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Energy potential from rice husk through direct combustion and fast pyrolysis: A review

Isabel Quispe [a,b,*], Rodrigo Navia [b,c,d], Ramzy Kahhat [a]

[a] Peruvian LCA Network, Department of Engineering, Pontificia Universidad Católica del Perú, Avenida Universitaria 1801, San Miguel, Lima 32, Peru
[b] Scientific and Technological Bioresources Nucleus, University of La Frontera, P.O. Box 54-D, Temuco, Chile
[c] Department of Chemical Engineering, University of La Frontera, P.O. Box 54-D, Temuco, Chile
[d] Centre for Biotechnology & Bioengineering (CeBiB), University of La Frontera, P.O. Box 54-D, Temuco, Chile

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ABSTRACT

Rapid population growth and consumption of goods and services imply that demand for energy and resources increases continuously. Energy consumption linked to non-renewable resources contributes to greenhouse gas emissions and enhances resource depletion. In this context, the use of agricultural solid residues such as rice husk, coffee husk, wheat straw, sugar cane bagasse, among others, has been widely studied as an alternative energy source in order to decrease the use of fossil fuels. However, rice husk is among those agricultural residues that are least used to obtain energy in developing countries. Approximately 134 million tonnes of rice husk are produced annually in the world, of which over 90% are burned in open air or discharged into rivers and oceans in order to dispose of them. This review examines the energetic potential of agricultural residues, focused on rice husk. The review describes direct combustion and fast pyrolysis technologies to transform rice husk into energy considering its physical and chemical properties. In addition, a review of existing studies analyzing these technologies from an environmental life cycle thinking perspective, contributing to their sustainable use, is performed.

Contents

* Corresponding author at: Peruvian LCA Network, Department of Engineering, Pontificia Universidad Católica del Perú, Avenida Universitaria 1801, San Miguel, Lima 32, Peru.
E-mail address: iquispe@pucp.edu.pe (I. Quispe).

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1. Introduction

Current environmental problems have different causes including global warming due to emissions of greenhouse gases (GHGs) which are generated mainly from the combustion of fossil fuels such as diesel, gasoline or coal (IPCC, 2007). Moreover, fossil fuel deposits take millions of years to accumulate, whereas these deposits are extracted rapidly. Given that the extraction rate is faster than the replenishment rate the resource will be finite in the sense that it will eventually be depleted (Höök and Pang, 2013; Capellán-Pérez et al., 2014). Facing this reality, governments have proposed policies to change their energy matrix in order to increase the share of renewable sources (Gabrielle et al., 2014). In this regard, research studies have aimed at obtaining energy from available biomass including agricultural solid residues, such as coffee husks, rice husks, sugar cane bagasse and wheat straw, among others, of which rice husk is one of the least used in developing countries (Prasertsan and Sajjakulnukit, 2006; Liu et al., 2008; Shafie et al., 2012a,b; Vitali et al., 2013). These residues may be used by direct combustion to generate energy or other advanced processes (i.e., pyrolysis) to generate solid, liquid and gaseous fuel products. Using biomass offers several advantages, including the mitigation of gaseous emissions such as CO_2, SOx and NOx (Saidur et al., 2011). This circumstance is linked to the low amount of S and N present in agricultural residues, as well as a minimal Cl content, which avoids chlorine related emissions. Moreover, if the biomass is completely burned, the amount of carbon dioxide produced is equal to the amount taken from the atmosphere during the growing stage (McKendry, 2002a,b). Another advantage is the diversification of fuel supply avoiding non-renewable resources depletion.

If agricultural residues such as rice husk were used to recover energy, then it would be necessary to perform an integral assessment considering all stages of its life cycle and comparing with the use of fossil fuels to identify the conditions and scenarios for a lower environmental impact.

On the other hand, the environmental analysis performed among the most commonly used technologies, such as direct combustion, pyrolysis or gasification, has been more qualitative than quantitative. This adds uncertainty when it comes to determining which is friendlier to the environment during its life cycle and not just in the stages of production and use of bioenergy. Thus, the purpose of this review is to examine the energy potential of agricultural residues, focused on rice husk. Moreover, a full description is given of direct combustion and fast pyrolysis technologies to transform rice husk into energy considering its physical and chemical properties. Finally, this review performs an environmental analysis, using life cycle thinking perspective as well as an analysis of the results obtained in life cycle assessment (LCA) studies available in the literature on the use of rice husk for energy purposes.

2. Energy recovery from rice husk

Literature review shows that research has been developed to obtain energy from agricultural residues considering residue characteristics, using different technologies and their operational conditions as the cases of Philippines and Myanmar (Pode et al., 2016; Pode, 2016; Burritt et al., 2009). In fact, if the biomass which includes agricultural residues were to be used in its integrity as a source of renewable energy resources, it would provide approximately 10% of the world energy (Okeh et al., 2014; Demirbas et al., 2009; Herbert and Krishnan, 2016; Antizar-Ladislao and Turrion-Gomez, 2008), thus, becoming an attractive alternative to fossil fuels.

2.1. Agricultural residues and rice husk available in the world

Governments worldwide, with the aim of diversifying their national energy matrices in order to become less dependent on fossil fuels, are considering renewable energy strategies using a wide variety of biomass sources (forest residues, agricultural residues and domestic solid waste) to contribute to the mitigation of GHG emissions (Zhang et al., 2010; Liu et al., 2012; Gabrielle et al., 2014). Generally, theoretical availability of agricultural residues is estimated by multiplying annual production by residue production ratio (Liu et al., 2012). However, certain studies have considered other criteria, such as crop rotation practices, harvest method, soil type or tillage management practices in order to estimate effective availability of agricultural residues (Melin, 2013; Muth et al., 2013; Monforti et al., 2013). Countries such as the United States, Canada or China have identified the availability of energy from effective available agricultural residues considering different criteria and ratios such as those shown in Table 1.

Available energy potential is estimated using the following expression:

$$EP_{(j)} = \sum_{i=1}^{n} ARA_{(i,j)} \times HV_{(i,j)} \tag{1}$$

where, $EP_{(j)}$ is the available energy potential of n crops at jth country or region in PJ, $ARA_{(i,j)}$ is the effective availability of agricultural residues of ith crop at jth country or region in tonne and $HV_{(i,j)}$ is the heating value of ith crop at jth country or region in $PJ tonne^{-1}$. The available energy potential affected by thermal or electrical efficiency of the used technologies is known as the technical energy potential. Energy conversion efficiency from chemical to thermal energy varies from 80% to 95% using technologies such as fluidized bed reactors, boilers, cyclonic fluidized-bed combustors, fluidized bed combustion boilers or conical fluidized-bed combustors (Natarajan et al., 1998; Lim et al., 2012; Madhiyanon et al., 2009; Saidur et al., 2011; Permchart and Kouprianov, 2004). On the other hand, the energy conversion efficiency from chemical to electrical energy can vary from 30% to 50% using steam turbines or fluidized bed combustion steam turbine (McKendry, 2002a,b; Shafie et al., 2012a,b).

Unfortunately, large amounts of biomass produced annually in developing countries, such as rice husk, straw, nut shells, fruit shells, fruit seeds, plant stovers, green leaves and molasses, are barely recuperated (Okeh et al., 2014). Out of all these residues, it should be noted that rice husk is one of the least used (Okeh et al., 2014), despite the fact that there are approximately 134 million tonnes annually available worldwide (as calculated in Table 2, based on Lim et al., 2012; Madhiyanon et al., 2009; Delivand et al., 2011; Alvarez et al., 2014). Moreover, 90% are burned in open air or discharged into rivers and oceans (Lim et al., 2012; Okeh et al., 2014; Vitali et al., 2013; Abril et al., 2009; Giusti, 2009), with the consequent impacts on the environment.

Rice husk is a residue generated when processing rice in mills. In the field, when rice is harvested, roots, stems and leaves are obtained, leaving the paddy (rice with husk). When the paddy passes through the mill, rice husk, dust and others are generated. Rice husk constitutes the most important residue ranging from 20% to 33% by weight of the paddy (Shafie et al., 2012a,b; Lim et al., 2012), although most studies consider 20% of the paddy as rice husks. Rice agricultural activity reaches a global annual production of 670 million tonnes of paddy, of which 91% is harvested in Asia (Madhiyanon et al., 2009; Delivand et al., 2011; Alvarez et al., 2014), 5% in America, 3% in Africa and the remaining 1% in Europe (CIAT, 2010; Okeh et al., 2014). Available rice husk in the world is estimated by multiplying the amount of paddy by the residue product ratio, in this case 0.2 (Shafie et al., 2012a,b). Energy