

学位論文の要約

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学位論文の題目

A Comparative Study of Solid Fuels from Lignocellulosic and Non-Lignocellulosic Biomass via Hydrothermal Carbonization

(水熱炭化によるリグノセルロース系および非リグノセルロース系バイオマスからの固体燃料生産)

学位論文の要約

Bioenergy as a primary energy is recognized worldwide to potentially prevent a temperature increase from the greenhouse effects, with a share scenario of 17% in 2050. One of the aspects to a successful energy transition is the effective conversion technologies for diverse feedstocks. Hydrothermal carbonization (HTC) is a promising technology, known for converting wide moisture-ranged biomasses without pre-drying. Needless to say, the energy crops for feedstocks vary in sources and constituents, as grouped into 1) 2nd generation, e.g., fibrous agricultural residues, typically consisting of cellulose, hemicellulose, and lignin (lignocellulose) and 2) 3rd generation, e.g., algae, often containing protein and lipid (non-lignocellulose). To fill the gap in biomass selection, a comprehensive study was conducted to investigate hydrochars derived from sorghum bagasse (SB) and microalgae (MA) under HTC at 150°C–250°C for 0.5–3.5 h.

(1) Significance of HTC

The RSM–CCD estimated that temperature and time can significantly control the solid recovery (MY) (p -values = 0.00) and gross heat release of hydrochars (HHV) (p -values = 0.00–0.03) at least in a linear relationship, regardless of the biomass types. The optimum conditions of maximizing HHV are achieved at 27.54 (SB) and 35.83 MJ kg⁻¹ (MA) by raising the temperatures to 250°C and times to 3.5 and 3.25 h.

(2) Fuel properties

Dehydration and decarboxylation predominated HTC. Fixed carbon (FC) developed more in the SB hydrochars, in contrast to the MA, which formed volatile hydrocarbon (VM) with a lower atomic O/C ratio. The tendency led to the higher HHV of MA hydrochars at 26.7–36.2 MJ kg⁻¹ than SB at 19.7–28.0 MJ kg⁻¹. However, SB hydrochars are assumed to combust more stably and ignite more decently as the fuel ratios (FR) approached 0.9–1.5. The original energy (EY) of SB also retained 1.8 times more than MA after HTC, rendering its conversion more techno-commercially feasible. Conflation of these fuel properties recommends SB hydrochar (severity factor / SF = 6.63) as steam coal, while MA hydrochar can broadly serve as steam (SF = 4.08–5.90) and coking coals (SF = 6.63), although MA cannot be developed beyond the current HTC severity due to emulsification.

(3) Chemical structures

Hydrolyzed sugars of SB (d-allose) underwent dehydration to form furanic intermediates (methyl furan) and condense into aromatic hydrocarbons (phenol), as supported by C–O reduction and C=C_(ar) formation. For MA, hydrolyzed fatty acids (hexadecanoic acid) were transformed and adsorbed as aliphatic hydrocarbons (hexene) and fatty amides (hexadecanamide) via decarboxylation and amidation as C–H_(al) increased drastically. Moreover, the stability of both hydrochars partially decreased as their crystallinity indices decreased (CI = 45.5%–24.3% (SB), 35.8%–18.0% (MA)).

(4) Combustion performance and fire-safety storage

As a preliminary, the model-free method and the Frank-Kamenetskii theory were successfully applied as the kinetic method for combustion. Using SB, the combustion occurred at 131°C–475°C, with flame igniting at 215°C (T_{ig}) and ember burning out at 433°C (T_b). The reactivity of ignition (D) and combustion (S) accelerated by 159 and 53 times as the heating rate increased. The activation energy (E) to initiate chain reaction was 132.91 kJ mol⁻¹. The fire-safe storage is advised below 83°C

and 84°C for cylindrical and rectangular box silos, respectively, with diameter and height of 15 and 10 m to prevent spontaneous ignition.

The possibility of a unified reaction, reflected by the presence of three different activation energies (E) throughout the combustion reaction, might reject the assumption of reaction model ($f(x)$) in determining the pre-exponential factor (A). Future work on the combustion kinetic triplets can be attempted by applying the model-fitting method to SB and MA biomasses and their hydrochars, which is coupled with peak deconvolution. Furthermore, the inorganic content and its behavior when discharged through HTC need to be examined to identify the potential of fouling and slagging during combustion.