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Review

Pretreatment for energy use of rice straw: A review

Foday Robert Kargbo*, Junjun Xing and Yanlin Zhang

College of Engineering and Technology, Huazhong Agricultural University, Wuhan, 430070, China.

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Utilization of rice straw as renewable energy source has attracted increasing interest since the past two decades. However, rice straw has low heating value, low bulk density and significant amount of alkali and alkaline compounds. This makes it difficult to handle, transport and store efficiently hence limiting the commercial use of rice straw. These properties can be improved by pretreatment of the residue. This paper therefore explores the literature for information on some fundamental pretreatment techniques of rice straw to provide a basis understanding on how it could be improved as an attractive fuel for energy production. The pretreatment technologies discussed in this paper include sizing, torrefaction washing/ leaching, bailing and pelletizing. The aforementioned treatments improve both physical and chemical properties of rice straw by increasing the energy conversion and combustion efficiencies, reduce slag formation in the furnaces and grates etc thus minimizing the associated costs and logistics of handling, transport and storage which could encourage the commercial use of rice straw as a feedstock for heat and power production.

Key words: Rice straw, pretreatment, biomass, renewable energy, heating value, bulk density, conversion and combustion efficiency.

INTRODUCTION

Straw as agricultural waste biomass could be a source of alternative energy to substitute fossil energy for reducing greenhouse gas emission as well as avoid the local pollution problems from open burning. Rice straw is attractive as a fuel because it is renewable and consider to be carbon dioxide neutral (Atchison, 1996; Jiang Gaoming, 2007) but has not yet been commercially used as a feedstock for heat and energy because of insufficient incentives or benefit for farmers to collect rice straw instead of field burning. Direct comparison of straw with coal, still the dominant solid fuel in electricity and heat generation, often reveal inferior properties of straw.

In particular, it has a low energy density and heating value, is a bulkier fuel (with poorer handling and transportation characteristics), its fibrous nature and high content of alkali could potentially cause slagging, fouling and grate sintering (Calvo et al., 2004; ENC, 2004). Straw contain silicon oxide (SiO_2) which could result in high quartz ashes that can cause erosion problems in the convective pass of the boiler and handling systems. These properties have negative impacts during energy conversion such as lower combustion efficiency and performance, high wear and maintenance for processing equipments and can cause operating problems that affect boiler/ furnace reliability and operating cost. This reduces the use of rice straw for energy production in many rice producing countries.

A major hurdle with respect to the utilization of rice straw for chemical and energy production is the associated costs and logistic of collecting, transport, handling and storage. Straw fuels have proved to be extremely difficult to burn in most combustion furnaces, especially those designed for power generation due to the rapid formation of deposits (Baxter et al., 1996) such deposits retard the rate of heat transfer, slag formation in the furnace and on grates hinder fuel feeding, combustion and ash removal and handling (Baxter, 1993; Jenkins et al, 1998). These problems increase the cost of generating power from low quality fuel because they reduced the facility efficiency, capacity and availability.

Pretreatment of straw has proved to increase both its physical and chemical properties thereby, minimizing the costs of transport, handling and storage. These applications concerned with improving combustion efficiency and reducing pollution emission. However, the pretreatment technologies must be especially efficient to compensate for the costs involved in straw collection, transport, hand-

*Corresponding author. E-mail: fodayrkargbo@yahoo.com. Tel: +862715172529575 or +862713277908018.

Table 1. Proximate composition and selected major elements of ash in rice straw, rice husk and wheat straw.

	Rice straw	Rice husk	Wheat straw
Proximate analysis(% dry fuel)			
Fixed carbon	15.86	16.22	17.71
Volatile matter	65.47	63.52	75.27
Ash	18.67	20.26	7.02
Total	100.00	100.00	100.00
Elemental composition of ash (%)			
SiO_2	74.67	91.42	55.32
CaO	3.01	3.21	6.14
MgO	1.75	< 0.01	1.06
Na_2O	0.96	0.21	1.71
K_2O	12.30	3.71	25.60

Source: Jenkins et al. (1998).

transport, handling and storage.

This review aims to give an overview of some of the available pretreatment technologies for energy application of rice straw. It also provides an overview of rice straw quality as this property has an influence on pretreatment efficiencies.

RICE STRAW QUALITY

The chemical composition of feedstock has a major influence on efficiency of bioenergy generation.

Table 1, List the chemical properties (fuel properties) of three agricultural residues: rice straw, rice husk and wheat straw to highlight the particulate differences in feedstock.

Rice straw has low quality feedstock primarily determined by a high ash content (10 - 17%) as compared to wheat straw (around 3%) and high silica content in ash in rice (SO_2 is 75%) straw and in wheat 55% (Baxter LL, 1993; Zevenhoren, 2000).

On the contrary rice straw feedstock has relatively low total alkali content (Na_2O and K_2O comprise < 15% of total ash) whereas wheat straws have < 25 alkali content in ash (Baxter et al., 1996). Based on its slagging index, Rs 0.04, fouling index, Rf 0.24. Rice straw is not expected to have significant operating problems or different emission compared with wheat straw and rice husk under similar operating condition (Shabbir and Trilib, 2009).

Rice husk which is also of poor feed quality, caused mainly by high silica content (Table 1), but its uniformity in size and easy procurement are advantages. Thus the preferred use of this biomass for energy is related to both availability and quality.

PRETREATMENT TECHNOLOGIES

Many different pretreatment techniques seem to be available for rice straw in principle (Figure 1), but Commercial use of rice straw for energy is still not found in many rice producing countries because of the associated costs and lack of incentives or benefits for farmers to collect the straw instead of burning it in the field which increases greenhouse emission and environmental pollution.

The sections below describe the principles procedures of the possible pretreatment technologies, their advantages and difficulties encountered in the use of rice straw.

Sizing

This involves the cutting of straw into smaller sizes to improve boiler efficiency. Dried rice straws with length ranges from 70 - 140 cm are cut to sizes less than 50 (10 - 5, 5 - 2 or < 2 mm) at the inlet by the blade at the rotating knife holder of a homemade machine (grinding and hammer mills). Preparation of rice straws for co-firing in a boiler requires reducing the material to smaller sizes to increase the energy conversion efficiency and combustion performance (Annamala, Wooldridge, 2001). Large particles biomass feedstock such as palm shell and wood chips could provide a boiler efficiency of about 70% while the small size biomass such as rice husk, cut straw and sawdust could provide boiler efficiency of 75% (Omori, 2006).

It is usually not practical and not necessary to bring the biomass feedstock to the same size and shape as coal. However large and spherical biomass particles cause challenges for fuel conversion efficiency such sizes would cause an incomplete combustion of biomass.

Fine sized straws (5 - 2 mm) improve the combustion behavior (strehler and stuetzle, 1987). However, large sizes (10 - 5 mm) of biomass does not adversely affect the combustion performance.

This technology is not commercially used and or not

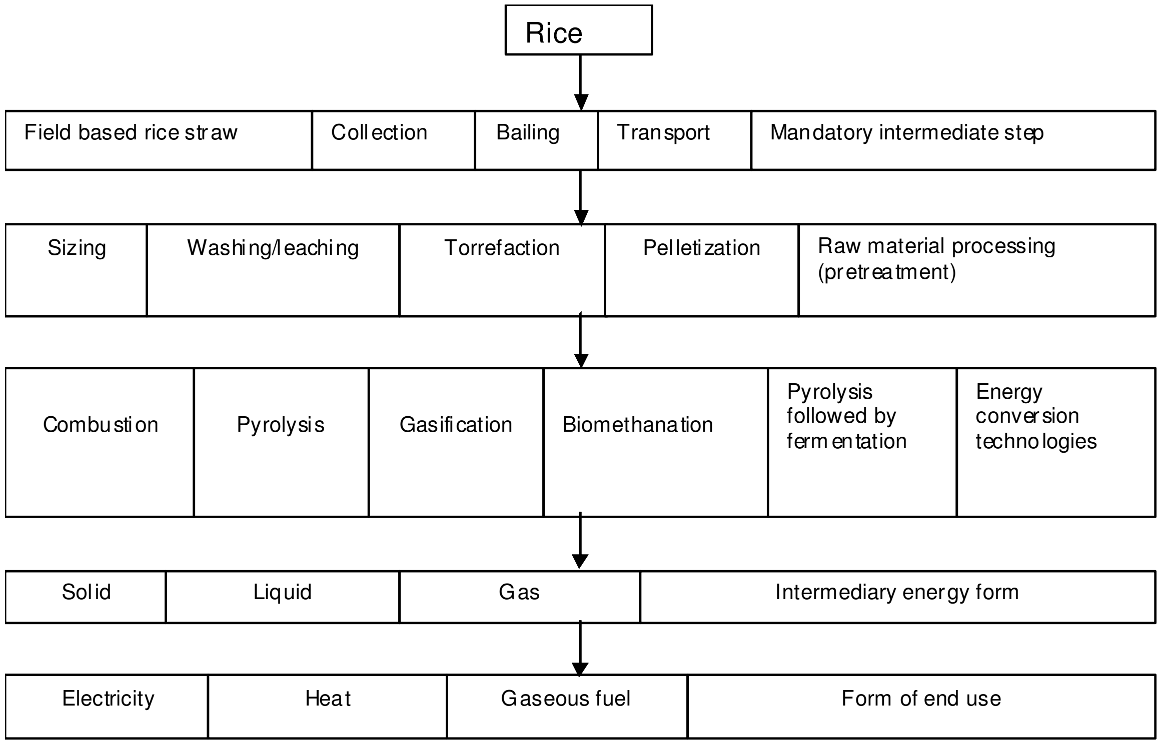

Figure 1. Pretreatment and energy conversion of rice straw (Fristsche, 2005).

feasible in most rice producing countries because of the costs related and unavailability of simple straw cutting or sizing machines.

Torrefaction

This is a pretreatment technology which serves to improve the properties of agricultural biomass in order to deal with such problems as high bulk volume, high moisture content and poor grindability in relation to thermochemical processing techniques for example combustion, co-combustion or gasification. It involves the combustion of biomass in a vertical reactor at temperature between 200 to 300°C for 30 min under inert atmosphere to obtained solid, liquid and gasses products of high porosity, greater reactivity during combustion and gasification. Volatile component of biomass is both reduced and altered producing a more thermally stable product.

It improves the grindability and fluidization properties of straw to enable more efficient co-firing in existing power stations. Torrefied biomass can be produced with grindability comparable to coal and with combustion reactivity comparable to wood. Torrefied wood showed an increase of approximately 15% in heating value and a decrease of approximately 73% in equilibrium moisture. The maximum increase of the heating value of the torrefied residue compared with the raw material is 17% (Jones et al., 2004) It also show that torrefied briquettes achieved hydrophobic character and remained unaffected when immersed in water (Asia pacific international symposium on combustion and energy utilization May, 2002).

Although this pretreatment technology has gathered interest in the past two decades, further understanding is required for optimization of the technology thus enhancing economic efficiency, which is crucial to the success of the treatment commercially and within industries.

Washing/ leaching

This is done to remove troublesome elements in the straws that cause slagging, fouling and possibly reduce corrosion in furnaces and other thermal conversion systems (Davidson et al., 2002; Miles et al., 1993). It is done by spraying water over the top of a 30 cm thick straw bed supported on an expanded steel mesh, pouring either tap or distilled water through the sample spread over a fine mesh stainless screen or submerging and soaking the sample in distilled water.

Elements including K, Na and Cl are easily remove in both tap and distilled water (Jenkins et al., 1995). Forty percent of K was removed from rice straw in 15 min of submergence (Garland, 1992) and total ash is reduced by 10% in rice straw.

The feedstock quality of rice straw would improve if it is exposed to precipitation in the field to leach the alkali and alkaline compounds. This process is dependent on the weather. However, the quality varies substantially with

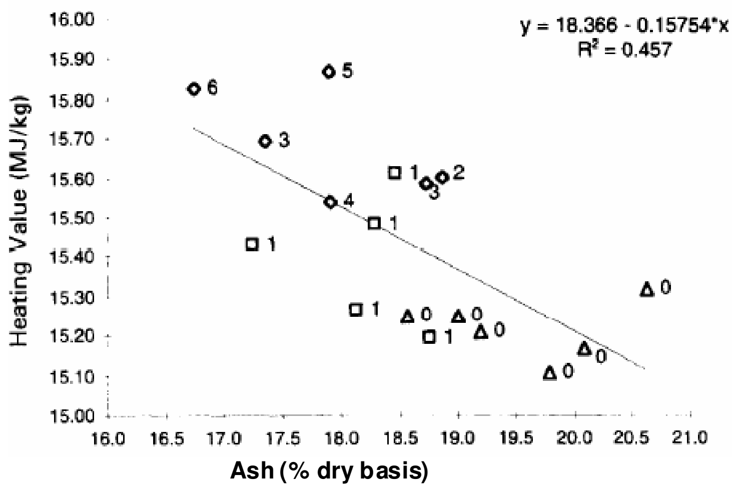

Figure 2. Higher heating value (dry basis) of untreated and washed rice straw. untreated (triangles), hand sprayed (squares), other washing treatments (diamonds) (Jenkins et al., 1995).

seasons as well as within regions.

Figure 2 shows heating values and ash content of treated and untreated samples of rice straw. The treated sample exhibits increasing heating values compared to untreated samples.

The economic potential of this technique has not been tested and requires further analysis. However, straw dewatering depends on the material and specific type of equipment, mechanical dewatering equipment may quickly reduce moisture content to as little as approximately (50%). Passive dewatering methods such as using filter bags that are impervious to rain but allow moisture to seep out, can achieve moisture content as low as (30%) at low cost, but long periods of time on the order of two to three months may be required.

Bailing

Field bailing is much the least expensive method for harvesting and packing rice straw (Dobie et al., 1980). Bailing can be (and commonly is) applied to improve the characteristics of agricultural residues for transportation and storage. Packed loose straws to bales of different sizes and shapes examples small square, round large square and compact bales can improve the low density attributed to straws. The bulk density of rice straw is around 75 kg for loose straw and 100 -180 kg in packed and bailed form as energy feedstock. The baled straw has relatively low moisture content and can be stored for long period without significant dry matter looses and deterioration in fuel quality (Dobie and Haq, 1980).

Transport of bailed straw can be up to 50% cheaper than transportation of loosed material and about 1% cheaper than that of wood chips (Caldwell et al., 1988). However, this method requires good transport system to carry the baled rice straws from the field to the power plant or storage. It is also dependant to weather and soil conditions of the field. This technique can be carried out efficiently in many developing countries with simple transport devices like bullock cart where trucks and trailers are not available.

Palletizing

This is a compacting process that produces homogenous fuel with high energy density into different shapes examples square, rectangle and cube with dimension of 50 x 50 x 50 mm³ (Loo Van et al., 2004a). It involves the following steps: drying, milling, conditioning, actual pelletizing and cooling of biomass.

An important advantage of pelletizing is that, it addresses the issue of low bulk density of biomass which has an impact on transportation costs as well as the required storage space in comparison with other biomass material and it can restrict the co- firing ratio due to limited capacity of boiler impact system.

The moisture content of the raw material before entering the pellet press must be 12 - 17% (w.b) and it is essential not to exceed these values (European Biomass Association, 2000).

If the material is too dry, the surface of the material may carbonize and the binders will burn before the process is finished, whereas if the material is too wet, then the moisture contained in the pressing cannot escape and enlarges the product volume, making it mechanically weak (Loo Van et al., 2004b).

Challenges related to this technique include problems during uploading and unloading of the pellets as they can be sensitive to mechanical damaging because they can absorbed moisture from the surrounding and can swell, loose shape and consistency causing handing problems (Livingston, 2005).

Pellets should be stored in closed halls or rooms, silo, bunkers, plastics and airtight zip bags (dry conditions) and storage times should be minimized to prevent absorbing atmospheric moisture. Pellets may be distributed in bags for small-scale applications. In case of co-firing however, the bulk material supply is necessary (Bergman et al., 2005).

SUMMARY AND CONCLUSION

Reduction in size of straws can be necessary or beneficial. The shorter the size the straw is cut (5 - 2 mm); the higher the density in storage or in bales; thus reducing costs of handling and storage, increases the conversion efficiency and combustion performance. However; large sizes of biomass (10 - 5 mm) does not adversely affect the combustion performance.

Torrefaction changes the straw properties to a much better fuel quality for combustion and gasification application by improving the efficiency of biomass utilization or reduce the cost of the transport and storage of the material and its heating value. Although the principles of torrefaction are known since 1930, currently no commercial process is available on the market. For successful market introduction, production costs of torrefied biofuel need to be competive with alternate bioconversion products and this will have to be tested during scaling -up of the technology.

Washing rice straw with water is effective in removing substantial amount of alkali metals. The removal of such elements is beneficial in increasing the fusion temperature of straw in furnaces; prolong life of boilers because corrosion problems are avoided, volatile matter release rates were substantially fast with washed samples than with untreated samples. However, straw washing has only been tested at small plants.

The energy losses caused by washing, drying and leaching of organic make out of approximately 10% of the calorific value of straw. Bailing improves the characteristics of straw for transportation and storage; increases bulk density and reduce moisture content to be stored for long periods with insignificant dry matter lost and deterioration in fuel quality.

The compaction of straw to homogenous fuel through pelletizing improves the bulk density of the straw thus reduces the costs of transportation as well as storage. Rice straw could be used as fuel for heat and power generation to replace fossil fuel to reduce greenhouse gas emission as well as prevent pollution from rice straw open burning. In addition, rice straw properties do not have significant impact process performance and significant emission of chlorinated organic compounds and NOx compared to wheat straw and rice husk under the same operation conditions therefore, suitable rice straw supply and competitive cost of energy are the main criteria for rice straw utilization.

The aforementioned pretreatment technologies of rice straw could increase both its physical and chemical properties for energy use. This reduces the associated costs and logistics of handling, transportation and storage.

Although detail economic consideration and analysis of these technologies are not mentioned in this paper. However, the discussion from this paper could be used for further work involving economic analysis of these pretreatment techniques to encourage rice straw utilization to avoiding open burning in rice producing countries and could be applied for research on other on other agricultural residues which is beyond the scope of this paper.

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