Bioresource Technology 149 (2013) 1–7

Contents lists available at ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

Pyrolysis decomposition of tamarind seed for alternative fuel

M.A. Kader [a,]*, M.R. Islam [a], M. Parveen [b], H. Haniu [b], K. Takai [b]

[a] Department of Mechanical Engineering, Rajshahi University of Engineering & Technology, Rajshahi 6204, Bangladesh
[b] Department of Mechanical Engineering, National University Corporation Kitami Institute of Technology, 165 Koen-cho, Kitami City, Hokkaido 090-8507, Japan

HIGHLIGHTS

- This paper highlights the conversion of tamarind seed into bio-oil by pyrolysis.
- Crushed seed was pyrolized in an internally heated fixed bed fire tube reactor.
- The maximum liquid yield was 45 wt% at 400 °C for a feed size of 3200 μm.
- Suitability of the liquid product obtained from tamarind seed as an alternative fuel.

ARTICLE INFO

Article history:
Received 16 June 2013
Received in revised form 5 September 2013
Accepted 6 September 2013
Available online 17 September 2013

Keywords:
Pyrolysis
Fixed bed
Tamarind seed
Renewable energy
Bio-fuel

ABSTRACT

The conversion of tamarind seed into bio-oil by pyrolysis has been taken into consideration in the present work. The major components of the system were fixed bed fire-tube heating reactor, liquid condenser and collector. The crushed tamarind seed in particle form was pyrolyzed in an electrically heated fixed bed reactor. The products were liquid, char and gasses. The parameters varied were reactor temperature, running time, gas flow rate and feed particle size. The maximum liquid yield was 45 wt% at 400 °C for a feed size of 3200 μm diameter at a gas flow rate of 6 l/min with a running time of 30 min. The obtained pyrolysis liquid at these optimum process conditions were analyzed for physical and chemical properties to be used as an alternative fuel. The results show the potential of tamarind seed as an important source of alternative fuel and chemicals as well.

1. Introduction

The demand of energy in the world is increasing at an alarming rate unlike its sources. The existing conventional sources of energy are inadequate to meet the increasing needs. In addition, the use of these conventional sources for energy causes various kinds of catastrophes such as global warming, acid rain, etc. Because of rising energy crisis and environmental degradation, bio-fuel is considered as one of the sources for substitution of conventional fuel. Pyrolysis is one of the most convenient and economical biomass to energy conversion processes which offers the advantages of a liquid product (bio-oil) that, it can be readily stored and transported. Pyrolysis produces vapor that can be collected as liquid fuel, combustible gasses that can be supplied for process heat partially and solid char. The bio-oil derived from pyrolysis can be used as boiler fuel, in diesel engine for power generation and as a source of some pure chemicals such as alcohol, phenol, aldehyde, organic acids, etc. (Oasmaa and Meier, 2002).

The tropical/subtropical based climate of India, Bangladesh, Africa, Australia, Florida, Malayasia, Oceania and Philippines is suitable for growing tamarind plants. A tamarind seed is 40–44 wt% of the whole tamarind fruit. Annual production of tamarind in India and Thailand is about 300,000 tons and 150,000 tons, respectively (El-Siddig et al., 2006). In Bangladesh the annual tamarind production is almost 12,000 tons (Parveen et al., 2011). Tamarind fruit pulp is used in curries, sauces, and juices. The seed is the by-products of tamarind pulp industry. Some countries use the seed to manufacture tamarind kernel powder while in India and Bangladesh it is accumulating as solid waste. So tamarind seed transformation into high energy-density renewable fuels, like charcoal and bio-oils, can significantly increase profitability of tamarind plantation. Thus, energy recovery from tamarind seed by pyrolysis technology may be worthwhile. Authors previous study (Parveen et al., 2011) for kinetics behavior of tamarind seed for production of bio-fuels by pyrolysis technology also proved the potentiality for the proposed conversion. Process conditions for pyrolysis-based recovery of fuels and chemicals from different oil seeds: castor seed (Singh and Shadangi, 2011); pomegranate seed (Suat and Selhan, 2009); polanga seed cake (Shadangi and Singh, 2012); cherry seed (Duman et al., 2011); karanja seed (Nayan

---

* Corresponding author. Tel.: +880 1722547052.
E-mail address: kader_042017@yahoo.com (M.A. Kader).

0960-8524/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.biortech.2013.09.032

et al., 2012); neem seed (Nayan et al., 2013); amazon tucuma seed (Lira et al., 2013) have already been studied with simple fixed bed batch mode reactor but neither tamarind seed nor fixed bed fire tube heating reactor system.

Therefore, the objective of this study was to develop a new heating system for pyrolysis for recovery of liquid hydrocarbons from tamarind seeds. The abundantly available tamarind seed was pyrolyzed in the internally heated fire-tube heating reactor system under N_2 atmosphere. The effects of operating temperature, feed size, running time and gas flow rate on the product yields were investigated. The whole pyrolysis liquids obtained at optimum operating conditions were characterized by physical and elemental analyses, GCV, FT-IR, and distillation.

2. Methods

2.1. Feed materials

The ripe tamarind fruits were collected locally in Rajshahi, Bangladesh and seeds were separated. The size of raw seeds were almost 14,000 μm. The seeds were crushed and sieved to the sizes 800 μm, 1800 μm, 3200 μm, 4100 μm and oven dried to remove moisture for 12 h at 110 °C prior to pyrolysis. The gross calorific value of the solid crushed seed is 21 MJ/kg. The raw material was characterized according to their proximate, ultimate and nutritional composition analysis. Proximate analysis identified the percentages of moisture (8–10 wt%), volatile (62–64 wt%), fixed carbon (20–21 wt%) and ash (4–5 wt%) content in the sample and the ultimate analysis carried out in CHNSO elemental analyzer to provide the elemental composition. The ultimate analysis shows that the crushed tamarind seed contains highest weight percentage of carbon (45.76 wt%) followed by oxygen (44.39 wt%) and hydrogen (9.59 wt%) with a fewer amount of sulfur (0.04 wt%) and nitrogen (0.22 wt%). These analyses are the most effective way of assessing the fuel type and quality. The pyrolytic conversion efficiency and heating value of derived liquid are greatly influenced by moisture content of biomass. Biomass, containing high moisture, has a tendency to decompose resulting in energy loss during storage. The percentage of volatile contents is very important parameters to select a biomass for pyrolysis conversion. Volatile matter evolves in the form of combustible gas and light hydrocarbon that can be condensed into liquid. Containing higher percentage of volatile in a feed material makes it more readily devolatized than solid fuel. On the other hand, liberating less amount of fixed carbon makes them more useful for pyrolysis. Likewise, less ash and moisture content are also favorable for pyrolysis reaction to produce liquid oil. The above analysis results show that the selected raw material is suitable for pyrolysis conversion to produce liquid oil. The nutritional composition analysis shows that tamarind seed contains mostly carbohydrates (56.4 wt%). It also contains protein (23 wt%), lipid (8.6 wt%), fiber (7.4 wt%) and ash (4.6 wt%).

2.2. Thermogravimetric and differential thermogravimetric analyses of feed materials

The thermogravimetric (TG) and differential thermogravimetric (DTG) analyses were done using a Pyris Diamond Thermogravimetric/Differential Thermal Analyzer. The samples (15–20 mg) were heated over the temperature range of 30–800 °C at constant heating rates of 10 and 60 °C/min in a high purity nitrogen atmosphere with a flow rate of 100 ml/min.

2.3. Experimental section

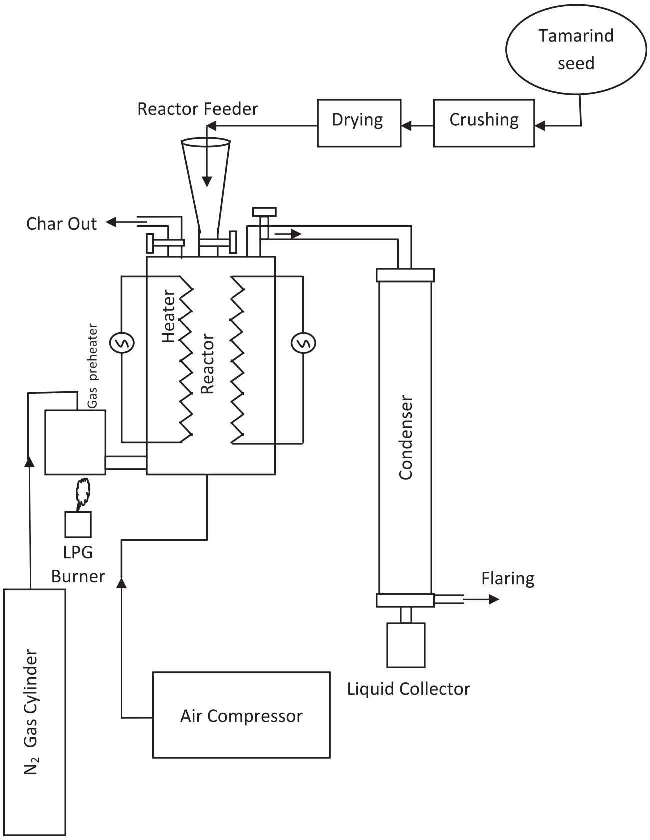

Fig. 1. Schematic diagram of the fixed-bed fire-tube heating pyrolysis system.

The schematic diagram of the experimental set-up has been presented in Fig. 1. The experimental unit consists of seven main components: (1) a fixed-bed fire-tube heating reactor chamber with a power system; (2) a reactor feeder; (3) an ice-cooled condenser; (4) a liquid collecting glass bottle; (5) a N_2 gas cylinder; (6) a N_2 gas pre-heater with Liquefied Petroleum Gas (LPG) burner and (7) an air compressor, a distributor plate was fitted to support the feedstock. The distributor plate was made of stainless-steel plate having 150 holes of 3 mm diameter. The N_2 gas inlet was 20 mm bellow the distributor plate. Eight equally spaced stainless steel of 10 mm diameter fire-tubes containing insulated electric coil of a total capacity 1.60 kW were fixed inside the reactor. The fire-tubes and pre-heated N_2 gas provided uniform heating across the cross-section of the reactor chamber. The reactor was thermally isolated with asbestos cylinder. The reactor height from the distributor to the gas exit was 270 mm and its diameter was 100 mm, which provided an apparent vapor residence time of 5 s. The sweeping gas flow rate or apparent vapor residence time for the fire-tube heating reactor system was calculated by the following equations:

$$V_{fsp} = \left[\frac{\pi d^2 l}{4} - \frac{n\pi d_1^2 l_1}{4}\right] \times \left(1 - \frac{V_m}{100}\right) + \frac{\pi d_2^2 l_2}{4} = 661\ \text{cm}^3 = 0.661\ \text{L}$$

and the sweeping gas flow rates, $v_f = v_{fsp}/t$ were 14, 10, 6 and 2 l/min for residence time, t = 3, 4, 7, and 20 s, respectively. Where for the present reactor system: internal diameter of the reactor, d = 10 cm; effective length of the reactor, l = 27 cm; length of each fire-tube, l_1 = 27 cm; diameter of fire-tube, d_1 = 1 cm; number of fire-tubes, n = 8; reactor volume occupied by feed materials, v_m = 70%; diameter of vapor outlet pipe, d_2 = 2.54 cm; and length of vapor outlet pipe (from reactor to condenser), l_2 = 15 cm. The vapor residence time (3, 4, 7 and 20 s) was calculated at room temperature. According to the gas law (Boil and Churl's combined law) the flow rate in the reactor varies with pyrolysis temperature.