CHAPTER 3

DEVELOPMENT OF MULTILEVEL TORREFACTION REACTOR FOR BIOMASS IMPROVEMENT

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3.1 INTRODUCTION

Torrefaction is known as one of the effective pretreatments for biomass energy conversion which can enhance the properties of biomass such as moisture content, hydrophobicity, heating value, energy density and oxygen/carbon (O/C) ratio (Ribeiro et al., 2018). Torrefaction is commonly known as heating biomass sample in an inert or limited oxygen environment under temperature range of 200 °C to 300 °C. The main constituents of biomass basically consisted of cellulose, hemicellulose and lignin. Based on the decomposition reactivity of each constituent of biomass, hemicellulose is significantly decomposed during torrefaction and followed by cellulose and lignin (Chen & Kuo, 2011). During torrefaction, inert gas such as nitrogen is commonly used as a torrefaction medium and this causes a burden in terms of operational cost. There were several alternatives have been introduced for the inert torrefaction such as the use of pressurized air (Nhuchhen & Basu, 2014), the use of aluminium air to prevent contact between air and sample (Nyakuma et al., 2014), the use of mineral fillers (Leontiev et al., 2019), the use of superheated steam (Zhang et al., 2021) and many others. Nhuchhen and Basu (2014) found that torrefaction of poplar wood under pressurised air gave similar energy yield if compared to those under pressurised nitrogen even though mass yield was smaller. Besides, Zhang et al. (2021) found that superheated steam torrefaction is superior if compared to the conventional torrefaction in terms of fuel quality. In addition, when superheated steam torrefaction was performed at 350 °C, torrefied products with sufficiently high higher heating value (HHV) of around 28 MJ/kg (similar to coal) could be obtained in only 15 minutes.

Continuous supply of inert gas for single level torrefaction is not worthwhile, therefore, a novel multilevel reactor was developed for torrefaction. Compared to the single level reactor, higher amount of samples could be torrefied in the multilevel reactor with the same amount of nitrogen gas. Based on the previous study (Rubeiro et al., 2018), it was found that the gaseous products from torrefaction mainly consisted of carbon monoxide (CO) and carbon dioxide (CO_2), thus these products have potential to be exploited for subsequent torrefaction process. Based on this fact, when a multilevel concept was used for torrefaction, the torrefaction medium for level 2 onwards was supposed to have a mixture of CO, CO_2 as well as nitrogen (N_2). In this chapter, the development stage of the reactor with multilevel concept and temperature profiles obtained from reactor functional testing are described. In addition, the result of initial testing in terms of physical appearance also is presented.

3.2 DESIGN AND DEVELOPMENT OF MULTILEVEL REACTOR

A novel multilevel reactor with four levels has been developed. This reactor mainly consisted of two components: (1) Reactor and (2) Mesh holder as shown by Figure 3.1. The concept is basically to utilise the mixture of nitrogen and gaseous products of torrefaction (at lower level) for the subsequent torrefaction process at higher level. Since the existence of oxygen is too limited, the occurrence of combustion could be avoided, thus causing torrefaction becomes successful. In terms of mass production, the single level reactor would cause burden in terms of operational cost since certain amount of costly inert gas (nitrogen) is consumed for one batch of biomass only. By using four-level torrefaction reactor, the same amount of nitrogen gas can be used for torrefaction of four batches of biomass simultaneously. In other words, the aim of the development of multilevel torrefaction reactor is to increase the amount of biofuel for the same amount of inert gas, thus saving the cost of nitrogen consumption.

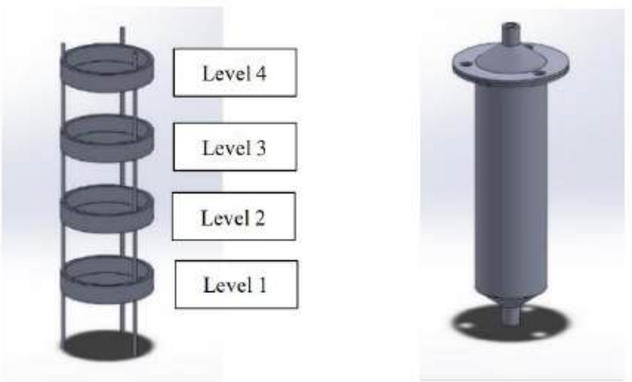

Figure 3.1 Four-level mesh holder and reactor

Solidwork software was used for designing the multilayer reactor. Three main parts of the reactor, namely as lower part, body part and upper part are shown in Figure 3.2.

Moreover, at the lower part reactor, the funnel is designed to connect with the nitrogen gas supply. The design allows nitrogen to flow from the bottom part to the upper part of the reactor. The supplied nitrogen gas comes from the nitrogen cylinder. This cylinder is connected to the pressure regulator and flow meter to control and maintain the gas flow rate to the reactor. The body part is the longest part with a cylindrical