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Evaluation of different binding materials in forming biomass briquettes with saw dust

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***Abstract* -** Biomass briquettes are often used as an energy source for cooking purpose and in some industries like bricks and bakery. The briquettes are produced by densification of waste biomass using various processes. In this study manual densification of saw dust was tested with three different binding agents; dry cow dung, wheat flour, and paper pulp. The samples with cow dung as binding agent failed with mould detaching and minimum required binder percentage for other two binders for successful forming were found to be 30%. Density of briquettes with 30% binder of wheat flour and paper pulp was found to be 373.7 kg/m^3 and 289.8 kg/m^3 respectively. Natural drying time was evaluated at 86~89% relative humidity and 25~30^{o}C ambient temperature. The time for achieving 15% moisture content (wet basis) was 55 hours. Compressive strength of the briquettes was tested for binder percentages of 30%, 40% and 50% (dry basis) of wheat flour and paper pulp binders. Results indicated that compressive strength increased with the increase of binder percentage. The briquettes with paper binder exhibited comparatively high compressive strength compared to wheat flour binder. Calorific values of briquettes formed having 30% paper binder and 30% wheat flour binder were found as 18.14MJ/kg and 20.04MJkg respectively, whereas the value of pure saw dust was 18.8 MJ/kg. The briquettes formed with paper pulp gave the minimum energy cost, the value being 0.16Rs./MJ.

Index Terms- Biomass briquettes, sawdust, renewable energy, biomass wastes

I. INTRODUCTION

Saw dust is an abundantly available solid waste in Sri Lanka. Large heaps of saw dust are common sight around the saw mills while some are appearing at the environmentally sensible areas such as river basins, estuaries and woodlands. The annual production of saw dust in the country is about 112,000MT which can be used to produce the energy products [1]. One of the suitable energy products is the Densified Biomass Briquette Fuel (DBBF) which can be used for cooking purposes and in industries like brick, tea and bakery. Several DBBF manufacturers are now in Sri Lanka, but they face difficulties with the cost of the briquette due to rising electricity bill. Therefore, manual densification is a suitable process. Therefore, developing a suitable technology for small scale manufacturers who can easily collect saw dust from saw mills produce biomass briquettes and sell while being in his living area is very important as a self-employment.

The main problem related to the manual densification process is the low pressure, hence low level of agglomeration of biomass particles. In general, pressure exerted on the mould is roughly classified as low pressure (up to 5MPa), intermediate pressure (5-100MPa), and High pressure (above 100MPa). Usually high pressure processes will release sufficient lignin to agglomerate the briquette. Intermediate pressure machines may or may not require external binder materials, depending upon the material whilst low pressure process essentially needs external binder materials. Identification of suitable binder materials in low pressure application was rarely investigated.

Many studies have been reported related to the chemistry behind the bonding of biomass particles. The understanding of binding of saw dust particles requires knowledge of the uniqueness of the wood structure for bond formation. The main components of the wood are the cellulose, hemi-celluloses and lignin. Further, main types of natural binding agents of biomass particles are lignin, protein and starch [2, 3]. The softening temperature of the lignin heavily depends on the moisture content of the raw material. It is around 90~100 ^{o}C at 30% moisture (wet basis) and around 130^{o}C at 10% (wet basis) moisture. So, Lignin is not softened at the ambient temperature. Likewise, protein acts as a binder in plasticized state which needs processing at high temperature too. Therefore, in ambient temperature processing, binding agents need to be supplied externally. These binding agents can be made of different materials. The waste materials or readily available materials are the best option for this type of applications for economic feasibility. As far as Sri Lankan situation is considered, cow dung, starch and paper pulp are possible materials.

Drying is the next energy consuming process in biomass briquette making. Moreover, quality of the briquette substantially depends on the method of drying. Drying refers to removal of water from solid by evaporation. This could be achieved through mechanical methods, thermal methods or naturally under atmospheric conditions. Natural drying is the most inexpensive method and it is suitable for the low dense saw dust DBBF.

The objective of this study was to compare different binding materials in the production of DBBF using saw dust under low pressure, in terms of reliability of the process, the quality attributes of the DBBF and the cost of the product.

I. Materials and Method

A. Collection and pre-treatment of raw materials

1) Base material

Saw dust was selected as the base material, which was taken from the heaps around the saw mills in *Moratuwa* area (Western province of Sri Lanka). Saw dust was sieved with a 2mm mesh and it was then tested for initial moisture content, and recorded as 27.2± 2.1 % (dry basis).

2) External Binding Material

Three types of commonly available external binding materials were used.

Dried cow dung: This material is available in the country for commercial purposes. It is easy to transport due to low weight and low stickiness. Firstly, lumps of cow dung were manually disintegrated to small particles. It was then tested for initial moisture content which was 62.8 ±6.8% (dry basis). The observed high standard deviation may be due to entrapping of high moisture content in the lumps of cow dung. Cow dung has many foreign particles which were removed before processing.

Newspaper waste: This is again amply available material in commercial level in Sri Lanka. The waste papers were manually torn to small pieces and soaked in water to form a gelatinized paste. Three to five days of soaking in water was required to get a sticky solution.

Wheat flour: Wheat flour was selected as a substitute for the starch. Since wheat flour is a relatively expensive food product, non-edible starch, like wild variety of Capioca could be utilized as energy product in commercial level application. The external binding agents which are derived from biological starch are regulated in EN 14961-2 and, only additives such as corn flour, potato flour or vegetable oil are allowed [4]. Initially, experimental trials were done with gelatinized wheat flour but it was found difficult to process due to stickiness. Therefore, wheat flour was used in powder form.

3) Experimental condition

In order to minimize the energy consumption of the compression process, manually applied pressure and ambient temperature was chosen. Additionally, saw dust was sieved with a 2mm mesh to reduce the energy demand and increase the degree of bonding. Further, natural drying was tested for the DBBF.

B. Equipment

1) Choice of Briquetting Machine:

Peterson press (Figure 1) was used as a densification device. It is relatively simple equipment having hydraulic jack and the frame. Cyclic pressure can be applied on the mould with a lever of the hydraulic jack (Max. 1500kg) until required compaction is obtained.

2) Size and shape of the Briquette and mould

Size of the briquette was selected with compaction geometry, height to Diameter ratio (H/D) being unity, which favours the combustion process [5, 6]. The exact dimensions selected were 35mm length and 35mm diameter. In addition to that, the shape of the briquette was selected as cylindrical for convenience.

Figure1- Peterson press

Size of the mould was 35 mm diameter and 100 mm height which was designed to make a 35mm diameter and 35mm height biomass briquette. A pictorial view of the mould and the hydraulic jack is shown in the Figure 2.

Figure 2 - Mould and briquette

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3) Other equipment

Domestic electric grinder/blender was used to crush the coarse particles of saw dust and ground particles were sieved with a 2mm mesh. Calorific value of the raw materials and briquettes were tested by using a bomb calorimeter (*Cussons* technology). Temperature increment within the calorimeter was measured with thermometer with accuracy of ±0.01°C and within the range of 27°C to 33°C. Furthermore, compressive strength of the briquettes was measured with a compression tester (*Siemec* 0.55kN Motor, 20kN Load cell).

C. Sample preparation

1) Blending of materials

Uniform distribution of binding materials in saw dust particle is a critical requirement for the proper binding action. Although starch was manually mixed with saw dust, cow dung and paper pulp binders were mixed with the domestic blender. Water was added as a medium to facilitate good mixing. Six samples for each binding agent were prepared with different percentages of binder content, 5%, 10%, 20%, 30%, 40% and 50%, and the rest being the base material.

2) Pressing

The material blends were filled up to the edge of the mould and it was pressed by the Peterson press. The pressure on the mould was recorded by a weighing balance placed under the hydraulic jack. When the lever of the hydraulic jack completed a cycle, the pressure applied on the mould reached the maximum for that cycle and each lever cycle was taken as a pressure cycle.

3) Drying

Resulting DBBF samples were dried in a naturally ventilated room with relative humidity (RH) 86% - 89% and ambient temperature 25°C - 30°C for three days. Weights of the DBBF samples were recorded in each hour which was used to calculate the moisture content of the product.

Finally the samples were kept in an oven at 105±2°C until a constant weight is achieved to determine the moisture content of samples.

4) Density

The density of samples was calculated by measuring the volume and weight. A venire calliper was used to measure the diameter and the height of a sample and an electronic balance was used to measure the weight.

5) Compression strength

No standard test methods have been established for testing of compressive strength of DBBF. Compressive strength is usually performed to identify the ability of the DBBF to withstand the crushing loads during handling, transporting and storing. It measures the maximum crushing stress of a DBBF before cracking or breaking.

Compressive strength with saw dust DBBF with the paper pulp and wheat flour binders were tested by increasing the binding agents (30%, 40% and 50%,dry basis) to identify the contribution of the binding agents for the strength of the product.

II. Results and Discussion

A. Process description

1) Mould detachment

The visual observations made on the stability of the briquette during mould detachment are summarized in Table 1. Saw dust samples with less percentage of binder showed a difficulty in binding the mass together and they were totally disintegrated at 110 kg load (1.12MPa). However, a clear improvement of the binding performance was observed with the increase of binder percentage of wheat flour and paper pulp. The samples made with wheat flour and paper pulp as binder gave stable briquettes when the binder was 30% or above. Further, behaviour of samples of DBBF made with cow dung as the binder was different where the addition of the binder did not give any contribution to the bonding of sawdust DBBF. This observation clearly eliminates the dry cow dung as a binding agent for saw dust. Hence further investigations were done only with the paper pulp and wheat flour binders (30% or more) only.

TABLE 1
VISUAL OBSERVATIONS OF MOULD DETACHING

Binder	Dry binder percentage					
	5%	10%	20%	30%	40%	50%
Cow dung	No	No	No	No	No	No
Wheat flour	No	No	No	Yes	Yes	Yes
Paper pulp	No	No	No	Yes	Yes	Yes

No = Briquettes were disintegrated when detaching from the mould
Yes = Briquettes were easily detached from the mould.

The observation with the binder-less saw dust briquettes proved that the impossibility of activation of natural binding agents such as lignin in the given process conditions. As described by Kaliyan *et al* (2010) lignin is squeezed out from the cell wall only with the elevated pressures (above 150MPa) or at the elevated temperatures [2] (glass transition temperature of lignin is 60°C to 90°C).

Cow dung is thought to be a famous binding material in its fresh form. However, it was revealed that the cow dung has lost this ability in the dry form. It is very hard to interpret this result due to limited information about the variation of composition of cow dung when it becomes old and dry. Starch and paper pulp are possible good binders as both are natural binding agents in biomass structure. The lignin is the major component in the paper pulp where it is broken down from the structure in the pulping process. Gelatinisation of starch during the mixing process also contributed to good binding properties.

2) Cyclic loading

The variation of load applied on the mould during the each compression cycle (sometimes called as compression factor) is presented in Fig 3. In this study a maximum load of 110kg was maintained for all the experiments. The corresponding maximum pressure was 11.43 kg/cm^2 and it was lower than the previously reported values of manual densification process, 60 kg/cm^2 [7]and 83 kg/cm^2 [8].

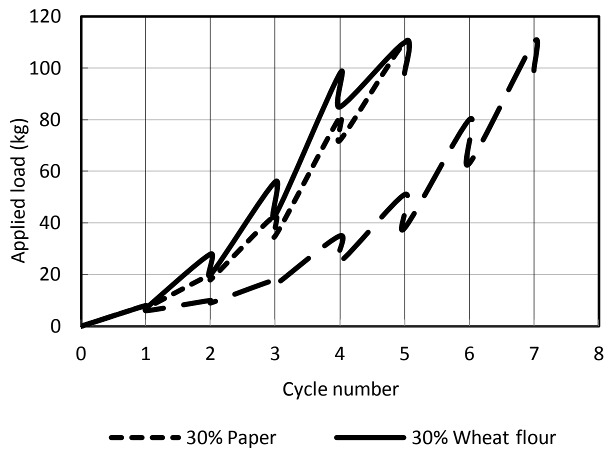

Figure 3 -The variation of applied load on the mould

The load was increased in a cyclic manner corresponding to pressure cycle of the lever. Mould pressure was directly related with the lever position. Pressure was reached to maximum when the lever was at the lowest position and then dropped before starting the next cycle. During the process, water was squeezed out from the holes around the mould. Small time gap was maintained between two pressure cycles to facilitate the squeezing of water out from the briquette. Repetitive pressure cycles were continued until the predetermined maximum load of 110kg was achieved. Number of pressure cycles needed to reach the maximum load was recorded and summarized in table 3.

TABLE 2
FORCE ACTING ON THE MOULD

	Maximum force (kg)	Number of force cycles
Cow dung	110 kg	7
Wheat flour	110 kg	5
Paper	110 kg	5

Table 2 shows that additional two force cycles were needed for the cow dung samples which demonstrates the demand of extra energy for the compression.

Water plays a dominant role in the particle bonding. Some of the added water escapes through the holes around the mould during the application of pressure and thin layer of water is created around the biomass particles which helped to increase the contact between particles [2]. Therefore, amount of water remains within the briquette is important for inter particle bonding [9]. Final moisture contents of the briquettes were 50.0% (wb) for the samples with wheat 30% and 52.0% (wb) for the samples with paper pulp 30%.

3) Natural drying process:

Figure 3 shows the variation of moisture content of the DBBF with respect to time under natural drying conditions.

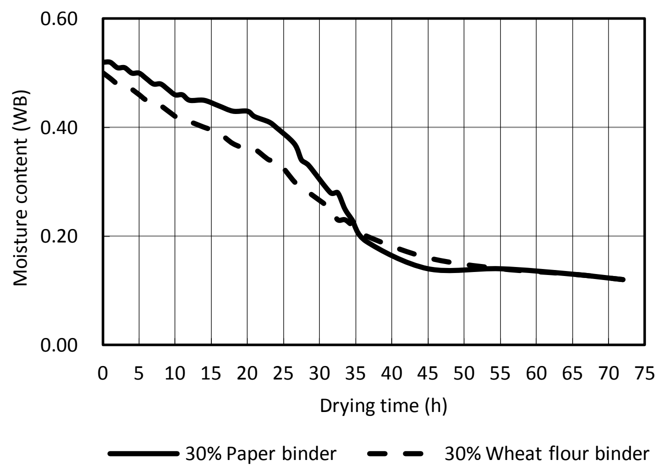

Figure 4 - Natural drying curve of saw dust briquettes

Generally, 20% (Wet basis) moisture content can be achieved over a period of 35 hours and 15% (Wet basis) over a period of 55 hours.

Initially, both paper and starch (30%) DBBF had moisture content (Wet basis) slightly above 50%. This was rapidly decreased in the first 35 hours until moisture content was reached to 20%. After that, slight decrement of moisture content was observed for next 35 hours and at the same time moisture content became stable at the 15% (55 hours from the beginning). More interestingly, both types of DBBF showed the same drying characteristic under same conditions.

The DBBF contained low dense bed of solid which has more water inside the porous structure. This water can exist as either free water in the porous structure, or as bound water. When briquette dries, water first moves from the porous structure until fibre saturation point is reached [10]. Thereafter, bound water may evaporate until the equilibrium moisture content is reached. In this study fibre saturation point of the DBBF was found to be 20% whereas the equilibrium moisture content was 15%. The optimum moisture content of the DBBF should lie within the range of 12% ~ 15% [11]. When the moisture content of the briquette reaches below 12%, low compression strength of the briquette is observed [12]. When it reaches above 15%, low heating value problems and other commercial problems such as pricing and transportation could arise.

Fine surface was observed with the final DBBF products. Surface quality of the briquette is related with the drying behaviour of the biomass solid. As demonstrated by Walker *et al*. (1993), to get the proper surface structure, the movement of moisture from the interior to the surface would equal to the evaporation of moisture from the surface to the environment [9]. If evaporation is too rapid excessively steep moisture gradient will result and this will be accompanied by drying stresses which may cause structural damages. In addition to that, Kaliyan *et al*. (2009) stated that 5% of the durability factors depend on the drying method [12]. Obviously, these favourable conditions were fulfilled by the natural drying process with the absence of forced air and resultant DBBF was free from cracks and fractures.

B. Quality of the DBBF

1) Size and density of the briquette samples:

Density of the briquette was calculated for paper pulp (30%) and wheat flour (30%) DBBF. Average of six samples of each was tested and the results are summarized in Table 4.

TABLE 3
DENSITY OF THE BRIQUETTE

Sample	Average density (kg/m^3) For 6 samples	Average Height (mm) For 6 samples
Wheat flour	373.7±8.3	55±1.8
Paper	289.8±6.5	36±2.1

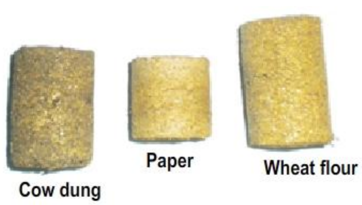

Figure 5 - Pictorial view of hand pressed briquettes

Diameter of the briquette was maintained as 35mm. But heights were varied with respect to the degree of compression at the maximum loading. As per the visual observation, the paper pulp briquettes were more compacted and rigid.

Average density of briquettes was significantly lower than 400 kg/m^3 which is generally accepted density level for normal handling and storage without deterioration [9].

2) Compressive strength of DBBF

The contribution of different binding agents for the strength of the DBBF is presented in the Figure 4. As a whole, the compressive strength increased with the increase of the binder percentage. This proved that the binding agents actively contribute to the binding process. Paper binder DBBF showed a higher compressive strength (0.124 N/mm^2 to 0.238 N/mm^2) than wheat flour DBBF (0.032 N/mm^2 to 0.055 N/mm^2). Further, the paper binder DBBF had a remarkable increment (91%) of the compressive strength with the increase of the binder percentage from 30% to 50% while wheat flour DBBF exhibited 71% increase.

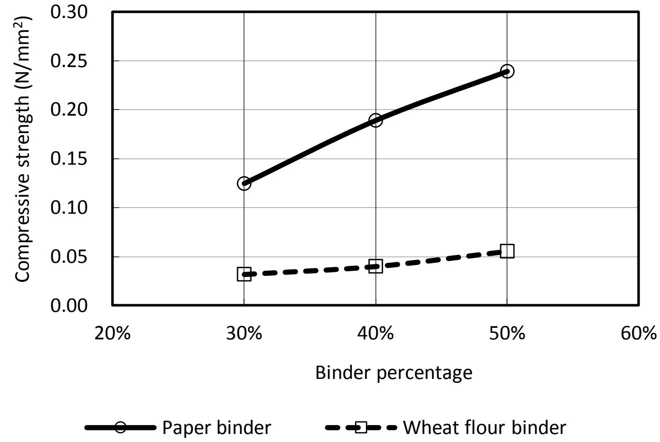

Figure 6 - Influence of binder % on compressive strength of saw dust briquettes

There was no recommended standard on the minimum acceptable level for the strength of the densified biomass [12]. Instead, it depends on the application requirements.

3. Combustion characteristics of DBBF

ASTM D5865 - 11a Standard Test Method for Gross Calorific Value of Coal and Coke was used to evaluate the calorific value of biomass materials with Bomb Calorimeter (Cussons technology). Calorific value (Higher Heating Value) of saw dust (raw material), DBBF with wheat flour (30%) and paper pulp (30%) were tested.

HHV, HHV_d, *LHV* of saw dust and DBBF were calculated using equation 2, 3, 4 and 5, and values are tabulated in Table 4.

$$W = \frac{m_1 H_1}{\Delta T_1} \quad (1)$$

$$HHV = \frac{\Delta T_2 W}{m_2} \quad (2)$$

$$HHV_d = \frac{HHV}{(1-M)} \quad (3)$$

$$LHV = HHV(1-M) - 2.447M \quad (4)$$

W - Energy equivalent of Calorimeter
m_1 - Weight of standard benzoic acid
m_2 - Weight of fuel
H1 - Heat of combustion of benzoic acid
ΔT_1 -Temperature rise in benzoic acid combustion
ΔT_2 - Temperature rise in fuel combustion
M - Moisture content of the biomass (wb)
HHV - Higher heating value determined by the calorimeter

HHV_d - Higher heating value of the biomass in MJ/kg of dry biomass

LHV -Lower heating value of biomass (MJ/kg dry biomass)

TABLE 4
CALORIFIC VALUES OF DBBF AND SAW DUST

Material	ΔT	MC	HHV $MJKg^{-1}$	HHV_d $MJKg^{-1}$	LHV $MJKg^{-1}$
Saw dust	2.28	0.28	18.88	26.23	18.20
30 % Paper pulp DBBF	2.19	0.20	18.14	22.67	17.65
30% Wheat flour DBBF	2.42	0.20	20.04	25.05	19.55

ΔT- Temperature increment in bomb calorimeter
MC – Moisture Ccontent

The calorific value (HHV) of the saw dust was found to be 18.8 MJ/kg at 28% moisture content. This value was found to be decreased in the DBBF with paper pulp and increased with wheat flour. In fact, heating value of briquettes depends on the fixed carbon content, ash content and moisture content [13]. Briquetting is the physical transformation of biomass in to densified product. Therefore, fixed carbon content and ash content remains as the original raw material. Fixed carbon content basically depends on the cellulose content of the selected biomass. Sharma and Mohan (1987) estimated the calorific value of pure cellulose as 17.3MJ/kg [14]. According to the literature, cellulose content of paper is nearly 95% and it could vary with the original wood from which the saw dust is obtained. There is no significant difference between experimental calorific value of 18.8 MJ/kg of saw dust in the present study and the previously reported value of 19.4 MJ/kg [15].

For the moist fuel, heating value decreases because a portion of the combustion heat is used to evaporate the moisture in the biomass and this evaporated moisture has not been condensed to return the heat back to the system. Therefore, an estimation of LHV with the equation 5 was obtained from the measured HHV by subtracting the heat of vaporization of water in the products. According to the study, wheat flour DBBF had the highest LHV which was higher than that of pure saw dust. The paper pulp DBBF showed a LHV slightly less than that of saw dust.

Equation 4 was used to determine the HHV and values were independent from the effect of moisture. Highest value was obtained with the pure saw dust and, calculated values for DBBF were lower than it, which means binding additives has a lower HHV_d than that of saw dust.

4) Comparison of DBBF made out of different binding agents

The binding ability of different binders with saw dust particles depends on the constituents of the saw dust and binder. In general, starch, lignin and water soluble fibre are good binders. Protein acts as a binder at plasticized state which needs processing at high temperature. Even though saw dust contains 40~50% cellulose and 30% lignin [14], activation of lignin cannot be achieved under certain process conditions. Therefore, starch, lignin or water soluble fibres are needed be added externally to increase the bonding of biomass in the briquette.

Firstly, in the pulping process, native cellulose breaks down into small particles. This can be observed with the degree of polymerization where, native cellulose is >3500, cellulose in paper is in the range 600~1000 and hemi cellulose in paper is in the range 500~300[16]. This Cellulose helps to enhance the bonding of saw dust particles in water soluble state. Lignin mainly exists as a binder of cellulose fibres, but in a paper it has separated from Cellulose and freely exists [17]. This lignin plays a dominant role in binding of saw dust particles.

Wheat flour contains 63% starch [18] which acts as a binder. Kaliyan et al. (2009) stated that the native starch has less binding ability than the gelatinized starch [12]. This occurs in the presence of heat and moisture and during the mechanical shearing in the densification process. Although gelatinization is a supportive process for the binding, wheat flour in this form was difficult to mix with the saw dust. Therefore, mixing of wheat flour with saw dust was done before adding water. However, considerable amount of wheat flour was drained out during the briquette densification process.

Cow dung DBBF was broken during the mould detaching proving the less ability of binding of cow dung with saw dust particles. Since, availability of limited knowledge about the change of composition of cow dung during drying process, it is hard to discuss about the binding observation of cow dung.

5) Comparison of sawdust DBBF with international norms

Quality of the DBBF was compared with the recommended values of quality parameters in EN 14961-3 Class B-1.2. (Briquettes made out of residues of wood processing industry). Results are summarized in Table 5. These briquettes industrially made at high temperature and high pressure.

TABLE 5
COMPARISON OF QUALITY OF DBBF WITH INTERNATIONAL NORMS

Parameter	Measurement	Recommended level	Experimental value
Moisture content	weight % as received	≤ 15	≤ 15
Ash content	weight % dry basis	≤ 3.0	Not tested
Particle density	g/cm^3	≥ 0.9	≤ 0.4
Additives	Additives percentage like starch, corn flour ect...	≤ 2	≥ 30

In order to meet the international norm EN 14961-3, saw dust DBBF is generally made in a high pressure process. Major deviation is particle density (much lower than the standard) and additive percentage (cannot increase 2%). However, moisture content can be achieved to 15% within 55 hours with natural drying process.

C. Comparison of energy cost

Estimation of energy cost was done by considering prices and calorific values of the raw materials. Transport cost, process cost and labour cost were not considered. Table 8 indicates the comparison of energy cost of DBBF (Saw dust briquette with 30% dry binder) with available energy sources in Sri Lanka.

TABLE 6
COMPARISON OF COST OF ENRGY

Raw material	**Cost/Price**	**Energy Content**	**Energy cost/Price**
Saw dust DBBF with 30 % Wheat flour binder (HHV_d)	31.80Rs/kg	25.05 MJ/kg	1.26 Rs/MJ Raw material cost
Saw dust DBBF with 30% Paper binder (HHV_d)	3.75Rs/kg	22.67 MJ/kg	0.16 Rs/MJ Raw material cost
Fuel wood	15 Rs/kg	15 MJ/kg	1.00 Rs/MJ
Electricity	12.5 Rs/kWh	3.6 MJ/kWh	3.57 Rs/MJ
LP Gas	198Rs/kg	45 MJ/kg	2.10 Rs/MJ

This Comparison was done based on the actual pricing in 2012. Electricity prices were taken by Public Consultation Documents on Setting of Tariff for the Period 2011-2015 Sri Lanka.

Saw dust DBBF with 30% dry binder is comparatively cheaper than LP gas and electricity. DBBF with paper pulp binder is the cheapest. However it should be noted that the labour cost was not considered for this comparison.

D. Future recommendations

Briquetting is a sustainable technology for meeting heat energy demand in Sri Lanka. Available biomass residues vary in a big range such as rice straw, hay, tea plantation residues, home garden residues, starch substitutes etc. In order to that, research can be extended to identify different biomass and to examine suitable composition for combination in biomass materials.

Burning characteristics of the briquette in different burners such as boilers, stoves, kiln etc. is different. This research would need to be adapted with the cooking stove developments to enhance the burning characteristics of briquettes.

Milling and mixing is energy consuming processes. Several kinds of manual milling and mixing machines have successfully run in the world, henceforth research can be extended in to that area to enhance the briquette project in Sri Lanka. Apart from that, particle size distribution can be increased above 2mm to find the optimum value.

Quality of the DBBF has standardized in European Union in EC 16940 guidelines for international briquette market. Same way Inland quality standards of DBBF can be developed by analysing burning characteristics and handling requirements in Sri Lankan context.

Even though availability of raw materials is high, handling and transportations should be improved with the proper technology. Such as, transportation of saw dust can easily achieved by using the packing of saw dust in a Flexible Intermediate Bulk Containers (FIBCs).

E. Economic evaluation

Forest products and agricultural residues are of great importance to Sri Lanka's overall energy supply. Still fuel wood is consumed for 79% of house hold energy requirement in Sri Lanka [19]. The resulting deforestation is a severe problem and would result in a complete depletion of forests within a few decades. Therefore, fuel wood is a limited resource and it is not advisable to depend only on fuel wood. Saw dust DBBF could be an acceptable solution for industrial boilers, furnaces and household applications.

1) Availability

Availability of raw material is an important parameter for economic feasibility. Table 7 shows calculated values with the aid of available data extracted from different sources.

TABLE 7
AVAILABILITY OF RAW MATERIALS IN SRI LANKA

Raw Material	**Availability (MT/Year)**	**Reference**
Saw dust	112000	[1]
Cow dung	1159	[16]
Wheat flour (Starch substitutes)	Potential to grow*	[20]
Paper	264000	[20]

Thirty percent of the land in Sri Lanka is under cultivation. The gross extent of land cultivated under major crops in hectares are, paddy 600,000, coconut 395,000, tea 211,000 and rubber 115,000. Other starchy crops such as cassava, cannas, *Innala* could also be cultivated in large scale along with these major crops. However, a proper mechanism for collection of raw materials such as saw dust, waste paper or starch derivatives has to be established.

Availability of saw dust around a major saw mill is about 277.5MT annually. Small scale manufacturers can be located around the saw mill and briquette making could be done throughout the year. Most of the saw mills are located in Moratuwa area and it is near to the capital city Colombo. As an additive, paper waste could be collected from urban areas hence saw dust-paper blend is a feasible option. Since Moratuwa is in the boundary of the *Kaluthara* district which is a high rain fall region non edible yams can be cultivated in this low populated area, hence saw dust-starch blend is also feasible with availability.

III. Conclusions

Manual densification of saw dust DBBF is possible with the piston press technology. However, binding agents should be added externally to get the proper binding. Dry cow dung, wheat flour and paper pulp are possible binders and dry cow dung was not suitable for it. Final DBBF was stable and fine surfaced. Since low density of the DBBF, natural drying can be used to dry DBBF. The briquettes with paper binder exhibited comparatively high compressive strength compared to wheat flour binder. Calorific value of briquettes obtained with 30% paper binder was 18.14 MJ/kg and with 30% wheat flour binder it was 20.04MJ/kg.

Energy cost of the saw dust DBBF is low compared to the convectional sources such as LP Gas, fuel wood and electricity. However, external binding agent percentage was quite high (30% or higher). So, initial establishment of raw material supply such as paper waste and starch substitute will need to be addressed for commercial level production.

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