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Studies on Interaction Effect of some Physical Characteristics of Water hyacinth Briquettes

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Abstract-The some engineering properties of briquettes made from water hyacinths (WH) of different binder ratios of plantain peels (PP) at different compaction pressure and particle sizes were investigated. Water hyacinth was processed into three particle sizes 0.5mm (D_1), 1.6mm (D_2) and 0.5mm (D_3), 4 pressure levels of 3MPa (P_1), 5MPa (P_2), 7MPa (P_3) and 9MPa (P_4) and 5 binder levels of 10% (B_1), 20% (B_2), 30% (B_3), 40% (B_4) and 50% (B_5) by weight of each sample. A steel cylindrical die of dimension 14.3mm height and 4.7 mm diameter was used to produce briquettes using hydraulic press with dwell time of 45 second. The compressive strength, shattering index, relaxed density, shattering index and water resistant capacity of the briquettes improved with increased binder proportion, compaction pressure and decreased particle size. The recorded engineering properties showed that WH briquettes are quality and reliable solid fuel. This study therefore suggests that optimal briquettes WH-PP production is at particle size, 0.5 mm; binder ratio, 40% and compaction pressure, 9 MPa ($D_1B_4P_4$). Production of WH briquettes is feasible.

Keywords: Aquatic weed, particle size, binder concentration, pressure, dimension

I INTRODUCTION

Water hyacinth was reported to be difficult to control through physical, chemical and biological means [1]. However, if water hyacinth is used for biofuel production, this could perhaps be the best method to both control and harvest. Fishing is the major occupation of the people in Niger Delta, Nigeria..The rate at which aquatic weed infestation in inland waters in Nigeria is alarming owing to fact that fishing is the major occupation of the people in Niger Delta, Nigeria. Presently, majority of the fish processors depend solely on mangrove trees as their fuel [1]. Among all the aquatic plants water hyacinth generated the highest interest among because of its high rate of invasion and colonisation. According to national survey carried out in 2001 more than 30 States and Federal Capital Territory of Nigeria experienced water hyacinth invasion [2].

Fuelwood is a main source of fuel employed for fish smoking and cooking and this has led to serious and grave deforestation, environmental degradation, misuse of soil forests and water resources and destruction of ecosystem [2, 3, 4, 5]. NEST [6] reported a total annual consumption of wood for domestic and industrial purposes in Nigeria ranged from 50-55 million cubic meters. With estimated shortfall of firewood in the Northern part of Nigeria is about 5-8 million cubic meters. The fuel wood extraction rate in the country is approximately four times the rate of afforestation. Fuelwood was used for domestic purposes (cooking, heating, barbequing) and industrial purposes (agro-industries, food processing) in both rural and urban areas [5]. Fossil fuel releases greenhouse gases and this contributed adversely to the global warming of the earth. Water hyacinth (*Eichhornia crassipes*) when utilized for production of briquettes and biogas could be an ideal source of generating revenue and as well as creating employment. Aquatic plans are potentially huge source of energy-giving materials.

Fuel briquette is utilized for household purposes and cottage industrial activities such as industrial and agro-industries and food processing. The fuel briquette has clean burning characteristic and it has a long shelf life without degradation. Entrepreneurs can produce briquettes from aquatic and agricultural wastes and sell in a local market for personal income. In this way, more money stays within the community and youth restiveness is brought into control. By adding values to some of the aquatic weeds that were previously nuisance, wealth are being generated and employment opportunity are being created. [7, 8, 9, 10].

Plantain is reported as one of the staple food grown in tropics. It contributed a major source of carbohydrate in Africa[11]. Plantain contains 35% carbohydrate, 0.2-0.3% fat, 1.2% protein, 6.0 -7.0% fibre and 0.8% ash. Plantain peels is one of the dominant agricultural waste in Niger Delta. The use of plantain peels in the production of biogas and soap manufacturing has been reported by Adeniji et al.[11], indicating waste prospect in plantain production. Much work has been reported on the use of banana fuel briquettes, as an alternative source of fuel but plantain has not received the desire attention. In spite of its potential in bio-energy, it is yet to be fully explored for the production of fuel briquettes. Choice of binder used is based on its availability, cost, and environmental friendliness. Binder is necessary in briquetting of material to produce briquettes with adequate mechanical properties under low pressure systems. Production of binderless briquettes from water hyacinth requires a high compaction pressure in the range of 80-200MPa according to Koser et al. [12]. Energy requirement in production of binderless water hyacinth as in Koser et al. [12] is considered high and unreasonable as this makes the cost of technology prohibitive [13]. Thus, the use of binder in water hyacinth briquettes is advocated. The valuable information on physical properties (such as compaction energy, relaxation ratio, water resistance capacity) of water hyacinth briquettes is required to bridge the existing gap of knowledge on briquetting of water hyacinth.

The range of pressure chosen falls within the acceptable range of manually produced briquette using hand press [13, 14, 15]. Bamigboye and Bolufawi [15], Chin and Siddique [14] and Ajayi and Lawal [16] reported binder inclusion at different levels (10 – 50%) by weight for production of briquettes for guinea corn residue and cassava starch as binder, rice bran residue and corn starch and sawdust from apepe and palm oil slurry as binder. Bamigboye and Bolufawi [15] and Olorunnisola [17] recommended particle size ranged from 0.5- 4.7 mm for the production of durable briquettes. Based on the above recommendations the following process variables were selected binder ratio levels 10, 20, 30, 40 and 50%, pressure levels 3, 5 7 and 9 MPa and particle size levels 0.5, 1.6 and 4.0 mm. The objectives of this study were to evaluate the effect of binder ratio, compaction pressure and particle size on some of the physical and mechanical properties of briquettes produced from water hyacinth.

II MATERIALS AND METHODS

A. *Preparation of Briquette Sample*

The production of briquettes samples for this study involved drying, size reduction and compaction operations. Plantain peels and water hyacinth were collected from Abuloma market and Aluu village, respectively, all in Port Harcourt, Rivers State, Nigeria. The raw materials (water hyacinth and plantain peels) were oven dried to about 7.9% moisture content dry basis. It was ground into different particle sizes using hammer mill and Tyler sieve (ASAE424.1.2003).Particle sizes were grouped into 0.5 mm, 1.6 mm and 4.0mm. Binder is in the ratio of 10, 20, 30, 40 and 50% by weight of the residue stock. It was hydrated with a determined amount of boiling water at 100^{o}C just to form gel. Mixing was done using manually operated mixer.

B. *Determination of Physical Properties*

The compressed and relaxed densities were investigated [18], Bamigboye and Bolufawi [15] and Olorunnisola [17]. Relaxation ratio was estimated according to Bamigboye and Bolufawi (2008) [15]. The moisture content of the sample was estimated using ASABE (2003) standard. The compaction ratio was calculated according to ASABE [18] standard. Resistance to moisture absorption was calculated based on Olorunnisola [17].

C. Statistical analysis

The experimental design for this study was 5 x 3 x 4 Randomized Complete Block Design. This study involved three particle sizes, (D_1, D_2, D_3) at levels 0.5, 1.6 and 4mm, pressure (P_1, P_2, P_3, P_4) at levels 3.0, 5.0, 7.0 and 9.0 MPa with plantain peels were used as binder (B_1, B_2- B_3, B_4, B_5) in the ratio of 10, 20, 30 40 and 50% by weight of feedstock. They were arranged in Complete Randomize Block Design (CRBD) with three replications. The obtained data was statistically analysed using Statistical Analysis System (SAS)(2007) and Microsoft Excel (2007) packages for Analysis of Variance (ANOVA), Duncan Multiply Range Tests (DMRT) and descriptive statistics.

III. RESULTS AND DISCUSSION

Relationship between binder ratios and particle sizes on compressed density ofbriquettes were shown in Table 1. The values of compressed density varied between551.16 (B_1D_1) and1048.92 (B_2D_3)($P<0.001$). Compressed density of briquettes at the different binder ratios and compaction pressure ranged from 617.64 (B_1P_1) to 1088.71Kg/m^3 (B_4P_4) (Table 2). The compressed density at the different binder ratios and particle sizes statistically important ($P<0.001$). The effect of particle size and compaction pressure varied between 622.83 ((B_1D_1) and 1031.37 (B_2D_3) ($P<0.001$) (Table 3). Binder ratio had significant effect on the compressed density of the briquettes ($P<0.05$)[19].The interaction between binder ratio, compaction pressure and particle size ranged from 508.86 ($D_1B_1P_1$) to 1179.34($D_3B_5P_4$) (Table 4) ($P<0.001$).

Relaxed density of briquettes at the different binder ratios and particle size were presented in Table 1. The values of relaxed density varied between 388.02 (B_1D_3) and 578.76 (B_4D_1) ($P<0.001$). Relaxes density for yellow corncob briquettes ranged between 314 and 464 kg/m^3 for particle size ranging from 2.10 to 6.60 mm [19]. Relaxed density of briquettes at the different binder ratios and compaction pressure ranged from 383.77(B_1P_1) to 507.07Kg/m^3 (B_4P_4) (Table 2). It was generally observed that relaxed density increased with increase in pressure and binder ratio. This observation could be attributed to the possible compactness in the water hyacinth briquettes and this could enhanced the mechanical handling.

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binder ratio. This observation could be attributed to the possible compactness in the water hyacinth residue as pressure increases and reduction in elastic recovery during relaxation of the briquette. The effect of particle size and compaction pressure varied between 396.00 ((B_1P_1) and 563.41 (D_1P_4) (Table 3). Relaxed density increased with increase in compaction pressure. The interaction between binder ratio, compaction pressure and particle size ranged from 388.86 ($D_3B_3P_1$) to 595.51 ($D_1B_4P_4$) ($P<0.001$) (Table 4).

TABLE 1. Summary of the Effect of Binder Ratio and Particle Size on the Measured physical Parameters

Properties	Binder ratio	Particle size (mm)			
		0.5	1.6	4	Mean
Compressed density (kg/m^3)	10	551.16	591.52	1040.73	727.80
	20	627.48	738.57	1048.92	804.99
	30	722.01	844.99	1017.88	861.63
	40	814.34	984.31	1049.7	949.45
	50	863.77	1010.31	999.58	957.89
	Mean	715.75	833.94	1031.362	860.35
Relaxed density (kg/m^3)	10	455.88	420.26	388.02	421.39
	20	487.26	435.63	402.21	441.70
	30	557.97	477.39	410.37	481.91
	40	578.76	478.52	430.8	492.90
	50	569.37	466.67	445.6	497.01
	Mean	529.84	455.69	415.4	466.98
Compaction ratio	10	3.53	4.29	9.09	5.64
	20	3.87	5.07	9.02	5.99
	30	4.00	5.44	8.17	5.87
	40	4.43	6.01	7.65	6.03
	50	4.24	5.74	6.97	5.65
	Mean	4.01	5.31	8.18	5.84
Relaxation ratio	10	1.21	1.34	2.73	1.98
	20	1.28	1.69	2.60	1.86
	30	1.28	1.72	2.47	1.82
	40	1.44	2.05	2.44	1.98
	50	1.49	2.16	2.29	1.98
	Mean	1.34	1.79	2.50	1.92
Water resistance capacity (%)	10	8.07	14.0	24.79	15.62
	20	7.09	12.39	15.36	11.61
	30	5.96	8.63	14.21	9.60
	40	4.93	8.41	11.31	8.22
	50	4.71	7.43	21.36	11.17
	Mean	6.15	10.17	17.41	11.24
Shattering index	10	0.77	0.58	0.51	0.62

	20	0.83	0.68	0.61	0.71
	30	0.9	0.78	0.66	0.78
	40	0.95	0.83	0.78	0.85
	50	0.92	0.85	0.79	0.85
	Mean	0.87	0.74	0.67	0.76

TABLE 2 Summary of the Effect of Binder Ratio and Pressure on the Measured Physical Parameters

Properties	Binder ratio	Compaction pressure (MPa)				
		3	5	7	9	Mean
Compressed density (kg/m^3)	10	617.64	678.15	770.12	845.29	727.8
	20	695.02	738.33	836.05	950.56	804.99
	30	760.73	819.32	883.78	982.67	861.63
	40	826.62	880.24	1002.22	1088.71	949.45
	50	879.04	900.1	970.55	1081.83	957.88
	Mean	755.81	803.23	892.54	989.81	860.35
Relaxed density (kg/m^3)	10	383.77	401.46	454.10	446.21	421.39
	20	420.51	415.46	448.78	482.06	441.70
	30	452.479	472.71	500.28	502.17	481.91
	40	473.99	489.93	499.99	507.67	492.90
	50	491.04	490.71	499.21	506.07	497.01
	Mean	444.36	454.05	480.47	488.84	466.98
Compaction ratio	10	4.98	5.50	6.26	6.92	5.91
	20	5.18	5.50	6.22	7.07	5.99
	30	5.22	5.59	6.01	6.67	5.87
	40	5.33	5.61	6.24	6.96	6.04
	50	5.21	5.31	5.73	6.37	5.65
	Mean	5.18	5.50	6.09	6.80	5.90
Relaxation ratio	10	1.66	1.74	1.77	1.88	1.67
	20	1.83	1.91	2.04	1.69	1.87
	30	1.79	1.83	2.03	1.81	1.87
	40	1.83	2.05	2.22	1.49	1.90
	50	1.89	1.87	1.98	2.17	1.98
	Mean	1.80	1.89	1.96	1.81	1.86
Water resistance capacity (%)	10	25.41	13.50	12.19	11.38	15.62
	20	13.27	12.37	10.71	10.12	11.61
	30	11.35	10.01	9.16	7.89	9.60
	40	10.23	9.15	8.59	14.06	10.50
	50	9.59	20.97	7.25	6.86	11.17
	Mean	13.97	13.20	9.58	10.06	11.70
Shattering index	10	0.55	0.60	0.62	0.70	0.62

	20	0.62	0.69	0.72	0.77	0.70
	30	0.72	0.79	0.79	0.81	0.78
	40	0.8	0.84	0.87	0.88	0.85
	50	0.82	0.85	0.88	0.88	0.86
	Mean	0.70	0.75	0.78	0.81	0.76

TABLE 3 Summary of the Effect of Pressure and Particle size on the Measured Physical Parameters

Properties	Compaction pressure (MPa)	Particle size (mm)			
		0.5	1.6	4	Mean
Compressed Density (kg/m^3)	3	622.83	712.59	932.02	755.81
	5	669.94	795.34	944.42	803.23
	7	738.53	877.79	1061.32	892.55
	9	831.71	950.04	1187.7	989.82
	Mean	715.753	833.94	1031.37	860.35
Relaxed density (kg/m^3)	3	508.11	428.97	396	444.36
	5	512.63	448.52	401.01	454.05
	7	535.26	471.3	434.86	480.47
	9	563.41	473.97	429.74	489.04
	Mean	529.85	455.69	415.40	466.98
Compaction ratio	3	3.49	4.54	7.51	5.18
	5	3.75	5.06	7.66	5.49
	7	4.15	5.59	8.52	6.09
	9	4.67	6.05	9.67	6.80
	Mean	4.02	5.31	8.34	5.89
Relaxation ratio	3	1.22	1.61	2.39	1.74
	5	1.29	1.76	2.37	1.81
	7	1.37	1.86	2.48	1.90
	9	1.48	1.94	2.77	2.06
	Mean	1.34	1.79	2.50	1.88
Water resistance Capacity (%)	3	7.44	11.84	22.62	13.97
	5	6.40	10.88	22.3	13.19
	7	5.69	9.66	13.39	9.58
	9	5.05	8.31	9.27	7.54
	Mean	6.64	10.17	16.90	11.07
Shattering index	3	0.79	0.7	0.62	0.70
	5	0.79	0.76	0.65	0.73
	7	0.79	0.74	0.69	0.74
	9	0.79	0.77	0.71	0.76
	Mean	0.79	0.74	0.67	0.73

TABLE 4: Summary of the Effect of Binder ratio, and Particle size on the Measured Physical parameters

Properties	Size	Binder	P1	P2	P3	P4	Mean
Compressed density (kg/m^3)	0.5	10	508.86	521.61	581.87	592.30	551.16
		20	529.13	559.04	1949.56	771.92	952.41
		30	611.88	672.68	736.75	866.75	722.01
		40	661.4	779.51	855.97	960.48	814.34
		50	802.89	816.87	868.21	967.10	863.77
		Mean	622.83	669.94	998.47	831.71	780.74
	1.6	10	504.39	552.54	630.21	678.92	591.52
		20	631.73	710.08	779.82	832.62	738.57
		30	728.19	826.99	882.20	942.54	844.98
		40	835.06	937.09	1048.33	1116.6	984.31
		50	863.55	949.98	1048.37	1179.4	1010.31
		Mean	712.59	795.34	877.79	950.04	833.93
	4.0	10	839.67	960.31	1098.29	1264.6	1040.73
		20	924.20	945.86	1078.48	1247.5	1048.92
		30	942.12	958.32	1032.38	1138.1	1017.89
		40	983.42	924.11	1102.37	1188.9	1049.70
		50	970.7	933.46	995.09	1099.7	999.58
		Mean	932.02	944.41	1061.32	1187.0	1031.36
Relaxed density (kg/m^3)	0.5	10	508.86	521.61	581.87	592.30	551.16
		20	529.13	559.04	1949.56	771.92	952.41
		30	611.88	672.68	736.75	866.75	722.01
		40	661.4	779.51	855.97	960.48	814.34
		50	802.89	816.87	868.21	967.10	863.77
		Mean	622.83	669.94	998.47	831.71	780.74
	1.6	10	426.83	431.02	469.51	499.41	456.69
		20	443.89	452.64	493.57	558.97	487.27
		30	445.02	462.34	510.83	491.37	477.39
		40	455.79	474.68	488.75	501.59	480.20
		50	444.29	471.48	472.39	478.51	466.67
		Mean	429.15	449.00	471.90	474.07	473.64
	4.0	10	338.83	362.75	451.44	399.04	388.02
		20	405.87	367.85	406.63	428.49	402.21
		30	380.81	405.70	419.99	434.99	410.37
		40	410.32	432.54	443.91	436.42	430.80
		50	444.15	436.21	452.32	449.72	445.60
		Mean	396.00	401.01	434.86	429.73	415.40
Compaction ratio	0.5	10	3.26	3.35	3.73	3.8	3.53
		20	3.27	3.46	4.02	4.77	3.88
		30	3.39	3.73	4.08	4.80	4.00

		40	3.60	4.25	4.66	5.23	4.44
		50	3.94	4.01	4.27	4.75	3.96
		Mean	3.49	3.76	4.15	4.68	3.96
	1.6	10	3.66	4.01	4.58	4.93	4.30
		20	4.34	4.88	5.36	5.72	5.08
		30	4.00	4.44	4.97	5.33	4.69
		40	5.11	5.73	6.40	6.83	6.02
		50	4.91	5.40	5.96	6.70	5.74
		Mean	4.40	4.89	5.46	5.90	5.16
	4.0	10	8.00	9.14	10.46	12.04	9.91
		20	7.95	8.15	9.27	10.73	9.02
		30	7.57	7.70	8.28	9.15	8.17
		40	7.3	6.84	7.67	8.81	7.65
		50	6.77	6.51	6.94	7.67	6.97
		Mean	7.52	7.67	8.52	9.67	8.34
Relaxation Ratio	0.5	10	1.21	1.20	1.24	1.19	1.21
		20	1.19	1.23	1.31	1.37	1.28
		30	1.15	1.21	1.29	1.49	1.28
		40	1.15	1.21	1.29	1.49	1.29
		50	1.37	1.45	1.51	1.63	1.49
		Mean	1.22	1.27	1.33	1.44	1.31
	1.6	10	1.30	1.36	1.43	1.28	1.34
		20	1.53	1.67	1.75	1.81	1.69
		30	1.44	1.80	1.74	1.95	1.73
		40	1.84	1.98	2.17	2.23	2.05
		50	1.94	2.01	2.23	2.46	2.16
		Mean	1.61	1.76	1.87	1.95	1.80
	4.0	10	2.48	.65	2.64	3.18	2.74
		20	2.28	2.58	2.65	2.91	2.61
		30	2.48	2.36	2.46	2.62	2.48
		40	2.40	2.14	2.48	2.73	2.44
		50	2.36	2.14	2.20	2.44	2.29
		Mean	2.40	2.37	2.49	2.78	2.51
Water resistance capacity (%)	0.5	10	9.29	8.80	7.56	6.64	8.07
		20	8.88	7.53	6.52	5.47	7.10
		30	7.35	5.83	5.61	5.06	6.00
		40	6.24	4.82	4.55	4.12	4.93
		50	5.49	5.06	4.26	4.01	4.71
		Mean	7.50	6.41	5.70	5.06	6.15
	1.6	10	15.97	14.37	13.27	12.4	14
		20	12.8	13.25	12	11.73	12.45
		30	10.77	9.27	8.23	6.28	8.65
		40	10.1	9.19	8.63	5.75	8.42
		50	9.6	8.59	6.17	5.4	7.44

		Mean	11.85	10.93	9.66	8.31	10.18
	4.0	10	14.7	17.33	15.73	15.1	15.72
		20	18.13	16.53	13.63	13.17	15.37
		30	15.93	14.93	13.67	12.33	14.22
		40	14.37	13.43	12.6	12.14	13.13
		50	13.7	12.37	11.33	11.17	12.14
		Mean	15.37	14.92	13.39	12.78	14.12
Shattering index	0.5	10	0.65	0.75	0.82	0.86	0.77
		20	0.70	0.80	0.85	0.92	0.82
		30	0.82	0.88	0.91	0.98	0.90
		40	0.91	0.93	0.96	0.99	0.95
		50	0.88	0.93	0.96	0.92	0.92
		Mean	0.79	0.86	0.90	0.93	0.87
	1.6	10	0.56	0.54	0.55	0.67	0.58
		20	0.63	0.72	0.67	0.70	0.68
		30	0.70	0.82	0.80	0.8	0.78
		40	0.79	0.85	0.84	0.83	0.83
		50	0.83	0.85	0.85	0.85	0.85
		Mean	0.71	0.76	0.74	0.77	0.74
	4.0	10	0.46	0.52	0.50	0.56	0.62
		20	0.55	0.57	0.64	0.66	0.65
		30	0.63	0.67	0.68	0.69	0.69
		40	0.71	0.74	0.81	0.83	0.71
		50	0.76	0.77	0.83	0.83	0.68
		Mean	0.62	0.65	0.68	0.72	0.68

The relaxation ratio of the briquettes varied between 1.21 (D_1B_1) and 2.73 (D_3B_5) ($P<0.001$) for studied binder ratios and particle sizes (Table 1). The low relaxation ratio values revealed that the briquettes exhibited low elastic property and more stabled. The interaction effect of pressure and binder on the relaxation ratio was determined as shown in Table 2. The relaxation ratio ranged from 1.66 (B_1P_1) to 2.17 (B_5P_4). According to Oladeji, (2012) reported the relaxation ratios of briquettes produced from corncob from white maize were corresponded to 2.86, 1.82; 1.89, 1.67; and 1.70, 1.33 for particle sizes 4.70 mm, 2.40 mm and 0.6 mm respectively, while the corresponding values for briquettes produced from corncob from yellow maize were 2.27, 1.96; 1.75, 1.67; and 1.45, 1.16 respectively.

Table 3 revealed the interaction between particle size and compaction pressure on relaxation ratio. The relaxation ratio ranged from 1.22 (D_1P_1) to 2.77 (D_3P_4) (Table 3). This is an indication that briquettes produced from particle size (D_1) were more stable than those from 1.6mm and 4mm particle sizes. Based on the study conducted by Saptoadi [21], revealed that particle sizes determine the briquettes porosity and also the finer the particle size, the higher the density, and the lesser the porosity. The corresponding relaxation ratios of corncob briquettes were 2.86, 1.82; 1.89, 1.67; and 1.70, 1.33 for particle sizes 0.6 mm, 2.4 mm and 4.7 mm respectively [22]..

The relationship between binder, compaction pressure and particle size on the relaxation ratio ranged between 1.15 ($D_1B_{3,4}P_1$) and 3.18 ($D_3B_1P_1$) (Table 4). The low values observedindicated that the briquette has good handling characteristics for packaging, storage and transportation. The result of analysis of variance revealed that there was significant difference among all the values obtained for relaxation ratio at the various binder levels (P<0.001). The effect of binder on the compaction ratio ranged from 3.53 (D_1B_3) to 9.09±0.25 (D_3B_1) (Table 1). This parameter is one of the major factors that determine the quality of briquettes in terms of mechanical handling, combustion characteristics and transportation cost.

Production of briquettes from guinea corn (Sorghum Bi-color) residue had compaction ratio differed from 3.194 to 9.730 [15]. The compaction ratio of briquettes produced from white corncob increased with increasing binder ratio [20]. The minimum compaction ratio was 4.98 (B_1P_1) and the maximum was B_4P_4 (6.96) (Table 2). The maximum and minimum effect of compaction pressure and particle size on compaction ratio were 3.49 (D_1P_1) to 9.67 (D_3P_4) (P<0.001) (Table 3).The effects of binder, compaction pressure and particle size on the compaction ratio of briquette ranged between 3.26 (D_1B_1 P_1) and 12.04 ($D_3B_2P_1$)(P<0.001) (Table 4).Corresponding compaction ratio in the range of 3.179 to 9.730 for briquetting guinea corn residue of particle sizes (0.6mm, 1.6mm and 4.7mm) and cassava starch (40, 45, 50 and 55%) was reported by Bamigboye and Bolufawi [15]. The implication of this observation is that void spaces were expelled at higher pressures and higher binder concentration in the residue.The relative change in height of briquettes when immersed in water was determined as shown in Table 1. The obtained result varied from 4.71 (D_1B_5) to 24.79% (D_3B_1) and the variation was significant (P<0.05). The water resistance capacity of the briquettes at different binder ratio and particle size showed positive relationship. The effect of compaction pressure and binder proportion on the water resistance capacity of the briquettes varied between 6.86 (B_5P_3) and 25.41 % (B_1P_1) and the variation was significant (P<0.05) (Table 2). The interaction between particle sizes and relative change in height varied from 5.05% (D_1P_4) to 22.62% (D_3P_1) (Table 3).The interaction effects of binder, compaction pressure and particle size on the relative change in the height of briquette ranged from 5.49 (D_1B_1 P_1) to 18.13% ($D_3B_2P_1$) and the variation was significant (P<0.001).

One hundred eighty (180) briquettes were produced and tested for some engineering properties. It was revealed that briquettes produced from processing variables of 0.50 mm (particle size D_1), 40% (binder ratio B_4) and 9 MPa (compaction pressure P_4) exhibited the most positive attributes (optimum levels). Briquettes produced from $D_1B_4P_4$ had the best physical and mechanical handling characteristics that compete favourably with other biomass briquettes.

IV. CONCLUSION

One hundred and eighty (180) briquettes were produced and the engineering properties of the briquette were investigated. The compressive strength, shattering index, relaxed density, shattering index and water resistant capacity of the briquettes improved with increased binder proportion, compaction pressure and decreased particle size. The result revealed that binder ratios, compaction pressure and particle sizes had significant influence on physical and mechanical properties of briquettes produced from water hyacinth and plantain peel. Based on this study the best water hyacinth briquettes are produced from optimum levels of processing variables of 0.50 mm (particle size D_1), 40% (binder ratio B_4) and 9 MPa (compaction pressure P_4). Briquettes produced from $D_1B_4P_4$ had the best physical and mechanical handling characteristics. The recorded engineering properties showed that WH briquettes are good quality and reliable solid fuel compete with other biomass briquettes. This study therefore suggests that optimal briquettes WH-PP production is at particle size, 0.5 mm; binder ratio, 40% and compaction pressure, 9 MPa ($D_1B_4P_4$). Production of WH briquettes is feasible.

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