Optimization of Rice straw Pretreatment using Hot water for Energy Generation

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ABSTRACT - Using rice straw for combustion in boilers has been quite effective and productive despite the drawbacks created by the ash content, which causes a range of severe ash related problems upon combustion such as slag formation, fouling, sintering and agglomeration. Here, hot water pretreatment of rice straw for ash removal has been studied using response surface methodology (RSM) and Analysis of Variance (ANOVA) by varying temperature, washing time and water-to-biomass ratio as independent variables. After generating a mathematical model, operating conditions were optimized and the effect of water washing on the calorific value of rice straw was investigated.

Key words: Optimization; Rice straw; Water washing; Ash removal

INTRODUCTION

Nowadays, there is a trending favor for utilizing the renewable energy resources. In the wake of issues with fossil fuels, biomass is commonly recognized as one of the vital alternatives (Bazargan, Bazargan, & McKay, 2015). Rice is the second most abundant crop after corn and it has few challenges during its combustion. Rice straw has both organic and inorganic constituents in it. Inorganic components react with each other at high temperatures, resulting some complications in the boiler systems. Moreover, high percentage presence of K and Cl in rice straw, leads to a high tendency for mainly ash fouling, slagging and other issues in boiler systems. The findings up to now, shows that water washing is a good treatment for problem causing chemical elements such as K, Na, Ca, Mg, Fe, Al, Si, Cl and S, which exist in Rice straw (Gudka, Jones, Williams, & Saddawi, 2016). In contrast, it has been found that heating and washing causes ~~for~~ a slight organic content loss, which adversely affects for the Biomass quality (Komilis, Kissas & Symeonidis, 2014). Here, hot water pretreatment of rice straw for ash removal has been studied using response surface methodology and Analysis of Variance with the objective of maximizing the ash removal while retaining the organic constituents. Three independent variables namely temperature, washing time and water-to-biomass ratio were considered under the Box-Behnken design (BBD) for the experiment. Then the operating conditions were optimized to maximize the ash removal while minimizing the usage of water and treating temperature. Finally, the effect of hot water washing on the calorific value of rice straw was qualitatively and quantitatively investigated.

METHODOLOGY

Sample preparation

Unwashed rice straw collected from a paddy field in Anuradhapura District was cut down to small pieces manually using a scissor and then grinded for a duration of 5 minutes. Then a Sieve Analysis was carried out according to the British Standard (BS en-993-1-1997) to select a particular particle size for experimentation.

Washing Procedure

Water was added into the water bath and the metal container was submerged in the middle of the hot bath. Water amount required to fulfill the relevant water-to-biomass ratio was added into the metal container. Water bath was heated to achieve the target temperature. 10g of Rice straw was added inside and agitated evenly under the specified temperature, up to the specified time. After washing and after two days of air drying, Moisture content and the Ash content of washed samples were determined following the British Standard method BS EN 14774-3:2009.

Design of Experiment

A 3-factor, 3-level Box-Behnken Design (BBD) was used for the Design of Experiments (DOE). The three parameters to evaluate were selected as temperature, washing time and water-to-biomass ratio. Ash removal percentage was used as the response variable. A total of 15 experiments were planned by the Design Expert v.10 statistical software in randomized order. A quadratic equation was used to model the mathematical relationship between the variables and the response.

Determination of the Calorific value

The air-dried straw sample was compressed from a hydraulic Press to densify as pellets and then, the calorific value was determined using the Bomb Calorimeter.

RESULTS AND DISCUSSION

Fit summary and Model fitting

After entering the ash removal% data into the Design-Expert software, it generates a fit summary which is used to identify which model should be chosen for in-depth study.

Based on those facts, quadratic model was the best for in-depth study of our design.

ANOVA (analysis of variance) table was used to evaluate the statistical significance of the selected quadratic model's coefficients and then to remove insignificant terms from the model.

Table 1. ANOVA for ash removal percentage after removal of insignificant terms

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	53.18	6	8.86	287.41	< 0.0001	significant
A-Temperature	19.01	1	19.01	573.48	< 0.0001	
B-Washing Time	28.85	1	28.85	870.43	< 0.0001	
C-Water to Biomas	0.69	1	0.69	20.92	0.0016	
AB	0.91	1	0.91	27.37	0.0008	
A²	0.75	1	0.75	22.53	0.0015	
B²	3.18	1	3.18	95.87	< 0.0001	
Residual	0.27	8	0.033			
Lack of Fit	0.20	6	0.033	1.00	0.5781	*not significant*
Pure Error	0.066	2	0.033			
Cor Total	53.44	14				

After removing the insignificant terms, empirical relationship between the response and independent variables was developed.

$$\text{Ash removal percentage (\%)} = -0.018298 + 0.25921 \times A + 0.23421 \times B + 5.8875 \times 10^{-3} \times C - 7.9375 \times 10^{-4} \times AB - 1.12096 \times 10^{-3} \times A^2 - 1.02737 \times 10^{-3} \times B^2$$

Where A is the temperature, B is the washing time and C is the water-to-biomass ratio, respectively.

Response surfaces

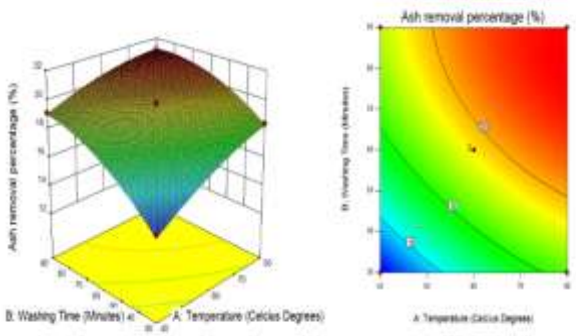

Figure 1. Effect of temperature and washing time on ash removal percentage

From figure 1, it is apparent that high temperature and high washing time leads to higher ash removal.

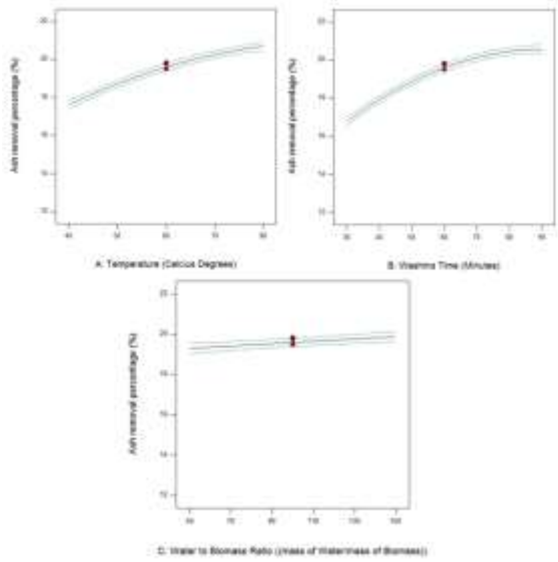

Figure 2. Effect of single factors

It is apparent that that the water-to-biomass ratio is less impactful for the ash removal percentage, rather than temperature or washing time.

Model optimization

Adequacy of the final model was checked using Normal Probability plots and Studentized Residuals plots to avoid misleading results and then proceeded into optimization part. The model was optimized then to meet the maximum ash removal%, minimum usage of water and minimum treating temperature.

CONCLUSION

Untreated rice straw has 15.3% ash in its composition and 21% of ash removal can be expected by treating with water at elevated temperatures. 19.831% ash removal can be expected at the optimum condition (56.7^{0}C of temperature, 73.8 min of washing time and 65.9 of water-to-biomass ratio). The calorific value of rice straw is dropped by 10-12% due to the pretreatment with hot water.

REFERENCES

Gudka, B., Jones, J. M., Lea-Langton, A. R., Williams, A., & Saddawi, A. (2015). *A review of the mitigation of deposition and emission problems during biomass combustion*

Komilis, D., Kissas, K., & Symeonidis, A. (2014). *Effect of organic matter and moisture on the calorific value of solid wastes*

Saddawi, A., Jones, J. M., Williams, A., & Le Coeur, C. (2012). *Commodity Fuels from Biomass through Pretreatment and Torrefaction*