COMPREHENSIVE EVALUATION OF RICE HUSKS AS A POTENTIAL SOLID BIOFUEL

Van Minh Duong[a], František Skácel[a], Jitka Hrbek[b]

[a]University of Chemistry and Technology Prague, Technická 5, 166 28 Prague 6, Czech Republic
[b]Vienna University of Technology, Getreidemarkt 9/166, 1060 Vienna, Austria
Email: Duong.Van.Minh@vscht.cz

As the common crop residues in Vietnam, rice husks can potentially be a technically efficient, economically viable and environmentally sustainable bio-energy option, release a considerable heat for thermo-chemical conversion systems. The report provides a comprehensive evaluation in the nature, physico-chemical property, fuel characteristic, ash composition and transformation phenomena of this biofuel. Analysed results show significant calorific value (16-17 MJ/kg), high ash and volatile contents, low S, Cl contents in the test pieces. Low alkali cations were reported in the ash compositions while the obtained Si value was relatively high. Ash softening and fusion processes were determined with heat generated continuously at constant rates (maintained at 550 ± 10 °C for 120 minutes, at 850 ± 10 °C for 240 minutes). First signs of deformation were recorded at temperature above 1450 °C, whereas volume expanding and bursting of internal gas bubbles were not presented. Further elemental determination of ash compositions explains the decomposition of ash-forming elements (Ca, Mg, Fe, Al, K, Na and P), by further oxidation (to higher oxidation states) and partial losses of volatile inorganic compounds.

Keywords: agriculture biomass, bioenergy, solid biofuel, rice husks, ash melting

Received: 21. 06. 2018, accepted: 20. 09. 2018

1. Introduction

In the global context, there is a growing interest in the diversification of biomass targeted to bio-energy production, gradually replacing conventional energy sources. Among the agricultural residues, rice husks and straws are important biomass source for heat and electricity generation due to their commodity vary widely [1, 2]. In Vietnam, large amount of rice husks and straws have been main field based residues of rice production for centuries. Recently, the use of rice husks and straws is highlighted as a potential non-woody biomass resource [3].

More than 65 % rice crops of which takes place in Vietnam, mainly in three dynamic harvests [4], starting from February to April (the winter-spring season), followed by the summer-autumn harvest (June to August) and respectively from October to December (the autumn-winter season). The total quantity of rice husks in Vietnam was estimated at 7.5 million tons per year, of which 52.5 % was generated during the winter-spring season [5]. The availability of rice husks supply depends on the rice production, harvesting episode, proportion in a paddy and bio-energy use schedule. The proportion of rice husks and straws to rice is approximately one. Particularly, rice straw is generally placed in a field for drying 3-5 days remain used non-commercially in traditional applications (such as cooking stoves); when its moisture content could be around 10-12 %.

Previous studies [6, 7] have summarized that the popular use of solid biofuel is direct combustion for heat, which is the most common technical option with the low efficiency. In practice, households use various fuels in combination not just one type of fuel, in which only 7 % of them use rice husks as a bio-energy. However, after pre-drying, rice husks and straws can be effectively burned with relatively weak environmental impacts. The use of rice husks for brick kiln (25 %) and other industrial purposes (10 %) is rapidly spread because of lower prices, local availability and reliability of supply. A higher efficiency alternative is using the gases synthesized from rice husk in a gasification system, such as CO, H_2 and volatile hydrocarbons for electricity generation followed by internal combustion engines and generators [8]. Pyrolysis is becoming more important with high potential of energy recovery process which generates char, oil and gas products, all of which was applied at the industrial production scale [9]. Moreover, the utilization of rice husks and electrical production shifting increase the efficiency of energy saving, and hence secure power supply.

Therefore, the thermo-chemical conversion of rice husks is an option to advance the eco-friendly and efficient production of heat and power, as well as the generation of valuable products for the chemical industry based on renewable carbon sources. Several pre-feasibility studies and pilot projects were carried out to install power plants in the Mekong river delta [11, 12]. The co-firing of rice husks in the combustion systems can be an innovative option with the aim of achieving more effective utilization. As the first relevant issue for all types of thermo-chemical conversion technologies, the physico-chemical characterization of rice husks must be analyzed in order to evaluate their ash fusion. The obtained values define the behavior of the fuel during the pyrolysis, gasification and combustion stages, and thus support the proper design and operation setting [13].

2. Experimental

2.1. Fuel analysis

The nature and efficiency of any thermo-chemical conversion process depends strongly on fuel properties, and hence influences the end-use applications and further flue gas controlling options. In practice, the whole process of biomass utilization including material supply, fuel analysis, application design, system testing, gaseous emissions, etc., strongly depends on the physical characteristics and chemical composition. The medium and large scale systems are suitable to combust low-quality fuel, while the smaller combustion plant demands higher fuel quality concerning the homogeneity.

Figure 1. Available sample size of 8-mm for rice husks pellets.

The qualities of biomass pellets vary widely, influenced mainly on the pre-treatment technologies applied. Figure 1 shows the use of 8 mm diameter pellets with the moisture content between 8-10 % (determined by oven dry method, CEN/TS 14774-2) is always the first step to reduce the bulky volume of raw materials during transportation and increase the heat exchange efficiency. Physical parameters are particle dimensions, bulk and energy density, gross and net calorific value and moisture content. Depending on the fuel preparation process, the particle size distribution is normally homogeneous, appropriate for small-scale fuel-feeding system and combustion units.

Table 1 summarizes the important values of investigated fuel. Recorded calorific values (determined by CEN/TS 14918:2009) approximately 16 MJ/kg indicate a potential heat release and the influence the process control during combustion, gasification and pyrolysis. Pellets moisture content specifies a considerable influence in the combustion behavior; the volume of flue gas produced and average residence drying time before gasification takes place.

Carbon and hydrogen, which are the main components of solid biofuel, explain the low calorific value of rice husks, in comparison to other biofuel. High amount of volatile matter in rice husks caries between 68.5 % (determined by CEN/TS 15148:2009) indicates major part of this fuel is vaporized before homogeneous gas phase combustion reactions take place strongly influences the thermal decomposition and combustion behavior [14].

Table 1. Physico-chemical properties of the tested rice husks.

Parameter	Value	Unit
w_C (dry)	0,431 6	-
w_H (dry)	0,051 8	-
w_N (dry)	0,004 7	-
w_S (dry)	0,000 6	-
w_{Cl} (dry)	0,000 9	-
w_{H_2O}	0,074 4	-
w_{ash}	0,149 9	-
w_{daf}	0,685	-
gross calorific value (dry)	16929	kJ/kg
net heating value (dry)	15791	kJ/kg

Nitrogen oxides, HCl, Cl_2, alkali chlorides formation, gaseous compounds of SO_2, SO_3 and alkali sulphates released during the combustion process are important not only for emission control but also in corrosion processes [15]. Emission and environmental issues can be controlled with the adequate concentration of nitrogen (according to CEN/TS 15104), chlorine and sulphur (specified in CEN/TS 15289) reported in the rice husks pellets.

2.2. Ash melting behavior

A number of researchers [16] reported that thermochemical conversion technologies involve a number of physical and chemical aspects of high complexity. Particularly, ash transformation during combustion of biomass is a very complex phenomenon, which can exhibit many essentially different scenarios [17]. The ash content value indicates a considerable influence on the technology applied, de-ashing process, transport, storage, utilization and disposal of the produced ash [18].

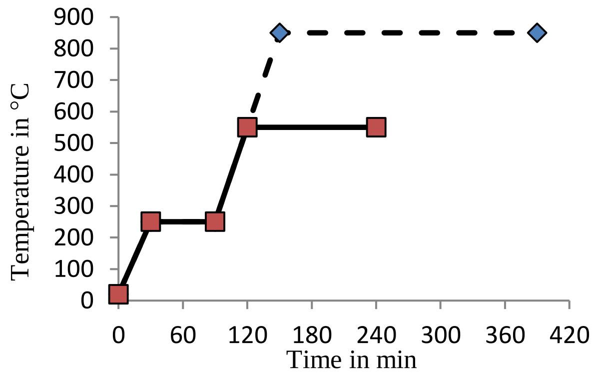

Figure 2. Ashing and conditioning of test portions in the different empirical conditions.

Each sample of rice husks was analyzed at least twice at the standard condition 550 °C for 120 min (specified in CEN/TS 14775) and the average value of the ash content is presented in mass percentage referring to the dry sample.

Ash softening and fusion processes were determined by optical standard lab-scale testing method according to DIN 51730. Different sets of ashes were conditioned (maintained constantly at 550 ± 10 °C for 120 minutes and practically at 850 ± 10 °C for 240 minutes) as showed in Figure 2. Test pieces were pressed to the small geometric bodies depicted in Figure 3. The heat was generated continuously at the constant rates, then the changes in shapes were simultaneously recorded by the optical system.

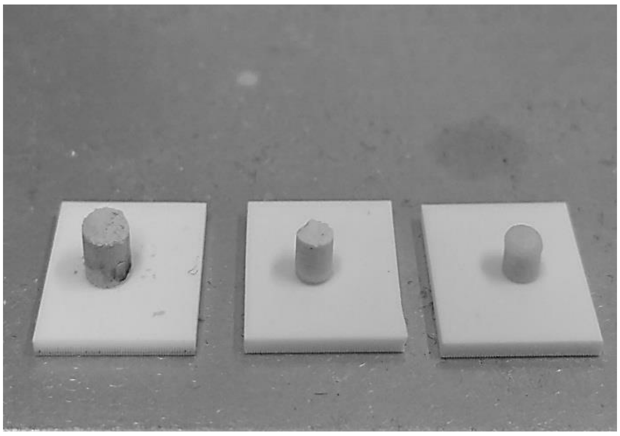

Figure 3. Test pieces observed (from left to right) in initial, shrinkage and deforming states

Beside the standard analyses methods to biofuels, the X-ray spectrometry on samples of conditioned ashes was applied for major and minor element analyses (according to CEN/TS 15290 and CEN/TS 15297).

3. Results and discussion

The recorded value 14.99 % in ash content of rice husks samples indicates a considerable influence on the combustion technology applied, de-ashing process, transport, storage, utilization and disposal of the produced ash. This high value usually lead to higher particulate matter emission, as an influence on the heat exchanger design, cleaning system and dust control technology.

Figure 4 shows the remarkable changes in ash characteristic and melting tendency between tested materials. The observed volume shrinking at 1000 °C only in the test specimens conditioned at 550 ± 10 °C for 120 min can be explained by the decomposition of major ash-forming elements (Fe, Mn, Ca, K, Cl, S, P, Al, Mg, Na and especially Si), by further oxidation (to higher oxidation states) and partial losses of volatile inorganic compounds. This phenomena practically recovered in the fly ash, and the decomposition of carbonates forming CO_2 mainly be released with other gaseous compounds.

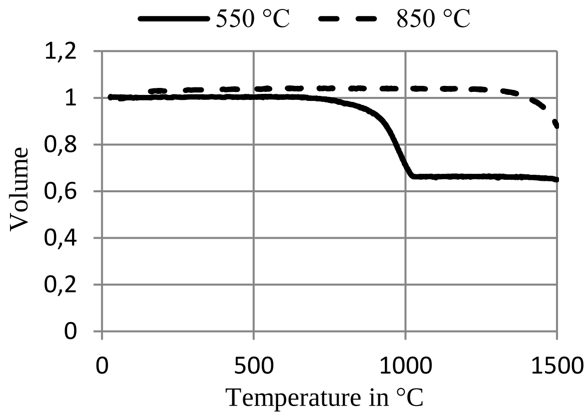

Figure 4. Observed difference in ash melting tendency

Rice husks specimens showed first signs of ash deformation at temperature above 1450 °C which is higher than the critical values of solid biofuel capable for the classic combustion or gasification processes in a fluidized bed. This high ash-melting point characterize rice husks as good solid biofuel for the modern combustion/gasification technologies, in terms of avoiding the sintering factors, decrease emission, minimize corrosion, maintain the operational safety control.

Volume expanding and bursting of internal gas bubbles were not presented in the test pieces. High concentration of major cations and ash-forming elements especially Si, Ca, Mg, K, Na and P were determined. Figure 5 shows the significant low alkali contents in the ash compositions while the obtained Si value was relatively high. The low alkali content is responsible for the high ash softening temperature, which in practical avoids the agglomeration of bed materials, minimize the risk of breakdown of the fluidized bed system and stop a combustion/gasification test at an early stage.

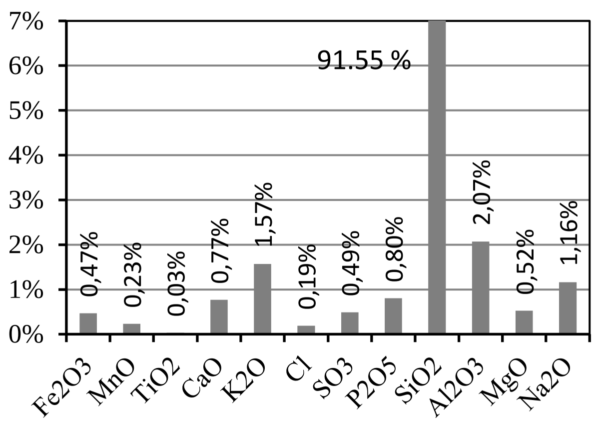

Figure 5. Ash elemental compositions in the tested specimens conditioned at 550 ± 10 °C for 120 min

4. Conclusions

The paper provides a comprehensive evaluation in nature, physico-chemical property, fuel characteristic, ash composition and transformation phenomena of rice husks. As a common source of biomass in the Vietnam, one of the world leading countries in rice production, they can be qualified as solid biofuels for energetic use.

Significant calorific values provide a potential heat release for industries, utilities, communities and households if appropriate bio-energy technologies applied. This biofuel shows high ash softening temperature, which is the advantage to avoid the technical issues in the thermo-chemical conversion systems. Specific elemental determination in the compositions of ashes is further recommended to avoid consequences related to slag formation and corrosion in the equipment.

Comparative analyzed results outlined an extensive principal baseline for further empirical investigation, cofiring of rice husks and other biofuel, innovative combustion technology, better efficiency performance. The shift to modern application using these biofuels should be performed corresponding to emission characteristic of solid and gaseous pollutants. Highlighting the benefits of greenhouse gas (GHG) reduction, rice husks can be a technically efficient, economically viable, and environmentally sustainable option, partly replaces conventional fuel.

Acknowledgements

This work was carried out under the Programme Erasmus+ Key Ation 1 in research exchange and staff mobility between member states. An acknowledgement would be given the European Commission for their excellent contributions. The authors would express their appreciation to the analytical groups at UCT Prague, TU Vienna and the University of Vienna for their excellent technical assistances.

References

1. Abe H. et al.: Potential for rural electrification based on biomass gasification in Cambodia; Biomass and Bioenergy 31(9), 2007, 656-664.
2. Chungsangunsit T. et al.: Environmental assessment of electricity production from rice husks: a case study in Thailand; International conference on electricity supply industry in transition: Issues and prospect for Asia, Bangkok, Thailand, 2004, Proceeding 20, 51-62.
3. Vietnam I. E.: Bagasse and other biomass-fired power plant in Ben Tre sugar company; a pre-feasibility study report. Vietnam Institute of Energy, Hanoi, Vietnam, 2006.
4. Nguyen N., Duong H. M.: Economic potential of renewable energy in Vietnam’s power sector; Energy Policy 37(5), 2009, 1601-1613.
5. Pham T. M. T. et al.: Greenhouse gas emission mitigation potential of rice husks for An Giang province, Vietnam. Biomass and Bioenergy 35(8), 2011, 3656-3666.
6. Fang M. X. et al.: Experimental study on rice husk combustion in a circulating fluidized bed; Fuel Process Technology 85, 2004, 1273-1282.
7. Bhattacharya S. C. et al.: Some aspects of fluidized bed combustion of paddy husk; Applied Energy 16 (4), 1984, 307-316.
8. Aigner I., Pfeifer C., Hofbauer H.: Gasification of coal and wood in a dual fluidized bed gasifier; Fuel 90 (7), 2011, 2404-2412.
9. Islam M. et al.: Techno-economics of rice husks pyrolysis, conversion with catalytic treatment to produce liquid fuel; Bioresour Technol 73(1), 2000, 67-75.
10. Armesto L. et al.: Combustion behavior of rice husks in a bubbling fluidized bed; Biomass and Bioenergy 23(3), 2002, 171-179.
11. Vietnam I. E.: Demonstration of rice husks fired power plant in An Giang province: a pre-feasibility study report; Vietnam Institute of Energy, Hanoi, Vietnam, 2004.
12. Nguyen V. H. & Nguyen, V. S.: Clean development mechanism project design documents for pilot grid connected rice husk fueled bio-power development projects in Mekong Delta; EEPSEA, 2006, Vietnam.
13. Schmid J. C. et al.: Steam gasification of exhausted olive pomace with a dual fluidized bed pilot plant at TU Wien; Technical report PHENOLIVE FP7-SME-2013-1-605357, 2016.
14. Mansaray K. G. et al.: Air gasification of rice husks in a dual distributor type fluidized bed gasifier; Biomass and Bioenergy 17(4), 1999, 315-332.
15. Permchart W., Kouprianov V. I.: Emission performance and combustion efficiency of a conical fluidized-bed combustor firing various biomass fuels; Bioresour Technol 92, 2004, 83-91.
16. Wopienka E., Hofbauer H.: Properties and slagging behavior of ashes from small-scale biomass combustion; Dissertation 2014, TU Wien, Austria.
17. Bostrom D. et al.: Ash transformation chemistry during combustion of biomass; Energy & Fuels 26, 2012, 85-93.
18. Natarajan E. et al.: Overview of combustion and gasification of rice husks in fluidized bed reactors; Biomass and Bioenergy 14(5), 1998, 533-546.