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Pyrolysis of water hyacinth in a fixed bed reactor: Parametric effects on product distribution, characterization and syngas evolutionary behavior

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ABSTRACT

In this investigation, the effect of operating parameters on product distribution for the conversion of water hyacinth into most valuable product bio oil as well as char and gases are investigated. To observe the parametric effect on product distribution, the temperature was varied 300–600 °C, heating rate 10–50 °C/min, particle size of the feed <0.5–2.5 mm and carrier gas nitrogen flow rate 0–12 lpm. The highest bio-oil yield of 44.9 wt% was obtained at 350 °C, 30 °C/min, particle feed size less than 0.5 mm and 6 lpm. The results show that the product yield is strongly influenced by the temperature variation whereas weakly affected by the heating rate. The biomass and the products were characterized by ultimate, proximate, DTG, FTIR, ^{1}H NMR, and GC–MS. Syngas evolution increase with the increase of temperature except CO_2. The quality of bio-oil is perspective as a source of value-added chemicals and char is a promising source for the production of carbonaceous materials as well as solid fuel.

1. Introduction

The continuous increasing of energy demand results rapid depletion of fossil fuel. Thus scientist are always trying to find out a new alternative source and technique that can mitigate energy crisis. Biofuels are currently considered one of the most potential alternative sources to replace fossil fuels as their utilization in motive energy production reducing the greenhouse gas emission, and harmful particulate matters (Kumar et al., 2017). Pyrolysis is considered one of the most convenient and reliable thermal conversion process to convert biomass into bioenergy due to its simple operation and low operating cost.

The first and second generation biofuel production via pyrolysis was mainly employed from consumable products such as maize, sugarcane, sorghums, soybean, bean, palm etc. which has a competition between food security and fuel. Thus third generation biofuel researcher attention to finding out the new renewable non consumable sources. Recently, pyrolysis of sunflower seed hull (Casoni et al., 2015), tamarind seed (Kader et al., 2013), rice husk and rice straw (Fu et al., 2011), jute dust (Choudhury et al., 2014), potato peel wastes (Liang et al., 2015), algae (Casoni et al., 2016; Ly et al., 2016, 2015), water hyacinth (Biswas et al., 2017) etc. attract the attention of researchers for the production of biofuels. Among this feedstocks, water hyacinth is potential for this location (Bangladesh).

The scientific name of water hyacinth is *Eichhornia crassipes* and in Bangladesh, it is known as *Kochuripana*. It is a free-floating extremely high rate of growth perennial hydrophyte plant generally grown in pond, cannel, river and lake. It is listed as a serious pest in Bangladesh because it's invasive draining oxygen and sunlight from the water bodies which results in death of many fishes. Thus, the water hyacinth is called "Terror of Bengal". In Bangladesh, water hyacinth is utilized as an animal feed, it's festering as a fertilizer and hardly as raw materials for biogas production. Thus this harmful pest is most potential for thermochemical conversion for the production of valuable products (bio-oil, char and gas). Bio-oil from water hyacinth is the main product of the pyrolysis of biomass, which is potential as a substitute for fossil fuels as it contains moderate higher heating value (HHV), thus it can be easily converted to high valuable products (Promdee et al., 2012). Furthermore, the pyrolysis of biomass also produces gas and char as byproducts. Bio-char from water hyacinth contains high carbon black which is potential for solid fuel and dispose char to soil could improve water retention capability (Kumar et al., 2013; Soenjaya et al., 2015). The char can be used as a fertilizer due to its N, P and K content (Morali and Şensöz, 2015). The gaseous products produced via pyrolysis mainly consist of CO_2, CO, H_2, CH_4 and other light hydrocarbons which can be used as a substitute for a natural gas generation (Morali and Şensöz, 2015).

Extensive literatures were found for pyrolysis of various biomass sources in a fixed bed reactor system but literatures exist on water hyacinth as a novel feedstocks are very limited which

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are primarily focused on thermal, physiochemical analysis or characterization (Hussain et al., 2017; Promdee et al., 2012; Soenjaya et al., 2015). Hu et al. (2015) optimized pyrolysis process conditions of water hyacinth for the production of syngas. Authors reported that the particle size less than 200 μm and temperature 900 °C was optimum conditions for producing syngas. Biswas et al. (2017) obtained a maximum bio-oil yield of 24.6 wt% at 400 °C through pyrolysis of water hyacinth in a fixed bed reactor. Gulab et al. (2018) pyrolysed water hyacinth in a fixed bed batch pyrolysis system in a temperature range of 150–450 °C and the reaction time was in the range of 60–100 min with a fixed quantity (5 wt%) of catalyst. Authors reported a maximum of 31.6% bio-oil was produced using Cu catalyst at the optimized conditions (450 °C, 60 min and 1 °C s^{-1} heating rate). The factors affects the operating conditions in a fixed bed still inconsistent. Since the fixed bed is most convenient pyrolysis system thus the goal of this investigation is to investigate parametric effect (temperature, heating rate, carrier gas flow rate, and particle size of the feed) on product yields of this novel feedstock in this system. Furthermore, the products were characterized to evaluate the potential of the products to be valorized as fuel or chemical feedstocks.

2. Materials and method

2.1. Preparation of biomass sample

The water hyacinth used as a biomass sample in this experiment were collected from the local canal at Dhaka, Bangladesh. The collected sample was washed for separating impurities and desiccating by the sun for removing the surface moisture for 8 h. After sizing the sample (by Philips HR2115) into different ranges (less than 0.5 mm, 0.5–1 mm, 1–1.5 mm, 1.5–2 mm and 2.0–2.5 mm), the sample was further dried to remove moisture for 12 h at 110 °C in an oven. The prepared feedstock was stored in an air-tight container.

2.2. Pyrolysis setup and experimental procedure

The schematic arrangement of the experimental setup is depicted in Fig. 1. The reactor (27 cm × 10 cm ID) was thermally isolated with asbestos and connected to nitrogen gas cylinder. The reactor was heated internally by eight equally spaced 10 mm diameter stainless steel fire tubes. The tubes containing an insulated electric coils and a total capacity of this coils was 1.6 kW. A Ni–Cr–Ni thermocouple with PID controller was fitted inside the reactor to control the temperature and heating rate. The sweeping gas flow rate was controlled by varying the flow valve. At first, nitrogen gas at 2 lpm (liter per minute) passed through the reactor for 5 min to create an oxygen-free atmosphere. The water hyacinth biomass (500 g) was fed into the reactor each time through the feed control valve for a different run. The pyrolysis temperature range for water hyacinth was determined based on the derivative thermogravimetric (DTG) analysis. The temperature inside the reactor was varied between 300 and 600 °C to with 50-degree increment. The vapor produced in the reactor pass through the two condensation trap contains 100 mL of isopropanol solvent each for highest tar capture. Isopropanol solvent was selected inspite of little loss of light hydrocarbon during evaporation so that the available alternative solvents found in local market are toxic whereas isopropanol evaporates quickly and relatively non-toxic. The temperature of condensation trap was upheld between −15 °C to −10 °C. The incondensable gasses passed through a wet scrubber and then vented to the exhaust while a smaller portion of the gases was stored in the gas sampling bottles for analysis. Duration of the experiment was held at the selected temperature or any points of reading for 15–20 min. A similar procedure was followed to observe the effect of heating rate, particles size, and sweeping gas flow rate by varying each parameter. After cool down the reactor naturally, the char pushed out from the reactor by compressed air for analysis. The gas samples inside the bottles were analyzed by GC–MS. The gas analyzer was calibrated against standard gas mixtures, and the combined accuracy of the gas analysis was ±0.1%. The liquid products were poured into a beaker and heated to 83 °C for the evaporation of isopropanol. Water content was determined via Karl Fischer titration method. Hydrophilic hydrogels were employed to remove the water content from biodiesel sample. The whole procedure was repeated for three times and the average value of each measured parameter was presented as the result. The percentage yield of bio-oil, char, and syngas was determined by the following Eqs. (1), (2), and (3) respectively.

$$\text{Pyro oil yield (wt\%)} = \frac{m_{oil}}{m_{biomass}} \times 100\% \quad (1)$$

$$\text{Char yield (wt\%)} = \frac{m_{char}}{m_{biomass}} \times 100\% \quad (2)$$

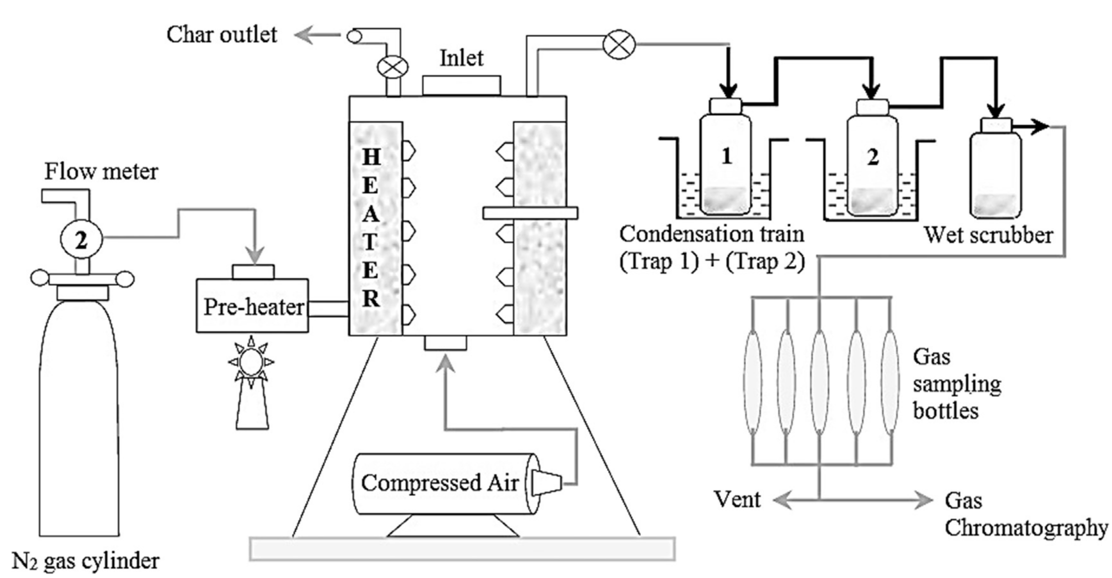

Fig. 1. Schematic of fixed bed pyrolysis system.