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Relationships between Major Constituents, Storage Conditions, and Higher Heating Values of Rice Straw

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Abstract

Relationships between higher heating values (HHVs) and major constituents (carbon, nitrogen, moisture, ash concentrations) of rice straw while examining storage conditions were investigated. Different storage periods and temperatures affect major constituents. To obtain high-accuracy predictions for HHVs, we analyzed the relationship between carbon and nitrogen concentrations, which is a better method than analyzing moisture and ash concentrations. HHV is calculated as $17007.89 - 9.17t + 0.05T$, where t and T are the number of storage days and biomass temperature, respectively, with coefficient of determination = 0.801 and significance level = 0.05. HHVs obtained from this relationship agreed well with those obtained using a bomb calorimeter, indicating that this relationship has the potential for use in estimating HHVs of rice straw.

[Keywords] rice straw, higher heating value, major constituents, carbon, nitrogen, storage conditions, biomass, energy

I Introduction

Rice straw is a renewable energy resource that is composed of chemical structures related to carbon, hydrogen, oxygen, nitrogen, sulfur, and chlorine, which are important compositions for the energy conversion process (Brown, 2004). A huge amount of rice straw is produced worldwide, and the average yield is 731.3 Mt/year (Keikhosro et al., 2006). If all of the rice straw were converted to energy, it would account for 11.91×10^{18} J, because the heating value of rice straw is 16.28 MJ/kg (Brown, 2004). This capability would allow populations to decrease the amount of fossil fuel they use, which would also reduce carbon dioxide emissions by approximately 2.74×10^{9} tons, in comparison with using coal to generate the same amount of electricity, for which 1 GJ of energy consumption results in 230 kg of carbon dioxide emissions (Klass, 1998).

Even though rice straw can be converted to energy, there are concerns about the cost of transferring rice straw from the fields to central conversion facilities owing to its low density. That means, it is too much volume for transport. However, many conversion technologies are being developed to produce economical on-farm conversion. Physical conversion is one technology used to convert biomass to energy. It includes firewood and pelletizing (or briquette). This technology is still an important method for generating energy that is widely used for households. Another technology is the biochemical conversion process that involves fermenting (aerobic and anaerobic) biomass using microorganisms to produce an energy source (biogas) and fertilizer. The biochemical conversion technologies include processes such as ethanol fermentation, hydrogen fermentation, and related method. Another important technology is thermochemical conversion. This technology has gained much attention nowadays owing to its ability to decrease the bulk of the biomass and to create easily transportable forms of energy. Thermochemical conversion technologies include directly burning or conventional steam approaches, combustion, pyrolysis, gasification (The Japan Institute of Energy, 2008).

However, searching the optimum utilization of each conversion processes is an essential goal for most studies. Therefore, to determine the energy output of the conversion methods, the heating value was considered as a main factor in many studies. The heating value is one of the most important fuel properties; it defines the amount of heat released from combustion (Huang et al., 2008). The heating value can be directly determined experimentally from a closed system such as the environments measured by adiabatic and isothermal calorimeters (Hsi and Kuo, 2008; Sheng and Azevedo, 2005). To obtain the heating value by adiabatic and isothermal calorimeters, the biomass is burned in a controlled, enclosed space and the net temperature rise or the enthalpy change is measured. The closed system controls the amount of energy that could be gained from or lost to the apparatus; therefore, both adiabatic and isothermal calorimeters indicate results with great accuracy. However, a closed system apparatus is very expensive.

Another important method obtains the heating value by indirect estimation from proximate and ultimate analyses

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using a mathematical relationship. Table 1 shows summary of equations in the literature that are used to predict the higher heating value (HHV) of biomass from proximate and ultimate analyses. These equations have been derived for analyzing the heating value of biomass. Equations 1–4 are based on ultimate analysis (carbon, hydrogen, oxygen, nitrogen, sulfur), and Eqs. 5 to 11 are based on proximate analysis (ash, volatile matter). The details are shown in Table 1.

Table 1 Summary of equations in literatures used to predict the higher heating value of biomass

Eq.	Model	Basis and assumptions	Ref.
1	HHV = $0.4373C - 1.6701$	This equation derives the HHV for biomass materials, and its accuracy was 5% for the entire range of biomass materials.	Channiwala and Parikh, 2002 citied from Tillman, 1978
2	HHV = $0.4571C - 2.7$	This equation derives the HHV based on the percentage of carbon in the biomass when the material is dry.	Brown, 2004
3	HHV = $0.3259C + 3.4597$	This equation derives the HHV for biomass materials, and R^2 was 0.758.	Sheng and Azevedo, 2005
4	HHV = $[33.5C + 142.3H - 15.4O - 14.5N] \times 10^{-2}$	This equation estimates the HHV for different lignocellulosic materials or biomass fuel.	Demirbas, 1997
5	HHV = $-1.3765 + 0.3137C + 0.7009H + 0.03180O$	This equation derives the HHV for biomass with a ±5% error.	Sheng and Azevedo, 2005
6	HHV = $0.196(F) + 14.119$	This equation is obtained from 16 different lignocellulosic sources, and the correlation coefficient was 0.9997.	Demirbas, 1997
7	HHV = $0.3133\ (100 - (V + F)) - 10.81408$ or HHV = $0.3133\ (100 - A) - 10.81408$	This equation derives the HHV for all types of biomass. The different residues are considered with errors < 10%.	Jiménez and González, 1991
8	HHV = $-2.737 - 0.16043M + 0.26676V$	These equations derive the HHV for rice straw and wheat straw with R^2 equal to 0.828 and 0.905, respectively.	Huang *et al.*, 2008
9	HHV = $18.65503 - 0.15473M - 0.20617A$		
10	HHV = $35.43 - 0.1835V - 0.3543A$	This equation derives the HHV for lignocelluosic materials and charcoals.	Cordero *et al.*, 2001
11	HHV = $19.914 - 0.2324A$	This equation derives the HHV for biomass with R^2 equal to 0.625.	Sheng and Azevedo, 2005

Note: HHV is the higher heating value, measured in MJ/kg; *C, H, O, N, S, A, V, M,* and *F* represent the carbon, hydrogen, oxygen, nitrogen, sulfur, ash, volatile matter, moisture, and fixed carbon concentration expressed in % of the material when it is dry.

The Food and Agriculture Organization of the United Nations (1994), however, reported that storage conditions might be a factor that changes the properties of biomass materials, because biomass materials deteriorate during storage because of biological degradation processes. These results corresponded with Phayom and Tanaka (2009) who found that the storage conditions, such as storage periods (after harvesting until 6 months), storage temperatures (10°C, 20°C, and 30°C), and the size of rice straw (untreated, cut, and milled), affected the constituents of rice straw (carbon, nitrogen, moisture, and ash concentrations), because most of the rice straw suffered degradation after harvest. Especially, during the first month of storage, concentrations of the rice straw constituents would decrease rapidly. In addition, the storage temperature of 30°C showed the greatest influence to the condition of the straw. As the storage period and storage temperature increased, carbon, nitrogen, moisture, and ash concentrations decreased from 39.9% to 33.4%, 0.50% to 0.35%, 22.1% to 11.8%, and 15.1% to 14.8%, respectively.

We sought an alternative method for determining the HHV based on two reasons: (1) The concentrations of carbon, nitrogen, moisture, and ash in rice straw vary depending on storage conditions, and (2) both previously mentioned methods to determining HHV are complicated and time-consuming processes that require set-up equipment, measuring methods, and calculating procedures. We investigated the relationship between the heating value and storage conditions to discover a way to provide a rapid, easy,