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PHYSICAL PROPERTIES AND DENSIFICATION OF RICE HUSK PELLETS OF DIFFERENT BINDING LEVEL WITH CHARCOAL

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ABSTRACT
Rice husks are generated from Paddy Rice (Oryza sativa). The residue is usually dumped and flared on the farms, where it constitutes fire, environmental and health hazards. Rice husks are potential feedstock for fuel energy generation. This research work determine the physical behavior of rice husk pellets of different densities with charcoal .the characteristics of

INTRODUCTION
BACK GROUND OF THE STUDY

Since the development of human kind, there has been a tremendous increase in energy consumption. Bio-energy provides about 10% of the world's total energy supply (About 47.2 EJ of bio-energy out of 479 EJ in 2005) and most of this bio-energy is use in residential sector for cooking and heating (Katimbo, *et al*, 2014). Approximately two billion people worldwide live in rural areas and most rural people and many urban dwellers in developing countries, all depends on wood fuels as their main or sole source of energy to cook their food and keep warm (Sanni and Yawas, 2009). Heavy reliance on firewood and charcoal for cooking and space heating would not solve our present energy crisis but rather it would lead to deforestation or desertification resulting in further scarcity of this resource (Salunkhe, *et al*, 2012). Agricultural residues and straw from crop production existing in the waste streams from commercial crop processing plants have little inherent value and have traditionally constituted a disposal problem (Osadolor, 2006). Biomass, if properly managed would offer many advantages, the most significa nt being renewable and sustainable energy feedstock. With advances in technology, some resources that have been classified as waste now form the basis for energy production (Mckendry, 2002). The large quantities of agricultural residues produced in Nigeria can play a significant role in meeting her energy demand. But these agricultural wastes and forest residues are neither managed effectively nor utilized efficiently in all developing countries [9]. The common practice is to burn these residues or they are left to decompose (Jekayinfa, and Omisakin, 2005); (Oladeji, (2012). This

the pellets determined are proximate analysis, physical properties,, durability(or shatter index), maximum and relaxed densities. The use of different compaction pressure and % binder ratios in producing pellets resulted in different physical and energetic properties of pellets. The results from the combustion rate test of 40g shows that rice husk pellets produced with tamarind starch and cassava starch attained higher temperature (about 620°C) in less than 7 minutes than the charcoal (about 375°C) and both can give high temperature with higher quantity of fuel. The caloric values of charcoal and rice husk pellets with cassava starch tamarind starch are 30.57 MJ/kg, 18.82MJ/kg and 17.39MJ/kg respectively. These results show that the pellets are capable of generating heat that is sufficient for cooking, space heating and baking with suitable appliances. The pellets can serve as substitute for charcoal users since it shows superior combustion characteristic less emission of CO (0.3ppm) and SO_2 (0.5ppm) over charcoal which has CO emission of 4.2ppm and SO_2 of 1.2ppm. the pellets produced with tamarind starch(Non-edible starch) exhibited good physical and energetic properties that are better than the pellets produced with cassava starch (Edible starch). The tamarind starch (from waste seeds) can therefore be used as a replacement for cassava starch which has competitive need.

Keywords: *Pellets, Rice Husk, Cassava Starch, Tamarind Starch and Binder Ratio*

burning or decomposition is a waste of available energy and this also contributes to atmospheric pollution (Oladeji, and Ogunsola, 2010). Therefore, the use of agricultural residues in raw form poses many challenges which include variable quality of the residue, low bulk density, cost of collection, and problems in transportation and storage (Sokhansanj, *et, al,* 2006).

One of the promising technology by which these agricultural residues could be converted to energy is pelletizing or briquetting process (Lucas, and Oladeji, 2011). Pelletizing is the process that involved conversion of agricultural waste into uniformly shaped pellets with higher density that are easy to use, transport and store (Raju, 2014). The pelletizing of biomass improves its handling characteristics, increases the volumetric calorific value, reduces transportation costs and makes it available for a variety of application. Pellets are viewed as an advanced fuel because of its clean burning nature and the fact that it can be stored for long periods of time without degradation ((Lucas, and Oladeji, 2011)).

Hence this study would focused on the production of solid bio-fuels (Rice husk pellets) as an alternative to wood charcoal using locally abundant agricultural wastes (rice husks) converted into pellets on a small scale using tamarind starch (non-edible starch) and cassava starch (edible starch) as binders.

MATERIALS AND METHODS

Rice husk were collected from Lokuwa rice mill and Samiare rice mill both in Mubi North local Government Area and Tamarind seed were obtained from foods Beverages in Yola, Adamawa State respectively. The rice husk were grounded and sieved into three different particles sizes. The tamarind and cassava starches were locally prepared.

Table 1.1: Mixing Proportion of the Produced Pellets

MIXTURES	PROPORTIONS
Rice husks : Cassava Starch	90: 10
Rice husks : Cassava Starch	80: 20
Rice husks : Cassava Starch	70 :30

Rice husks: Tamarind Starch	90: 10
Rice husks : Tamarind Starch	80: 20
Rice husks : Tamarind Starch	70 : 30

RESUILTS AND DISSCUSSION

Table 1.2 present 20% of CS and TS with rice husk length (mm) of different compaction pressure of P_1 (0.2), P_2 (0.4) and P_3 (0.6) of constant diameter.

Table 1:2 Results at 20% CS and TS with different Compaction Pressure

Compaction Pressure (MPa)	RH: CS Length (mm)	RH: TS Length (mm)	Diameter (mm)
	21.0	21.0	16
	20.0	20.0	16
P_1 (0.2)	21.0	21.0	16
	21.0	21.0	16
	20.0	20.0	16
	21.0	21.0	16
	20.0	19.0	16
	19.5	20.0	16
P_2 (0.4)	20.0	19.5	16
	20.0	19.5	16
	20.0	20.0	16
	19.0	20.0	16
	19.0	18.0	16
	19.0	19.0	16
P_3 (0.6)	20.0	19.3	16
	19.0	19.5	16
	18.0	19.0	16
	19.0	18.9	16

Table 1.3 present the maximum density (Kgm^{-3}) of various binder ratios of rice pellets, with various compaction pressure, it is observed that the values of the maximum density obtained are high because of its moisture content.

Table 1.3: Results of Maximum Densities of Pellets in Kgm^{-3}

Pellets	Binder Ratios (%)	Compaction Pressure (Mpa)	Density (Kgm^{-3})
		P_1(0.2)	865
		P_2(0.4)	1000
	B_1(10)	P_3(0.6)	1025
		P_1(0.2)	988
	B_2(20)	P_2(0.4)	1006
RH:TS		P_3(0.6)	1033
		P_1(0.2)	709
		P_2(0.4)	950
	B_3(30)	P_3(0.6)	1015
		P_1(0.2)	987
		P_2(0.4)	1078
	B_1(10)	P_3(0.6)	1051
		P_1(0.2)	1068
	B_2(20)	P_2(0.4)	1089
		P_3(0.6)	1097
RH:CS		P_1(0.2)	909
		P_2(0.4)	1017
	B_3(30)	P_3(0.6)	1036

Table 1.4 presents the relaxed densities ($Kg\text{-}m^3$) of various binder ratios of rice pellets, with various compaction pressures; it is observed that the values of the relaxed density obtained are low because it has been dry under sun

Table 1.4: Results of Relaxed Densities of Pellets in Kgm^{-3}

Pellets	Binder Ratios (%)	Compaction Pressure (Mpa)	Density (Kgm^{-3})
		P_1(0.2)	674
		P_2(0.4)	729

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RH:TS	B_1(10)	P_3(0.6)	732
	B_2(20)	P_1(0.2)	705
		P_2(0.4)	717
		P_3(0.6)	725
	B_3(30)	P_1(0.2)	665
		P_2(0.4)	680
		P_3(0.6)	701
RH:CS	B_1(10)	P_1(0.2)	805
		P_2(0.4)	813
		P_3(0.6)	817
	B_2(20)	P_1(0.2)	793
		P_2(0.4)	835
		P_3(0.6)	880
	B_3(30)	P_1(0.2)	855
		P_2(0.4)	880
		P_3(0.6)	910

Table 1.5 Table 1.4 presents the calorific value (MJ/kg) and ash content of various binder ratios of rice pellets, with compaction pressures; it is observed that the calorific values of cassava starch is a bit higher than that of tamarind starch

Table 1.5: Results of Calorific Values and Ash Contents of Pellets and Charcoal

Fuels	Binder Ratio (%)	Calorific Value (MJ/kg)	Ash content
RH + TS	B_1(10)	17.13	11.11
	B_2(20)	17.20	11.00
	B_3(30)	17.39	10.00
RH + CS	B_1(10)	18.88	15.31
	B_2(20)	18.13	17.00
	B_3(30)	18.82	15.00
Charcoal	———	30.57	8.08

Table 1.6: Results of 40g Pellets at 10% Binder Ratio and Charcoal

Time (min)	RH : TS (Temp °C)	RH : CS (Temp °C)	Charcoal (Temp °C)
0	36	36	36
1	493	483	335

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2	576	535	373
3	529	539	371
4	523	521	368
5	520	509	364
6	481	495	360
7	460	470	353
8	449	451	349
9	437	430	345
10	438	390	340
11	314	342	329
12	287	300	318
13	273	261	312
14	267	253	316
15	263	240	313
16	260	214	311
17	255	205	308
18	242	200	314
19	230	195	309
20	226	190	307

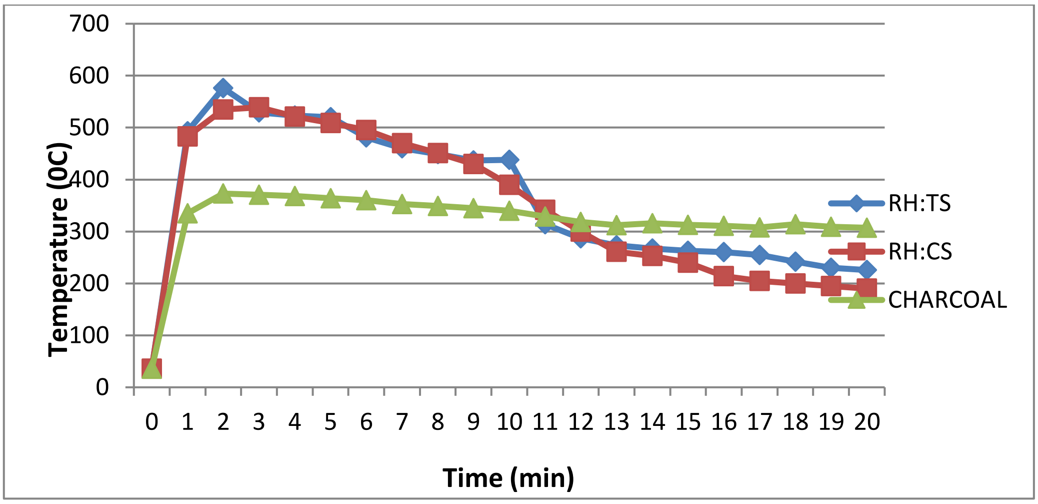

Figure 1.1: 40g Rice Husk at 10% Binder Ratio and Charcoal

Table 1.7: Results of 40g Pellets at 20% Binder Ratio and Charcoal

Time (min)	RH : TS (Temp °C)	RH : CS (Temp °C)	Charcoal (Temp °C)
0	36	36	36
1	513	508	335
2	519	564	373

3	562	602	371
4	548	544	368
5	532	512	364
6	465	491	360
7	416	412	353
8	386	375	349
9	286	353	345
10	255	334	340
11	265	303	329
12	251	294	318
13	277	278	312
14	257	269	316
15	229	261	313
16	223	235	311
17	217	229	308
18	208	213	314
19	196	200	309
20	193	185	307

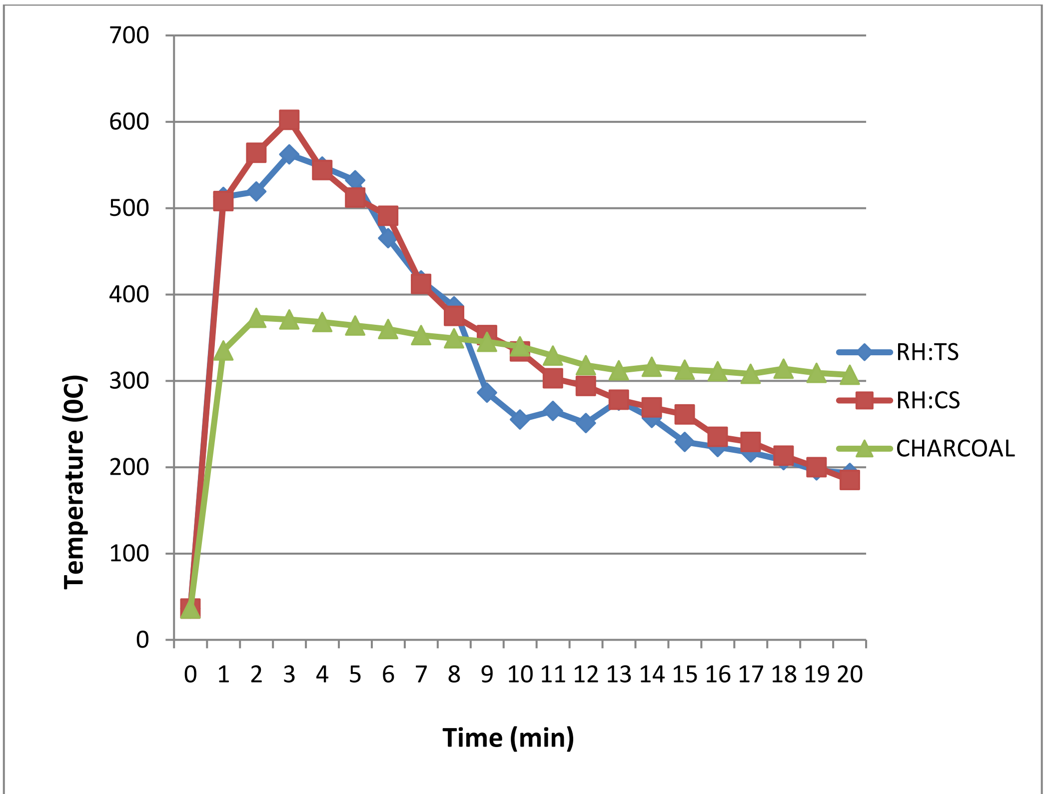

Figure 1.2: 40g of Rice Husk Pellets at 20% binder ratio and charcoal

Table 1.8: Results of 40g Pellets At 30% Binder Ratio and Charcoal

Time (min)	RH : TS (Temp ℃)	RH : CS (Temp ℃)	Charcoal (Temp ℃)
0	36	36	36
1	518	489	335
2	530	512	373
3	533	520	371
4	545	503	368
5	558	473	364
6	471	409	360
7	451	377	353
8	465	360	349
9	440	353	345
10	401	285	340
11	344	282	329
12	310	232	318
13	294	210	312
14	282	193	316
15	265	191	313
16	246	187	311
17	220	185	308
18	208	175	314

19	177	167	309
20	176	159	307

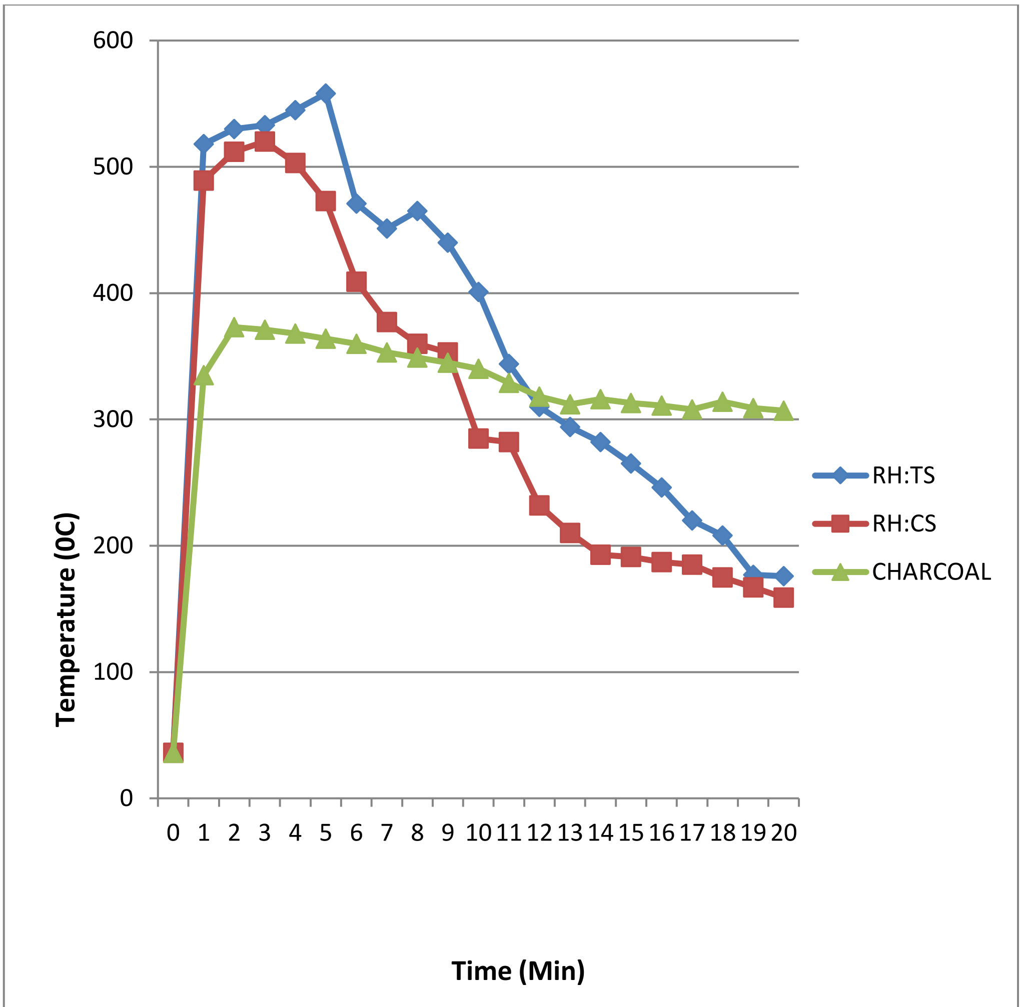

Figure 1.3: 40g Rice Husk Pellets at 30% Binder Ratio and Charcoal

Table 1.9: Results of Physical Properties and Densification of Pellets with Charcoal

Parameters	Units	RH : TS	RH : CS	Charcoal
Calorific Value	MJ/kg	17.39	18.82	30.57
Ash Content	% of weight	10.00	15.00	8.08
Volatile Matter	% of weight			-

Moisture content	% of weight	24.14	15.63	-
Fixed Carbon	% of weight			
Durability (shatter index)	% of weight	97.8, 93.6, 91.3	97.5, 96.6, 92.3	-
Compressive Strength	Kg f	166.30	113.6	
Flame height	cm	6 - 10	6 - 10	1 - 2
Temperature	°C	176 - 562	159 - 602	312 - 373
Length	mm	20	20	-
Diameter	mm	16	16	-
Area	m^2	2.011×10^{-4}	2.011×10^{-4}	-
Volume	m^3	4.022×10^{-6}	4.022×10^{-6}	-
Maximum density	Kg/m^3	1227	1126	-
Relaxed Density	Kg/m^3	701	910	-
Texture	-	Rough	Rough	Rough
Color	-	Brownish	Brownish	Black

DISCUSSION OF RESULTS

Pellet Dimension

Table 1.1 present the dimensions of the pellets, it was observed from the results that the length of the rice husk pellets was influence by the compaction pressure. The length of the pellets decreases as the pressure of the compaction increases. This was in line with the observation of (Japhet, *et, al* 2015) that compaction pressure has great influence of the physical and energetic properties of pellets. The geometric dimensions of pellets, both diameter and length are so important factors with respect to combustion. Thinner pellets allowed a more uniform combustion rate than thicker ones, especially on small furnace and the length of the pellets affected the fuel feeding properties as reported in (Liu, *et al,* 2005)

Maximum and Relaxed Densities of Pellets

The maximum densities of pellets for the compaction pressure of 0.2Mpa, 0.4Mpa and 0.6Mpa varies from 709kg/m^3 – 1033kg/m^3 for pellets with TS and 909kg/m^3 – 1097kg/m^3 for the pellets with CS as presented in Table 1.3. These values are higher than the relaxed densities of the pellets as seen in Table 1.4. It was observed that the higher the compaction pressure, the higher the densities but the reverse was the case with the binder ratio. A general increase in the maximum density was noticed at all binder ratios as reported by (Oladeji, and Enweremadu. (2012). The values of maximum densities obtained with percentage of binder and compaction pressures are more than the minimum value of 600kg/m^3 recommended by (Mani, *et al,* 2006)and (Gilbert, *et al,* 2009) for efficient transportation and safe storage. As presented in Table 1.4, the relaxed densities of the pellets varied from 674kg/m^3 - 910kg/m^3. Furthermore, it was observed that 20% ratio by weight of the binder gives higher maximum density, relaxed density and good quality pellets in terms of energetic view point than the other two ratios (i.e. 10% and 30%). These values corroborated with the finding of (Nasiru, *et al*, 2015) and (Oladeji, and Enweremadu. 2012) which states that 20% binder ratio exhibited the most Positive attributes of good quality briquettes.

Calorific Values and Ash Content of Pellets and Charcoal

From the results presented in Table 1.5, Charcoal has the highest heating value of 30.57 MJ/kg then pellets with CS have 18.88MJ/kg and lastly pellets with TS have 17.39MJ/kg. The rice husk pellets makes an excellent fuel although its calorific value is less than that of charcoal as reported in

(Jekayinfa and Scholz, 2009). It was however, observed that the Calorific values increases with increase in concentration of the binders and this is in conformity with the findings of (Oyelaran, *et al*, 2014), but the reserved was the case with the ash content of the solid Bio fuels as seen in Table 1.5. Based on the results obtained in Table 1.5above, it was found that most of the pellets fulfill the minimum requirement of calorific value for commercial pellets (≥ 17500J/g), as stated by DIN 5173 (Loo, and Koppejan, 2008). From the results of Table 1.5, it was found that pellets with TS having the highest binder ratio by weight (30%) has a calorific value of 17.13MJ/kg; while pellets with the lowest value of binder ratio by weight (10%) has the lowest value of 17.13MJ/kg. this proved that the gross calorific value is mostly influenced by the compaction of pellets (i.e. the binder ratio and type of biomass)

The results for the calorific values obtained in Table 1.5 showed that the pellets with TS (17.39MJ/kg). and the pellets with CS (18.88MJ/kg) still has a high energy content that can meet domestic needs such as cooking and space heating. The ash content which is the organic matter left out after complete combustion of the biomass was found to be 8%, 10% and 15% for charcoal and pellets with TS and CS respectively. This is the percentage of impurity that will not burn during and after combustion. The low ash content indicates that it is suitable for thermal utilization. Higher ash content in a fuel usually leads to lower calorific value (Loo, and Koppejan, 2008). These values are higher than that of wood pellets as reported by (Obenbeger, and Thek, 2002). However, it showed that about 70% - 80% of the fuel can be burnt completely and will likely produce a substantial heat that is needed for domestic use.

Combustion Rate of Pellets and Charcoal

From the results in Tables 1.6.1.7 and 1.8, the complete combustion of pellets with excess air gives ash, water and carbon dioxides as shown below:

Pellets + O_2 (g) Ash (s) + H_2O (steam) + CO_2 (g)

The combustion rate test was conducted in a form of open fire under indoor condition. After ignition, the fuel was allowed to flame and readings were taking at one minute interval for 20 minutes, then it is allowed to completely burnt. It was observed that the pellets maintained their shape even in the ash form. Some tests were carried out using 40g of rice husk pellets with different binder ratios (i.e. 10%, 20% and 30%) for TS, CS and the Charcoal and the results were then compared. The results of the tests are shown in Tables 1.6, 1.7, 1.8 and figures1.1, 1.2 and 1.3 respectively, compares with combustion rates of 40g of the fuels.

Figure 1.1, shown the comparisons of combustion rate of 40g rice husk pellets at 10% binder ratios and charcoal, the rice husk pellets with TS as binder attained a maximum temperature of 576°C in 2 minutes, then it started decreasing gradually down to 226°C in 20 minutes and that of the rice husk pellets with CS as binder attained a maximum temperature of 539°C in 3minutes and a minimum temperature of 190°C in 20 minutes, while that of the charcoal attained the maximum o temperature of 373°C in 2 minutes and gradually decreases down to 307°C in 20 minutes. Figure1. 2, shows the comparisons combustion rate of 40g rice husk pellets with two binders at 20% binder ratios with charcoal. The pellets with TS as binder attained a maximum temperature of 562°C in 3 minutes and a minimum temperature of 193°C in 20 minutes. Likewise, pellets with CS as binder attained a maximum temperature of 558°C in 5 minutes and 176°C minimum temperature. It also clearly showed that a temperature above 100°C can be maintained for more than 30 minutes. This shows that the binder ratio has a great influence on the combustion of solid Bio fuels and this is true as this (binder ratio) has effects on the density of the pellets.

Figure 1.3, shows the comparisons of combustion rate of 40g rice husk pellets at 30% binder ratio (TS and CS) and charcoal. In these cases, the rice husk pellets with TS generated a temperature of 558°C in 5 minutes, which gradually reduces to 176°C after 20 minutes, while rice husk pellets with CS generated a temperature of 520°C. This dropped gradually to 159°C in 20 minutes. The high temperature (about 620°C) recorded for the produced rice husk pellets in this work are in the conformity with the findings of (Kyauta, 2007), the maize cobs and groundnut shell pellets attained temperature of 600°C and 750°C respectively. It was observed that the solid Bio fuels (i.e. rice husk pellets) produced with TS and CS burnt with a flame temperature of about 620°C. The flame heights of the pellets were between 6 and 10 cm and that of the charcoal is about 1-2 cm depending on the quantity of the fuel and burning conditions. The fuel samples started the combustion stabilized both change to blue flame.

Fuel and Physical Properties of Pellets and Charcoal

Table 1.9, show the durability of the rice husk pellets with tamarind starch is 97.8%, 93.6% and 91.3% for binder ratios of 30%, 20% and 10% respectively. While that of pellets with cassava starch as binder has durability of 97.5%, 96.6% and 92.3% for the same binder ratios of 30%, 20% and 10% respectively. These values compare favorably with the values of 95%, 93.52%, 91.55%, 90% and 88.90% obtained by (Oyelaran, *et al,* 2014) and (Maraver, *et al,* 2010). The observed increased in durability with increase in starch content can also be attributed the adhesive role the starch played in the pellets as reported in (Olorunnisola, 2007). This implies that the rice husk pellets are good for handling storage and transportation purpose and also meet the requirement for commercial pellets

Table 1.9 shows the results of the fuel and physical properties of pellets and charcoal, the percentage of fixed carbon and volatile matters for pellets were 6.7% and 80% while that of charcoal are 9.35% and 75% respectively. Volatile matter refers to the part of the biomass that is released when the biomass is heated up to (500°C to 550°C). During this heating process the biomass decomposes into volatile gases, according to (Andrew, and Agidi, 2015). However, the rice husk pellets and charcoal used has a higher volatile matter of 80% and 75% respectively. This is high and it is signifies easy ignition and increase in the flame length as observed by (Loo, and Koppejan, 2008).

The fixed carbon of a fuel is the percentage of carbon available for combustion, for the pellets and charcoal, it was found to be 6.7% and 9.35% respectively. The low fixed carbon content makes it tend to prolong cooking time by its low heat release. The moisture content of the pellets and the charcoal is found to be 12.5% and 11% respectively. This results was within the limits of 15% recommended by (Wilaipon, 2008), for the briquetting of agro- residues.

CONCLUSION

The following Conclusions were drawn from the Research:

i. Agricultural wastes such as rice husk are potential raw material for pellets production and the quality of pellets produced from the rice husk are highly influenced by the binder types used for the work.
ii. The binding effect, combustion characteristic, compressive force, durability and physical properties of the rice husk pellets produced with tamarind starch were better than the pellets produced with cassava starch. This clearly shows that tamarind starch (Non – edible starch) which apparently has never been used for any densification technology can be used as a replacement for cassava starch (edible starch) which has a competitive need.

RECOMMENDATIONS

For further study, the following Recommendation was made:

i. Research should be made by using order binding methods, such as banana peel, gum Arabic etc.
ii. Research should be carried out on design, construction and testing of pellets machine for all other Agricultural- residues.

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