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The effect of alkali treatment on rice husk moisture content and drying kinetics

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ABSTRACT

The utilization of rice husks for energy production is often problematic due to their high ash content. A simple method for silica ash removal is the treatment of the husks with sodium hydroxide solutions. The alkali treatment can induce other changes to the husks which need to be investigated. Here, the effects of alkali treatment on the moisture content and drying kinetics of the samples were investigated. The alkali treatment is shown to result in an increase in moisture retention by the as-prepared biomass. Response surface methodology (RSM) using a Box–Behnken design (BBD) is employed to investigate the effects of various input parameters, namely reaction temperature, duration, and alkali mass ratio on moisture uptake of the rice husk. In addition, the drying kinetics of the as-prepared samples are modeled and compared to raw husk prior to treatment. The results show a small increase in the effective diffusivity and a significant decrease in the activation energy required for drying the treated samples.

1. Introduction

With increased problems associated with fossil fuels, agricultural residues and other biomass are frequently recognized as important alternatives for the global energy crisis [1–3]. Rice is currently one of the most cultivated plants with just under 700 Mt produced each year. China, India, and Indonesia are the highest producers in the world, respectively [4]. The rice grain is covered and protected by an outer layer known as the husk, hull, or chaff which is not edible and is removed in the first stage of the milling process. For every 100 kg of milled paddy, about 20–22 kg of husk is disposed [5,6]. Among other things, the composition of the rice husk is influenced by environmental conditions such as the weather. The silica mass fraction of dry rice husk is generally higher in the dry season than in the wet season (18% mean vs 15% mean) [5].

Using rice husks as feedstock for energy production [7–13] is among the most popular utilizations of these wastes. Other applications have also been proposed [14–19]. The high silica ash content of rice husks [20] is one of the hindrances of using these wastes for electricity generation. The higher heating

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Table 1 – Experimental values used in the BBD.

Factor	Name	Units	Low (−1) value	Center (0) value	High (+1) value
X_1	Temperature	K	298.16	330.66	363.16
X_2	Time	s	14,400	50,400	86,400
X_3	Mass ratio of alkali to husk	kg kg^{-1}	0.01	0.13	0.25

value of biomass reportedly decreases due to high ash content [21]. During heat and power generation from rice husks, the ash may melt and adhere to heat transfer surfaces. The slagging and deposition of ash can lead to decreased safety, reliability, and economy. Slagging and fouling also result in corrosion and erosion problems which reduce the utilization efficiency and lifetime of the equipment. Hence the existence of excessive ash can increase the probability of unwanted shutdown for maintenance and cleaning [22–25]. Using alkali treatment in order to remove silica ash in the form of sodium silicate is a common and effective solution for ash reduction [26–37].

When moist biomass is used for gasification or pyrolysis processes, energy consumption is increased due to dewatering. In combustion processes moisture reduces the lower heating value (LHV) [38]. This is because of the non-recoverable heat loss carried by the moist flue gas. Hence plant operation is worsened and the combustion efficiency is diminished. High moisture can also lead to lower combustion temperatures causing incomplete combustion and the emission of pollutants due to the formation of undesired reaction products [39]. In addition, more auxiliary fuel is required to render moist feedstock combustible [40]. Although combustion can be sustained with a moisture mass fraction above 50%, the optimum sought mass fraction is below 15% [41].

On the other hand, Response Surface Methodology (RSM) is a technique used for analyzing the effects of various variables on selected responses. RSM has been used as a powerful tool for a wide variety of experimental designs [42–44]. In this manuscript, RSM is used to discern the effects that alkali treatment may have on the moisture uptake of the rice husks. In addition, the drying kinetics of the raw sample is compared to that of the alkali-treated sample.

2. Materials and methods

2.1. *Alkali treatment*

The rice (IR 8 variety) were grown in a paddy field in the Hunan province of mainland China and harvested and milled in July 2012. The rice husks were donated to the research group by Peako Biomass Energy Ltd and used in the alkali treatment experiments without prior washing or treatment. In each experimental run, a sodium hydroxide solution was used to treat the husk at a desired temperature and duration under reflux. For all experiments, 500 mg of dry husks were placed in 50 cm^3 of the solution. The slurry was agitated with a magnetic stirrer to ensure adequate mixing. After the reaction, the remaining solids were washed with 2 L of water to ensure all soluble fractions were removed. The as-prepared samples were then collected and dried.

2.2. *Design of experiment*

Temperature (X_1), treatment duration (X_2), and mass ratio of alkali to husk (X_3) were used as the three input variables for a 3-factor, 3-level Box–Behnken Design of Experiment (BBDOE). One of the primary advantages of using a BBDOE is that the experimental points remain within the defined experimental boundaries. In other words, extreme treatment combinations such as those of corner and star points of other designs are avoided. The mass ratio of alkali to husk is defined as the NaOH mass used in the solution per unit mass of the dry husk. For example, a 0.25 ratio means the weight of NaOH used in the solution is one fourth of the dry weight of the rice husk. The moisture mass fraction was used as the response variable. Table 1 shows the low, center, and high levels of each factor denoted as −1, 0 and +1.

Design Expert v.7 statistical software was used to plan 17 experiments in randomized order. The mathematical relationship between the variables and the response was modeled using a polynomial equation:

$$Y = \beta_0 + \sum_{i=1}^{3}\beta_i X_i + \sum_{i=1}^{3}\beta_{ii} X_i^2 + \sum_{i=1}^{2}\sum_{j=i+1}^{3}\beta_{ij} X_i X_j \quad (1)$$

where Y is the predicted response (moisture mass fraction) and X_i and X_j are the independent variables (temperature, treatment duration, and alkali to husk mass ratio). The intercept term, linear effects, squared effects and interaction effects are respectively denoted β_0, β_i, β_{ii} and β_{ij}.

2.3. *Drying kinetics*

To determine the effects of alkali pretreatment on drying characteristics, the samples were dried at constant temperatures of 333, 353 and 373 K, using a thermogravimetric analyzer. The sample materials were distributed uniformly in a Platinum sample pan of 1 mm height with sample mass of 7 ± 1 mg. The nominal thickness of the material was considered to be the same as the height of the sample pan.

The drying processes can be modeled by defining a dependent variable called the moisture ratio (MR) that associates the gradient of the sample moisture content to both initial and equilibrium moisture contents. The equation of moisture ratio is defined as follows [38]:

$$MR = \frac{M - M_e}{M_o - M_e} \quad (2)$$

where M represents the moisture mass fraction at any time, t; M_o is the initial moisture mass fraction; and M_e is the equilibrium moisture mass fraction of the sample. The equilibrium moisture mass fraction is the point at which further drying does not decrease the sample weight.

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