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Recovery of diesel-like fuel from waste palm oil by pyrolysis using a microwave heated bed of activated carbon

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ABSTRACT

Microwave pyrolysis using a well-mixed bed of activated carbon as both the microwave absorber and reaction bed was investigated for its potential to recover useful products from waste palm cooking oil – a cooking oil widely used in Asia. The carbon bed provided rapid heating (~18 °C/min) and a localized reaction hot zone that thermally promoted extensive pyrolysis cracking of the waste oil at 450 °C, leading to increased production of a biofuel product in a process taking less than 25 min. It also created a reducing reaction environment that prevented the formation of undesirable oxidized compounds in the biofuel. The pyrolysis produced a biofuel product that is low in oxygen, free of sulphur, carboxylic acid and triglycerides, and which also contains light C_{10}-C_{15} hydrocarbons and a high calorific value nearly comparable to diesel fuel, thus showing great potential to be used as fuel. This pyrolysis approach offers an attractive alternative to transesterification that avoids the use of solvents and catalysts, and the need to remove free fatty acids and glycerol from the hydrocarbon product. The pyrolysis apparatus operated with an electrical power input of 1.12 kW was capable of producing a biofuel with an energy content equivalent to about 3 kW, showing a positive energy ratio of 2.7 and ≥73% recovery of the energy input to the system. The results show that the pyrolysis approach has huge potential as a technically and energetically viable means for the recovery of biofuels from the waste oil.

1. Introduction

Cooking oil can be derived from various biological resources such as seeds from plants (e.g. sunflower oil, sesame oil), nuts (e.g. soybean oil, peanut oil), and fruits (e.g. palm oil, olive oil). Once the cooking oil is used, it becomes an undesirable waste that needs to be properly disposed of. The production of waste cooking oil has been increasing each year throughout the world. For example, United States generated approximately 10 million tons of waste cooking oil each year [1], whereas China generated approximately 5 million tons/year of waste cooking oil [2]. Due to the large amount of waste cooking oil generated annually, the disposal of waste cooking oil has become a challenge and concern to the modern society.

Recently, pyrolysis techniques have been reported to show increased efficiency in transforming biomass and waste materials into potential fuel products [3–8]. Pyrolysis is a thermal degradation process that can be used to treat waste materials in an oxygen-free atmosphere to produce liquid oil, gases and char. It has been reported that the liquid oil and gases can be utilized as a chemical feedstock or they can be upgraded to obtain light hydrocarbons for use as a fuel, and the char produced can also be

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used as a substitute for activated carbon [9]. There has been further development in the conversion of triglyceride-based vegetable oil into biofuel by pyrolysis techniques [10]. Waste cooking oil, containing significant amounts of triglycerides, represents a potential feedstock to be converted into a biofuel. The waste oil is readily available in large quantity, do not contend with other food crops, and presents a cost effective resource for biofuel production by pyrolysis techniques.

Microwave pyrolysis has recently shown advantages over conventional pyrolysis techniques that use traditional thermal heat sources in transforming waste materials into potential fuel products [7,11–15]. The microwave technique involves the use of carbonaceous materials as a microwave absorber, which is heated by microwave radiation to reach the target temperature in order for extensive pyrolysis to occur. The use of microwave heating shows excellent heat transfer compared to conventional heating since microwave energy can penetrate the material being heated and in turn generates heat throughout the volume of the material, and thus providing a rapid and energy-efficient heating process which also facilitates increased production rates. This type of pyrolysis process may result in a different heating mechanism which can promote certain chemical reactions leading to an improved yield of desirable products.

Most pyrolysis studies on biomass conversion have focused on processes heated by a conventional heating source (e.g. furnace, oven). There have been limited reports on the application of pyrolysis to the treatment and recycling of waste cooking oil, except for a study performed by Omar and Robinson [12] on conventional and microwave-assisted pyrolysis of rapeseed oil in which the authors had focused on the effects of temperature and microwave power. These microwave pyrolysis experiments were performed in the absence of specifically added microwave absorber, and it was shown that low amounts microwave energy were absorbed by the waste oil and this resulted in low yields of pyrolysis products. This indicates that waste cooking oil requires heating by contact with materials of high microwave absorbency to achieve higher temperatures in order for extensive pyrolysis to occur.

Carbonaceous materials such as particulate carbon have been used as microwave absorber to heat materials that are poor microwave-absorbers to achieve high temperatures by microwave radiation [9]. They are known to have high microwave absorbency, heat tolerance, and low in cost, and thus they are widely used for such heating applications [16]. The use of carbonaceous materials as a reaction bed has been shown to be an effective method of recovering and recycling chemicals present in troublesome wastes such as waste engine oil [9,14,17] and plastic waste [18].

In this study, an alternative pyrolysis approach was proposed for the recovery of diesel fuel from waste palm cooking oil (WPCO) by pyrolysis using a microwave heated bed of activated carbon (AC) - a carbonaceous material with a high surface area. The AC bed can act as both the microwave absorber and the energy transferring agent necessary for heating WPCO, and the AC can also act as a catalyst to pyrolyze the WPCO to yield products that can constitute diesel fuel. Thus, such a pyrolysis approach has the potential to maximize the production of potentially useful pyrolysis products for use as a fuel or chemical feedstock. This paper reports an investigation on the pyrolysis of WPCO over a range of process temperature (200–550 °C). The yield and characteristics of pyrolysis products were examined with an emphasis on the composition of the liquid fraction generated from the pyrolysis process; this fraction is of particular interest due to its high energy content and potential to be upgraded as a substitute for diesel fuel or other bio-based hydrocarbon products [19].

2. Materials and methods

2.1. Preparation of WPCO and AC

WPCO was collected from a fried chicken restaurant in Kuala Terengganu, Malaysia. The WPCO was filtered by Whatman No. 4 filter paper to remove unwanted suspended food particles. The filtered oil was collected and stored in glass bottles wrapped with aluminium foil. The glass bottles were filled up completely to prevent oxidation of the oil during storage. The WPCO was analyzed for its characteristics and these are presented in Table 1.

AC with a particle size ranging from 0.5 to 2.0 mm was obtained and used as a bed of microwave absorber to heat and pyrolyze the WPCO. The AC was detected to have a porous structure and a high surface area of 850 m^2/g. It was pre-heated to 800 °C for 2 h to remove any water and sulphur-containing compounds.

2.2. Microwave pyrolysis experiments on WPCO

Microwave pyrolysis of WPCO was conducted in a stirred batch reactor heated by a modified 800 W microwave oven operating at a frequency of 2.45 GHz (Fig. 1). Approximately 100 g of WPCO was placed in a pyrolysis reactor (150 × 100 × 100 mm). 150 g of AC was added to the reactor for use as a bed of the microwave absorber to absorb and convert microwave energy to heat for pyrolyzing the WPCO; the ratio of WPCO to AC is 1:1.5. The AC was stirred to ensure a uniform temperature distribution throughout the reactor. The microwave oven was then switched on to heat the bed of AC and WPCO from room temperature to the target process temperature ranging from 200 °C to 550 °C at which the WPCO was pyrolyzed at the appropriate process temperatures. The process temperature was selected for study as it is the most important parameter that dictates the thermal cracking of the WPCO. A stainless steel type K thermocouple connected to an Autonics dual indicator temperature controller was used to measure the temperature of the reaction zone within the reactor. When the microwave oven had been heated to the target temperature, the temperature controller also functioned to maintain the oven at the target temperature. The reactor was purged with nitrogen gas at a flow rate of 0.2 L/min to maintain an inert atmosphere in the reactor. The reactor was covered with ceramic fiber blanket to minimize the heat loss occurred during the heating and pyrolysis process.

Pyrolysis products in gaseous form (termed 'pyrolysis volatiles') were generated during the pyrolysis process and these gases then left the reactor and passed through a condensation system consisting of Vigreux and Liebig condensers in addition to an ice bath. The gases were either collected as non-condensable pyrolysis gases

Table 1
Characteristics of WPCO.

Elemental composition (wt%)	
C	71.2
H	13.3
N	0.8
S	0
O[a]	14.7
Calorific value (CV) (MJ/kg)	39.2
Fatty acid composition (wt%)	
Palmitic acid ($C_{16}H_{32}O_2$)	25
Stearic acid ($C_{18}H_{36}O_2$)	8
Oleic acid ($C_{18}H_{34}O_2$)	29
Linoleic acid ($C_{18}H_{32}O_2$)	12

[a] Oxygen calculated by mass difference.