

Evaluation of the Performances of Biomass Briquettes Produced with Invasive *Eichornia crassipes* (Water hyacinth), Wood Residues and Cow Dung for Small and Medium Scale Industries

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Abstract

Conventional energy resources decrease worldwide with increasing population and technology advancement. Sustainable Energy Authority of Sri Lanka focuses on total replacement of fossil fuel by renewable energy sources by 2050. Water hyacinth is a renewable energy source as it has considerable energy potential within and it is invasive to Sri Lanka. This study aims to identify the ideal proportion of the saw dust: water hyacinth and cow dung: water hyacinth to produce briquettes for biomass boilers in industries. Saw dust was mixed with water hyacinth in 25:75-S1, 50:50-S2 and 75:25-S3 proportions. Cow dung was mixed with water hyacinth as above proportions (C1, C2 and C3). Energy briquettes were manufactured using screw type extruder briquetting machine. Energy properties including moisture content, volatile matter content, ash content, fixed carbon and calorific value and mechanical properties including bulk density, durability, water resistance capacity and water boiling time were measured and fuel wood value indices of briquettes were calculated.

In saw dust-water hyacinth briquettes, there is no any significant difference between three types for fuel value indices and density. S2 type of briquettes perform better as they have significantly higher calorific value (19.17 kJ/g) and water resistance capacity (98.73%) and significantly lower moisture content (5.32%) and water boiling time (10 minutes). In cow dung-water hyacinth briquettes, C1 and C2 types of briquettes have significantly higher FVI. C2 type of briquette have significantly higher volatile matter content (75.54%) and significantly lower moisture content 5.81%) and fixed carbon content (10.0%). C1 type of briquettes took significantly lower time (21 minutes) to boil one litre of water. C2 type of water hyacinth-cow dung briquettes can be considered as the best in terms of energy and mechanical properties.

Keywords: Renewable energy; Water hyacinth; Biomass briquettes

Introduction

Majority (90%) of world's energy comes from non-renewable conventional energy sources such as coal, crude oil and natural gases which have limited availability. Oil is the leading source of the world's energy consumption, accounting for 32.9% [1]. Increasing demand by the world's growing population for households, industries and commercial buildings make non-renewable energy sources more scarcer and it will lead to exhaust these resources in the near future. International Energy Outlook (2013) predicted that the energy consumption of the world will grow by 56% between year 2010 and 2040 [2]. On the other hand, conventional energy sources are significant contributors of global warming, and other environmental issues this affect human health. Security of supply and heightened environmental concern of conventional energy resources bring the attention to renewable energy sources in the world. Therefore, it is necessary to explore the potential of renewable and environmental friendly alternative energy sources [3]. In 2010, 16.7% of global energy consumption was generated by renewable energy resources [4]. Hydropower is the leading global renewable energy source, supplying 71% for electricity generation of all renewable electricity at the end of year 2015 [1]. Significant new development in hydropower is concentrated in the markets of Asia particularly China, Latin America and Africa. Bioenergy is the largest renewable energy source with 14% out of 18% renewables [1].

Bioenergy is shifting from being a traditional energy source to rather a modern commodity. USA and Brazil lead the production and consumption of liquid biofuels for transport. Electricity production from forest products and residues type of biomass is prominent in Europe and North America. In the past few years, biomass usage increases in developing countries in Asia and Africa [1]. Japanese energy

policy is set out in its fourth Strategic Energy Policies (SEPs), adopted in 2014 which had outlined a goal of 70% energy self-sufficiency and 70% zero-emissions generation ratio by 2030. Ministry of Economy, Trade and Industry (METI) in Japan prepared the 2015 "Long-Term Energy Supply and Demand Outlook" to 2030 which was adopted in July 2015. It focuses the electricity supply mix for 2030, which projected declines in the share for natural gas, coal and oil and return to nuclear energy and strong increments in renewable energy usage. It focuses on renewables more than in previous plans, where 13.5% of the electricity generated in 2020 and 23% in 2030. According to the plan, hydropower will account for about 9% (corresponding to 93.9 to 98.1 TWh), 7% of solar power (corresponding to 74.9 TWh) and 4.1% of biomass (corresponding to between 39.4 and 49 TWh) [5,6]. China's gross domestic product (GDP) grew by an estimated 9.2% in 2011 and by 7.8% in 2012 and this ongoing high growth rate has drastically been increasing Chinese energy consumption. China being the world's second largest oil consumer is seeking to consolidate Chinese government energy policy and to formalize a more comprehensive energy agenda,

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incorporating new and lower carbon technologies as an element of national energy planning. In Five-Year Plan (2011-2015), China expects to reduce energy and carbon intensity via enhanced energy efficiency and diversification of the energy mix by being the world's largest hydropower producer. Indian energy policy focuses on securing energy sources for sustainable economic development. Ministry of New and Renewable Energy (MNRE) in India aims to increase the share of renewable energy to 6% of India's total energy matrix and to 10% of the electricity mix by 2022. According to MNRE, India has 288 biomass power and cogeneration plants generate 2.7 GW of installed capacity with the potential to reach 18 GW in total generating capacity [7].

In Sri Lanka, a National Energy Policy was introduced in 2006, highlighting the importance of promoting energy efficiency and conservation and the main thrust of the policy is to promote indigenous energy resources. In 2006, electricity production from renewable energy sources in Sri Lanka was so far limited to investors who could afford around USD one million. The 'Net Metering' scheme was introduced in Sri Lanka by the government for the first time in 2009 in order to allow electricity consumers to produce and sell electricity to the national grid. This is a great step to harness renewable energy resources island wide in small scale. According to the estimation, a 70% of the national biomass consumption comes under the informal sector, for household cooking, small commercial and industrial applications and the rest is utilized for industrial usage and electricity generation. Electricity generation from biomass has been growing in Sri Lanka and 10 villages had been electrified by dendro power in Sri Lanka until 2011 [8]. Government of Sri Lanka identified that dendro power as a long term power generation option for grid-connected and off-grid communities. Biomass power plants in Sri Lanka are currently operated mostly deploying fuel wood and agricultural waste where maintaining a regular supply of biomass has been foreseen as the major problem. Strategies have been implemented to solve this problem by promoting gliricidia plantations in rural areas which would be an additional income for rural community. Power generation using solid waste is also being encouraged which dilutes the issue of the disposal of solid wastes. The current government policies have given a target of using 20% renewable energy by 2020 and to be energy independent by 2050. Energy sector development plan (2015-2025) focuses on developing renewable energy sector including biomass energy, hydro power, solar power and wind energy to fulfil country's energy demand [3]. In 2010, Sri Lanka has produced 53.38% of total electricity requirements from renewable energy sources, out of which 46.56% accounted for large hydro and the rest 6.83% were born by Non-Conventional Renewable Energy (NCRE) sources including small hydro, wind power, biomass and solar [9]. The most available forms of biomass types in Sri Lanka are fuel wood, municipal waste, industrial waste and agricultural waste and industries have been moving to operate their boilers, driers, furnace etc. using biomass instead of furnace oil and diesel.

Briquetting is the process of compaction or densification of biomass residues into different sizes and shapes by pressing loose biomass residues, or waste to produce a solid and they have numerous applications which include both domestic and industrial applications. Briquetting improves the biomass fuel characteristics mainly bulk density and other physical properties than of raw material and increment in calorific value of the end product called briquettes [10-13]. Briquetting technologies can be done in different pressure levels; high pressure compaction and medium pressure compaction with a heating device and low pressure compaction with a binder on the basis of compaction [14,15]. High compaction technology or binder less technology consists of the piston press and the screw press. Screw type

extruder briquetting machine with die and punch performs better than piston press as it produces briquettes with materials of moisture content less than 10%, output from the machine is continuous, briquettes are denser and stronger and more suitable to use in boilers, kilns and gasifiers.

Combustion performance of briquettes are very good as the central hole incorporated into briquettes produced by a screw extruder helps to achieve uniform and efficient combustion and also surfaces of these briquettes are carbonized and require low maintenance [16,17]. Briquettes have several advantages over fuel wood in terms of greater heat intensity and uniform and ideal physical dimensions and combustion characteristics result in more efficient energy conversion [18]. Compared to fire wood or loose biomass, briquettes give much higher thermal efficiency because of low moisture and higher density. Briquettes make handling, storage and transportation easy compared to raw agricultural residues and wastes and also it resolve the disposal and pollution issues often created by biomass residues [19,20]. Briquettes can fill the energy gap in cooking and water heating in households, heating productive processes such as tobacco curing, fruits, tea drying, poultry rearing, firing ceramics and clay wares such as improved cook stoves, pottery, bricks, fuel for gasifiers to generate electricity and powering boilers to generate steam. Therefore, briquetting aids efficient utilization of biomass wastes and it avoids dust pollution associated with direct combustion of loose biomass. Briquette usage helps to reduce deforestation by providing a substitute to fuel-wood with biomass residues.

Eichornia crassipes (Water hyacinth) is native to Amazon River basin of South America especially in Brazil [21]. The introduction of *Eichornia crassipes* to other parts of the world was initiated mainly due to its ornamental value given for its attractive blue, lilac to purplish flowers and round to oval leaves [22]. *Eichornia crassipes* is an erect, free-floating, stoloniferous, perennial macrophyte [23]. It lives at the air water interface and form two distinct canopies called leaf canopies and root canopies [24]. The plants differ in size from a few centimeters to over a meter in height [25]. It has become one of the world's most serious aquatic weed with the human support in more than 50 countries in the tropical and subtropical regions during the past century [26].

Invasion of *Eichornia crassipes* creates many ecological and socio-economic impacts [27]. It challenges the ecological stability of water bodies [28]. *Eichornia crassipes* mats reduce dissolved oxygen concentration, sunlight penetration and phytoplankton productivity and limit access to breeding, nursery and feeding grounds of some economically important fish species [25,27,29]. Complex root structure of water hyacinth plant produces higher sedimentation rate and from the water hyacinth leaves evaporation rate increases than from open water [21]. *Eichornia crassipes* excludes native aquatic plants, alters the habitats of the aquatic organisms and creates threat to the aquatic organisms [30]. Rapid growth of water hyacinth clogs major waterways and creates problems associated mainly with navigation, irrigation, water supply, hydroelectricity and fishing in many countries [31]. *Eichornia crassipes* plants provide refuge for disease carrying vectors and also aggregate mosquito breeding problems by hindering insecticide applications [32].

The spread of invasive alien species is not easy to manage. However, *Eichornia crassipes* can be utilized in many ways as a solution for its aggressive growth. As it has lignocellulose material, many tropical regions of the world use water hyacinth biomass to produce ethanol [14]. Lignocellulosic biomass comprises of cellulose, hemicellulose and lignin. Water hyacinth contains low amounts of lignin and cellulose and

high amounts hemicellulose [33-35]. The cellulose and hemicellulose can be more easily converted to fermentable sugar for the bio fuel industry. However, direct combustions of *Eichornia crassipes* plant are not preferable as it has low density, low calorific value in a unit volume and high moisture content. Therefore, water hyacinth could be used as a dry matter energy source by improving the thermal value of biomass by applying briquetting technology [36].

Water hyacinth has been used to produce briquettes in several countries. A study conducted in Nigeria has concluded that stable briquettes could be formed from water hyacinth cow dung mixtures and it can be used as an alternative energy source to kerosene and fuel wood [37]. Another study in Nigeria presents the processing of water hyacinth with starch binder into biomass briquettes made by manually operated briquetting machine for cooking purposes. It concludes that water hyacinth briquettes can serve as an alternative energy source and cooking time can be improved when the water hyacinth briquette is aided with some pieces of wood [38]. A study in Kenya, explored water hyacinth briquettes as an alternative to the local wood fuels through a pilot briquette production process and it encourages water hyacinth as alternative energy source over fuel woods according to its abundance and energy potential [39].

Present study was designed with the objective of identifying the ideal proportion of saw dust to water hyacinth and cow dung to water hyacinth to produce briquettes with best energy and mechanical properties. Specific objectives of the study are to identify the proportion of saw dust: water hyacinth to obtain the optimal Fuel Value Index (FVI), to identify the proportion of cow dung: water hyacinth to obtain the optimal FVI, to evaluate the energy properties of saw dust-water hyacinth briquettes as well as cow dung-water hyacinth briquettes, and to evaluate the mechanical properties of saw dust-water hyacinth briquettes as well as cow dung-water hyacinth briquettes. Several study hypotheses were tested;

1. Ho: There is a significant difference in the fuel value indices of different proportion of saw dust-water hyacinth briquettes.
2. Ho: There is a significant difference in the fuel value indices of different proportion of cow dung-water hyacinth briquettes.
3. Ho: There is a significance difference in energy properties of different proportion of saw dust-water hyacinth briquettes.
4. Ho: There is a significance difference in mechanical properties of different proportion of saw dust-water hyacinth briquettes.
5. Ho: There is a significance difference in energy properties of different proportion of cow dung-water hyacinth briquettes.
6. Ho: There is a significance difference in mechanical properties of different proportion of cow dung-water hyacinth briquettes.

Methodology

Water hyacinth plants were harvested from fresh water lakes in Vavuniya district, Sri Lanka. Collected plants were washed to avoid foreign matters such as stone, soil and mud [40]. Then they were chopped into small pieces, spread over a mat and allowed to sun dry for 3 to 5 days. The dried plant materials were ground using a milling machine and sieved with a mesh size of 3 mm to obtain particles in the size range from 1 to 3 mm. Dried cow dung were crushed manually and sieved using a sieve with the mesh size of 3 mm to obtain particles in the size range from 1 to 3 mm. Procedure repeated for wood chips of *Azadirachta indica* acquired as a saw mill residue from the saw mills in the area. Pre-processed raw materials were separately packed

in air tight polythene bags to prevent moisture reabsorption until briquetting. Pre-processed saw dust materials were thoroughly mixed with pre-processed water hyacinth materials in 25:75 (S1), 50:50 (S2), and 75:25 (S3) ratios by weight until a uniformly blended mixture were obtained. Procedure was repeated with pre-processed cow dung and water hyacinth materials to obtain 25:75 (C1), 50:50 (C2), and 75:25 (C3) ratios. Briquettes were produced from each mixture using screw type extruder briquetting machine at 270-300°C internal temperature and at pressure level of 120-130 MPa. Screw type briquetting machine produces a continuous cylindrical biomass briquette and it was manually cut into standard size 75 mm to 90 mm length briquettes which are the standard size in the local market. Outer diameter of the briquette is 65 mm and inner middle hole diameter is 20 mm (Figure 1).

Energy properties including moisture content, volatile matter content, fixed carbon content, ash content and calorific value were measured [41,42]. Mechanical properties including bulk density [37], durability [19], water resistance capacity [43] and water boiling time [37] were measured. And Fuel Value Index (FVI) was calculated [44]. Methods used in measuring energy and mechanical properties are listed in (Table 1).

After measuring each and every parameter, energy and mechanical values of saw dust-water hyacinth and cow dung-water hyacinth briquettes were subjected to one way One Way ANOVA in MINITAB version 14 after following Anderson Darling Normality test. Moisture content, volatile matter content, ash content, fixed carbon contents, durability and water resistance tests were subjected to arcsine transformation before doing Normality test. ANOVA was followed by Tukey's pair wise comparison test.

Results and Discussion

Performance of saw dust-water hyacinth briquettes

Biomass briquettes with moisture content more than 15% are poor and weak [18,45,46]. All the types of the saw dust-water hyacinth and cow dung water hyacinth briquettes had moisture content below 10% which are in acceptable range. When considering volatile matter content, biomass generally has volatile mater content of around 70-86% of the weight of the dry biomass which makes the fuel very reactive



Figure 1: Measuring outer diameter of the produced briquette.

Properties	Method followed/Equation used	Modification from reference base
Moisture content	Oven dried method	
Ash content	Loss of Ignition method	
Durability	Drop test at 1.8 m height	Dropping height increased up to 2.4 m if briquette does not break at initial height (1.8 m)
Water boiling time	Water boiling test	One litre of water is boiled
Fuel Vale Index	FVI= $\frac{\text{Calorific value (kJ/g)} \times \text{Density (g/cm}^3\text{)}}{\text{Ash content (g/g)} \times \text{Moisture content (g/g)}}$	
Calorific value	$\text{Calorific value} = \frac{[(W + w) \times (T_1 - T_2)]}{X}$ <p>X=weight of fuel sample taken (kg)</p> <p>W=Weight of water in calorimeter (kg)</p> <p>w=water equivalent of apparatus</p> <p>T1=initial temperature of water (°C)</p> <p>T2=final temperature of water (°C)</p> <p>Bomb calorimeter</p>	

Table 1: Method followed to measure mentioned energy and mechanical properties.

and ensures faster combustion rate during the devitalization phase than other fuels such as coal [47,48]. And all the three types of the saw dust-water hyacinth briquettes had volatile matter content within the acceptable level of 70-86%.

Among the three cow dung-water hyacinth briquettes C2 (Cow dung: water hyacinth=50:50) type of briquettes had significantly higher volatile matter content of 75.53% which was in the acceptable level. Low-grade fuels such as dung tend to have a low volatile content resulting in smouldering combustion [49]. Complying with this, C3 type which had cow dung in larger proportion had significantly lower volatile matter content.

Ash content, which is the non-combustible component of biomass and the amount affect the fuel efficiency. Ash deposits on heat transfer surfaces of boilers affect the handling and accelerate corrosion thus reducing efficiency of the burning process [50]. Biomass residues normally have lower ash content except for rice husk with 20% ash [14,48]. S2 type of briquettes had significantly high ash content of 11% than S2 and S3 briquette types. All the three type of cow dung - water hyacinth briquettes had ash below 10%. The fixed carbon is the percentage of carbon available for char combustion. This is not equal to the total amount of carbon in the fuel since a significant amount is released as hydrocarbons in the volatiles [51]. Therefore, lower level of fixed carbon is desirable in biomass briquettes as it ensures high volatile matter content. All the S1, S2 and S3 briquette types had fixed carbon content below 13.2% and there was no significance difference among values. All the three types of cow dung - water hyacinth briquettes had fixed carbon content below 33.36%. C2 type of briquettes had significantly lower amount of fixed carbon (10%) as it had higher amount of volatile matter (75.54%). C3 type of briquette had higher amount of fixed carbon content (33.36%). This resulted in poor performance in water boiling test and C3 type of a briquette took 38 minutes to boil one litre of water while C1 and C2 took only 21 and 33 minutes respectively (Figures 2 and 3).

The water resistance capacity is the ability of briquettes to resist

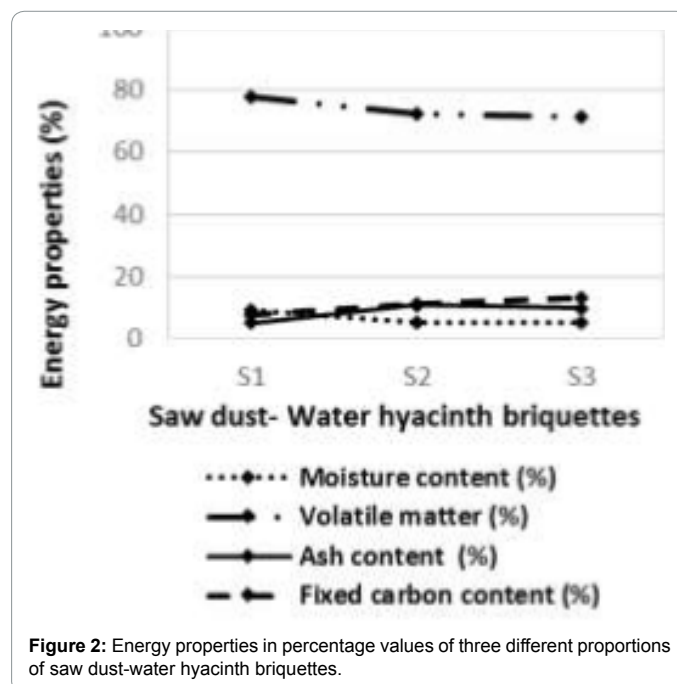
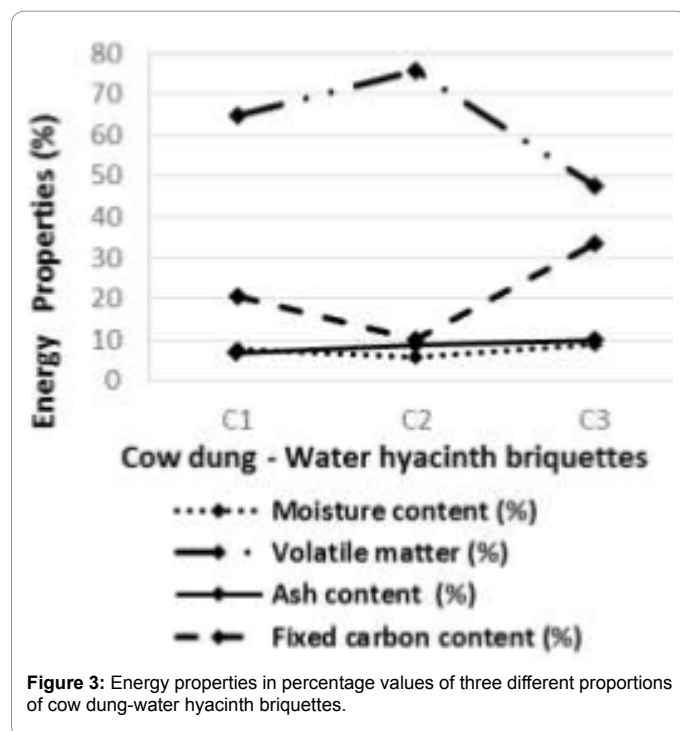


Figure 2: Energy properties in percentage values of three different proportions of saw dust-water hyacinth briquettes.

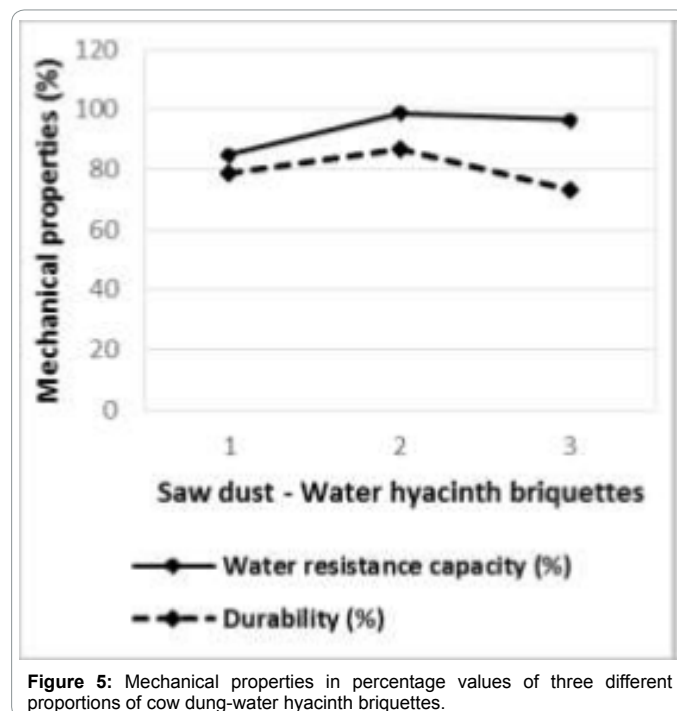
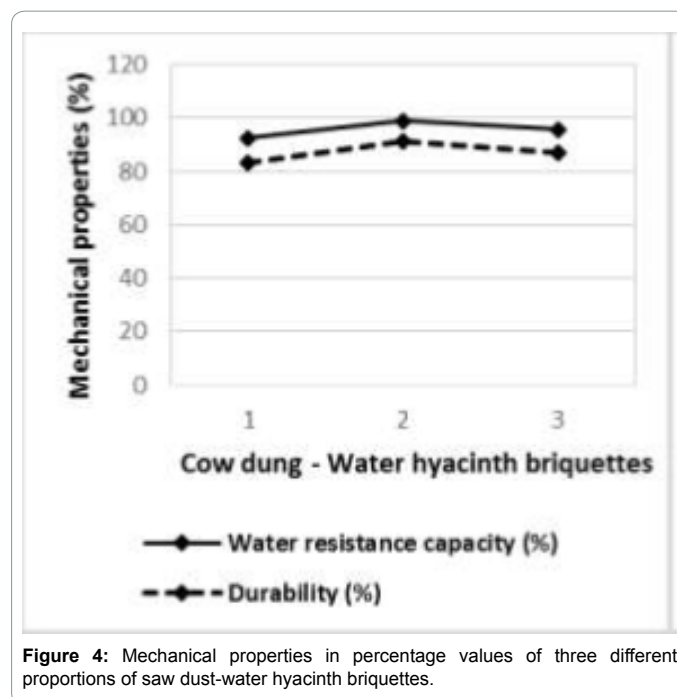
against disintegration and adsorption of water during transportation and storage [52]. S1 (Saw dust: Water hyacinth=25:75) type of briquettes had significantly lower water resistance capacity than S2 and S3 types. This may be due to high proportion of water hyacinth used in this S1 type of briquette. Water resistance is high when porosity is less where the briquettes are made with higher proportion of saw dust and briquettes made with high proportion of leaves are porous and allow more water to penetrate [11]. There was no significance difference observed for water resistance capacity of cow dung-water hyacinth briquettes and the values of water resistance capacity range between 92%-98%.



This may be due to less porosity occur between cow dung particles. Durability is the ability of a briquette to withstand when handling, storing and using the briquettes [19]. Durability of saw dust-water hyacinth briquettes ranged from 73-87% and there was no significance difference. Durability values of all cow dung-water hyacinth briquettes were higher than 83% and they did not significantly differ.

Calorific value is the most important fuel property that determines the energy content of a fuel [47,53]. When considering the calorific values of commonly used fuel species in Sri Lanka, it ranges from 13.025 kJ/g to 20.724 kJ/g [54]. Calorific values of S1 and S2 briquette types lied within this range. S2 (Saw dust: Water hyacinth 50:50) type of briquette had significantly higher calorific value (19.174 kJ/ g) which is a near to the higher value in the calorific value range of fuel woods such as *Calliandra calothyrsus* and *Eucalyptus grandis* used in Sri Lanka. S3 (Saw dust: Water hyacinth 75:25) type briquettes had significantly lower calorific value and it may be due to the partial burning occurred during the production of this briquette type. Water boiling time is less where calorific value is high. S2 type of saw dust-water hyacinth briquettes has higher calorific value and therefore lower water boiling time which is advantageous to consider these briquettes as efficient fuel. When considering the calorific values of cow dung-water hyacinth briquettes, C1 type briquettes had significantly higher amount of calorific value (12.938 kJ/g) than C2 and C3 types. When compared with the UNDP (2013) records of commonly existing fuel wood species calorific value range of Sri Lanka (13.025 kJ/g to 20.724 kJ/g), it is similar to the calorific value of fuel wood species *Pariserianthus falcataria*. Therefore these briquettes took less time (21 minutes) to boil one litre of water in the water boiling test (Figures 4-7).

When considering the particle size, generally biomass material of 6 to 8 mm particle size with 10-20% powdery component gives the best results [19]. According to this, comparatively cow dung-water hyacinth briquettes took longer time to boil one litre of water than saw dust-water hyacinth briquettes. This may be because the prepared cow dung particles are smaller compared to the saw dust particle and



those cow dung particle can be more densified as the particle size is small. In a study, it is reported that porosity exhibited between inter and intra-particles which enable easy infiltration of oxygen and out flow of combustion briquettes. Finer particle size result in lower porosities and this hindered mass transfer, such as drying, devolatilization and char burning processes and ultimately it leads to reduction in burning rates [40]. Complying with this study among cow dung-water hyacinth briquette C3 type which had the high amount of cow dung in proportion took longer time (38 minutes) to boil one litre of water.

Saw dust-water hyacinth briquettes of three different types have

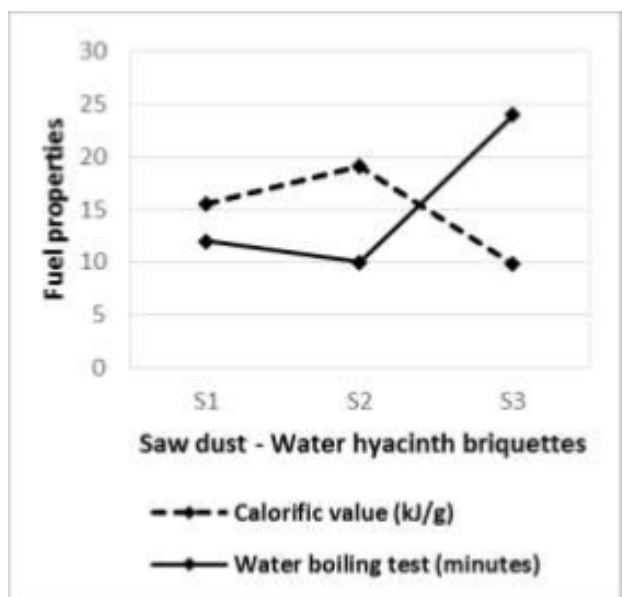


Figure 6: Calorific value and water boiling time of three different proportions of saw dust-water hyacinth briquettes.

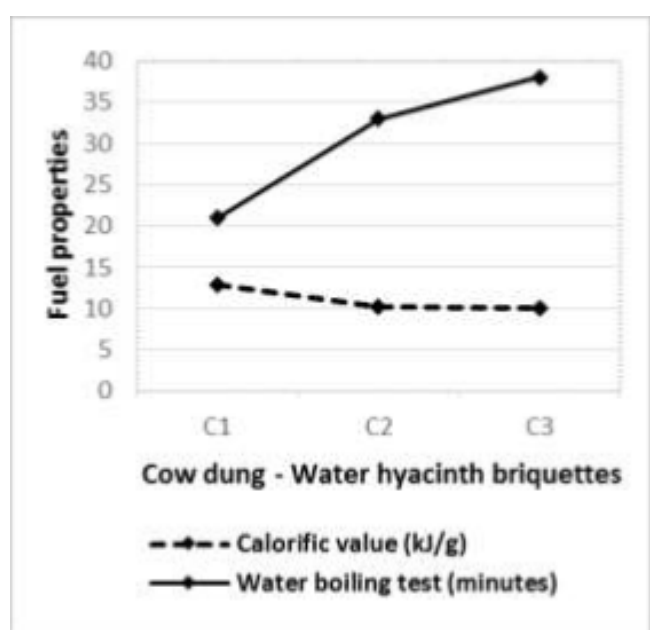


Figure 7: Calorific value and water boiling time of three different proportions of cow dung-water hyacinth briquettes.

no significance difference for bulk density. And all the three types of cow dung - water hyacinth briquettes were significantly different for bulk density. Bulk density increased with increasing proportion of cow dung. Similar to these results, a study conducted in Nigeria with water hyacinth and cow dung briquettes concluded that relaxed density is high where the cow dung amount is high in the produced briquette [37].

In general, biomass energy densities are approximately one-tenth that of fossil fuels such as petroleum or high quality coal [48]. Density of compacted biomass briquettes of individual biomass materials varied

from 542-794 kg/m³ [19,48,55]. Using screw extruder briquetting machine which is the technology used in this study 1000-1200 Kg/m³ density can be obtained for the biomass briquettes [56]. The densities of saw dust-water hyacinth briquettes were lower than that because the briquetting machine, used to produce these briquettes are originally designed to produce saw dust briquettes. If the briquetting machine is modified specifically to the water hyacinth briquettes bulk density can be increased (Figures 8 and 9).

The selection of ideal proportion of the briquette from the saw dust - water hyacinth and cow dung-water hyacinth briquettes is mainly based on the FVI. FVI is an important parameter to determine desirable fuel wood species [54]. Higher FVI of a particular fuel wood species ensures positive fuel wood traits. When considering Fuel wood Value Indices of the three types of the saw dust-water hyacinth briquettes S1, S2 and S3, there was no statistical significance difference among those briquettes. When considering cow dung-water hyacinth briquettes, there was a significant difference in FVI between C2 and C3 type of briquettes. C3 had significantly lower FVI than C2 type of briquettes. And C1 briquettes did not significantly vary with C2 and C3 types of briquettes. This shows that C2 and C1 types of briquette performing better than C3 briquette type.

Conclusion

According to the study results, there is no any significant difference between three different types of saw dust- water hyacinth briquettes S1 (Saw dust: Water hyacinth=25:75), S2 (Saw dust: Water hyacinth=50:50) and S3 (Saw dust: Water hyacinth=75:25) for FVI. Further energy and mechanical properties which are not included in FVI can be compared to select the better performing briquette out of the three types of saw dust-water hyacinth briquettes. When considering the energy and mechanical properties including volatile matter content, fixed carbon content, durability, water resistance capacity and water boiling time which are not included in the FVI calculation, there were no any significance differences for fixed carbon content and durability. However, water resistance capacity was significantly higher and water boiling time was significantly lower in S2 type of briquette as S2 type of briquettes show higher calorific value which are desirable properties for a fuel. Therefore it can be concluded that S2 type of briquettes which have saw dust and water hyacinth in 50 to 50 proportion perform well than the other types of saw dust - water hyacinth briquettes. Thermal energy that can be generated by 1L of diesel can be replaced by 2.29 kg of saw dust (50): water hyacinth (50) briquettes.

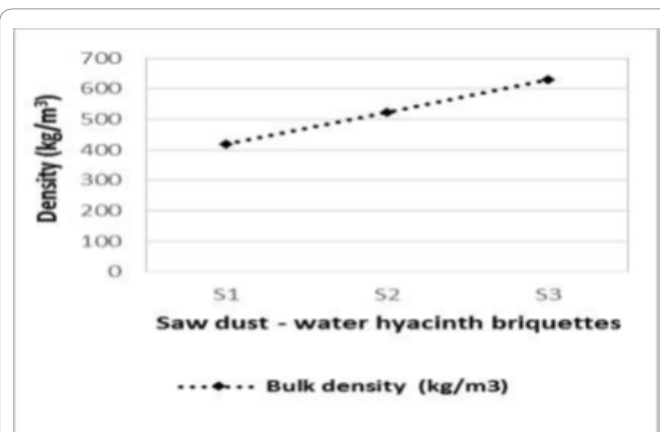


Figure 8: Bulk density of three different proportions of saw dust - water hyacinth briquettes.

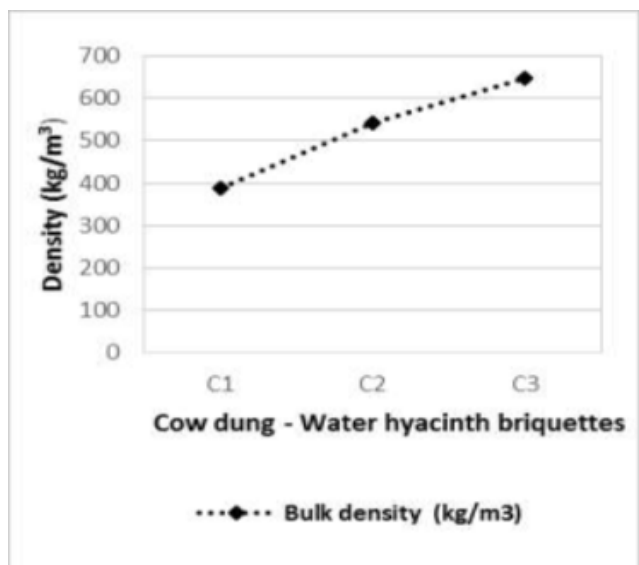


Figure 9: Bulk density of three different proportions of cow dung-water hyacinth briquettes.

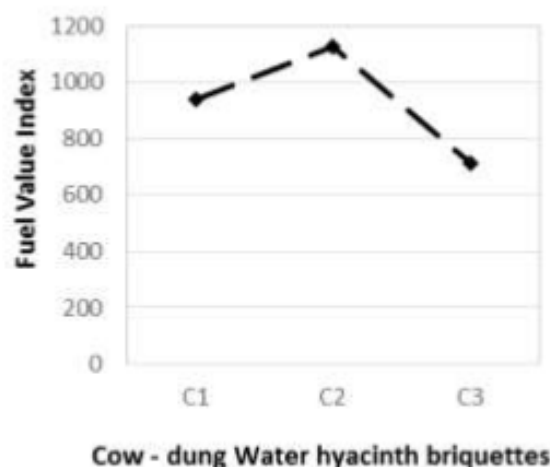


Figure 11: Fuel value index of three different proportions of cow dung-water hyacinth briquettes.

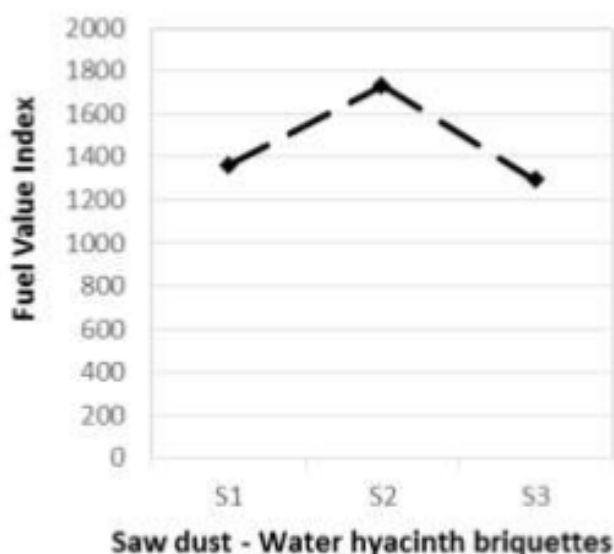


Figure 10: Fuel value index of three different proportions of saw dust-water hyacinth briquettes.

When considering cow dung-water hyacinth briquettes, C3 (Cow dung (75): Water hyacinth (25)) type of briquettes have significantly lower FVI and C1 (Cow dung: Water hyacinth=25:75) and C2 (Cow dung (50):Water hyacinth (50)) type of briquettes have significantly higher FVI. Therefore these two briquettes are performing better than C3 type of briquettes. However, when considering the energy and mechanical properties including volatile matter content, fixed carbon content, durability, water resistance capacity and water boiling time which are not included in the FVI calculation, there is no any significant different in water resistance capacity and durability between C1 and C2 types of briquettes. And C2 type of briquettes have significantly higher volatile matter content and significantly lower fixed carbon content.

Therefore C2 briquette type can be selected as the best combination (Figures 10 and 11).

Water hyacinth mixing with saw dust or cow dung in a 50:50 can be used as a good source of dry matter energy source. Depending on the availability either saw dust or cow dung can be used. However, when both choices are available saw dust: water hyacinth is better than cow dung: water hyacinth briquettes.

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