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Name: Ruksathamcharoen Sirawasith (16D50018)
Tittle: Clean solid biofuel production from palm empty fruit bunch employing hydrothermal treatment and water washing for co-combustion with coal

This research proposes integration of the washed hydrochar derived from empty fruit bunch (EFB) into the coal-fired power generator. Various aspects essential in EFB treatment, transportation and energy conversion were investigated in this study. The fuel characteristics, biological composition and combustion characteristics of the untreated EFB (RAW-EFB), the hydrothermally treated EFB (HT-EFB) and the hydrothermally treated-washed EFB (HTW-EFB) were studied and compared. Investigation on the binder-less pelletization performance of EFB and the hydrochars were carried out to determine the optimal pelletizing temperature for HTW-EFB. To determine the optimal blending ratio of washed hydrochar and coal, HTW-EFB was co-combusted with sub-bituminous coal in a thermogravimetric analyzer and a fixed bed reactor to study the combustion characteristics, kinetics and emissions of the blended fuel at various blending ratios. The contents of this thesis are as follows:

Chapter 1. Introduction

In this chapter, the background and objectives of this study are presented. The disposal difficulties of EFB and its energy potential are discussed to present the motivation of the research. The current thermochemical conversion technologies of lignocellulosic biomass are reviewed with the emphasis on the hydrothermal treatment (HT) and co-combustion with coal. The pelletization mechanisms along with the glass transition behavior of lignin are discussed in this chapter. Various methods in measuring the grindability of solid fuel are reviewed. The knowledge gap in the co-combustion of washed hydrochar derived from EFB is explained and the objectives and the originality of this research are stated.

Chapter 2. Effects of hydrothermal treatment and water washing on the chemical properties, structure and combustion characteristics of empty fruit bunch

In this chapter, effects of HT temperature (180 – 220°C) and water washing on the fuel properties, structure, combustion characteristics and kinetics of EFB combustion was carried out. The mentioned properties of HTW-EFB from lab-scale were compared with that of commercial-scale to investigate the scaling effects. For the lab-scale samples, EFB was hydrothermally (HT) treated at the temperature of 180, 200 and 220°C for 30 mins and washed using water at 60°C for 15 mins for removing alkaline metals. For the commercial-scale sample, EFB was HT treated at 2 MPA for 30 mins and washed with room temperature water using the centrifugal machine for 30 mins. Results indicated that combination of the hydrothermal and the washing treatments (HTW) improved the fuel properties of EFB significantly with an increase in the calorific value up to 23.3 MJ/kg. The alkaline contents of HTW-EFB were reduced when compared with that of untreated EFB. In addition, an increase in the porosity of EFB was observed after the HTW process. Significant changes in the combustion behavior were observed when EFB underwent HTW. The ignition temperature of the hydrochars was between 290 to 296°C with the burnout temperature from 438 to 485°C. From the kinetic study, the first-order reaction and the one-dimensional diffusion are the main mechanisms in the combustion of volatiles while the one-dimensional diffusion is the main mechanism for the combustion of the fixed carbon of the hydrochars. The activation energy of HTW-EFBs were between 99.96 to 138.26 kJ/mol in the devolatilization stage and 10.97 to 27.56 kJ/mol in the char combustion stage. HTW-EFB from commercial-scale showed better fuel properties than that of lab-scale despite the low treatment temperature ranging between 150 and 180 °C during the holding time.

Chapter 3. Investigation of the improvement in binder-less pelletization performance of washed hydrochar derived from empty fruit bunch

This study examined the effects of the hydrothermal treatment and the pelletizing temperature on the physical characteristics of EFB pellets. RAW-EFB and HTW-EFB from commercial-scale reactor was utilized for this study. RAW-EFB was blended to the size below 2 mm, while HTW-EFB was directly pelletized. The samples were pelletized using the single pellet making device at a pressure of 60 MPa and the temperature of 100, 150 and 200°C. Results indicated that combination of the hydrothermal treatment and the water washing significantly reduced the hemicellulose content of EFB from 23.55% to 1.24% causing the lignin content of HTW-EFB to increase due to the concentration effect. Moreover, the particle size of HTW-EFB was significantly reduced compared with that of RAW-EFB. The changes in the biological composition and the particle size of HTW-EFB significantly improved the pelletization performance of EFB especially when it was pelletized at 100°C. At the pelletizing temperature of 100°C, the pellet durability index (PDI) and the compressive strength of EFB increased from 78.1% and 18.8 N/mm to 98.7% and 51.4 N/mm, respectively, when it was treated. Notable increase in the pellet properties of untreated EFB were also observed as the pelletizing temperature increased. At the pelletizing temperature of 200°C, PDI and the compressive strength increased to 92.8% and 46.1 N/mm, respectively. However, only slight improvement in the characteristics of the washed hydrochar pellets were observed as the pelletizing temperature increased.

Chapter 4. Effects of the hydrothermal treatment and water washing on co-combustion of empty fruit bunch with coal: co-combustion characteristics, kinetics, NO emissions

This chapter studied the effects of HT and the water washing on co-combustion of EFB with coal. The thermogravimetric analysis (TGA) was employed to study the thermal behaviors and kinetics of the blended fuel. HTW-EFB from the commercial-scale reactor was mixed with sub-bituminous coal at the ratio of 10, 20, 30, 40 and 50% on the mass basis. Approximately 5 mg of sample was used for each experiment. The sample was heated at the rate of 5ºC min^{-1} under the air flow rate of 150 ml min^{-1} from the room temperature to 800ºC. The Coast-Redfern method was used to calculate the kinetics of the samples. Results showed that treated EFB showed two combustion steps: from 290ºC to 350ºC (combustion of volatiles) and from 370ºC to 445ºC (combustion of char). However, only one combustion step was observed for coal, from 330ºC to 462ºC. The HTW-EFB/coal blend showed only two combustion steps indicating the synergistic effect. The increase in the blend ratio increased the reactivity in the first combustion step while reducing the reactivity in the second combustion step as well as the ignition temperature and the burnout temperature. The results of the kinetic analysis showed that the D1(diffusion model) mechanism was the main mechanism for the first stage of co-combustion. On the other hand, the O1 (first-order chemical reaction) model was observed to be the controlling mechanisms in the second stage of co-combustion.

For the NO emission test, HTW-EFB was co-fired with coal in a fixed bed reactor. The mixture of Ar and O_2 was used as a carrier gas to avoid any thermal NO generation from the co-combustion. For all the tests, 0.2g of the blended fuel was mixed with 5 g of silica sand to prevent the ash agglomeration. The carrier gas was injected to the combustor at 2L/min and the combustion temperature was 900°C. The results showed that the NO emission and NO conversion of HTW-EFB was lower than that of coal. In addition, the increase in the blending ratio resulted in a gradual reduction of NO emission as well as NO conversion. From the results of both TGA and NO emission test, the blending ratio of 30% was recommended for the co-combustion.

Chapter 5. Conclusions

This chapter summarizes the important concluding remarks of this thesis.