1. Introduction

Fossil fuels ~~is our~~are the world's primary source of energy, ~~in the world with~~accounting for more than 80 % of global energy consumption. Overconsumption of this non-renewable energy ~~could~~ contributes to global warming due to the massive emissions of greenhouse gases. The problems related to fossil fuels and the serious environmental concerns have motivated~~s~~ ~~people~~efforts towards sustainability and enhanced engagement in green technology.

Biomass is considered one of the key solutions for our alternative energy ~~source~~needs. Roughly ~~approximately about~~ 90% of biomass is disposed of as waste~~s~~ in the palm oil industry~~mill~~[2]. In addition, 351 palm oil mills in ~~m~~Malaysia produced 30 million tonnes of empty fruit bunches (EFB) from 83 million dry tonnes of solid biomass in 2012. The abundance of underutilised biomass feedstock ~~which are underutilised~~ has gained growing interest among researchers as a potential solid-fuel energy resource.

However, biomass feedstock cannot be directly ~~fead~~implemented into the existing combustion system due to ~~its~~ unfavourable properties, such as low calorific value, high moisture content and reduction in quality via biodegradation. ~~The b~~Biomass requires ~~a~~ prior pre-treatment, which is achieved through a process known as torrefaction, to enhance its quality as ~~the~~a solid fuel. Torrefaction is a lignocellulosic biomass pre-treatment process at low temperatures between 473 K and 573 K under an inert atmosphere. It is a cheap technology but it ~~needs~~requires additional operating costs due to the need for thermal energy and nitrogen as a carrier gas. If torrefaction ~~can~~could be carried out in the presence of oxygen, ~~this will~~it would reduce ~~the~~ operating expenses by utili~~z~~sing flue gas from the burners[4]. Therefore, this study~~,~~ aims to investigate the effects of oxygen ~~towards~~on the torrefaction of EFB.

2. Experimental

The biomass residues used in this study ~~were the~~consisted of empty fruit bunches (EFB) ~~which were~~ collected from Felcra Nasaruddin ~~O~~oil palm mill in Bota, Perak, Malaysia. ~~P~~prior to ~~the~~ torrefaction treatment~~,~~ EFB were first chopped into smaller sizes and dried at 105 °C overnight ~~for~~to remove the moisture ~~removal~~. The~~n,~~ EFB ~~were~~was then grounded and further sieved to obtain a uniform particle~~s~~ size~~,~~ ranging from 0.25 mm to 0.50 mm.

~~t~~The experimental system where the torrefaction process was conducted consisted~~s~~ of a vertical tubular reactor made of stainless steel with an internal diameter of 0.028 m and a length of 0.56 m~~, where the torrefaction process was conducted~~. The torrefaction reactor was connected to a condenser ~~which~~that was immersed in ice cubes ~~in order~~ to collect the condensable gases (Figure 1). A 5 g sample of empty fruit bunches ~~sample~~ was placed in the centre of the reactor supported by~~with a~~ glass wool and held with wire ~~acting as its supporter and holder, respectively~~. Then, the system was flushed with torrefaction gas for 15 minutes with a flow rate of 100 mL/min. After the system was flushed~~ing the system~~, the flow rate of torrefaction gas was reduced to 30 mL/min and the temperature of the reactor was raised from room temperature to the desired temperature using an electric furnace at a rate of 10 °C/min. Once the desired temperature was reached, the torrefaction temperature was maintained for 30 minutes. The torrefaction process produces solid,

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Commented [.2]: There is no need to use 'approximately' here as 'roughly' is already being used to denote the lack of accuracy.

Commented [.3]: Countries like 'Malaysia' should start with an upper-case letter.

Commented [.4]: You possibly mean 'fed' here instead of 'fead'; however, 'implemented' might be a better word.

Commented [.5]: For the sake of consistency, use British spelling.

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liquid and non-condensable products. When cooled, ~~T~~the solid torrefied biomass was retrieved ~~later~~ from the reactor after it ~~has cooled down and being~~was weighed. The condensed vapour phase was collected in a condenser and weighed. The solid yield is an important indicator ~~to~~when evaluating~~e~~ the severity of the torrefaction condition ~~towards~~of biomass. It can be calculated as in the following equation ~~1~~:

$$Y_m = \frac{m_{torrefied}}{m_{raw}} \times 100\ \%\ (1)$$

where Y_m is the solid yield, $m_{torrefied}$ is the mass of torrefaction products and m_{raw} is the mass of torrefaction reactants. All weights reported were based on a dry basis.

The bulk densities~~y~~ of the untorrefied and torrefied biomass ~~was~~were determined by measuring the mass of a known volume of EFB sample, which ~~has been~~was placed in a measuring cylinder. T~~han t~~he density was then measured based on the known volume and mass obtained.

The calorific values were determined using a bomb calorimeter~~,~~ (model C2000 series manufactured by IKA Werke)~~,~~ The ~~obtained~~ calorific value obtained from the bomb calorimeter, which included the latent heat of the vapour, ~~is~~was produced from the sample.

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