World Academy of Science, Engineering and Technology 68 2012

Low Pressure Binder-Less Densification of Fibrous Biomass Material using a Screw Press

Tsietsi J. Pilusa, Robert Huberts, Edison Muzenda

Abstract**—**In this study, the theoretical relationship between pressure and density was investigated on cylindrical hollow fuel briquettes produced of a mixture of fibrous biomass material using a screw press without any chemical binder. The fuel briquettes were made of biomass and other waste material such as spent coffee beans, mielie husks, saw dust and coal fines under pressures of 0.878-2.2 Mega Pascals (MPa). The material was densified into briquettes of outer diameter of 100mm, inner diameter of 35mm and 50mm long. It was observed that manual screw compression action produces briquettes of relatively low density as compared to the ones made using hydraulic compression action. The pressure and density relationship was obtained in the form of power law and compare well with other cylindrical solid briquettes made using hydraulic compression action. The produced briquettes have a dry density of 989 kg/m^3 and contain 26.30% fixed carbon, 39.34% volatile matter, 10.9% moisture and 10.46% ash as per dry proximate analysis. The bomb calorimeter tests have shown the briquettes yielding a gross calorific value of 18.9MJ/kg.

Keywords**—**Bio briquettes, biomass fuel, coffee grounds, fuel briquettes

I. Introduction

BRIQUETTING of biomass is a densification process which improves its handling characteristics, enhances its volumetric calorific value, reduces transportation cost and produces a uniform, clean, stable fuel or an input for further refining processes [4]. Fuel briquettes are bonded by the random alignment of fibers, generated when plant fibres and shredded waste paper are soaked in water. The process occurs at ambient temperature at a pressure of 1.5 to 3.0 MPa. To a large degree, the bonding force in the fuel briquette is mechanical, not chemical. Because of this, retaining fiber integrity and the right degree of plasticity in the mixture is crucial to the quality of the fuel briquette [5].

Briquetting of biomass has been found to be a viable technology for upgrading biomass materials, including agricultural residues, particularly in developing countries where there are abundant bio-waste resources. The technology converts the bio-waste into forms which are combustible in typical burners. The physical characteristics and, hence, combustion characteristics of the briquettes formed depend on several factors among which the briquetting pressure is controlled. This was confirmed by experimental investigations during which the samples were densified under pressure ranges of 5–15 MPa [6].

T. J. Pilusa is with the Process, Energy and Environmental Technology Station at the University of Johannesburg, Doornfontein, Johannesburg, 2028, South Africa (phone: +2711-559-6438; fax: +2711-559-6881; e-mail: jefreyp@ uj.ac.za).

R. Huberts is with the Department of Chemical Engineering at the University of Johannesburg, Faculty of Engineering and the Built Environment, Doornfontein, Johannesburg, 2018, South Africa (phone: +2711-559-6517; fax: +2711-559-6430; e-mail: roberth@uj.ac.za).

E. Muzenda is with the Department of Chemical Engineering at the University of Johannesburg, Faculty of Engineering and the Built Environment, Doornfontein, Johannesburg, 2018, South Africa (phone: +2711-559-6817; fax: +2711-559-6430; e-mail: emuzenda@uj.ac.za).

II. Materials and Methods

A. Briquettes Production

Fuel briquettes were made of a mixture containing 32% spent coffee grounds, 23% coal fines, 11% saw dust, 18% mielie husks, 10% waste paper and 6% paper pulp contaminated water, at moderately low pressure, of about 0.878-2.2 MPa, using hand operated screw press as shown in Fig. 1. All briquettes had an outer diameter of 100mm, inner diameter of 35mm and were 50mm long. There was no need for a chemical binder; the material components underwent natural binding by interlocking themselves by means of partially decomposed plant fibers. This would allow the measurement and estimation the maximum possible briquetting pressure attained by the press. Parameters such as moisture contents and densities of the briquettes were measured.

Fig. 1 Production of briquettes using a manually operated screw press

B. Pressure Density Relationship

The relationship between the briquetting pressure and briquette density has been studied by many researchers in the past [4]. The relationship between pressure and density for straw was proposed in a form of a simple power law at high briquetting pressures [7]. This power law was developed for solid briquettes with diameters ranging between 40mm and 60mm. O'Dogherty & Wheeler found an exponential relationship of the form:

$$D = a \ln P + b. \tag{1}$$

Where P is the briquetting pressure measured in MPa, D is the density of the briquettes in kg/m^3 and a, b are empirical constants which vary for different feed stocks. The constants for briquetting straw obtained by O'Dogherty & Wheeler are as follows:

40mm diameter, a=0.0389, b=0.0045
50mm diameter, a=0.871; b=0.0036
60mm diameter, a=0.189; b=0.0033

Faborode & O'Callagham expanded O'Dogherty & Wheeler's work and also noticed an exponential relationship between the briquetting pressure and density of the briquette when briquetting is conducted at moderately low pressure. This relationship is more relevant to the fuel briquettes due to the fact that it was developed on cylindrical shaped briquettes with a hole at the centre

$$P = ae^{bD} \tag{2}$$

C. Axial Load and Pressure Estimation

The minimum force exerted by a screw mechanism is mainly dependent on the geometry of the screw and applied toque. The biomass blend was fed through the funnel of the press into the perforated cylinder, which is closed with a cam-lock solid steel disc at the bottom as shown in Fig. 2. A rotational force applied on the handle of the screw rod was transferred into an axial load, pushing the piston against the material in the cylinder. This force was maintained by the nut and as the screw rod is tuned, the axial load increases periodically. The design specifications of the screw thread used in the screw press were used to validate the pressure measured during densification process. It was assumed that the applied toque is weight equivalent of the handle and the perpendicular distance from the screw pivot. The design specifications are as follows:

- Applied toque (T) =27,935N.mm
- Major thread diameter (D) =30mm
- Thread radius (r_o)= 15mm
- Thread depth (h) = 3.8mm
- Coefficient of screw thread and mating(f) =0.15
- Thread pitch (L) = 3.74mm
- Thread angle at bearing surface (θ_n)=150 radians

Fig. 2 Screw press equipment used for making fuel briquettes.

The following equations were used to calculate the axial load of the screw press [8].

Minor thread radius:

$$r_i = r_o - h \tag{3}$$

Mean thread radius:

$$r_m = \left(\frac{r_o + r_i}{2}\right) \tag{4}$$

Angle of thread at mean radius:

$$\alpha = \tan^{-1}\left(\frac{L}{2.\pi.r_m}\right) \tag{5}$$

Thread angle at bearing surface:

$$\theta_n = \tan\theta.\cos\alpha \tag{6}$$

Thread constant:

$$R_c = r_m \times \left[\left(\frac{\dfrac{\tan(\alpha)_{rad} + f}{\cos(\theta_n)_{rad}}}{\dfrac{1 - f.\tan(\alpha)_{rad}}{\cos(\theta_n)_{rad}}}\right) + f\right] \tag{7}$$

Minimum axial load

$$\therefore F_{\min} = \frac{T}{R_c} \tag{8}$$

The briquetting pressure is calculated from first principles using the following equation.

$$P = \frac{F}{A_c} \tag{9}$$

Where,

F = Force perpendicular to the cross section area of the briquette (N)

A_c = Cross sectional area of the briquette (m^2)

P = Briquetting pressure (Pa)

III. RESULTS AND DISCUSSIONS

The force applied on to the screw handle by one hand may be estimated as 22.6 kg weight equivalent, including the mass of the handle. This result in a weight of 221.7 N, which is equivalent to the tangential force exerted on the handle. Based on the general arrangement drawing in Fig.3, a resultant force of 221.7 N is applied at perpendicular distance from the origin. The resulting toque was obtained as 27.9 kN.mm and the axial load was verified by calculations using (3-9). The results showed an axial load parallel to the thread axis of 6.5kN when the screw friction coefficient was 0.15. If the screw thread was greased, the friction coefficient could be reduced and the maximum axial load of 15.1kN, neglecting friction effects.

If these loads are exerted over a cross-sectional area of $0.00689m^2$ as calculated using the briquettes dimensions, the resulting die pressure will range between 0.878MPa and 2.2 MPa. These figures correspond to the briquetting pressures measured during the experiment with minimum pressures and maximum pressure of 0.840MPa and 2.102MPa respectively.

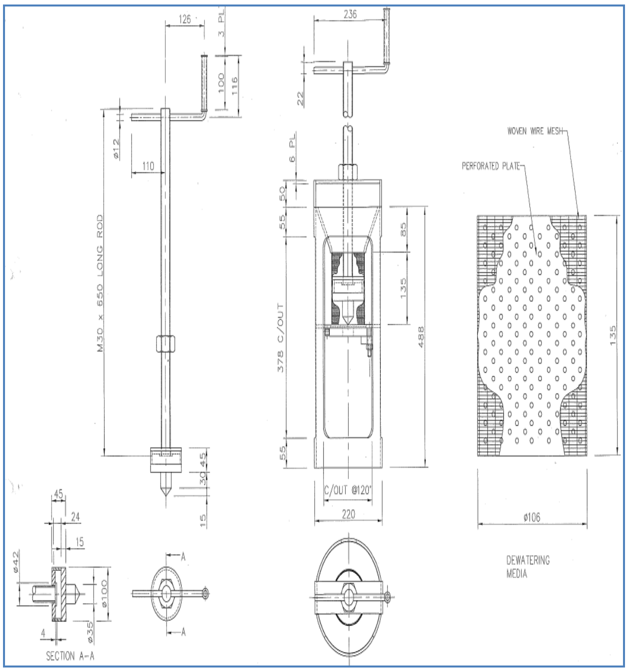

Fig. 3 General arrangement drawing of the screw press

The pressure attained by the screw press falls within the moderately low briquetting pressure range of 1.5-3.0 MPa as reported by previous researchers [4]. However the quality of the briquettes was good due to the binding characteristics of the partially decomposed material in the mixture. The briquettes produced by the screw press appeared to be more compact and stable. This is justified by the theoretical pressure exerted by the screw mechanism (0.878-2.2 MPa) as well as the dewatering characteristics provided by the compaction chamber of the press. Although the pressure achieved by the screw press is slightly lower than the pressures reported in the past [5] the briquettes were more durable. An impact test was conducted whereby dry briquettes were dropped from a 2m high building onto a brick paved floor and no material disintegration was noticed.

Table I shows a variation of briquetting pressure and density and its effect on the final moisture content. The results indicate an exponential relationship between the pressure and dry density of the briquettes. Since the briquettes were made at moderately low pressure (below 5MPa), the power law is applicable to the pressure density relationship [7]. An exponential trend line was fitted on the curve in order to obtain the empirical constants for the feed stocks used in making the fuel briquettes. The following empirical constants for the material used in making eco-fuel briquettes of 100mm outer diameter and 35mm inner diameter were found as (a = 0.3209 and b = 0.002). These empirical constants look reasonable when compared to the ones determined by previous researchers [7].

TABLE I
PHYSICAL PROPERTIES OF BRIQUETTES MADE USING A SCREW PRESS

Description	Test 1	Test 2	Test 3	Test 4
Pressure (MPa)	0.840	0.954	1.432	1.832
Wet-Density (kg/m^3)	1,089	1,032	1,045	1,115
Dry-Density (kg/m^3)	506	573	787	917
Moisture –wet basis (%)	63.5	58.7	43.3	33.9
Moisture- dry basis (%)	18.9	15.1	13.71	13.1

The results presented in Fig. 4 indicate that the briquettes made using the screw follow the empirical model suggested by previous researchers [3]. This implies that if the material is pressed at pressures of 6-8 MPa, briquettes of higher densities ($1200kg/m^3$) could be achieved. The screw pressing mechanism has the lower pressing force over a given cross sectional area compared to other hydraulic presses, resulting with final briquettes of lower densities (989 kg/m^3). However the final moisture of the briquette from the screw press is much lower which gives the briquettes better drying characteristics. This is due to the better dewatering and rotational compaction mechanism provided by the screw press.

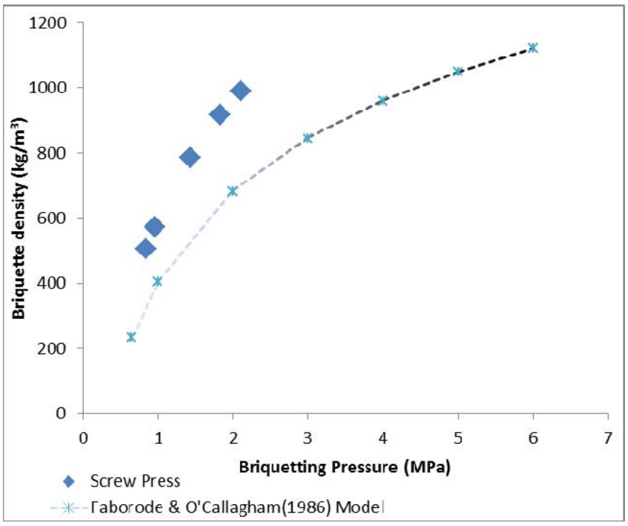

Fig. 4 Pressure & density relationship of eco-fuel briquettes

IV. CONCLUSION

It has been observed that the briquettes made from the screw press were stable and compact with a density of 989 kg/m^3 and wet cake moisture content of 28.87%. The exponential relationship between the die pressure and dry cake density exits. The proximate analysis of the dry briquettes have shown that the briquettes contain 26.30% fixed carbon, 39.34% volatile matter, 10.9% moisture and 10.46% ash.

The bomb calorimeter tests have shown the briquettes yielding a gross calorific value of 18.9MJ/kg. The test results have proven that the briquettes can be sufficiently compacted without applying a significant amount of pressure. This was confirmed by visual inspection of the briquettes produced and the impact test conducted.

V. RECOMMENDATIONS

The density-pressure relationship on this specific shape of briquettes made from different mixture of fibrous biomass need to be investigated to evaluate the cut point. Utilization of manually operated equipment with good dewatering characteristics at low pressure is recommended as it reduces the energy input required for densification and drying.

ACKNOWLEDGMENT

The authors gratefully acknowledge the financial support provided the National Research Foundation, South Africa and the University of Johannesburg's Research Committee.

REFERENCES

[1] A. Debdoubi, A. Elamarti & E.Colacio, "Production of fuel briquettes from esparto partially pyrolyzed". Energy Conversion and Management, vol.46, pp. 1877-1884, 2005.
[2] A.Demirbas and A.Sahin, "Evaluation of biomass residue: Briquetting waste paper and wheat straw mixtures". Fuel Processing Technology, vol.55: pp.175-183. 1997.
[3] M.O. Faborode and J.R. O'Callagham, "Theoretical analysis of compression of fibrous agricultural materials". Journal of Agricultural Engineering, vol.35, pp. 175-179. 1996.
[4] E. Granada, L.M. Lopez Gonzelez, J.L Miguez and J. Moran, "Fuel lignocellulosic briquettes die design and product study". Renewable Energy, vol. 27, pp. 561-573. 2002.
[5] Z. Husain, Z. Zainac and Z. Abdullah Z. "Briquetting of palm fibre and shell from the processing of palm nuts to palm oil". Biomass and Energy, vol. 22, pp.505-509. Jan 2002.
[6] S. Mani, L.G Tabil and S. Sokhansanj, "Specific energy requirement for compacting corn stover". Bioresource Technology, vol 97, pp.1420-1426, 2006.
[7] H.J. O'Dogherty and J.A Wheeler, "Compression of straw to high densities in close cylindrical dies". Journal of Agricultural Engineering, 29: 61-71. 1984.
[8] http://www.engineersedge.com/gears/screw-axial-thrust-load-calculations.htm, Accessed 26-01-2011

Tsietsi J. Pilusa holds a Master's degree in Chemical Engineering from the University of Johannesburg. He has more than 7 years' experience, in mining, metallurgy and waste management industries. Currently, he is a Station Engineer in the Process, Energy and Environmental Technology Station at the University of Johannesburg. His main areas of research are in alternative fuels, waste to energy, environmental pollution and waste management. His research involves classifications of industrial wastes, energy recovery, beneficiations processes and energy utilization mechanisms.

Robert Huberts holds a PhD in Chemical Engineering from the University of the Witwatersrand. Currently, he is a Senior Lecturer in the Department of Chemical Engineering at the University of Johannesburg. Robert has over 15 years' experience in in the field of hydrometallurgy and mineral processing. He has more than **8** years' experience in academia. Robert's teaching interests and experience are in heat and mass transfer operations, production engineering and chemical engineering technology. His main areas of research are in bacterial leaching, bio waste to energy and anaerobic digestion.

Edison Muzenda is an Associate Professor, Research and Postgraduate Coordinator as well as Head of the Environmental and Process Systems Engineering Research Group in the Department of Chemical Engineering at the University of Johannesburg. Professor Muzenda holds a BSc Hons (ZIM, **1994**) and a PhD in Chemical Engineering (Birmingham, **2000**). He has more than **15** years' experience in academia. Edison's teaching interests and experience are in unit operations, multi-stage separation processes, environmental engineering, chemical engineering thermodynamics, entrepreneurship skills, professional engineering skills, research methodology as well as process economics, management and optimization.

He is a recipient of several awards and scholarships for academic excellence. His research interests are in waste water treatment, gas scrubbing, environment, waste minimization and utilization, energy as well as phase equilibrium measurement and computation. He has published more than **85** international peer reviewed and refereed scientific articles in journals, conferences and books. Edison has supervised over 18 postgraduate students as well as more than 130 Honours and BTech research students. He serves as reviewer for a number of reputable international conferences and journals. He has also chaired several sessions at International Conferences. Edison is an associate member of the Institution of Chemical Engineers (AMIChemE), member of the International Association of Engineers (IAENG); associate member of Water Institute of Southern Africa (WISA) and member of the International scientific committee of the World Academy of Science, Engineering and Technology (WASET) as well a member of the Scientific Technical Committee and Editorial Board of the Planetary Scientific Research Centre. Edison is recognized in Marquis Who's Who 2012 as Engineering Educator.