

## Fixed bed slow pyrolysis of biomass solid waste for bio-char

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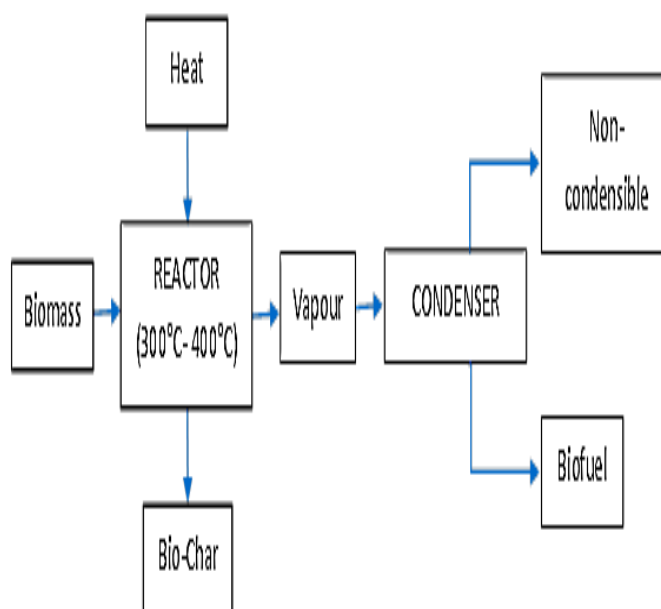
**Abstract.** Biomass solid waste in the form of rice husk particle is pyrolyzed in a fixed bed pyrolysis reactor. The reactor is made of stainless steel with dimensions of 76 mm in diameter and 90 cm in length. Rice husk is collected locally from Brunei–Muara district of Brunei Darussalam which is processed for pyrolysis. The particles are selected in the millimeter range. It is oven-dried at 105°C for 6 hours after being air-dried prior to pyrolysis. The reactor bed is heated by means of saw-dust in a biomass source heater. A temperature range of 390- 410°C is maintained with an apparent vapor residence time of 30 min. Nitrogen gas is passed through the reactor system to make the atmosphere inert. A water-cooled condenser is used to derive bio-oil from the condensable vapors. The system is subjected to pyrolysis for a running time of 60 min. The products obtained are solid bio-char, liquid bio-oil and pyrolytic bio-gases. The solid char yield is found to be 45% by weight of solid biomass feedstock and the liquid product yield is found to be 29% by weight of solid biomass feedstock. The rest is gas flared into the atmosphere. The bio-char is retained in the reactor and collected at the end of the experimental run. The bio-char is found to be black in color retaining its original shape. The bio-char product is subjected to energy analysis for its higher heating value (HHV) by means of an oxygen bomb calorimeter. It is found to be 20.3 MJ/kg. The density of the bio-char is found to be 238.5 kg/m<sup>3</sup> with an energy density of 4.85 GJ/m<sup>3</sup>.

### 1. Introduction

Energy is an indispensable item in the everyday life of the present world. However, the current world is driven by fossil fuels that has been depleting at a faster rate. The demand is exceeding the supply [1]. Besides the environmental pollution from the combustion of fossil fuel is a serious concern of the world at this time. Thus, a search for alternative sources of energy appears to be an imperative option. For this purpose the renewable sources of energy is considered to be the most suitable option. Among different renewable sources of energy, biomass is considered to be a very good option. Biomass is now considered to be a contributor of bio-fuels alternative to crude petroleum oil providing clean energy and value added products [2]. Biomass has high carbon content, low ash content and it is renewable in nature. Biomass can easily be obtained from agricultural residues or green waste. Woods and other forms of biomass including energy crops and agricultural and forestry wastes are some of the main renewable energy resources available [3]. Like wind, solar and other renewable energy sources, biomass can make a positive impact on the atmosphere by reducing the dependence on climate change-inducing fossil fuels. Biomass solid wastes are available abundantly in most parts of the world. Mostly these are either unused or underutilized. The disposal of the large amount of the wastes is a problem as well. Thus, biomass is a promising eco-friendly alternative source of renewable energy in the context of current scenario [4]. From the characterization studies of biomass solid wastes it is found that these wastes have good prospects to be used as feedstock for better energy recovery in the form of solid bio-char, liquid oil and gaseous products [5, 6]. Besides value-added products can be obtained from the liquid pyrolysis oil [7]. Also, the char has its potential to be used as fuel [8]. One of the possible ways for this energy and value-added products recovery is to adopt the slow pyrolysis process for the conversion of carbonaceous



biomass solid wastes into solid char [9]. Slow pyrolysis has been used to enhance char production at low temperature and low heating rates. In this process, the vapour residence time is too high in the range of 5 to 30 min and the components in the vapour phase continue to react with each other resulting the formation of solid char and other liquids [10]. This char is known as bio-char. The reaction pathway of the slow pyrolysis process is shown in Figure 1. The slow pyrolysis is considered to be one of the most promising emerging technologies for this purpose. It is the thermal degradation of the carbonaceous solid wastes into solid char at low temperature in the absence of oxygen or air so that combustion or gasification does not take place. The slow pyrolysis is meant for solid product although liquid oil and gases are produced depending upon the heating rate, reactor bed temperature and apparent vapour residence time.



**Figure 1.** Reaction pathway of slow pyrolysis process.

Rice husk is an abundant agricultural by-product in countries like Brunei, Malaysia, China, Thailand, India and Bangladesh which have large paddy crops. It constitutes one fifth by weight of paddy harvested [11]. It is estimated that over 100 million tons of rice husk are generated annually with 90% accounted for by the developing countries [12]. Mostly this is under-utilized as a source of heat energy. The disposal of this waste is an environmental issue. According to Yatim [13], Malaysia generates 3.41 million cubic meter of rice husk every year. Burning the waste in an uncontrolled manner causes serious emission problems causing environmental issue. Besides rice husk waste possesses favourable physical and thermal characteristics as depicted by characterization study and TG analysis [3]. Thus, the objective of this present study is to convert biomass solid waste in the form of rice husk particles into bio-char in a fixed bed pyrolysis system recently designed and fabricated in the Manufacturing Laboratory of the Mechanical Engineering Programme Area of Universiti Teknologi Brunei (UTB), Brunei Darussalam. A few selective characterization study of the bio-char is also considered in the paper.

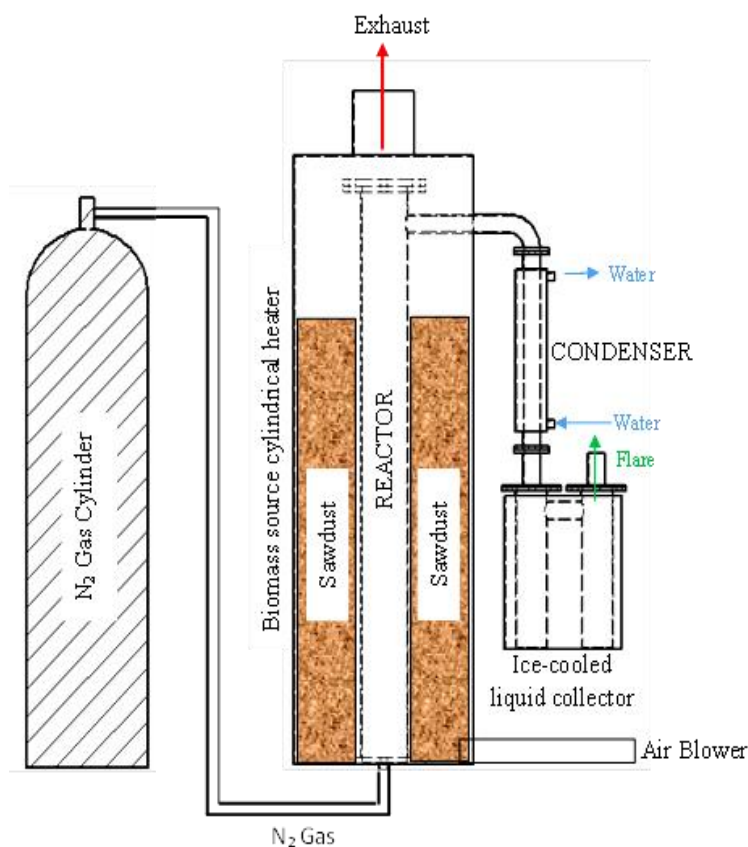
## **2. Experimental methods**

### *2.1. Materials*

The feedstock for pyrolysis considered in this study is biomass in the form of rice husk particles in the size range of millimeters as received. It is collected from the local Rice Mills at Wasan Area of Brunei - Muara district of Brunei Darussalam. The fuel for biomass heating source is saw- dust which is also renewable in nature. It is collected from the local saw-mills in Brunei Darussalam that is burnt in the biomass source heater by supplying air with the aid of a blower to provide heat for the pyrolysis reactor.

### *2.2. Experimental set-up*

The experimental set-up is a simple fixed bed pyrolysis reactor system. It consists of a fixed bed reactor, a liquid condenser, two ice-cooled liquid collectors and a biomass source heater. The schematic diagram of fixed bed pyrolysis reactor system is shown in Figure 2. The diameter of the fixed bed reactor is 76 mm and the length is 90 cm. The pyrolysis reactor system is made of stainless steel so that it can withstand high temperature application in the corrosive atmosphere as the liquid oil is usually corrosive in nature. The condenser and liquid collectors are also made of stainless steel. Nitrogen gas is supplied from a nitrogen gas cylinder to the reactor to make inert atmosphere inside the pyrolysis system. A tube and shell type water cooled condenser is used so that the condensable vapours in the reactor are cooled rapidly to be condensed into liquid product. Two liquid collectors are placed subsequently in order to be ice-cooled for further condensation of the vapours while the non-condensable gases are flared into atmosphere.



**Figure 2.** Schematic diagram of fixed bed pyrolysis reactor system.

### 2.3. Methods and procedures

In this study the slow type of pyrolysis of rice husk is considered for its simplicity and appropriateness to convert carbonaceous solid material into solid char. For this a slow pyrolysis reactor is designed and fabricated. The reactor bed temperature is maintained between 390 to 410°C with a high vapor residence time of 30 min with a slow gas flow rate. Initially the feedstock is air-dried. Then it is oven-dried at 105°C for 6 hours prior to pyrolysis. The fixed bed reactor is filled up with the rice husk to be pyrolyzed. The fixed bed pyrolysis experimental set-up is presented in Figure 3.



**Figure 3.** Fixed bed pyrolysis experimental set-up.

The set-up is assembled and sealed using rubber and liquid gasket. Nitrogen gas is supplied from a nitrogen gas cylinder to the reactor which is controlled by a gas flow regulator. The reactor is maintained at a low temperature range of 390 to 410°C at an apparent vapour residence time of 30 min. It is heated by means of a heater of biomass source to attain necessary heating in order to achieve the temperature in the range of 400°C. The water-cooled condenser condenses the vapours into liquid oil which is collected in the ice-cooled liquid collectors while the gas is flared into the atmosphere. After the completion of the pyrolysis run for 60 min, the system is cooled down and dismantled. The bio-char retained in the reactor is collected at the end of each experimental run. The liquid products are then collected and weighed. The amount of gaseous products is determined by difference.

### **3. Results and discussion**

#### *3.1. Product yields*

Three types of product are obtained in this pyrolysis study. These are solid bio-char, liquid oil, and gases. The thermal degradation of lignin and hemicellulose results in considerable amount of rigid amorphous carbon matrix

referred as bio-char. The solid char is found to be 45% by weight of the total solid biomass feedstock in this study. The bio-char obtained is shown in Figure 4. It is found that the char retained the original geometrical shape of the rice husk feedstock particle with a dark black colour. The product yield is found to be in good agreement with the results of other pyrolysis studies conducted by Islam [3] which was found to vary in the range of 40 to 53 wt% of solid biomass feedstock in case of rice husk and oil palm shell. However, Jahirul, Rasul, Chowdhury and Ashwath [4] reported the char yield to be a maximum of 35 wt% of feedstock. The char product yield obtained in this study is found to be higher than the solid product yields obtained by Williams and Besler [14] in their experimental studies on rice husk pyrolysis. However, their study was at higher reactor bed temperature.



**Figure 4.** Solid bio-char obtained from slow pyrolysis of rice-husk.

The liquid product yield is found to be 29% by weight of the total solid rice husk feedstock which is found to be in good agreement with other pyrolysis studies performed by Islam [3] and Williams and Besler [9]. The remaining non-condensable gas is determined by difference which is flared into atmosphere as shown in Figure 5.





**Figure 5.** Pyrolytic bio-gas flared to atmosphere.

### *3.2. Product characterization*

The bio-char is characterized for its properties. The higher heating value (HHV) is determined by means of an oxygen bomb calorimeter following the standard test procedures. It is determined to be 20.3 MJ/kg which is found to be better than the HHV of the solid rice husk waste. The density of the bio-char is found to be 238.5 kg/m<sup>3</sup> and hence, the energy density of the bio-char is found to be 4.85 GJ/m<sup>3</sup>. The properties obtained are found to be in good agreement with those obtained from similar studies for other biomass derived solid char [3]. The bio-oil is also collected as shown in Figure 6. It is found to be a single-phase, deep brown coloured liquid with an acrid smell. No phase separation is found to take place. The bio-oil is characterized for some of its properties. The density of the bio-oil is found to be 1,051 kg/m<sup>3</sup> and the pH value is found to be 3.0. The density of the oil is comparable with other biomass-derived pyrolysis oils [3]. The pH value indicates that the oil is acidic in nature; and hence, corrosive which is typical in case of pyrolysis oils as supported by other similar studies.



**Figure 6.** Liquid bio-oil obtained from slow pyrolysis of rice-husk.

#### 4. Conclusions and recommendations

The rice husk solid waste is successfully pyrolyzed into bio-char, bio-oil and pyrolytic bio-gases. The solid bio-char product yield is found to be 45% by weight of the biomass solid feedstock at a reactor bed temperature of 400°C with an vapor residence time of 30 min for millimeter range rice husk feedstock. The liquid bio-oil yield is found to be 29% by weight of the biomass solid feedstock. Thus, the product yields in the form of bio-char and bio-oil are found to be in very good proportions. The heating value of the bio-char is found to be 20.3 MJ/kg which is quite higher than that of the rice husk solid waste. The energy density is estimated to be 4.85 GJ/m<sup>3</sup>. Thus, it reveals the fact that the bio-char has its potential to be used as a fuel. Further studies are recommended to find the variation of product yields with reactor bed temperature and feedstock particle size. Also the liquid and solid products are recommended to be characterized for other fuel properties, their functional group compositional analysis by FTIR analysis and the identification of the chemical compounds by GC and GC/MS analysis.



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