of US 20 -US 28 in early of this decade (Yergin, 2007, O'Neill 2007).

Economic growth is therefore vulnerable to the oil price especially for those heavy industrialised and net oil importing countries. Although Malaysia is currently a significant producer of oil and natural gas, the proven oil reserves of 3.0 billion barrels has significantly declined from a peak of 4.6 billion barrels in 1996. Database from Energy Information Administration (EIA, 2007) shows that with the reducing production and increasing domestic consumption as shown in Figure 1.1, Malaysia will be a net importing country by 2010 and the country oil reserve will eventually exhausted in 12 years time unless new exploration shows positive results.

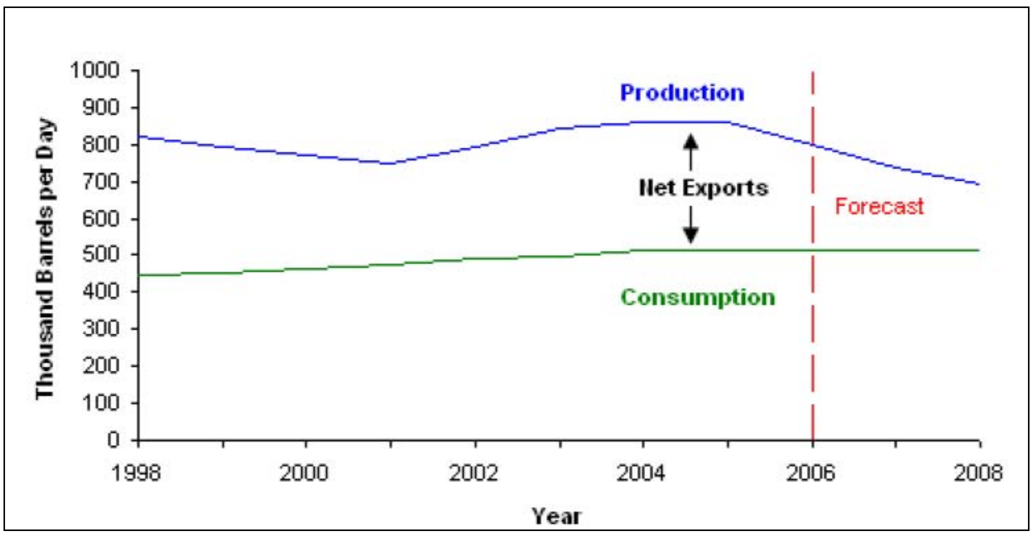

Figure 1.1: Malaysia's petroleum oil production and consumption, 1998-2008 (EIA, 2007)

In this scarcity of petroleum depletion and the rising demand for alternative resources, biomass is gaining higher attention as it is one of the most available renewable energy resources that can be use to reduce the dependency on fossil resources (Williams et. al., 2000). Agricultural waste is one form of the biomass which is generated continuously in enormous amount from the agriculture activities. Some of these agricultural wastes are utilised as fuel for energy recovery scheme to generate the heat and electricity required for the milling processes. However, the utilisation of biomass for energy conversion through combustion is still considered limited due to its poor fuel properties such as high moisture and ash contents, low bulk density, low energy content. These properties causing difficulties in storage, handling and transport which constraint the biomass application as commodity fuels. Exceed biomass generated not only created waste disposal problems but also considered as waste of primary resources.

The agro-industrial sector in Malaysia generates significant amount of biomass solid wastes. As the world main producer of palm oil, Malaysia has oil palm trees (elaeis guineansis) cultivated at more than 52% of its total plantation area. Therefore, among the biomass available, oil palm wastes including oil palm shell, oil palm fibre and empty fruit bunches are generated at largest capacity compared with other Malaysian biomass resources as shown in Table 1.1. Only some of the oil palm wastes are being applied as boiler fuels for steam and electricity production in palm oil milling industry and the utilisation of other biomass still remaining limited. Thus, it is huge challenge but also excellent opportunity on the development to utilise these abundant biomass resources.

Table 1.1: Availability of major biomass resources in Malaysia of 2005

Biomass	Annual availability (MT/yr)
Empty Fruit Bunches	17.37 [a]
Oil Palm Fibre	13.34 [a]
Oil Palm Shell	5.40 [b]
Rice Husk	3.68 [b]
Rubber wood residue	1.52 [b]

a. MPOB (2007)

b. Koh (2006)

Utilisation of biomass can be achieved through thermochemical conversion processes, including combustion, gasification and pyrolysis. Among these technologies, fast pyrolysis of biomass has emerged as the most promising technology to make use of the waste biomass resources to produce value added products. Fast pyrolysis is a process in which biomass is rapidly heated to moderately high temperature (usually 350 ^{o}C to 650 ^{o}C which higher than carbonization, lower than gasification and combustion) in the absence of oxidizing agent (Scott, 1982, Bridgwater et. al., 2000). In fast pyrolysis process, solid biomass is converted from solid to form char, gas and most importantly high yields of liquid products which is known as pyrolysis oil, or bio-oil. The bio-oil could be processed into liquid fuel for power generation or raw material for chemical feedstock such as phenol.

Besides bio-oil as the primary product, the fast pyrolysis process also generates pyrolysed char and gases as secondary products but with significant application values. The non-condensable gases produced from pyrolysis reaction are readily combustible and can be used to recover the heating content. Solid char is high carbon content material which contains of significant heating value and can be used to manufacture activated carbon and burned for energy.

1.2 Statement of the Research Problems

The research work on the fast pyrolysis and its applications in Universiti Teknologi Malaysia (UTM) was initiated since early 1990 (Ani, 2006). A laboratory scale fast pyrolysis system based on fluidised bed reactor was developed by Ramlan (1995) with input capacity of 0.6-1.0 kg/h. Various biomass including oil palm shell, scrap tyre, and rice husk had been used as raw materials in the lab scale pyrolysis reactor for the bio-oil production to study its characteristics. It is notable that this unit was the first and only laboratory unit available on fast pyrolysis for liquid production research in Asia region until year 1998 (Bridgwater et. al., 2000). Oil palm shell is considered as the most suitable raw material for its abundant availability and rich chemical content in the bio-oil produced. Wong et. al. (2002) has successfully converted the bio-oil to phenolic resin and produced adhesives, which is applicable to be applied on wood and composite products. Research on the application of phenolic compounds extracted from pyrolysis oil to be used as chemicals flooding material for enhanced oil recovery from depleted reservoirs at low pressure has been carried out by Goh et. al. (2006). Due to the need of more investigation on the application and utilisation of the pyrolysis bio-oil, a fast pyrolysis system with 10 times capacity of the laboratory scale system has been developed. However there are still a lot of experiments and modifications need to be done in order to produce maximum bio-oil production. This thesis extensively discusses the design and development of the new pilot scale system.

1.3 Research Objectives

The centre theme of this research is to investigate the influences of various parameters on the pyrolysis products yield and to determine the optimum operating conditions that produce maximum bio-oil from fast pyrolysis of oil palm shell.

1.4 Research Scopes

A fast pyrolysis system was commissioned ad extensive experimental works were carried out to accomplish the objectives. Figure 1.2 exhibits the flow diagram designed to achieve the objectives within the scopes of this research. The contents of the scope which have been completed within the study included,

- The design of a 6 kg/h pilot scale continuous fast pyrolysis system is based on the principles of bubbling fluidisation. The performance of a fluidised bed reactor could be influenced mainly by the reactor diameters, bed materials, and carrier gas flow rates. The reactor capacity, vapours residence times and system performance are mutually influenced by these parameters. Therefore, a cold model study and a heating performance study are carried out in the development process to ensure the reactor can be operated according to desired conditions before it is used in the actual fast pyrolysis experiment.

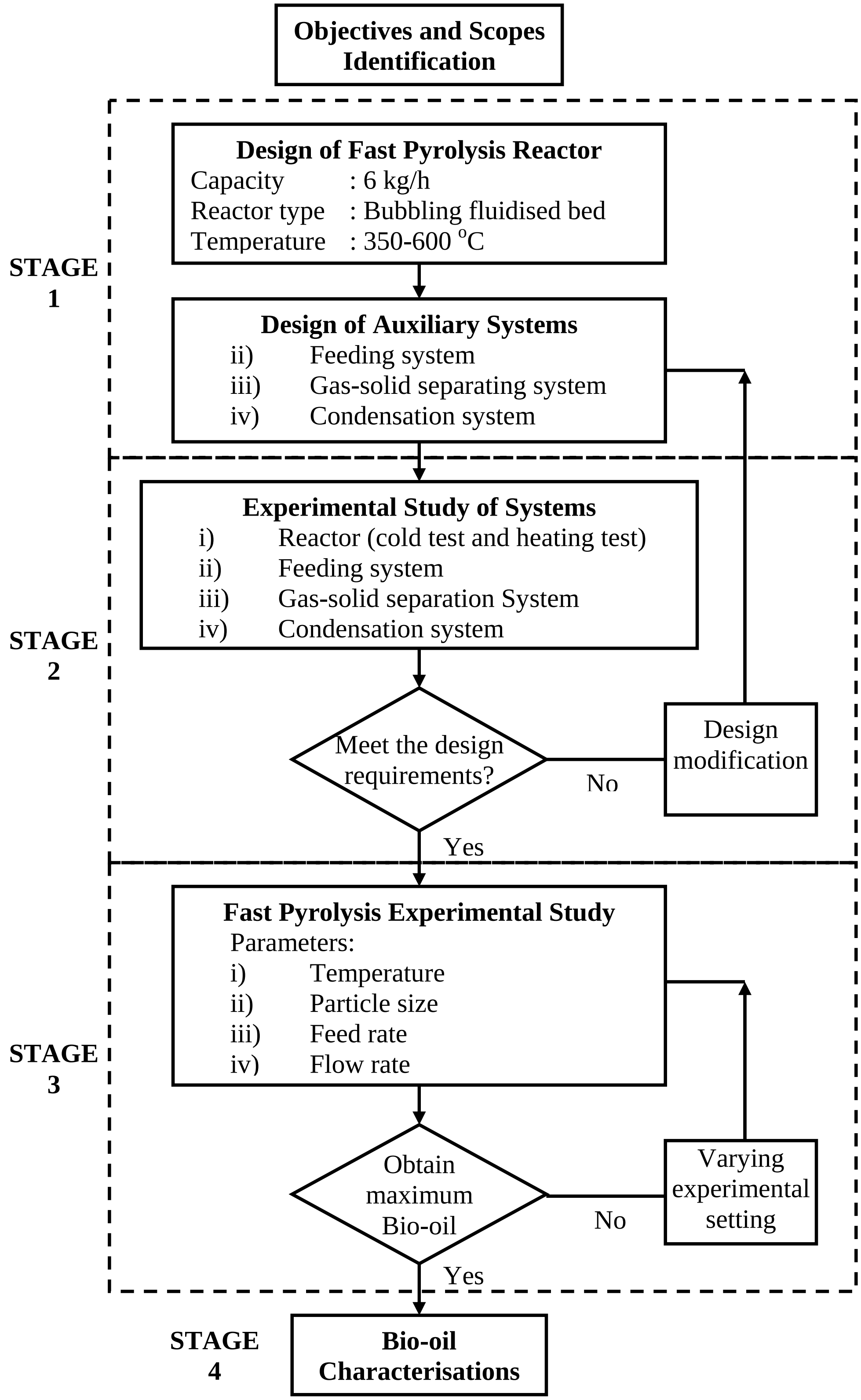

Figure 1.2: Flow diagram of research planning

- The system is designed primarily for oil palm solid wastes. However, only oil palm shell will be used as the feedstock for the experimental purpose in this study. Testing results of other oil palm solid wastes are not included in this thesis.

- Several auxiliary systems are essential to achieve continuous fast pyrolysis process, each of these systems are developed and tested independently. These auxiliary systems include a variable speed feeding system, a gas-solid separation system, and a two-stage condensation system.

- The continuous fast pyrolysis experiments are performed with various parameters, in order to determine the operating conditions which will generate highest yield of bio-oil. The major parameters investigated in this research include reactor temperatures, nitrogen gas flow rate, feedstock particle sizes, and feeding rates.

- Selected bio-oil samples produced under various experimental conditions are analysed in various laboratories in order to examine their physical and chemical properties.

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