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Research Paper

Thermophysical characterization of oil palm shell (OPS) and OPS char synthesized by the microwave pyrolysis of OPS

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HIGHLIGHTS

- OPS char has been synthesized by the microwave pyrolysis of OPS.
- Thermophysical properties of OPS & OPS char are temperature dependent.
- At room temperature, thermophysical properties of OPS are higher than OPS char.
- Rise in temperature lowers thermal conductivity of OPS & OPS char.
- Low thermal conductivity of OPS char makes it suitable insulating material.

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ABSTRACT

Thermochemical conversion of OPS has gained huge attention among the researchers mainly because it converts the waste OPS into energy rich value added by-products. Thermophysical properties play a very crucial role in the thermal treatment of OPS and govern the heat transfer phenomenon of the material. Temperature dependence of thermophysical properties of OPS and OPS char has been investigated within the temperature range between 30 and 110 °C. OPS char is synthesized by the microwave pyrolysis of OPS. Thermogravimetric analysis of OPS and OPS char confirmed that OPS is more thermally stable as compared to OPS char. Moreover, it gave information about the degradation behavior of OPS and OPS char. Thermophysical properties was measured by thermal analyzer, based on the transient hot wire technique which is suitable to measure the thermal conductivity at elevated temperatures. At room temperature, thermal conductivity and thermal diffusivity of OPS are 0.199 W/m K and 0.142 mm^2/s respectively and are 15.07% and 12.67% higher than that of OPS char. Specific heat capacity of OPS and OPS char are found to be almost same (1.139 kJ/kg K for OPS and 1.108 kJ/kg K for OPS char). Thermal conductivity and thermal diffusivity values lowered on increasing the temperature while specific heat capacity increased linearly on increasing the temperature. Low thermal conductivity and thermal diffusivity values of OPS implies that the conventional conductive heating is less effective and inefficient for the thermal treatment of OPS.

1. Introduction

Conversion of biomass based waste materials into value added energy product is investigated worldwide. Many biomass based materials have been studied for their constructive utilization by thermal or bio-conversion techniques. Oil palm trees, in Malaysia are planted on more than 3.8 million hectare area and it is expected that by the year 2020 it will increase to 5 million hectare [1]. Huge amount of palm shell waste is being produced from the oil palm mills every year in the form of empty fruit bunch (EFB), Oil palm shell (OPS), palm fiber and palm oil mill effluent [2]. OPS is one of the biomass waste materials which has attracted many researchers in the recent past as it can be used to produce energy rich by-products such as bio-oil and bio-syngas by its thermal degradation . The residue remained after the thermal degradation is termed as bio char. Because of its high carbon content bio char can be used as asphalt binder [3]. Bio char can also be utilized in various areas such as in agriculture industry it is used

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for soil procurement [4], in chemical industry it is used for the removal of phenol [5] and tetracycline [6], in purification industry it is used as adsorbent to remove heavy metals like Hg [7], Pb [8], Zn [8], Cr [9], Cd [10], and Ni [11].

In most of the cases, agricultural wastes and biomass based materials are thermally treated for their re-utilization. Thermophysical properties of a material govern the heat transfer properties the material and are very crucial in the thermal treatment of the material. The amount of heat which can be passed through it and its speed is completely determined by the thermophysical properties of the material. Biomass based char materials are being studied for their utilization in various applications such as supercapacitor electrode, electronic packaging material, insulation, humidity regulation, and protection from electromagnetic radiation [12–16]. In few of these applications the material is exposed to the thermal radiation (i.e. heat) and knowledge of thermophysical properties of OPS and OPS char will be a useful for the utilization of these materials to any of these applications as thermophysical properties will lead us to know the heat flow characteristic of OPS and OPS char within the material. Therefore, for the effective and efficient heat treatment of the material, it is highly important to know its thermophysical properties. Thermal properties are very critical and should be known for the better storage, transportation and handling of the biomass based materials. Effect of various parameters such as moisture content, particle size, and processing temperature, on thermal conductivity of agricultural, food and biomass based materials have been investigated and reported in literature by different researchers [17–24].

Thermal conductivity of wood pellets increased from 0.146 to 0.192 W/m K on increasing the moisture content from 1.4% to 9.0% (wet basis) while specific heat increased from 1.074 to 1.253 kJ/kg K [21]. Gupta et al. [20] synthesized softwood char by the pyrolysis of softwood bark and reported that thermal conductivity and specific heat of softwood bark and softwood char are temperature dependent. Thermal conductivity of soybean is reported to be increased from 0.1157 to 0.1726 W/m K on increasing the moisture content from 8.1% dry basis to 25% while thermal diffusivity increased linearly from 2.94×10^{-4} to 3.07×10^{-4} m^2/h [25]. Ahn et al. reported that the thermal conductivity and specific heat capacity values of wheat straw, sawdust and cornstalks are moisture content and particle size dependent [26]. In another study conducted by Mahapatra et al. [27] on the thermal properties of searicea Lepsezeda, found that on increasing the moisture content of sericea lespedeza pellet from 7.26% to 15.55% (wet basis), thermal conductivity and thermal diffusivity value does not change significantly while specific heat capacity increased from 0.260.14 to 314.85 J/kg K. Chandrashekhar and Viswanathan [24] investigated Arebica and Robostica coffee with varying moisture content and it was reported that thermal conductivity and specific heat capacity for both these decreased while thermal diffusivity increased with rise in the moisture content. Fasina and Sokhansanj [19] studied effect of moisture content on the thermal conductivity of alfalfa pellets using the plane heat source method for the efficient design of pellet cooler and to select the suitable ventilating and cooling equipment. Other than this, thermal conductivity of few other agricultural and biomass based materials such as cotton [28], tobacco [29], gram [22], rice husk [30], white pine wood [31] cotton tobacco leaves waste from tissue paper manufacturing [32] (Maze husk, Paddy straw, Coconut pith, Groundnut shell) [33], etc. have been studied and reported for their improved processing and better utilization. Acknowledging the importance of determination of thermophysical properties for the materials in their thermal treatment, many studies have been conducted to understand the heat transfer phenomenon in biomass based materials and to develop theatrical models to predict the thermal conductivity [34–37].

In the thermal conversion of OPS into bio-oil and other energy rich products, OPS is thermally degraded into liquid and gaseous constituents by transferring heat to it. Microwave heating is a relatively new technique for the heat treatment of materials and is considered to be a potential alternative to the conventional conductive heating. In the electromagnetic spectrum, microwave radiation falls in between the infra-red radiation and radio frequency radiation with wavelength ranging between 1 m and 1 mm corresponding to the frequency of 300 MHz to 300 GHz [38]. Conventional heating is a surface heating process in which the heat is transported from outward to inward direction through conduction. This process involves a significant heat loss (or energy loss) which makes the conductive heating inefficient [39]. In microwave heating the material is heated through the radiation mode of heating with the minimum loss of energy, making the heating process more efficient and economic. Microwave heating provides rapid heating as compared to the conventional conductive heating [38–41]. Microwave heating is used in food processing, wood drying, curing and preheating of ceramics and molding and treatment of plastics and rubbers. Other than this, there is a growing interest of microwave heating to speed up the chemical reactions [42–44].

Based on the study of the available literature and to the best knowledge of the authors Thermophysical properties of OPS and OPS char synthesized by the microwave pyrolysis of OPS at elevated temperatures have never been reported. In the present study, we have synthesized OPS char from the microwave pyrolysis of OPS and then investigated the thermophysical properties of OPS and OPS char in the temperature range of 30–110 °C. The study will be helpful to understand the heat flow mechanism in the material at the room temperature as well as at the elevated temperatures. The investigation will also provide some key information about OPS and OPS char such as the amount of heat which can be passed through it, rapidity of the heat flow and how much heat it can absorb without offering rise in temperature. Knowing the thermophysical properties of OPS, more effective and efficient methods for the heat transfer can be developed for the conversion of OPS into bio-oil and bio-syngas and these techniques may be utilized for the other biomass based materials also. Moreover, knowledge of thermophysical properties can also be useful for choosing between microwave and conventional conductive heating technologies for the pyrolysis of OPS and other biomass based materials. In few of the applications the temperature of the material is expected to be increased. Therefore, the thermophysical properties of OPS char at elevated temperature are important to be known. These properties will provide primary information whether OPS char is suitable for these applications or not.

2. Experimental

2.1. Material

The oil palm shell (OPS) used in the present study was supplied by Seri Ulu Langat Palm Oil Mill Dengkil, Selangor, Malaysia. Supplied OPS was brownish granular particles. OPS char used in this study were produced by the microwave pyrolysis of this supplied oil palm shell.

2.2. Synthesis of OPS char

The OPS supplied by the mil was washed with fresh water so that the undesired water soluble impurities and dust can be removed. The particle size distribution analysis shows that most of the OPS particles (>82%) have particle size >1400 μm. A detailed description of methodology for particle size determination and