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Evaluation of Improved Wood Burning Stoves Using Tsirir, Marke and Kalgo Wood Species Found In Bauchi State, Nigeria

[1]Lawal, A. M., [2]Muhammad, I. S., [3]Hussaini, S. S.
[1,2,3]*Mechanical Engineering Department, Abubakar Tatari Ali Polytechnic, Bauchi, Nigeria*

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ABSTRACT
The performance of three different wood cook stoves fueled with Tsisir, Marke and Kalgo wood species were evaluated in accordance with standard laboratory procedures to determine the thermal and combustion properties of the fuel woods.The samples were obtained within Bauchi state (Tsirir and Kalgo from Yankari Game Reserve, Marke from Toro) and identified in the herbarium of the Biological Programmes of Abubakar Tafawa Balewa University, Bauchi. The wood species were first dried under the sun for six weeks before being used. The results revealed that Tsirir exhibited the highest heat content (24.0J/kg) and flame temperature (478^{0}C) followed by Marke (18.5J/kg, 430^{0}C) and Kalgo(15.8J/kg, 302^{0}C). However, oxygen index analyses shows that Kalgohad the highest value of 32% while others exhibited lower values. From the analysis of the three stoves, stove 2 shows better efficiency with Markehaving highest fuel consumption of 30.95g/min and closely followed by Kalgo, andTsirir with values of 18.05g/min, and 7.30g/min respectively. Conversely, for the same stove Tsirir has the highest mean combustion temperature of 115.40^{0}C, while Marke (114.53^{0}C) and Kalgo (108.40^{0}C) are presented in the descending order for the same experimental duration.Having identified the best stove sample and tree species to be used as stove and fuel wood, there is the need to study the growing rate of these species in order to determine which among them are fast growing so that their plantation could be encouraged.

KEYWORDS: Calorific value, fuel consumption, flame temperature, wood, stove

I. INTRODUCTION

Energy supplies in Nigeria are mainly through the conventional fuels, oil, natural gas and coal. These serve as the most common and secured source of energy for various purposes. The demand for energy is constantly increasing due to population growth, modernization of human life as well as progress of modern science and technology.

In Nigeria, despite the quantity of fossil fuel, the vast majority of rural and urban populace depend largely on fuel wood to meet most of their energy needs for cooking and heating. Trees are being indiscriminately fell to meet the fuel wood demand with no systematic replacement, until when serious desertification, desert encroachment and soil erosion were experienced in some parts of the country (Garba & Atiku, 1997). Hence concerted efforts are required to change this trend and to protect the environment. The long-term aspiration in respect of cooking energy is the complete substitution of wood-fuel by other sources such as gas, kerosene, solar and electricity, but these changes may take a few decades to materialize (Danshehu et al, 1995).

Traditionally, cooking is done by burning of fuel wood and crops residues in an open fire place known as three stone stoves. This method is very inefficient as only 5 to 10% of the potential energy in the fuel wood is utilized in the cooking process (Danshehu et al, 1996). The consumption of fuel wood would thus be much higher under the customary three stone stoves. The convenient and efficient improved wood-burning stove developed in the past at various institutions and communities (e.g., Usman Danfodio University Sokoto (UDU), University of Nigeria Nsuka (UN) and Abubakar Tafawa Balewa University Bauchi (ATBU) in Nigeria, have reported some significant savings in fuel wood and time coupled with advantages of being less hazardous due to the provision of chimney (Danshehu et al, 1996). It has been found out that the efficiencies vary from 20.77% (under outdoor conditions) to 27.78% (for indoor conditions) for clay stoves, which is an improvement over the traditional metal tripod – 9.55% and 13.88% for outdoor and indoor conditions respectively (Akinbode, 1991).

Another important substitute to fuel wood is briquettes. These are made from by – products of agricultural wastes (rice husks and maize mixed with binders such as resins (e.g., gum Arabic, starch and possibly synthetic resins) compacted to make solid and shaped using the briquette machine. If the briquettes are proved to be environment – friendly, it will reduce the rate of cutting down fuel – wood for cooking, and serve as an alternative energy source.

It has been found out that the influx of air, heat losses across the stove walls, type of material used for the stove, the height of the chimney, the varying number of pot – holes all contribute to the increase or decrease in efficiency of the improved wood burning stoves and also affect the cooking time (Adisa et al, 1999). Several attempts have been made to modify this stove, to arrest the effect of smoke generated on the user and reduce its high fuel consumption. The modification of this stove implies improving the efficiency in utilization of the fuel. The present practice of using 3 – stone type wood stove is very wasteful, time consuming and posses a lot of health hazards. The main focus here comparatively analyze combustion characteristics of the selected tropical fuel wood species, and the performance of wood burning stove samples in terms of fuel wood consumption, generated heat content and stove energy saving efficiency.

II. MATERIALS AND METHODS

2.1 Materials

2.1.1 Brief description of the fuel wood species

Tsirir (Combretum nigricans): In Hausa language the tree is known as 'Tsirir'. It is mostly found in drier areas of Northern Nigeria, such as Sokoto and some part of Bauchi state. The tree is about 7.63 metres in average height when fully grown. The bark is nearly smooth, pinkish – brown. The surface is often fibrous in texture and has a characteristics gum which is reddish in colour.

Marke (Anageissusleocarpus): This tree is known as 'Marke' in Hausa language. It is found in most parts of the Savannah areas from the driest regions to the borders of the forest zone. A fully grown tree is about 27.45 metres high, with branches ascending usually from low down and often dropping at the ends. The bark of the tree is grey to the pale brown, while the fuel wood is greyish outside dark brown at the heart and very hard.

Kalgo (Piliosigmareticulatum): It is commonly found in Bauchi, Sokoto and other parts of tropical areas of Nigeria. It is also known as 'Kalgo' in Hausa language. The size of the tree when fully grown is about 9.15 metres high. The bark is dark grey sometimes rust coloured. Its fuel wood is brown, stronger and tough.

2.1.2 Preparation of fuel wood species

The samples were obtained within Bauchi state (Tsirir and Kalgo from Yankari Game Reserve, Marke from Toro) and identified in the herbarium of the Biological Programmes of Abubakar Tafawa Balewa University, Bauchi. The wood species were first dried under the sun for six weeks before being used.

2.1.3 Description of wood stoves

The stove(s) used as the experimental test rigs consist of the following parts which are adopted from Abubakar (2011):

i. **Stove body:** The bodies of the stove were made with locally available clay within Bauchi metropolis. Rice husk and saw dust were used as binding materials. The stoves were reinforced with a wire mesh to give them additional strength to withstand sudden and variable shock loads associated with traditional methods involved in cooking. The stove bodies were fired to improve its strength and durability. The stove body is provided with a firebox entrance at the front end, with holes on top (pot holes).
ii. **Fire box:** Fuel wood is fed directly into the firebox; the entrance serves as air inlet and the fire box serve as the combustion chamber.
iii. **Pot holes:** This is an opening (or opening for a multiple pot design) provided on the top of the stove body to serve as a place for mounting the cooking pots (exit flue opening(s)). The hole sizes were based on the diameters of the locally available cooking pots and each hole was made to be slightly less than the maximum diameter of the cooking pots to be mounted.
iv. **Baffle:** The purpose of the baffle is to ensure maximum heat efficiency and stabilization of flame, since it is important to retain heat generated for as long as possible and in close proximity to the cooking pot for two pot hole stove design, it is made under the second pot hole.

International Journal of Advances in Engineering and Management (IJAEM)
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v. **Damper:** The damper is a moveable metal plate to regulate the flow of air and gases through the stove. It is incorporated to the chimney and appropriately adjusted to open or completely block the chimney.

vi. **Chimney:** This is employed to provide draught to draw air into the combustion chamber, to overcome the various flow resistances in the stove as well as an exit to for smoke and soot. The chimney is in the form of short cylinders and incorporated according to the required chimney height design.

vii. **Grate:** This is made of wire mesh, placed in the fire box. The fuel wood is spread evenly on the grate so that air has easy access to it. It is used to divide the fuel wood entrance into two so that air can get into the combustion chamber. It also serves as a means of separating ash from the unburnt fuel wood and charcoal which can be reused.

viii. **Ash tray:** This is provided for the collection of ash falling from the grate. The ash is emptied after every cooking activity to avoid ash accumulation in the firebox.

ix. **Hole cover:** This is provided as temporary cover with only one hole for the multi-pot whole design so that there would be minimal heat loss through the other hole.

2.1.4 Configuration of wood burning stoves

1. **Stove 1:** This stove has no grate in its combustion chamber. The stove size is 500mm x 300mm x 250mm and has a wall thickness of 30mm. This stove is an adoption of the wood burning from Sokoto Energy Research Center (SERC).
2. **Stove 2:** This stove has a grate and a firebox inlet entrance that was projected outside the stove body with the dimension 100mm x 80mm x 65mm which also serves as support to fuel wood. It is incorporated with a secondary air inlet below the firebox inlet entrance. The stove size is 450mm x 250mm x 200mm and the stove wall thickness is 50mm (Adisa, 2003).

- **Stove 3:** The stove is constructed with two holes with all the components described in stove sample 1 above. It is similar to stove one but it is incorporated with a grate and the stove size is 500mm x 300mm x 250mm and the wall thickness is 40mm. The stove is an adoption of the wood burning stove from the Sokoto Energy Research Center (SERC).

2.2 Experimental Methods

2.2.1 Thermal and combustion properties of fuel woods

The following experimental procedures were used in the determination of the following thermal and combustion properties of the fuel woods under study.

i. Calorific value: The calorific value of the fuel woods which is the heat liberated when a unit quantity of the fuel wood was completely burnt is determined by using fuel/food calorimeter model LO 4-340, manufactured by Griffin and George Limited, England.

ii. Flame temperature: The flame temperature of each fuel wood under study was measured with the aid of a German made HBC. Geroz, Watt metre, model 4014 connected to thermocouple. The probe of the thermocouple is positioned at the blue zone of the flame of each combusting fuel wood samples. The test procedures are replicated and the final result for each wood is the mean of the replicated attempt.

iii. **Limiting oxygen index (LOI):** This test was carried out in accordance with the ASTM D2863 methods. The relationship of the limiting oxygen index and the mixture of oxygen and nitrogen are given by the expression equation 2.1.

$$LOI(\%) = \frac{O_2}{O_2 + N_2} \times 100 \qquad \text{... (2.1)}$$

Where; $O_2 =$ Volumetriv flow of oxygen (cm^3/min), $N_2 =$ Volumetric flow of nitrogen (cm^3/min).

iv. Wind velocity: The values of the daily average wind velocity for Bauchi metropolis was collected from the Metrological department to cover the period of the experiments.

2.2.2 Performance evaluation of wood burning stoves

The water boiling test (WBT) was employed to measure the expected stove performance (Danshehu et al, 1995). In this case, pieces of Tsirir fuel wood were weighed in a weighing balance before being used to boil one liter of water in stove sample 1. However, after the water is completely boiled, the fire is extinguished and the remaining wood pieces is collected and weighed, to determine the weight of fuel wood consumption required to boil the water. The time taken for the water to boil was also observed with a stop watch and recorded. The same procedures were also repeated for sample stove 2 and 3 respectively and the other fuel wood species.

International Journal of Advances in Engineering and Management (IJAEM)
Volume 3, Issue 12 Dec 2021, pp: 962-972 www.ijaem.net ISSN: 2395-5252

3.2.3 Determination of fuel wood combustion temperature for stove samples

Tsirir fuel wood specie was used as a fuel for sample stove 1. The flame temperature of the fuel wood under study was measured with the aid of a German made HBC, Geroz Watt Metre, model 4014 connected to thermocouple. The probe of the thermocouple is positioned at four different equidistant points, and the readings of the combustion temperature were taken after every minute for an experimental duration of twenty minutes. Similar procedure was also replicated for Aduwa, Chediya, Kalgo, Kuka and Marke wood species, and for the remaining stove samples 1 and 2 respectively.

III. RESULTS

3.1 Results of thermal and combustion properties of fuel wood

The properties of the fuel wood analyzed are presented in table 6.

Table 3.1: Properties of fuel woods

Properties	Tsirir	Marke	Kalgo
Moisture content	-	-	-
Calorific value (J/kg)	24.0	18.5	15.8
Flame temperature (^{0}C)	478.0	430.0	302.0
Oxygen index (%)	24.0	25.0	32.0
Air velocity (m/s)	33.9	33.9	33.9
Volume of water (l)	1.0	1.0	1.0

Table 3.1 and figure 3.1 revealed that Tsirirexhibited the highest heat content (24.0J/kg) followed byMarke (18.5J/kg). Kalgo has the least calorific value of 15.8J/kg.

Figure 3.2 revealed thatTsirirexhibited the highest flame temperature of 478^{0}C, while others such as Markeand Kalgo has 430^{0}C and 302^{0}Crespectively.

Oxygen index analyses shown in figure 3.3 also revealed that Kalgo exhibited the highest value of 32% while others exhibited lower values.

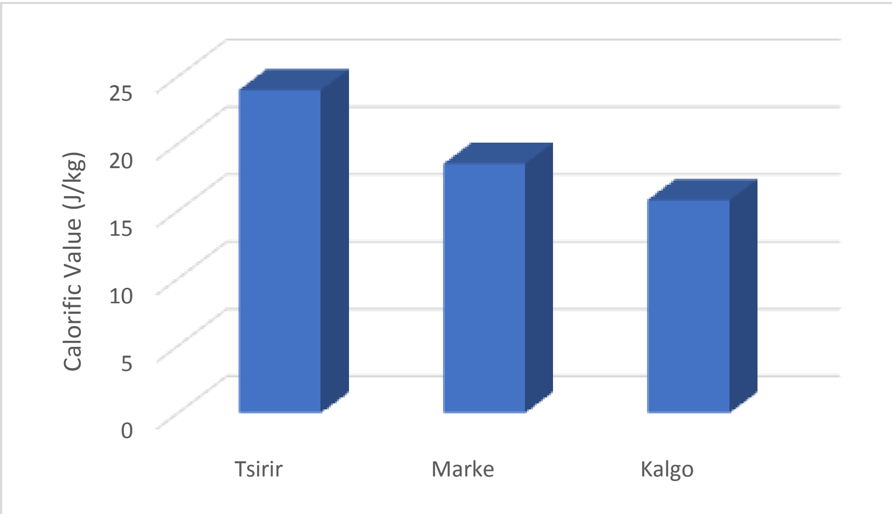

Figure 3.1: Calorific values of wood fuels

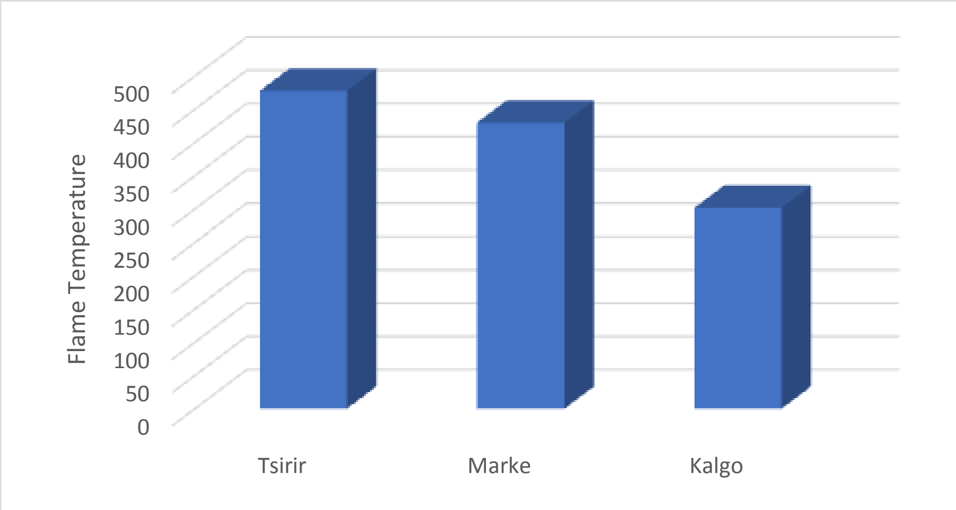

Figure 3.2: Flame temperatures of wood fuels

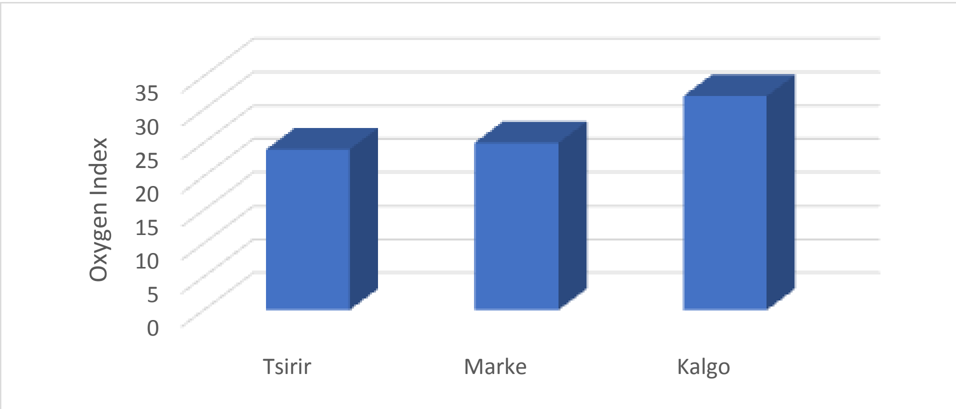

Figure 3.3: Oxygen index of wood fuels

3.2 Results of Performance of Wood Burning stoves

Fuel wood consumption rate was analyzed for the three stoves under survey. From table 3.2, stove 1 has a significant higher fuel consumption rate for the case of Kalgo (i.e., 12.00g/min). This is closely followed by the consumption rates of Marke, and Tsirir with a fuel consumption rate of 10.94g/min and 5.53g/min respectively.

The result for stove 2 showsMarke with the highest fuel consumption of 30.95g/min and closely followed by Kalgo, and Tsirir with values of18.05g/min, and 7.30g/min respectively.
The result of the analysis using stove 3 also revealed thatMarke (21.69g/min) exhibited the highest fuel wood consumption rate and Tsirir having the least fuel consumption rate.
Figure 3.4 shows the profiles of the fuel consumption rate of the three different stoves.

Table 3.2: Effect of fuel wood burning rate of stove types at a mean air velocity of 33.9m/s

Types of fuel wood	**Fuel wood burning rate (g/mins)**		
	Stove 1	Stove 2	Stove 3
Tsirir	5.53	7.30	10.89
Marke	10.94	30.95	21.69
Kalgo	12.00	18.05	16.94

International Journal of Advances in Engineering and Management (IJAEM)
Volume 3, Issue 12 Dec 2021, pp: 962-972 www.ijaem.net ISSN: 2395-5252

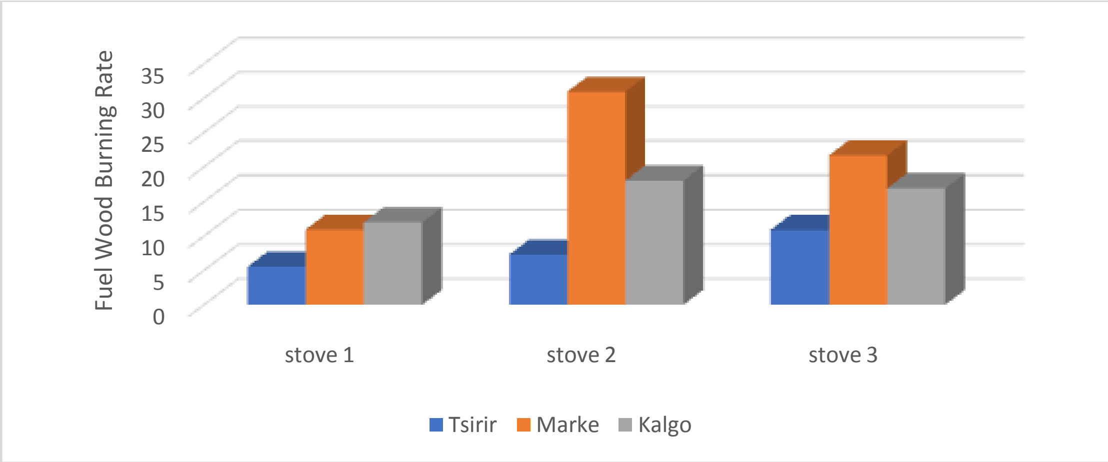

Figure 3.4: Profile of wood burning rate

3.3 Results of the mean fuel wood combustion temperature in stove samples

At maximum burning duration of twenty minutes, table 3.3 and figure 3.5 show that Tsirir exhibited the highest mean combustion temperature of 102.50^{0}C for sample stove 1. While, the means combustion temperature ofMarke (92.22^{0}C) and Kalgo (87.05^{0}C) follows respectively.

In the case of sample stove 2, the results in table 3.4 and figure 3.6 revealed that Tsirir has the highest mean combustion temperature of 115.40^{0}C, while Marke (114.53^{0}C) and Kalgo (108.40^{0}C) are presented in the descending order for the same experimental duration.

Results of mean combustion temperature of sample stove 3 in table 3.7 and illustrated in figure 3.7 revealed that Marke and Kalgo demonstrated the highest combustion temperature of 96.38^{0}C with Tsirir having the least combustion temperature of 87.55^{0}C.

Figures 3.5, 3.6 and 3.7 show that for all stove samples, combustion temperature increases with fuel wood burning duration.

Table 3.3: Wood burning temperature of different wood types in sample stove 1

Types of fuel wood	**Burning duration (mins)**	**Combustion temperature (^{0}C)**				
		T1	T2	T3	T4	Mean
Tsirir	5	19.2	23.4	29.8	33.2	26.40
	10	53	65	71.2	81.4	67.65
	15	80.7	80.2	89.2	90.1	85.05
	20	98.2	100.2	101.2	110.4	102.50
Marke	5	19.8	20.6	24.8	26	22.80
	10	44.4	52	55.1	65.4	54.23
	15	70.1	83.4	86.2	93.2	83.23
	20	78.4	90.1	99.3	101.3	92.28
Kalgo	5	17.8	18.5	23	24.2	20.88
	10	39.5	45.6	77.5	80.3	60.73
	15	60.7	65.1	79.4	89	73.55
	20	75.8	79.9	94.1	98.4	87.05

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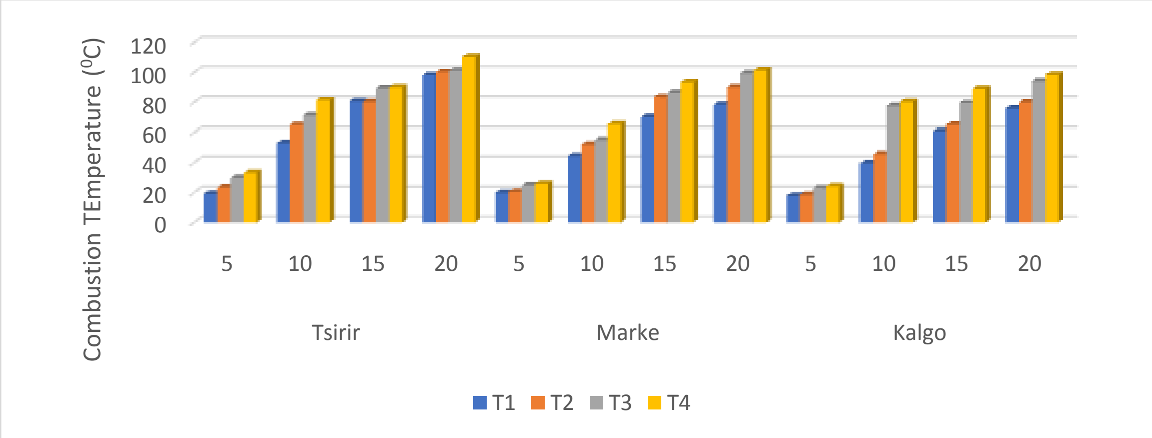

Figure 3.5: Fuel combustion temperature for stove 1

Table 3.4: Wood burning temperature of different wood types in sample 2

Types of fuel wood	**Burning duration (mins)**	**Combustion temperature (^{0}C)**				
		T1	T2	T3	T4	Mean
Tsirir	5	31.6	35.4	63.8	69.3	50.03
	10	79.1	88.4	106.3	115.5	97.33
	15	85.8	97.8	115.6	129.1	107.08
	20	95.3	108.7	121.7	135.9	115.40
Marke	5	27.8	35.8	41.3	43.8	37.18
	10	69.7	89.5	103.2	109.6	93.00
	15	76.8	95.8	113.7	118.9	101.30
	20	96	107.3	124.6	130.2	114.53
Kalgo	5	23.5	25.4	44	47.3	35.05
	10	58.8	63.5	97.8	105.2	81.33
	15	75.7	78.6	106.4	110.3	92.75
	20	94.6	98.3	118.2	122.5	108.40

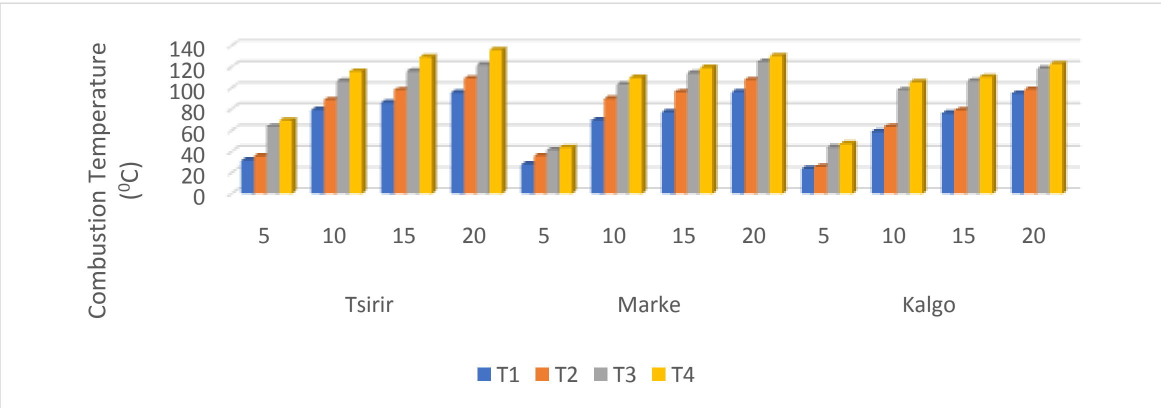

Figure 3.6: Fuel combustion temperature for stove 2

International Journal of Advances in Engineering and Management (IJAEM)
Volume 3, Issue 12 Dec 2021, pp: 962-972 www.ijaem.net ISSN: 2395-5252

Table 3.5: Wood burning temperature of different wood types in sample stove 3

Types of fuel wood	Burning duration (mins)	Combustion temperature (^{0}C)				
		T1	T2	T3	T4	Mean
Tsirir	5	23.3	24.2	28.3	34.9	27.68
	10	52.2	60.5	70.7	87.2	67.65
	15	61.4	72.4	81.8	97.8	78.35
	20	68.2	80.4	92.9	108.7	87.55
Marke	5	20	25.2	28	31.7	26.23
	10	50.1	63.1	74.1	89.3	69.15
	15	80.3	83.8	89.5	93.33	86.73
	20	89.2	93.1	99.5	103.7	96.38
Kalgo	5	40.2	58.5	70.2	89.2	64.53
	10	53.2	58.5	70.2	89.2	67.78
	15	68.6	74.6	84.8	96	81.00
	20	85.8	93.2	99.8	106.7	96.38

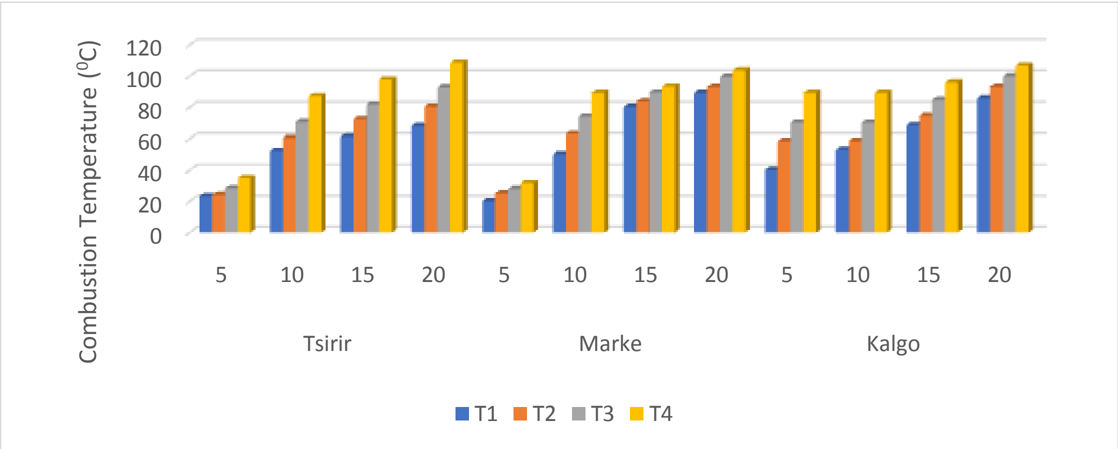

Figure 3.7: Fuel combustion temperature for stove 3

3.4 Results of wood burning efficiency in stove samples

Figure 3.8 revealed that sample stove 2 produced the highest fuel wood combustion efficiency in all the fuel wood tested while sample stove 1 and 3 show varying combustion efficiencies. Tsirir has the highest combustion temperature.

Table 3.6: Mean combustion temperatures for stove 1, 2 and 3

Types of fuel wood	**Burning duration (mins)**	**Mean Combustion temperature (^{0}C) for stove**		
		1	2	3
Tsirir	5	26.40	50.03	27.68
	10	67.65	97.33	67.65
	15	85.05	107.08	78.35

International Journal of Advances in Engineering and Management (IJAEM)
Volume 3, Issue 12 Dec 2021, pp: 962-972 www.ijaem.net ISSN: 2395-5252

	20	102.50	115.40	87.55
Marke	5	22.80	37.18	26.23
	10	54.23	93.00	69.15
	15	83.23	101.30	86.73
	20	92.28	114.53	96.38
Kalgo	5	20.88	35.05	64.53
	10	60.73	81.33	67.78
	15	73.55	92.75	81.00
	20	87.05	108.40	96.38

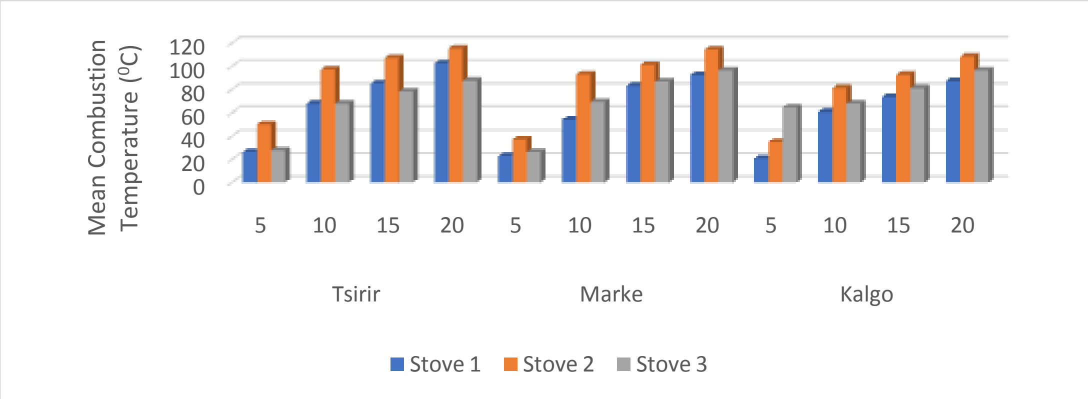

Figure 3.8: Mean Combustion temperatures of the three sample stoves

IV. DISCUSSION OF RESULTS

4.1 Discussion on Thermal Properties of Fuel Wood

It was observed that the calorific value and flame temperature of Tsirir fuel wood is higher than the other fuel woods tested. It could also be seen that the result of the oxygen index is higher with Kalgo and least with Tsirir. The implication of the outcome of these results is that, the higher the calorific value of a fuel wood, the higher the likely hood to generate higher flame temperature, and the lower oxygen index is required to support the combustion of the fuel woods. Moisture content which influenced the combustion efficiency and characteristics of fuel woods may also have affected the performance of the fuels.

4.2 Discussion on Fuel Wood Consumption Rate

Analysis of fuel wood combustion rate showed that Kalgo exhibited the highest combustion rate when compared to others with Tsirir having the least. The fuel wood consumption rate is highest for sample stove 2 with 33.9m/s as mean air velocity. The rate of burning (and hence the rate of heat released) is determined by the manner in which the air required for combustion gets supplied to the burning wood. Therefore, the finding that a proportional relationship exists between fuel wood consumption rate (and burning rates) and air supply seems relevant in the present context. It was further noted that if the burning phase is steady, then burning rate is characteristic of flaming combustion, and is dependent on the measured airflow through the air vent under the fire box.

4.3 Discussion on Fuel Wood Combustion Temperature

Fuel wood combustion temperature in table 3.3, 3.4 and 3.5 showed that Tsirir has the highest combustion temperatures within the combustion chamber of sample stove 1 and 2 but least in stove 3. However, the result is not consistent with the interpretation of the calorific value and flame temperature of Tsirir,Marke andKalgo in table 3.1 and figures 3.1 and 3.2 respectively due to combustion temperature variation influenced by the size of the wood pieces, its geometry, voilage and moisture content.

Further, it was also noted that the outcome combustion temperature reading for sample stove 2 in table 3.4, clearly indicated that a more efficient combustion leading to higher combustion temperature has taken place.

International Journal of Advances in Engineering and Management (IJAEM)
Volume 3, Issue 12 Dec 2021, pp: 962-972 www.ijaem.net ISSN: 2395-5252

4.4 Discussion on Combustion Efficiency of Wood Burning Stoves

From the results, sample stove 2 exhibited higher combustion efficiency than the other two stoves. This is attributed to the design configuration of the cook stove which includes chimney and air vent to generate secondary air in addition to the primary air.

V. CONCLUSION AND RECOMMENDATION

The growing gap between availability and demand for firewood, coupled with the scarcity and increasing price of fossil fuels, the poor thermal performance and pollution caused by traditional stoves as a result of burning inappropriate wood species, forced the attention of this work on the thermal characteristics of some of these wood species. These factors which include calorific value, flame temperature and burning rates led to the development of some efficient wood burning stoves. The adoption and largescale propagation of improved wood stoves coupled with utilization of appropriate wood species could help in improving the health of rural and urban users and in making a more efficient utilization of the available firewood resources.

From the study of combustion properties of different wood fuels using different stoves, the following could be concluded from the results of the study.

1. Tsirir exhibited higher calorific values and flame temperature than Kalgo and Marke fuel wood.
2. Conversely Tsirir demonstrated lower oxygen index than Kalgo, and Marke fuel woods respectively.
3. The burning rates of Tsirir higher than Marke and Kalgofuel woods, owing to its higher calorific value, lower oxygen index and weight of the fuel wood pieces and moisture content.
4. Sample stove 2 exhibited better combustion efficiency for all fuel wood samples under study, owing to the incorporation of an vent chimney and inlets for inflow of primary and secondary air to circulate and produce stoichiometric combustion.

5.3 Recommendation

Having identified the best stove sample and tree species to be used as stove and fuel wood, there is the need to study the growing rate of these species in order to determine which among them are fast growing so that their plantation could be encouraged and also a critical study of the stove combustion chamber, wall thickness as well as the secondary air inlet in order to have a stove with optimal performance efficiency.

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