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Research Paper

The moisture sorption characteristics and modelling of agricultural biomass

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The moisture sorption properties of typical biomass samples (tobacco stem, rice husk, wheat straw, cotton stalk, corn straw and rice straw) were investigated under different conditions, and the adsorption kinetics was analysed with pseudo order models. The equilibrium moisture content (EMC) was simulated with different models based on biomass property and adsorption process. Results showed that the adsorption process of biomass can be divided into two ranges: rapid adsorption and slow adsorption process. A pseudo-second order model could better describe the moisture sorption process than a pseudo-first order model. Equilibrium moisture content (EMC) mainly depended on biomass type and environmental humidity. A modified Halsey model provided the best fit to EMC of biomass and this model can be used to predict EMC of biomass.

1. Introduction

Biomass has gained worldwide attention as a renewable energy source for thermochemical conversion (Aysu & Küçük, 2014; Damartzis & Zabaniotou, 2011; Wei et al., 2006). Biomass is hygroscopic in nature, and thus adsorbs moisture from its surroundings. The inherently high moisture content of biomass is a critical issue. However, when considering gathering and recycling these materials, it requires more energy for preprocessing, transportation, and conversion, and all of which can considerably increase the cost of utilisation (Kaewluan & Pipatmanomai, 2011; Medic, Darr, Shah, & Rahn, 2012; Serrano, Monedero, Lapuerta, & Portero, 2011). Further, water in biomass feedstock can affect the pyrolysis behaviour of biomass, e.g. the distribution of pyrolysis products, the physical and chemical properties of liquid oil and solid char, and the composition of gas (Burhenne, Damiani, & Aicher, 2013; Demirbas, 2004). To this effect, sufficient working knowledge of biomass moisture content is conducive to the

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Nomenclature

EMC, q_e, y	Equilibrium moisture content, %
TS	Tobacco stem
RK	Rice husk
WS	Wheat straw
CTS	Cotton stalk
CS	Corn straw
RS	Rice straw
$FTIR$	Fourier Transform Infrared spectroscopy
ERH	Equilibrium relative humidity, %
MC	Moisture content, %
W_t	Mass of the sample at time t, g
W_0	Initial mass of dried sample, g
q_t	Moisture content adsorbed (%) at time t, %
t	time, min
k_1, k_2	Rate constants
b_i	Regression coefficient
x_i	Experimental parameters
σ_i, σ_y	Standard deviation of x_i, y
T	Temperature, °C
A, B, C	Constants
RSS	Residual sum of squares
$RMSE$	Root mean squared error
MRE	Mean relative error
R^2	Coefficient of determination
EMC_C	Calculated value of EMC
n	Number of test data points
df	Degree of freedom

development of appropriate pretreatment methods and storage operations that support the material transportation and conversion, and, ultimately, increase the value of its utilisation. Equilibrium moisture content (EMC) is a vital parameter in evaluating the effect of external conditions on biomass moisture (Mohamed et al., 2005; Soysal & Öztekin, 1999). Moisture content of biomass that has reached a relatively steady state at certain relative humidity and temperature is known as EMC. The temperature and humidity of environmental conditions are key parameters determining EMC of biomass. Higher humidity results in a higher EMC under the same temperature, while lower temperatures lead to a higher EMC under constant humidity (Jamali, Kouhila, Mohamed, Idlimam, & Lamharrar, 2006; Karunanithy, Muthukumarappan, & Donepudi, 2013a). Arabhosseini, Huisman, and Muller (2010) found that EMC of miscanthus decreased with increasing temperature from 25 °C to 70 °C at constant humidity, and the typical S-shaped curves between EMC and equilibrium relative humidity were found for stems and leaves while the EMC values of stems were slightly lower compared to those of leaves. In addition to the temperature and humidity of the environment, EMC of biomass can be affected by its physicochemical properties. The EMC of biomass may depend on the composition, porosity, microstructure, specific surface area and other physicochemical properties (Arslan & Toğrul, 2005; Choudhury, Sahu, & Sharma, 2011; Karunanithy, Muthukumarappan, & Donepudi, 2013b). However, there little reported research on the effects of the physicochemical properties of biomass on EMC. It is important to study the physicochemical properties of biomass to better estimate the EMC of biomass.

Previous studies have investigated the EMC of different biomass such as flax straw, hemp stalk, and reed canary grass (Nilsson, Svennerstedt, & Wretfors, 2005), selected corn stover components (Igathinathane, Womac, Sokhansanj, & Pordesimo, 2005), miscanthus leaves and stems (Arabhosseini et al., 2010), amaranthus stems (Stencl et al., 2010), pine (Acharjee, Coronella, & Vasquez, 2011), aspen (He et al., 2013), corn stover and big bluestem (Karunanithy et al., 2013a). Agricultural biomass appears to be the most attractive feedstock due to its abundance, cheapness and renewability. However, relatively few studies have explored the moisture sorption process and EMC of agricultural biomass, such as wheat straw, cotton stalk, and rice straw. Different biomass materials display various moisture sorption characteristics. Therefore, it is necessary to study the moisture sorption process to better understand the hygroscopicity of biomass as a whole.

The physicochemical properties effect biomass EMC but the effect has been rarely discussed in the previous studies, therefore the mechanism of moisture sorption remains unknown. This research focusses on the effects of humidity, temperature and sample mass on the hygroscopicity of different agricultural biomass samples, and the impact of physicochemical properties on EMC of biomass. The aims of the study were to predict moisture sorption characteristics and mechanism of agriculture biomass and to explore the main influence factors that determine biomass EMC.

2. Materials and methods

2.1. Materials

Six different agriculture biomass products; tobacco stem (TS), rice husk (RK), wheat straw (WS), cotton stalk (CTS), corn straw (CS) and rice straw (RS) were selected in this study. Biomass samples were obtained from Wuhan, Hubei, China. The samples were firstly air-dried, and then ground to pass the sieves with 60 and 120 mesh. The particle size of biomass was 0.12–0.25 mm.

2.2. Biomass characterisation

The bulk density was the ratio of dry mass and volume. True density was determined by automatic true density analyser (Micromeritics, AccuPyc 1330, USA). Porosity was calculated on the basis of bulk density and true density (Githinji, 2014).

The surface organic functional groups of biomass were characterised by Fourier Transform Infrared spectroscopy (FTIR) analysis. To obtain FTIR spectra, samples were mixed with KBr (1:200, w/w) and ground, then the mixture was pressed into pellets. The biomass infrared spectra were recorded on a VERTEX 70 spectrometer (Bruker, VERTEX 70, Germany) at a resolution of 2 cm^{-1} and accumulation of 120 scans. Each spectrum was scanned from 400 cm^{-1} to 4000 cm^{-1} wave numbers.