学位論文審査の要旨

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学位論文題名

Torrefaction of high moisture content biomass using fresh dairy manure
(乳牛ふんを用いた高含水率バイオマスの半炭化)

The PhD dissertation consists of 94 pages in total, 25 figures, 1 tables, and one accepted journal as a reference paper. The dissertation is summarized as follows:

Biomass is one of the major choices for alternative energy sources. However, certain drawback of raw biomass such as high moisture content sets the limitation of its use. Thus, pretreatment is necessary in order to remove the limitation. Torrefaction is an emerging technique for upgrading biomass. It is a thermal decomposition treatment used to convert biomass into a solid fuel. The conversion process is operated at low temperatures ranges from 200 °C - 300 °C under an inert atmospheric conditions. It will produce a solid fuel product called torrefied biomass, bio-char or bio-coal. Other names for torrefaction are slow and mild pyrolysis, high temperature drying as well as roasting. Generally, torrefaction can be achieved after successive stages of drying, post-drying, torrefaction and cooling. During the process, biomass is decomposed, oxygen is removed, and the fibrous structure and tenacity are destructed. These resultant characteristics give in the advantages of torrefied biomass over the non-torrefied biomass; torrefied biomass is more grindable and hydrophobic, contains high calorific value, and easily transported and stored. In general, torrefaction is conducted using dried or very low moisture content of feedstock. Also, inert condition is applied. However, there have been no reports on direct usage of high moisture content biomass as a feedstock during torrefaction.

By using high moisture content biomass, the prediction for whole biomass degradation processes can be improved, beneficial to clarify the mechanism of biomass torrefaction. In addition, a simplified approach by implementing torrefaction in atmospheric condition can be adapted for real life scenario that offer low cost benefit. Thus, considering the points above, this research aims to better understand the torrefaction process, particularly on using high moisture content biomass from fresh dairy manure. Additionally, the research applies oxidative condition for bioenergy production. The research works are divided to two sections as follows;

1. **Investigation on the capability of high moisture content dairy manure to become a solid product through torrefaction.**

The advantages of torrefaction on biomass have been discovered. However, to the time this study was conducted, limited data have been published related with the direct usage of high moisture content livestock manure as a feedstock for torrefaction. In addition, there have been no information on wet manure torrefied through an industrial rotary kiln reactor. In this study, torrefaction for fresh dairy manure with 84.1% moisture content was carried out at three different temperatures (200 °C, 250 °C and 300 °C). For this purpose, an industrial rotary kiln combustion type reactor was used. As a result, wet dairy manure was converted to a solid product or torrefied manure. Due to its high moisture content, at least three cycles of non-continuous thermal treatment were required to complete the torrefaction. Production efficiency calculations showed that the fresh dairy manure was torrefied better at higher temperatures (250 °C and 300 °C) with lower energy consumption and in a shorter time.

2. **Thermal decomposition of high moisture content biomass using dairy manure**

Due to non-continuous steps, the thermal reaction of torrefaction on high moisture content biomass in oxidative condition could not be easily determined from the industrial rotary kiln combustion type reactor. Nevertheless, on the basis of characteristics and properties of the solid torrefied manure, drying and thermal decomposition steps were strongly involved. Hence, a continuous thermal degradation of high moisture content dairy manure in an oxidative condition was conducted using a laboratory oven. The weight loss profile data was collected and treated as a major source to understanding the reaction. In addition, gas production and sample temperature data were also collected. Resultants mass profile, gas production and sample temperature data confirmed that the torrefaction reaction involved a simultaneous process of drying and degradation. For a comprehensive prediction, the author has developed a simplified mathematical model for both process based on exponential model.

The above results show the feasibility of direct usage of high moisture content biomass for torrefaction. The experiment works clarified the torrefaction consists two major process: drying and thermal decomposition. Moreover, the developed mathematical model is consistent with the experimental results and can greatly contributes to the production of solid torrefied product.

Therefore, we acknowledge that Sitty Nur Syafa Binti Bakri, is qualified to be granted the degree of Doctor of Philosophy in Agriculture from Hokkaido University.