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Cardboard/sawdust briquettes as biomass fuel: Physical–mechanical and thermal characteristics

B. Lela [a], M. Barišić [a], S. Nižetić [b,*]

[a] Department of Production Engineering, University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, R. Boskovica 32, 21000 Split, Croatia
[b] Department of Thermodynamics and Heat Engines, Laboratory for Thermodynamics and Energy Efficiency, University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, R. Boskovica 32, 21000 Split, Croatia

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ABSTRACT

This paper elaborates experimental analysis of cardboard/sawdust briquettes as a viable option for biomass fuel. Physical–mechanical and thermal characteristics of cardboard/sawdust briquettes were investigated. The influence of the main parameters on heating content was also examined through an ANOVA and regression analysis, i.e. pressure influence (that was applied in a punch-and-die process), cardboard/sawdust ratio influence and finally drying temperature influence. In order to find the maximum heating value, minimum ash content and maximum compressive strength optimization were done. The optimal values obtained for the studied briquetting process parameters are a compression force of 588.6 kN, a sawdust mass of 46.66% and a drying temperature of 22 °C. According to the mathematical model obtained, these optimal values give a maximum higher heating value of 17.41 MJ/kg, a minimum ash content of 6.62% and a maximum compressive strength of 149.54 N/mm. Finally, Cardboard/sawdust briquettes showed potential for application as viable biomass fuel.

1. Introduction

The constant industrial activity rise and world population growth increase is directly related to the increase of overall energy consumption and it is estimated that energy demand will surpass 50% by 2025 (Ragauskas et al., 2006). Nowadays, almost 80% of the world's energy supply is provided by fossil fuels (Sims et al., 2007), which harmful impacts to the environment. A Possible solution to reduce the previously mentioned issues, besides conventional or alternative renewable energy options (Duić et al., 2011; Nižetić et al., 2014; Lund, 2014; Nižetić et al., 2015; Rezaie et al., 2011; Nižetić, 2011; Nižetić, 2015), is to investigate and to find novel biomass fuels. Namely, right behind coal, gas and oil biomass is the third largest energy resource in the world (Tumuluru et al., 2011) and it covers approximately 10% of global energy consumption where more than 80% of it is used as traditional fuel to cover heating demands in developing countries for building facilities (Sims et al., 2007).

Nowadays, biomass can be recovered by thermal processes such as incineration with energy recovery, pyrolysis, steam reforming, wet oxidation, composting, recycling, land reclamation and soil enhancement (Monte et al., 2009; Nunes et al., 2016; Liu and Han, 2015; Rada and Ragazzi, 2014; Magdziarz and Wilk, 2013; Moedinger et al., 2013; Mochidaa et al., 2012; Rada et al., 2014a, b; 2009; Pandey et al., 2009). Biomass to bioenergy conversion and major limitations in utilizing biomass, such as low bulk density (which makes it difficult to store), transport and interface with bio refinery systems, etc. were analyzed in Tumuluru et al. (2011), Monte et al. (2009), Arzola et al. (2014), Nalladurai and Morey (2009), Li et al. (2001). Furthermore, biomass densification systems were adapted from other processing industries. Pellet mills, briquette presses, and screw extruders are most commonly used for bioenergy production (Tumuluru et al., 2011).

Densified biomass quality depends on a number of process variables (die temperature and geometry, pressure, binders and of biomass mix pre-heating Tumuluru et al., 2011), so controlling of the process variables enables achievement of the desired density, durability, and of biomass quality.

Fuel briquettes can be made from various waste materials such as sawdust, paper, leaves, grass, rice husks, olive cake and other agricultural waste in many combinations (Li et al., 2001; Plíštil et al., 2005; Garivait et al., 2006; Brleka et al. 2013; Marques et al., 2011; Olorunnisola, 2007). Municipal solid waste typically consists of 40–45% of paper products (Holik, 2013)and the majority of paper is usually recovered by recycling. For example, the recycled paper rate in Europe was 71.7% in 2013, (Cepi report, 2013), although around 21% of paper consumption was not recyclable

* Corresponding author.
E-mail address: snizetic@fesb.hr (S. Nižetić).

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due to technical and economic reasons (Naylor network, 2014) (the previous surely represents a significant potential energy source).

Paper recycling technology could be expensive as it requires de-inking and decontamination processes. On the other hand, waste paper re-use reduces paper quality in relation to screw-holding strength, (Olorunnisola, 2007). Eventually, waste paper utilization for purposes other than recycling ensures price stability on the waste paper market (Gado et al., 2014). Paper can be easily separated from solid waste and is generally not contaminated with metals and other non-combustible materials which has a high heating value. Additionally, paper has a low sulphur content and low nitrogen oxide emissions (Gado et al., 2014; Demirbas and Sahin, 1998; Li and Liu, 2000).

All the previously mentioned facts only prove that paper briquettes can be used as an alternative source of fuel. Oother potential alternative waste fuels were analyzed in the research studies (Magdziarz and Wilk, 2013; Rada and Ragazzi, 2014; Rada et al., 2014a,b).

The main objective of this paper was to determine the physical–mechanical and thermal characteristics of cardboard/sawdust briquettes and cardboard was chosen purposely as it has the highest heating value (Magdziarz and Wilk, 2013) in comparison with other types of paper. Furthermore, an ANOVA and regression analysis was carried out to investigate the effect of the most influential parameters (pressure, cardboard/sawdust ratio and drying temperature) on heating value, ash and moisture content, relaxed density and compressive strength in cleft i.e. to determine their optimal values. Finally, the main research outcome was the determination of optimal influential parameters, i.e. their specific values that maximize heating value and minimize ash content after a combustion process.

2. Brief overview of previous research findings

Authors in Gado et al. (2014) examined paper compaction, corrugated board and the mixture of paper and green waste using pressures from 1 to 10 MPa. They concluded that office papers had the best physical properties while corrugated board had a higher heating value. Mixed waste paper and wheat straw was investigated in Demirbas and Sahin (1998) where the effect of briquetting pressure on density, moisture content, bending and compressive strength were also analyzed. Authors in Li and Liu (2000) studied the compressive strength, abrasion, impact resistance, and combustion characteristics for five types of waste paper that can be found in municipal solid waste. They varied moisture content and ranged pressure from 34 to 138 MPa and found that pressure at around 70 MPa was an optimal one from a quality aspect and economical point of view (the crucial research outcome found was that waste paper briquettes had a heating value equivalent to lignite fuels). The effect of sawdust and paper fiber mixtures, pressure influence on density, resiliency, combustion behavior, abrasion and impact resistance were studied in Kong et al. (2012). They concluded that the sawdust and paper mass ratio in the amount of 1–3, compressed at a room temperature of under 6 MPa (using a hydraulic press) is a cost-effective way to produce bio-fuel. The effect of briquette geometry on burn-rate was examined in Chaney et al. (2008). The authors used soaked newspaper as material for briquettes (which were oven dried at 105 °C). They showed that the burn rate of the briquettes was steady and controllable, that the boundary conditions, density and area/volume ratio of the briquettes significantly affected the burn rate.

None of the above mentioned researchers involved the design of experiments in their studies which would result in mathematical models that would relate certain parameters in briquette production to specific indicators of briquette quality such as heating value, strength, etc. Heating (calorific) value is the most important characteristic of every fuel and regarding biomass, its magnitude depends from chemical composition, particle size, processing temperature and feed pre-treatment (Tumuluru et al., 2011; Garivait et al., 2006). Moisture content affects briquette physical parameters such as durability, density, heating value and combustion efficiency (Tarasov et al., 2013) but the most important ones are initial moisture content, processing temperature and pressure (Garivait et al., 2006). Ash content affects stove efficiency and the frequency of stove cleaning (Tarasov et al., 2013) and it is therefore desired to have it as low as possible. All the above mentioned issues seek a study that will use the design of experiments (DOE) to investigate the influence of cardboard/sawdust ratio, densification force and drying temperature on heating value, ash and moisture content and briquette physical–mechanical (i.e. compressive strength in cleft and relaxed density) characteristics.

3. Description of experimental approach for briquette production

A specific experimental rig for briquette production is presented in Fig. 1, and it is consisted of a mould, punch and pressing plate. The bore in the mould was 38.6 mm in diameter and with a height of 110 mm. Cardboard/sawdust mixture was loaded in the mould and compressed up to a force specified by the plan of experiments (where sawdust weight percentage within briquettes varied from 0% to 46.66%). Compression force was measured by load cell C6A 1MN. Briquettes were ejected from the mould immediately after reaching the desired force and the ejecting force was 0.2 to 0.3 kN. Depending on the final compression force, briquette height varied from 6 to 9 mm. According to the experimental results, it was concluded that the compression force should be at minimum 100 kN to obtain briquettes with satisfactory strength, i.e. mechanical properties. In relation to the previous, the compression force varied from 147.15 to 588.6 kN. It is known that compression force does not affect biomass heating value (Tumuluru et al., 2011) but was included as an input factor due to its influence on both moisture and ash content as well as on physical–mechanical properties.

The briquettes were made out of three-layer corrugated cardboard (which is used for packaging boxes) and sawdust in specific weight ratios. The briquettes were taken from a local landfill of

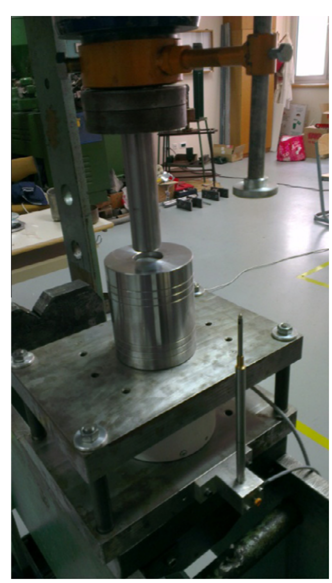

Fig. 1. A specific experimental rig for briquette production.