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Effect of torrefaction on yield and quality of pyrolytic products of arecanut husk: An agro-processing wastes

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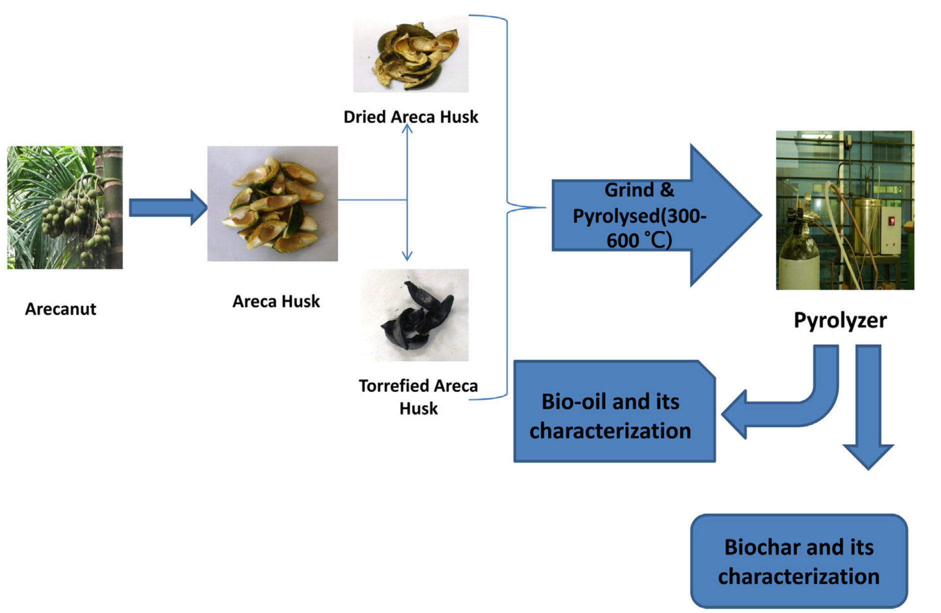
HIGHLIGHTS

- Torrefaction of arecanut husk was investigated at four different temperatures.
- Pyrolysis of both raw and torrefied areca husk was carried out from 300 to 600 °C.
- Physicochemical characterization of liquid and solid products were carried out.
- Raw and torrefied biochar were used as adsorbent to remove heavy metal from aqueous solutions.

GRAPHICAL ABSTRACT



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ABSTRACT

In the present study, arecanut husk, an agro-processing waste of areca plam industry highly prevalent in the north-eastern region of India, was investigated for its suitability as a prospective bioenergy feedstock for thermo-chemical conversion. Pretreatment of areca husk using torrefaction was performed in a fixed bed reactor with varying reaction temperature (200, 225, 250 and 275 °C). The torrefied areca husk was subsequently pyrolyzed from temperature range of 300–600 °C with heating rate of 40 °C/min to obtain biooil and biochar. The torrefied areca husk, pyrolysis products were characterized by using different techniques. The energy and mass yield of torrefied biomass were found to be decreased with an increase in the torrefaction temperature. Further, biochar were found to be effective in removal of As (V) from aqueous solutions but efficiency of removal was better in case of torrefied biochar. Chemical composition of bio-oil is also influenced by torrefaction process.

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1. Introduction

Due to decline in petroleum resources and economic, environmental, and political concerns regarding petroleum based economy, it becomes very important to develop new process for the renewable fuels and chemicals (Anqing et al., 2012). According to the World Energy Outlook (2006) renewable energy sources are expected to be the fastest growing energy sources. Among the various resources of renewable energy, biomass is widely available and is considered to be carbon neutral. Biomass can be converted into fuels and chemicals through thermo-chemical and biochemical processes. Among the various thermo-chemical conversion processes, pyrolysis has gained special attention as it can convert biomass directly into solid (biochar), liquid (aquous phase + biooil) and gaseous products. Further, the pyrolysis has the ability to utilize almost all types of biomass and recover both energy and chemical value of the feedstock (Bordoloi et al., 2015).

Raw biomass is generally characterized by its high moisture content, volatility, lower heating value and energy density compared to fossil fuels (Shoujie et al., 2014). Other disadvantages associated with raw biomass are smoke emission during combustion, its hygroscopic nature, uneven/heterogeneous composition and difficulties in its transportation (Poudel et al., 2015). In order to reduce these drawbacks, biomass needs to be pretreated to improve its quality for efficient energy conversion. Among various pretreatment methods, torrefaction is considered to be very attractive due to its advantages, such as higher energy density as well as grindability of the biomass. Torrefaction is a thermal treatment that is operated at a temperature range from 200 to 300 °C under an inert atmosphere. It causes decomposition of hemicelluloses, whereas it dehydrates cellulose and lignin resulting in modification in the structure and composition of biomass (Shoujie et al., 2014). Apart from this, it also reduces oxygen-to-carbon (O/C) ratio, which in turn increases the HHV; strong biomass fibers becomes brittle, which improves grindability which enhances the efficiency during pyrolysis (Poudel et al., 2015).

The success of any biofuel programme primarily depends on a number of factors, such as feedstock availability, production costs and utilization of organic wastes and residues (Bordoloi et al., 2015). Production of biofuels from lignocellulosic biowaste by thermo-chemical conversion helps to achieve the twin objectives of waste management and energy and chemicals recovery. In this regard, the husk of arecanut left over before it is being processed is a lignocellulosic biowastes and can be a feedstock for energy recovery. Arecanut (*Areca catechu L.*) is a tropical plant found all over South East Asia mainly in India, Bangladesh, China, Indonesia and Myanmar. Production of arecanut in the world was about 10.33 lakh tones from an area of 8.29 lakh hectares in 2009–10. India ranks first in terms of both area (47%) and production (47%) of arecanut. Even though India stands first in global production of arecanut, it is ranked 4th in terms of productivity, after China, Myanmar and Thailand and followed by Malaysia, Bangladesh and Indonesia (http://www.krishisewa.com/articles/production-technology/61-arecanut.html). In the year 2014–2015, India (Karnataka, Kerala, Assam, Maharashtra, West Bengal and some parts of Tripura) contributed to the production of 125,925 MT of arecanut with productivity 1302 kg ha^{-1}. (http://www.kerenvis.nic.in/database/agriculture_828.aspx). The arecanut husk is fibrous and constitutes 50–75% of the total volume and weight of the fruit. The quantity of arecanut husk obtained from an arecanut garden is approximately 5.5–6 metric tons per hectares per year. The dumped husk often creates landfill and serious nuisance to the surroundings (Das and Singh, 2015). Therefore, current investigation draws the attention regarding the potential utilization of these husks through thermo-chemical conversion. Moreover, the biochar obtained as co-product during pyrolysis is now gaining much attention for its function as a biosorbent for environmental remediation. Biochar, as a low-cost adsorbent for heavy metal removal from aqueous solution is promising and an emerging waste water treatment technology. Among the heavy metals arsenic (As) is a rather important environmental pollutant with severe carcinogenic impacts on human beings (Choong et al., 2007). The Environmental Protection Agency (EPA), as well as the European Commission guidelines set up a limit of 10 mg/L for As concentration in drinking water (Agrafiotia et al., 2014).

Several studies have been reported focusing the benefit of using torrefaction as pretreatment method and application of biochar for pollutants removal from aqueous solution. Arias et al. (2008) reported the torrefaction of woody biomass (eucalyptus) was carried out at the temperature range of 240–280 °C and found that the grindability of the torrefied biomass was improved than raw biomass. Kinetic parameters were found to be influenced by torrefaction process. Zheng et al. (2013) reported the torrefaction of corncobs in an auger reactor at 250–300 °C at residence times of 10–60 min. The torrefied corncobs were fast pyrolyzed in a bubbling fluidized bed reactor at 470 °C to obtain high-quality bio-oil. The heating value and pH of the bio-oil improved due to pretreatment of biomass through torrefaction. Poudel et al. (2015) studied the effect of torrefaction on food waste and found that both temperature and time influence the thermal and physical properties of the torrefied products. The use of biochar, as a cost effective sorbent for heavy metal removal from contaminated water and soils has already been reported by many researchers. The majority of studies are focused on the immobilization of metal cations, such as Pb, Cu, Ni and Cd (Inyang et al., 2012; Jiang et al., 2012; Liu and Zhang, 2009; Park et al., 2011; Regmi et al., 2012; Uchimiya et al., 2010), while limited research has been conducted on As(V) and Cr (VI) removal by biochar. Mohan et al. (2007) studied As (III) removal from water by woody biomass-derived biochars, showing that oak bark char has a significant potential for As(III) adsorption.

In this study, the torrefaction of arecanut husk at four different temperature and their fuel properties has been discussed. The pyrolysis was carried out for the raw and torrefied arecanut husks to investigate the influence of torrefaction on the yield and composition of biooil and biochar. This study also investigate the feasibility of using biochars from both raw and torrefied areca husk for the removal of heavy metal ions from contaminated water.

2. Material and methods

2.1. Raw material and its characterization

Arecanut husk collected from Napaam village of Tezpur, Assam, was subjected to sundry before any further processing. The sun dried sample was then further processed in two ways, one by mechanical size reduction of husk and the other way was torrefaction. Both raw arecanut husk (RAH) and torrefied arecanut husk (TAH) samples were ground with a Wiley mill. The ground samples were allowed to pass through 0.2 mm (70mesh). Samples were then oven dried and kept in desiccators for further analysis and pyrolysis experiments. Proximate analysis of RAH and TAH samples were carried out using ASTM D3172-07a method. Ultimate analysis of the samples was carried out using a CHNS elemental analyzer (Euro EA elemental analyzer). Calorific value of the samples was determined by using a bomb calorimeter (5E-1AC/ML, Auto bomb calorimeter) according to ASTM D2015.

2.2. Preparation of TAH

Arecanut husks were torrefied using a fixed bed reactor to investigate the effects of torrefaction on its physico-chemical prop-