Development of Briquettes from Waste Wood (Sawdust) for Use in Low-income Households in Piura, Peru

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***Abstract*— The paper presents the results of a project focused on the development of briquettes from the waste wood (sawdust) resulting from the main waste from timber companies located in the Piura Region of Peru. This waste wood currently lacks a useful purpose, and its indiscriminate burning generates CO and CO_2 emissions.**

Through a drying and compression process, sawdust briquettes were obtained with the following features: 19.8 MJ x kg, 10% of humidity, 894 kg/m3, 1.3% of ashes, 15,29% of fixed carbon, and 83.41% of volatile matter.

The results achieved show that sawdust briquettes are a perfect substitute for the fuels coming from illegal logging of the dry forest reserve in Piura that are currently used in domestic stoves (e.g. charcoal, firewood) by 55.81% of families in the region.

In order to investigate the acceptance of the substitute product, eleven communication and awareness workshops were conducted reaching over 600 families, in addition to product testing for 127 families in five low-income areas of the Piura region.

***Index Terms*— Biomass, briquettes, Piura, sawdust, timber companies.**

I. Introduction

THE interest in forest conservation is largely due to the important role forests play in the global carbon cycle as a mean of reducing global emissions of greenhouse gasses [1] [2] [3]. However, in the last few decades, South American forests have continued to record large losses of covered area [4]. The rich biodiversity of these tropical forests continues to be in danger of deforestation despite initiatives from Latin American countries, such as the increase of protected areas [5].

In the region of Piura in Peru, there are 389,685 homes of which 55.81% use firewood and charcoal daily as domestic fuel according to the Istituto Nacional de Estadística del Perú - INEI [6]. The Ministry of Environment (1977) states that this material coming from the cutting of dry forest areas characteristic of the region and protected areas such as the Northwest Biosphere Reserve. This situation is compounded by the emission of greenhouse gasses as a result of open indiscriminate burning of wood waste (sawdust, chips and shavings among others) representing approximately 42% of the production from sawmills, which is equivalent to burning 861.84 m^3 of wood waste per year in the region according to the INEI [7] [8] [9] [10].

Following a premise from United Nations [4], greater efforts and innovative approaches are required to reduce the loss of biodiversity in ecosystems such as forests, and to lower CO and CO_2 emissions to curb climate change.

Against this regional context, the proposed objective is the productive use of sawdust from lumber companies through the production of briquettes as an ecological fuel product to avoid further polluting the environment; the briquettes will also serve as a direct replacement for materials such as firewood from illegal logging.

Section 2 consists of a study of the context of compacted biomass to demonstrate the benefits of using sawdust briquettes versus other types of processable waste. Section 3 describes the research methodology including pilot test conditions and the parameters of the sawdust briquettes for analysis. In order to investigate the acceptance of the new substitute, surveys and product tests are proposed for families of low-income areas in the Piura region that use firewood or charcoal in their stoves.

Section 4 presents the analysis of briquettes samples and other materials used as fuel for domestic consumption in the region and the positive results of product testing for the 127 families selected. These results support the conclusions presented in Section 5.

II. Compacted Biomass

Several studies exist regarding the use of compacted biomass as an energy source. Many of these studies are focused on comparing the economical-environmental impact of compacted biomass as a substitute for traditional fuel materials with emphasis on the effect of greenhouse gases,

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in which the value of biomass briquettes are highlighted as a cost-effective option to reduce CO and CO_2 and meet the millenium development objectives according to the United Nations [4] [11] [12] [13] [14] [2].

Other studies focused on analyzing the compacted biomass market, especially the briquettes and pellets in different European, American and Asian countries, mainly analyzing key factors of demand, in which the need for political support and promotion mechanisms are highlighted in order for this substitute to reduce heavy dependence on traditional fuels [15] [16] [17] [18] [19]. The main advantages attributed to these types of compacted biomass, compared to other types of biofuels, are higher energy density, lower transportation and storage costs, uniform product quality such as constant humidity content and higher mass fluency, among others [20] [21].

The biomass briquettes and pellets are mainly produced from agricultural waste material, livestock, industrial/urban waste or a mixture thereof. However, the material mostly commonly used is a typical waste from the timber industry: sawdust. Compared to agricultural raw material, sawdust has a lower ash content, lower risks of corrosion and dirtying, requires high temperatures of ash deformation (>1200ºC) and also requires no additives or thickeners to increase production costs since humidity and the actual wood lignin work as natural adhesive [22] [23] [24] [25].

Table I depicts a usage comparative between sawdust and other agricultural waste with regard to the main feature and advantage of these material: the low percentage of ash content in dry material and the low percentage of sulfides and clorides in ash after the combustion.

TABLE I
COMPARISON TABLE OF SAWDUST BRIQUETTES AND PELLETS MADE WITH DIFFERENT AGRICULTURE MATERIALS

Technical features	MJ x Kg (of dry material)	Ashes content (% of dry material)	Sulphur (% of ash)	Chlorine (% of ash)
Sawdust	20.3	0.6	0.03	0.01
Salix (agricultural crop)	20	2.9	0.03	0.03
Straw	18.9	5	0.08	0.12
RCG (grass adapted for cultivation)	19	4.5	0.09	0.09
Cañamo (plant fibre)	19.1	2.3	0.06	0.01
Cereal residues	19.8	9.8	0.21	0.16
Rape flour	19.5	7.4	0.91	0.03
Rape cake	26	5.3	0.4	0.01
Distillery waste	21.2	5.6	0.62	0.28

Source: [20] [25]

In Peru, there are no design standards for compacted biomass as there are in European countries, where dimensions range from 6 to 8 mm in diameter for pellets and 7.5 to 9 cm for briquettes with a length of 4 to 5 times the diameter size for the design of both [26] [27] [28] [29].

For industrial production of compacted biomass from sawdust, adequate process controls focused on risk management are required as this material is a forestry residue with one of the largest environmental impact, being a contaminant agent of soil and water. In addition, when in the open, it is harmful to human health and a safety risk with regard to fire and spontaneous combustion [30] [31] [32].

However, the basic process of making sawdust briquettes (Figure 1) is not as demanding on the particle size, which reduces production costs compared to the process of pellet production. At the industrial level, drying is one of the most important stages as the combustion of wet wood waste reduces energy efficiency and increases hydrocarbon emissions and other unwanted particles, besides generating further problems in the compacting stage and causing crack problems in the briquettes [33].

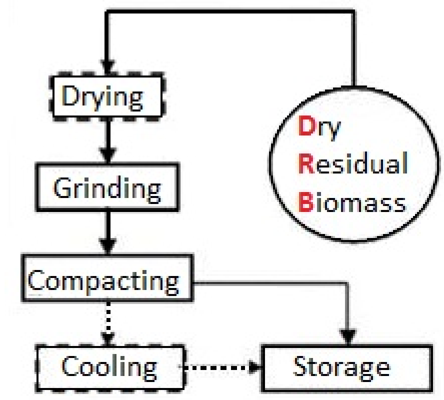

Figure 1. Diagram of compaction process of residual biomass.
Source: [34]

TABLE II
BRIQUETTE DESIGNS

Pressure type	Shape	Material	Market
Extrusion		Mixed Wood	Belgium
Extrusion		Thick Wood	Germany
Vacuum chamber		Mixed Wood	Germany
Piston		Mixed Wood	Spain
Piston		Fine Wood	Austria

Source: [35]

Moreover, consumption of biomass briquettes for rural domestic use has shown to have better economic performance advantages over other traditional products such as firewood and charcoal [36] [37]. However, demand has

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been affected by social, cultural and industrial factors of traditional products. Its growth is based on the shortage of raw materials for the other traditional products, leading to the necessity for an alternative [38] [39].

People need to be trained on the use of briquettes from bio-fuels like sawdust, and the traditional stoves need to undergo improvements, an investment that is not very appealing to the people considering their low income [39].

III. METHODOLOGY

Given the facts previously mentioned in this study, the following initial research considerations are presented in Table III:

TABLE III
INITIAL CONSIDERATIONS OF RESEARCH

Factor	Initial consideration
General objective	a) To demonstrate the possibilities of using the waste from timber companies to make sawdust briquettes and carry out pilot tests for fuel for domestic consumption.
Specific objectives	b) Analysis of technical features of sawdust briquette and comparison with domestic bio-fuels for consumption in the region. c) Analysis of sawdust briquettes through product testing to determine the valuation, perception, opinion and expectations of the target study segment compared to bio-fuels currently used.
Type of methodology	Deductive/Analytical
Object of study	-Congona sawdust (Brosimum uleanum Mildbe), -Low-income households using firewood or charcoal as fuel in their stoves.
Comparative technical features	Caloric power, moisture, bulk density, carbon amount, ash amount, amount of chlorine and sulphur.
Population information gathering tools	- Polls of end users on firewood and carbon use and their combustion. - Product testing.

Source: Self-made

A. Pilot test

In the production of briquettes for pilot testing, the only material used was Congona sawdust (Brosimum uleanum Mildbe), a tree species typical of the jungle region of Peru. Its wood is used for light construction and interior works [40].

The focus of the pilot test was on three general activities of the basic production process of sawdust briquettes [34]. They are described as follows:

a) **Collection of raw materials.** Sucking of sawdust from sawing machines to the company's raw material warehouse using a network of pipes and a suction motor. At this point, the sawdust has moisture content of greater than 10%.
b) **Drying of the raw material.** At this point, the advantageous environmental conditions of the region play a significant role, allowing for the high temperatures that help reduce moisture humidity to less than 10% within 24 hours.
c) **Compacting.** Use of a hydraulic piston briquetting machine, allowing for greater pressure of up to 5 MPa and obtaining briquettes with a circular cross section of 6 cm in diameter and 12 cm in length.

In all the activities, safety measures were implemented for those involved, which also reduced the environmental risks of the process [30].

In order to evaluate the acceptability of the substitute product with the target segment, the briquettes were conveniently packaged. They were grouped, sealed and labelled in groups of six (approx. 1.2kg).

B. Technical features

For the comparative technical analysis of the briquettes, the main energy, physical and chemical features were selected, showing the standards and methods used for measurement as shown in Table IV below.

TABLE IV
TECHNICAL FEATURES

Feature	**Standard/Method**	**Unit**
Caloric power	ASTM D-2015-66 (1972)	MJ x Kg
Bulk density	NTP 251,011	Kg x m^3
Moisture	Gravimetry AOAC 1984	% (wet basis)
Ash content	ASTM D-1762	%
Volatile matter	ASTM D-1762	%
Fixed carbon	ASTM D-1762	%
Chlorine content	Argentometry	%
Sulphur content	Atomic absorption	%

Source: Self-made

Also, bio-fuels selected for comparison of technical features with sawdust briquettes were those fuels currently used by residents of the area: charcoal, bagasse, sawdust, carob firewood and eucalyptus firewood.

IV. RESULTS

A. Technical feature analysis of sawdust briquettes

Results achieved in laboratory tests (see Table V and VI) were positive regarding the calorific power of sawdust briquettes. These were similar to the values obtained by Nilsson, Bernesson & Hansson (2011) and Stolarski et al. (2013), which are also found in similar levels to those obtained by the two types of firewood analyzed except for charcoal.

The bulk density obtained for sawdust briquettes is below 1000kg/m^3, which influences its combustion behaviour. Denser particles show a greater burning time [24].

The moisture percentage of the briquette made with the pilot test is 10%, placing it in the upper limit of commercial briquettes in Europe [41]. The bulk density value obtained is a favourable indication of the briquette machine's performance in the pilot test; results could be improved with the use of semi-industrial and industrial methods during

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drying [33].

TABLE V
COMPARATIVE TABLE OF TECHNICAL FEATURES OF BIO-FUELS IN THE PIURA REGION

Feature	Calorific power	Bulk density	Moisture	Ash content
Unit	MJ x Kg	Kg/m3	% (wet basis)	%
Charcoal	30,8	680	4.76	1.53
Sawdust briquette	19,8	894	10.00	1.3
Bagasse	17,3	169	67.1	1.94
Sawdust	18,9	220	15.8	1.39
Carob firewood	19,3	820	17.4	0.92
Eucalyptus firewood	19,5	630	18.7	0.21

Source: Self-made from sample analysis N°02/01-2013. Universidad Nacional Agraria La Molina. Laboratory of pulp and paper.

TABLE VI
COMPARATIVE TABLE OF TECHNICAL FEATURES OF BIO-FUELS IN THE PIURA REGION

Feature	Volatile matter	Fixed carbon	Chlorine content	Sulphur content
Unit	%	%	%(ppm)	%(ppm)
Charcoal	24.96	73.51	0.15	0.15
Sawdust briquette	83.41	15.29	0.15	0.00
Bagasse	86.00	12.06	0.25	0.12
Sawdust	82.89	16.32	0.26	0.00
Carob firewood	82.28	16.8	0.33	0.03
Eucalyptus firewood	89.31	10.48	0.16	0.00

Source: Self-made from sample analysis N°02/01-2013. Universidad Nacional Agraria La Molina. Laboratory of pulp and paper.

The ash content of the sawdust briquettes is higher than the reference value (<0.5) and the value obtained by the carob and eucalyptus firewoods. However, it is still lower than the value obtained by charcoal and bagasse [24].

The volatile matter value of the sawdust briquettes is higher than the other bio-fuels analyzed except for the eucalyptus firewood. The value gives an idea of the flame length during the combustion process and the ease of ignition for each type of biomass [42].

The sawdust briquette's percentage of fixed carbon is lower than charcoal's. This value indicates a better result during combustion and a lesser probability of CO_2 generation [43].

In relation to the amount of colour and sulphur, it should be noted that the sawdust briquette has values below the standard values [27]. An important advantage of the sawdust briquettes over the rest of materials used is the sulphur content, which is 0% in order to avoid contaminating the environment with sulphur dioxide emissions during combustion.

B. *Analysis of expectations, perception, public feedback*

The 127 families who participated in the surveys and product testing belong to five locations in two provinces of the Piura region: La Arena, La Unión, Catacaos, Tambogrande, and Ignacio Escudero [44].

Survey results show that low-income households use 85% firewood and 22% charcoal, fuels used three times a day at 77.2%. 66% of the households use stoves made of overlapping bricks and 15% use stoves made of mud bricks. Only 4.7% have improved stoves.

Also, bad burning practices are prevalent for firewood and charcoal ignition. 84.3% use plastic bags for firewood or charcoal ignition, generating large amounts of smoke containing greenhouse gasses and chlorofluorocarbons [45]. This reveals a widespread lack of awareness regarding the dangers of pollution and poisoning.

Another important piece of information reveals that 20.5% of the families go to the field to cut wood and 33.9% purchase and chop wood. They consider logging a risky activity that demands effort and long journeys. 45.7% of those who purchase firewood spend about 31% of their monthly income. Among them, 58.3% consider the ease of use and custom as the main benefit of using firewood or charcoal, while 33% consider performance as the main benefit. It should be noted that people are aware of the disadvantages caused by the use of firewood and charcoal to health (74%) and pollution (48%), with 36% expressing a degree of satisfaction with their use and 37% expressing a degree of indifference.

The product test results show a high degree of satisfaction with the use of sawdust briquettes (81.1%), with an intended use of 98.4%. The most highly valued features of sawdust briquettes are presented in Table VII, listed from high to low importance.

TABLE VII
VALUED FEATURES OF SAWDUST BRIQUETTES BY FAMILIES CURRENTLY USING FIREWOOD AND CHARCOAL IN THEIR STOVES

Features	Percentage (%)
Ease of use	59.8
Performance	58.3
Health care	57.5
Environment care	33.9
Easy to carry	24.4
Easy to store	22.0
Price	17.3
Other	15.7

Source: Self-made

In assessing sawdust briquettes, the ease of use (59.8%), performance (58.3%) and health care (57.5%) results stand out. The packaging was accepted by 74%, with a preference for the name of "leña ecológica" (green firewood) instead of "briquetas de aserrin" (sawdust briquettes). The perceived price of the briquettes was US$1.49/kg, and their willingness to pay was US$0.75/kg, higher than the US$0.14/kg production cost.

TABLE VIII
COMPARATIVE DATA OF SAWDUST BRIQUETTES VS. FIREWOOD

	Sawdust briquettes	Firewood
Time on (min)*	3.371	4.274
Open environment (min)	5.230	6.969
Closed environment (min)	5.390	5.848
Semi-open environment (min)	3.999	6.172
Cooking time (min)*	26.645	29.910
Mud stove (min)	26.316	30.000

Improved stove (min)	24.833	30.833
Metal stove (min)	28.600	37.900
Brick stove (min)	31.131	33.940
Kg used*	0.4536	0.8020

*Descriptive statistics without outlier data.

Source: Self-made

Comparative results of fuel currently used vs. the new product are observed in Table 7 above, which reveals positive results. In “Time on”, it took 4.27 minutes to light the wood compared to 3.37 minutes to light the briquettes. Food cooking time improved from 29.91 minutes using firewood to 26.64 minutes using briquettes. Finally, kilograms of fuel used to cook different types of meals were 0.8kg for firewood and 0.45kg for briquettes.

V. Conclusions

The domestic use of sawdust briquettes in low-income families constitutes an important alternative that should be further developed as it allows for the economic revaluation of wood waste and the mitigation of greenhouse gas emissions.

The sawdust briquette has positive results compared to the bio-fuel materials currently used, with a higher bulk density, similar levels of calorific power, less moisture, and low levels of fixed carbon, chlorine and sulphur, promoting a healthier environment for the consumer and the environment.

The energy content of sawdust briquettes is considered sufficient for domestic use in low-income sectors. Including different traditional fuels in sawdust briquettes would increase its calorific power but would also increase costs that the resident is unable to pay.

The different bio-fuel materials used in the comparison have high energy potential such as sugarcane bagasse, which has a low bulk density level indicating an opportunity that could be evaluated to produce briquettes from this material.

The use of sawdust briquettes was very well received by the target families, not only for the cost savings involved but also for the higher performance, ease of use and health care issues. Communication and awareness workshops played a very important awareness role in using sawdust briquettes as substitute for traditional fuel materials.

The dimensions of the briquettes facilitated their use in product testing, but different lengths and sliced portions could be considered in the future to facilitate the regulation of their consumption.

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