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INVESTIGATION OF MECHANICAL & COMBUSTIBLE PROPERTIES OF BRIQUETTES PRODUCED FROM RICE HUSK USING POLYSTYRENE FOAM ADHESIVE AS A BINDER

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ABSTRACT

This paper is about determining the mechanical and combustible properties of briquettes produced from rice husk using polystyrene foam adhesives as a binder. These two properties are critical in determining the quality of briquettes produced from a waste agricultural material in order to maintain its compactness without losing its shape or compromising its fuel properties. For the briquettes produced under six different pressure applications at interval of 10kN/m^2 from 40 – 90 kN/m^2, mechanical properties like density, compressive strength, impact resistance, abrasion resistance and water resistance were determined. Combustible properties determined were afterglow time, specific fuel consumption, burning rates, power or energy output, percentage heat utilized, flame propagation rates and percentage ash content. The sensitivity of these parameters to changes in the moulding pressure applications were determined to give the best condition for moulding briquettes with respect to the aforementioned properties and also the suitability of polystyrene foam adhesive as a binder.

Index Terms: *Binder, briquettes, combustible properties, mechanical properties, rice husk, polystyrene foam adhesives.*

1. INTRODUCTION

Fapetu (2000a) described the incessant increase in demand for wood as a source of fuel to be responsible for fuel wood crisis experienced in Nigeria and many other neighboring countries. The African continent accounts for about 12% of the world population but consumes only 4% of global energy production. This is due to the traditional energy sources mostly used such as firewood, twigs and charcoal in developing countries such as Nigeria.

In Nigeria, like many other third world countries, recycling of waste products especially agricultural wastes into useful resources is rarely practiced. This resulted into serious environmental problems in the form of refuse heap on the streets, drainage systems and water ways. The consequence of this is flooding on rainy days due to blockage of water ways (Yahya & Ibrahim, 2012).

Hood (2010) defined briquette as a block of compressed mass of agricultural waste such as wood, rice husk, rice straw, corn cob etc. The molded biomass is one of the most significant sources of energy in developing countries especially in the rural areas.

The effective use of any new type of biomass fuel depends on its performance. To evaluate the performance of any solid fuel, it is burnt in a specific biomass stove such as a furnace or in enclosed equipment (Fapetu, 2000b). This is to determine the comparative performance of the fuel to the stove, the expected fuel savings offered by a stove and obtaining the parameters necessary for optimizing the solid fuel in relation to its stove.

1.1 ADHESIVES

An adhesive is a substance used to make two distinct surfaces stick together. It is usually made from Gum Arabic, Styrofoam, and some other additives. Most type of adhesives work by forming a bond with surfaces by filling or occupying the pits and fissures of surfaces (Hood, 2010). Rudawska (2012) pointed out that factors like resistance to slippage and shrinkage, malleability, cohesive strength and surface tension determines the effectiveness of adhesives.

Gum Arabic which is also referred to as chaargund, char goond, meska or acacia gum is a gum of natural source made of hardened sap of a complex mixture of polysaccharides and glycoprotein. It was used formerly as stabilizers in food industries but commonly used nowadays for making glue and adhesives (Oladeji *et al*., 2009).

From Dangler (1985), polystyrene is a synthetic aromatic polymer which was formed from the repetition of many identical monomer units of styrene. This polymer obtained could be rigid or foamed. Extrusion of polystyrene resulted into a light foamy substance referred to as "Styrofoam". Styrofoam is lightly weighted due to its air bubbles content which made it a good insulating material (Yucel *et al*., 2003).

2. MATERIALS AND METHODS

2.1 RICE HUSK PREPARATION

The rice husks were sourced at rice milling centre Yelwa market, along Baffajo road Bauchi State, Nigeria. The materials obtained were sun-dried to reduce the moisture content to about 5%. The dried rice husk was sieved into 1.18mm particle sizes to produce uniform briquettes. Oversized materials were discarded.

2.2 PREPARATION OF THE ADHESIVE

The Styrofoam were obtained from refuse dump, pre-treated to remove impurities and then crushed into smaller fragments after which 400g (20.43%) of it were weighed and dissolve in 1.2litres (42.95%) of gasoline and 200ml (8.07%) of ethanol mixture and stirred gently to obtain a uniform mix in accordance with ASTM E 711-89 (2004). Later, 61.5%-28.9% of the ratio of water to gum Arabic were then added to the mixture and stirred properly for a stable mix after which 10g (0.15%) of silica gel was then added to enhance the emulsion effect of the Adhesive (Osemeahon *et al.*, 2013).

2.3 BRIQUETTE FORMATION

The prepared binder and rice husk were mixed in a vessel and vigorously stirred to attain uniformity and enhance adhesion. The mixture was then fed into a mould of 15cm height and10cm diameter. The content in the mould was placed between round dies of the ELE International compression machine where it was compressed by setting the compression force to 40kN/m^2. Briquette was ejected from the mould after 5 minutes and kept steady on a flat plank placed on an undisturbed pavement. The same procedure was repeated for 50kN/m^2, 60kN/m^2, 70kN/m^2, 80kN/m^2 and 90kN/m^2 compression forces. The briquettes formulated at varying pressures were air-dried for 3 days. Step wise procedure on the production of briquette is shown in Figure 1.

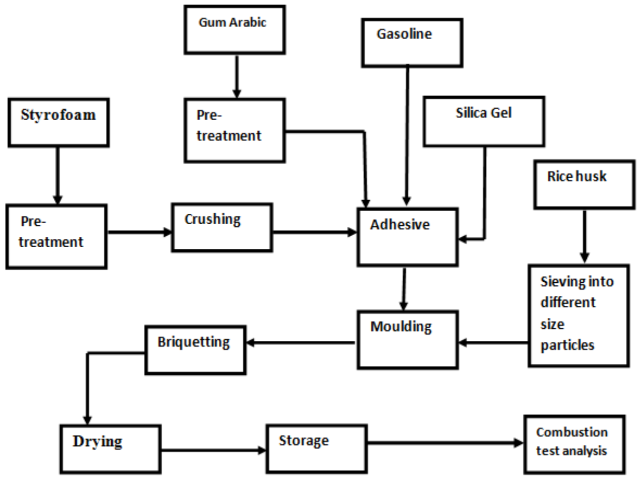

Figure 1: Briquettes production flow diagram

2.4 TESTS FOR MECHANICAL PROPERTIES

Density: To characterize the briquetting of a biomass material, density is an important property to consider as stated by Jaan *et al.* (2010). High density of briquette indicates a high energy per volume ratio. As a result of this high energy briquettes are desired this is also important in handling, transportation and storage of the biowaste. Density of briquette is a function of the density of the actual biowaste and the pressure of moulding the briquette (Mitchual *et al.*, 2013).

$$Density = \frac{Mass\ of\ Biomass}{Volume} \qquad (1)$$

To determine its bulk density, the average density of the whole briquette is considered. Equation 1 shows the formula for its determination.

Compressive Strength: This is the maximum crushing load the biomass briquette can withstand before it collapse, crack or break. It is a measure of the durability of the briquette (Richard, 1990).

$$Compressive\ Strength = \frac{Crushing\ Load}{Area\ of\ Sample} \qquad (2)$$

Impact Resistance Index: This is considered to be the best test for the strength of the briquette produced as reported by Holley (1983). This is done by dropping briquette pellet on a hard surface to observe the extent with which it disintegrates. It can be determined using Equation 3.

$$IRI = \frac{100\ X\ Average\ Drops}{Average\ number\ of\ pieces} \qquad (3)$$

Water Resistance Index: To determine the Water Resistance Index (WRI), the briquette was weighed and immersed in cold water and left for close to 20 minutes to enable water absorption. It was removed and reweighed. The WRI was then calculated using Equation 4 (Holley, 1983).

$$WRI = \frac{100 - \%\ Water\ Absorbed}{100} \qquad (4)$$

Abrasion resistance index: According to Grover and Mishra (2002), Abrasion Resistance Index (ARI) was normally carried out to simulate the mechanical handling of briquettes to predict its durability over a period of time. This is carried out in a tumbler drum that revolves at 50rpm for 100 times. ARI usually determined by the formula shown in Equation 5.

$$ARI = \frac{Weight\ after\ tumbling}{Weight\ before\ tumbling} \qquad (5)$$

2.5 TESTS FOR COMBUSTIBLE PROPERTIES

Briquettes produced at different compression pressure of moulding were tested for their combustible properties which were derived from a Water Boiling Test (WBT) and calculated from Equation 6-11. [(Musa, 2007); (Oladeji *et al.*, 2009); (Jaan *et al.*, 2010); (Mitchual *et al.*, 2013); (Olawole, 2009); (David *et al.*, 2013)].

Afterglow time: According to Musa (2007), this is an estimate of the time it takes an individual briquette to burn before restocking when they are applied in cooking and heating processes. This is determined by igniting a dry sample of briquette in a combustion chamber. Immediately a consistent flame is established, the flame was blown out and the time it takes for this process was recorded.

Specific Fuel Consumption (SFC): This was determined by burning a briquette fuel in a combustion furnace of which the burning was used to heat a particular quantity of water. It is expressed as the mass of briquette burnt per mass of water.

$$SFC = \frac{\text{mass of fuel}(\ M_f)}{\text{mass of water }(M_f)} \qquad (6)$$

Combustion/Burning Rate (BR): This evaluates the rate with which a briquette biomass burn in air as expressed in Equation 7.

$$BR = \frac{\text{mass of briquette fuel }(M_f)}{\text{time }(t)} \qquad (7)$$

Percentage Ash content (PAC): It is the ratio of the mass of ash obtained after combustion to the mass of dry sample of briquette which is usually expressed as a percentage as shown in Equation 8.

$$PAC = \frac{\text{mass of ash residue }(m_a)}{\text{mass of dried sample }(m_f)} \text{ x } 100\% \qquad (8)$$

Flame propagation rate (FPR): This is a measure of how flame spread in a combustion environment outwards from the point where it originated when burning briquettes. It is expressed as shown in Equation 9.

$$FPR - \frac{\text{graduated length }(D)}{\text{time }(t)} \qquad (9)$$

Percentage Heat Utilized (PHU): also referred to as the thermal efficiency is the ratio of the net heat transferred to the water being heated to the net heat released by the briquette fuel. Equation 10 gives the expression to determine the PHU.

$$P.H.U = \left(\frac{m_w c_p (T_b - T_o) + m_c L}{m_f E_f}\right) \times 100 \qquad (10)$$

Power Output: The Power Output (PO) of a briquette is the evaluation of the quantity of heat given off from the biomass at a particular time.

$$PO = \frac{\text{mass of fuel x calorific value }(M_f \text{x } M_f}{\text{time}} \qquad (11)$$

3. RESULTS AND DISCUSSION

3.1 EFFECT OF MOLDING ON MECHANICAL PROPERTIES

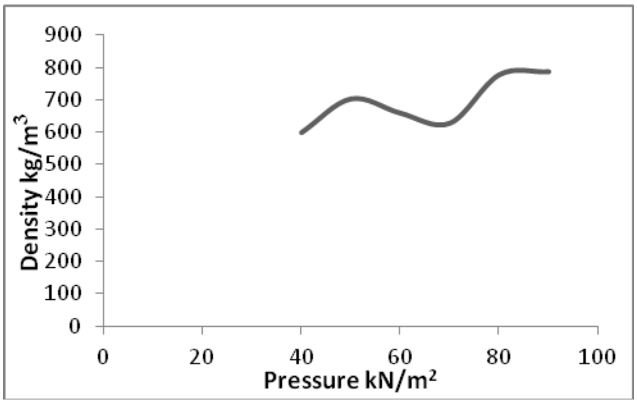

Figure 2: Effect of molding pressure on briquette density

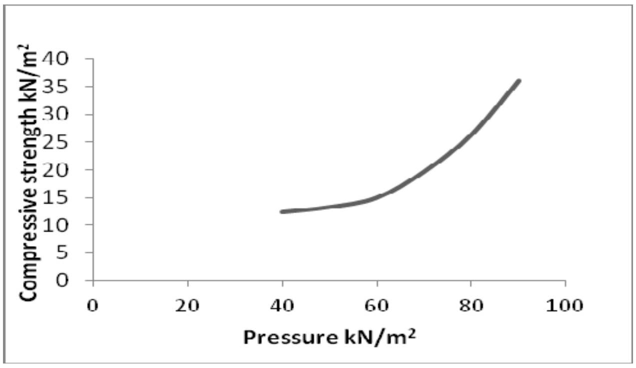

Figure 3: Effect of molding pressure on compressive strength

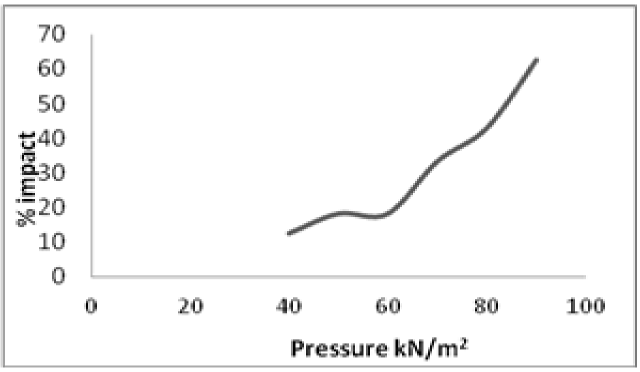

Figure 4: Effect of molding pressure on impact resistance of briquette.

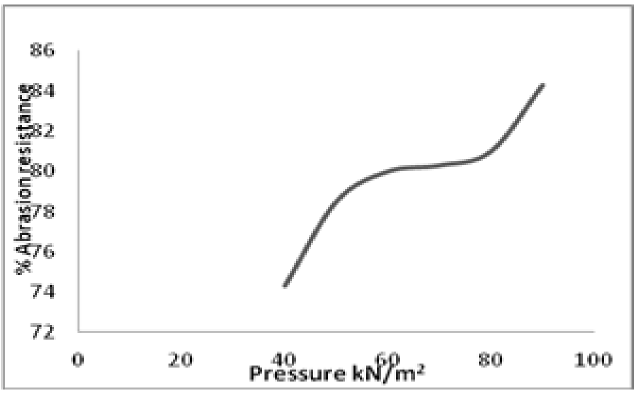

Figure 5: Effect of molding pressure on abrasion resistance

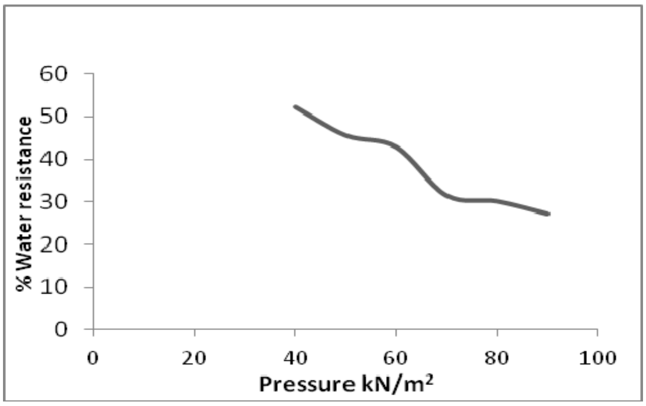

Figure 6: Effect of molding pressure on briquette water resistance.

From the pressure-density curve in Figure 2, the required density of the briquette was obtained as 642.76kg/m^3 at a compression pressure of 70kN/m^2. This is higher than that obtained from Olorunnisola (2007) given as 524kg/m^3 with a compression pressure of 75kN/m^2 and using starch as the binder.

Figure 3 indicates that the compressive strength increases with increase in compression pressure. The curve shows that the most effective compressive strength of the briquettes is 17.3kN/m^2 which falls within 60kN/m^2 and 70kN/m^2 compression pressure caused by the effect of the binder as against 13.45kN/m^2 obtained by Olorunnisola (2007) with a pressure of 70kN/m^2 using starch as the binding agent.

The Impact resistance of the fuel material was found to increase as the compression pressure was increased as shown in Figure 4 but shown little effect on impact from 40-60kN/m^2 compression. From the plot, it was observed that the most effective percentage impact resistance of the briquette produced was 33.3% at a pressure of 70kN/m^2 as against the one obtained from literature by Musa (2007) which is 26.4% at a pressure of 65kN/m^2 using starch as the binder.

The ability of the produced briquette to resist abrasion increases with increase in compression pressure as depicted in Figure 5. From the plot, it was deduced that the effect of the adhesive in resisting abrasion is felt mostly at a compression pressure range of 60-70kN/m^2 with a percentage resistance of 80% as against 69% obtained from literature with a pressure of 75kn/m^2 by Grover and Mishra (2002) who used animal glue as the binding agent.

Figure 6 shows the effect of compression pressure in moulding briquettes on water resistance. From the plot, water resistance decreases with increase in moulding pressure. It can be seen that at a pressure of 70kN/m^2, there is an equilibrium point with 32.75% water resistance compared to the 36.5% obtained by Grover and Mishra, (2002) using starch as the binding agent. From these results, it can be asserted that of all the mechanical properties investigated in this research, the density, compressive strength, impact resistance and abrasion resistance show the most efficient and effective range behaviour of the binder for a compression pressure range of 60-70kN/m^2 but shows the least water resistance behaviour compared to other binder used in literature irrespective of particle sizes.

3.2 EFFECT OF MOLDING PRESSURE ON COMBUSTIBLE PROPERTIES

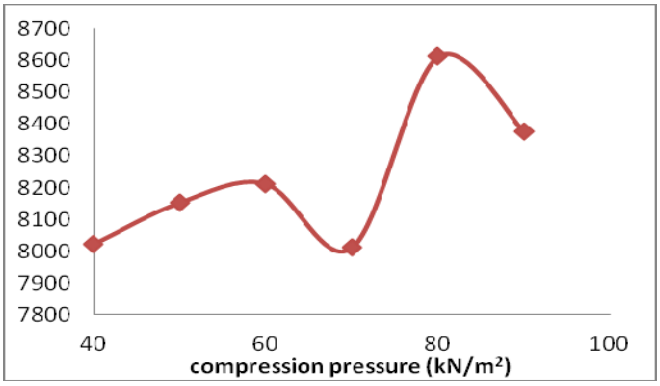

Figure 7: Effect of compression pressure on Afterglow time of the briquette.

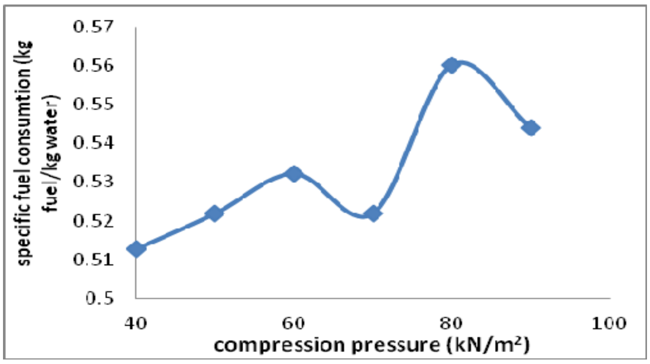

Figure 8: Effect of compression pressure on specific fuel consumption of briquette

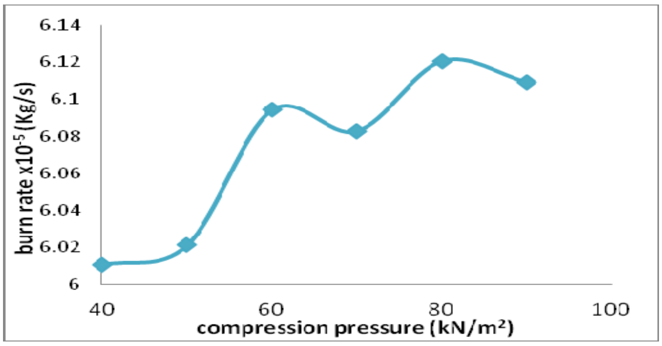

Figure 9: Effect of compression pressure on Burning rate of briquette

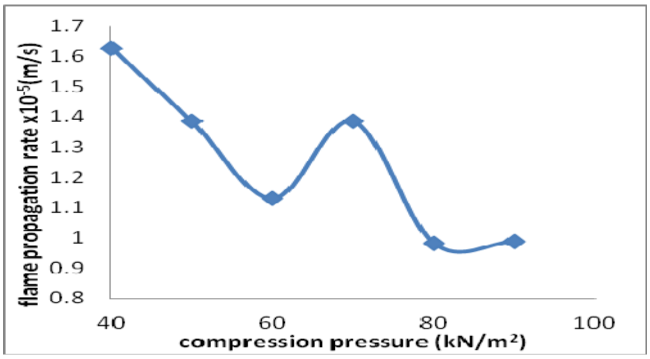

Figure 10: Effect of compression pressure on Flame propagation of briquette.

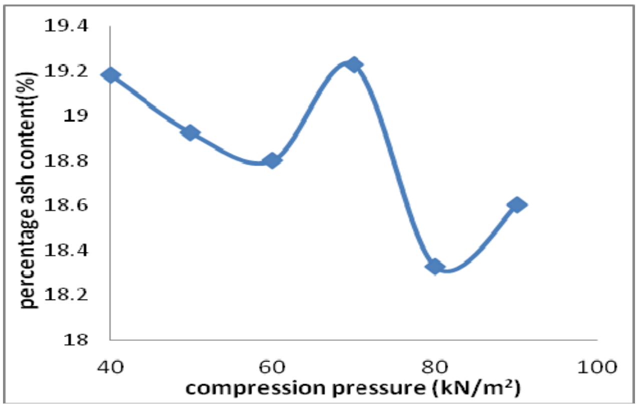

Figure 11: Effect of compression pressure on percentage ash content of briquette

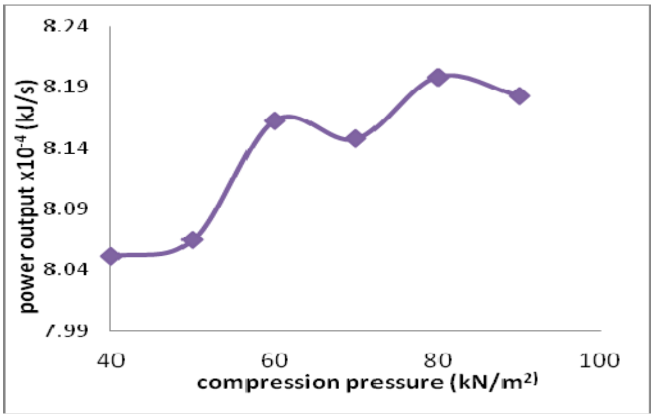

Figure 12: Effect of compression pressure on power output of briquette

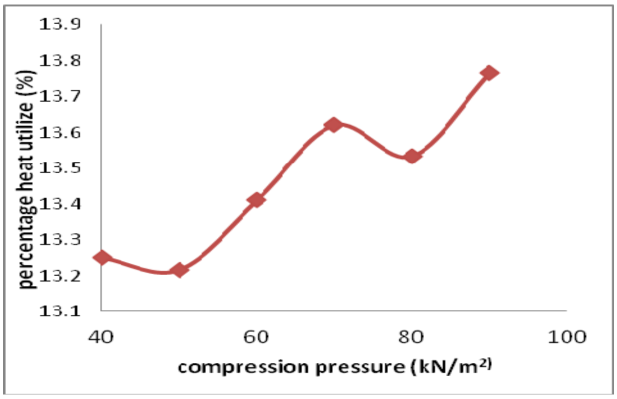

Figure 13: Effect of compression pressure on percentage heat utilized of briquette

Figure 7 shows how the variation in the briquette moulding compression pressure affects its Afterglow time. Afterglow time is a factor of how long the briquettes burned before restock especially when they are used in cooking and heating.The Afterglow time increases with increases in compression pressure with the exception of 60 - 70kN/m^2 range where drop in Afterglow time was noticed.

The sensitivity of the specific briquette fuel consumption on changes in compression pressure was shown in Figure 8. Specific fuel consumption was found to increase with increase in compression presssure of moulding the briquette. As the compression is increased, the spaces between particles of rice husk and the binder is reduced thereby having more mass of solid fuel per area of the mould for combustion. The same trend was noticed for burning rate with change in compression pressure shown in Figure 9.

Flame propagation rate decreases drastically as the compression pressure increases as shown in Figure 10. This indicates how the flame develops and spreads in the combustion of the briquettes. Flame propagation depends on the Oxygen distribution within the fuel. Oxygen located in spaces between particles of biomass is reduced as the pressure increases which as a result reduces the propagation of flame.

Figure 11-13 showed the effect of changes in compression presure to mould briquettes on percentage ash content, power output and percentage heat utilized respectively. From the plots, it was observed that to obtain more heat utilization and power output, the compression pressure must be increased.The reverse is the case for the percentage ash content which reduces as the pressure of compression is increased, with exception to ranges 60-70 & 80-90 kN/m^2 where increments were noticed.

4. CONCLUSIONS

The potential of producing briquettes from Rice husk using Polystyrene foam adhesive as a binder was discovered to be promising in terms of its mechanical and combustible properties.

These properties were found to vary as the compression pressure of moulding the briquettes was increased from 40 to 90kN/m^2 at an interval of 10 kN/m^2. It is imperative to chose an optimal compression pressure needed to produce briquettes with the required quality based on these properties.

REFERENCES

1. ASTM Standard E711-87. 2004. Standard Test method for Gross Calorific Value of Refuse-Derived fuel by the Bomb Calorimeter. ASTM International: West Conshohocken, PA.
2. Dangler, M. C. 1985. The Leaching Of Styrene from Styrofoam Cups. Cal Poly Senior Project: 85-1704.
3. David, K. C., Daudi, M. N. and Jason, M. G. 2013. Effect of Binder Types and Amount On Physical and Combustion Characteristics. International Journal of Engineering Research and Science & Technology, Vol. 2, No. 1, 13-20. ISSN: 2319-5991
4. Fapetu, O.P. 2000a. Production of Charcoal from Tropical Biomass for industrial and Metallurgical Process. Nigerian Journal of Engineering Management Vol. 1 No 2 pp. 34 – 37.
5. Fapetu, O.P. 2000b. Management of Energy from Biomass. Nigeria Journal of Engineering Management, Vol. 7 (17): 789-793.

6. Grover, P. D. and Mishra S.K. 1996. Biomass Briquetting, Technology and Practices, Regional Wood Energy Development Programme in Asia. Field document No. 46. FAO: Bangkok, Thailand.

7. Holley, C. A. 1983. The densification of biomass by roll briquetting. Proceedings of the Institute for Briquetting and Agglomeration (IBA), 18: 95-102.

8. Hood, A.H. 2010. Biomass Briquetting in Sudan: A Feasibility Study. United State Agency for International Development. 57-61, Elsevier B.V

9. Jaan, K., Priit, K., Aare, A., Viktor, L., Peter, K., Lubomir, Š. and Ülo, K. 2010. Determination of physical, mechanical and burning characteristics of polymeric waste material briquettes. Estonian Journal of Engineering, 16(4): 307–316.

10. Mitchual, S. J., Frimpong-Mensah, K. and Darkwa N. A. 2013. Effect of species, particle size and compacting pressure on relaxed density and compressive strength of fuel briquettes. International Journal of Energy and Environmental Engineering, 4:30 doi:10.1186/2251-6832-4-30.

11. Musa, N.A. 2007. Comparative Fuel Characterization of Rice husk and Groundnut shell Briquettes. NJRED. 6(2):23-26.

12. Oladeji, J.T., Enweremadu, C.C. and Olafimihan E.O. 2009. Conversion of Agricultural Wastes into Biomass Briquettes. International Journal of Applied Agricultural and Apicultural Research. 5(2): 116-123.

13. Oladeji, J.T. 2010. Fuel Characterization of Briquettes Produced from Rice Husk Resides. Pacific Journal of Science and Technology. 11(1):101-106.

14. Olawole, A. K., 2009. Performance of Composite Sawdust Briquette Fuel in a Biomass Stove under Simulated Condition. AU Journal of Technology, 12(4): 284-288.

15. Olorunnisola, A.O. 2007. Production of Fuel Briquettes from Waste Paper and Coconut Husk Admixture. Agricultural Engineering International: the CIGR E-journal. Manuscript EE 06 006 Vol. IX Phitsanulok, Thailand, American Journal of Applied Sciences. 5(12):1808-1811.

16. Osemeahon, S.A., Barminas, J.T. and Jang, A.L. 2013. Development of Waste Polystyrene as a binder for emulsion paint formulation I: Effect of polystyrene Concentration. The International Journal of Engineering and Science (IJES), 2(8): 30-35. ISSN (e): 2319 – 1813

17. Richards, S. R. (1990). Physical Testing of Fuel Briquettes, Fuel Processing Technology, 25: 89 - 100.

18. Rudawska, A. (2012). Adhesive Properties, Scanning Electron Microscopy, Dr. Viacheslav Kazmiruk (Ed.), ISBN: 978-953-51-0092-8, InTech, DOI: 10.5772/37011. Available and accessed online september, 2014 from: http://www.intechopen.com/books/scanning-electron-microscopy/adhesive-properties.

19. Yahaya, D.B. and Ibrahim, T.G. 2012. Development of rice husk briquettes for use as fuel. Research Journal in Engineering and Applied Sciences 1(2): 130-133.

20. Yucel, K.T., Basyigit, C. and Özel, C. 2003. Thermal Insulation Properties of Expanded Polystyrene as Construction and Insulating Materials, Fifteenth Symposium on Thermophysical Properties, Boulder-Colorado-USA.