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RESEARCH ARTICLE

EFFICIENCY OF A MODIFIED CONICAL METALLIC COOKING STOVE INCORPORATING CLAY FOR OPTIMAL CHARCOAL CONSUMPTION IN KARA REGION - TOGO

Hodo-Abalo Samah, N'detigma Kata and Kodjo Kpodé
LaMERE, Faculty of Sciences and Technologies, University of Kara-Togo.

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Abstract

An acceptability survey of improved charcoal stoves conducted in some households in the Kara region in Togo revealed that 40% of households use the clay cookestove and 30% the conical cookestove. Unfortunately the configuration of the clay stove requires permanent maintenance. To combine the advantages of the two both types of stoves widely used, a modified conical cookestove model integrating clay with an optimized thickness of 4 centimeters is proposed and tested. The procedure used is similar to that proposed by a group of experts for the Household Energy and Health Program of the Shell Foundation. The results showed that thermal efficiency of modified conical cookestove is improved about 17.35% relatively to conical cooking stove but compared to the clay cookestove, the improvement about 5.18% only is reported. The specific consumption of the modified conical stove save 2.76% of charcoal relatively to conical cookestove while over consumption of 2.62% is reported relatively to the clay cooking stove. The study found that the modified conical cookestove offer an alternative to replace the clay cooking stove and can solve the problem of maintenance and durability. Modified conical cookestove or clay cookestove is suitable for long cooking while the conical cooking stove is better for short cooking.

Introduction:-

In developing countries, cookestoves account for more than half of total residential energy use and in many poor countries, over 80% of household energy use is for cooking [1]. The ever-increasing evolution of the population will certainly contribute to increase the demand for their cooking needs [2]. Excessive use of biomass as energy constitute one of the factors degrading not only the environment but also providing greenhouse gases such as carbon dioxide, carbon monoxide, ... Policy interventions that target this group of biomass users through the dissemination of improved stoves are the cheapest way to save fuel through improved stove designs, thus achieving higher levels of energy efficiency as well as reduced levels of emissions harmful to humans and the environment. It is therefore wise to develop efficient and clean energy technologies in order to reduce polluting emissions and mitigate climate change.Simple technologies such as improved cooking stoves have been developed to help reduce deforestation and minimize loss of wildlife habitat. Although improved cooking stoves have been developed to reduce fuel consumption in households, most are designed to use wood or charcoal as fuel, thus depending on forest resources for their operations. There are many designs for improved cooking stoves and it is necessary to evaluate their performance in order to make recommendations on the different designs and the conditions of use. Regardless of the

Corresponding Author:- Hodo-Abalo Samah
Address:- LaMERE -Université De Kara, BP: 404 Kara, Togo.

design, improved cooking stoves must be more energy efficient than conventional cooking methods such as the three stones put in place to justify their implementation. Apart from reports of projects in some specific regions, there is very little scientific work about improved cooking stove using wood or charcoal as fuel.A comprehensive review of 50 different cooking stove models by MacCarty et al.[3] tested several different stoves and found that, on average, the fuel use was reduced by 33%, CO emissions by 75%, and PM emissions by 46% in comparison to the three-stone fire.

An acceptability survey of improved charcoal stoves conducted in some households in the Kara region in Togo revealed that 40% of households use the clay stove and 30% the conical charcoal stove. Unfortunately the configuration of the clay stove requires permanent maintenance. To combine the advantages of both two types of stoves widely used, a conical stove model integrating clay with an optimized thickness of 4 centimeters is proposed and tested. The purpose of the tests carried out, is to compare the proposed model to the both two cookestoves and provide information relating to the operating performance of these stoves. The tests are carried out at the Laboratory Materials Renewable Energy and Environment (LaMERE) at the University of Kara.

Methods And Materials:-

Water Boiling Tests (WBT) are simple simulations of short procedures normally followed when cooking a meal. These tests measure the fuel consumed and the time required for boiling. WBT are used to compare the performance of different stoves or the performance of the same stove in different operational situations. The procedure used in this study is similar to that proposed by a group of experts for the Household Energy and Health Program of the Shell Foundation and that used at the Laboratory on Solar Energy [4-6]. The test consists of three phases:

1. Cold-start high-power phase, the test begins with the stove at room temperature and uses fuel from a pre-weighed bundle of fuel to boil a measured quantity of water in a standard pot. The tester then replaces the boiled water with a fresh pot of ambient temperature water to perform the second phase.
2. Hot-start high-power phase is conducted after the first phase while stove is still hot. Again, the tester uses fuel from a pre-weighed bundle of fuel to boil a measured quantity of water in a standard pot. Repeating the test with a hot stove helps to identify differences in performance between a stove when it is cold and when it is hot. This is particularly important for stoves with high thermal mass, since these stoves may be kept warm in practice.
3. Simmer low power phase provides the amount of fuel required to simmer a measured amount of water at just below boiling point for 45 minutes. This step simulates the long cooking of legumes or pulses common throughout much of the world.

Devices	Devices characteristics
Digital thermometer with probe (HI98509-Checktemp-HANNA instruments)	Range: -50°C to 150°C Resolution : 0.1°C Accurency: ∓0.2 ℃ (-30 °C to 120 °C)
Trade balance	ACS series Resolution: 0.1g Max: 40 Kg
Anemometer	Type: Testo 425 Range: 0 to 20m/s
Mini Temperature & Humidity Meter	Range: 0 to 100% Resolution: 0.1 %
Laboratory stopwatch	PHYWE, sports timer

Table 1:- Measuring devices characteristics.

To implement the different phases of the described protocol, a certain number of measuring instruments were used. Table 1 shows the characteristics of the measuring devices used while in figure 1.a is shown differents steps in designing the conical cookestove incorporating clay. The experimental set up of the tests carried out, is represented in figure 1.b. The cookestoves number 1 (conical metallic cooking stove) and number 3 (Clay cooking stove) are the most cookestoves used in Kara region while the stove number 2 (Modified conical cooking stove) is the proposed model to take in to account the advantages of both two stoves. So this model is a double-walled conical metallic cooking stove incorporating optimized thickness of 4 centimeters of clay to add thermal mass to the stove and limit also maintenance (figure 1 a). The model has the same shape with the conical model developed at the University of Lomé [7]. The clay cooking stove is made traditionally without any precise dimensions but is fair appreciated by households in Kara region. This traditional model requires maintenance after each operation of cooking to ensure it longevity. In Table 2,are given the characteristics of the different cooking stoves.

Characteristics	Conical cookestove	Modified conical cookestove	clay cookestove
Height (cm)	40	40	25
Depth of combustion chamber (cm)	18	18	7
Diameter(cm)	20	20	19
Ceramic thickness (cm)	-	4	-
Air inlet size (cm)	12×10	12×10	-

Table 2:- Studied cooking stoves characteristics

Figure 1 a:- Steps in designing of the conical cooking stove incorporating clay.

Figure 1 b:- Cookestoves tested: 1-Conical cookestove, 2- Modified conical cookestove, 3 clay cookestove.

Main control parameters:-

Four mains control parameters are used in this study

- The specific fuel consumption

It's a measure of the amount of fuel required to boil or simmer one liter of water. This parameter is obtained by the equivalent dry fuel used minus the energy in the remaining charcoal, divided by the liters of water remaining at the end of the test:

$$SC_j = \frac{f_{jd}}{w_{jr}} \quad (1)$$

$j = c$for high power-cold start
$j = h$for high power- hot start
$j = s$for low power- simmering

- The thermal efficiency
  The thermal efficiency is a ratio of the work done by heating and evaporating water to the energy consumed by burning fuel. It is an estimate of the total energy produced by the fire that is used to heat the water in the pot. It is calculated in the following way:
  $$TE = \frac{4.186(T1_{jf} - T1_{ji})(P1_{ji} - P1) + 2260.w_{jv}}{f_{jd}.LHV} \quad (2)$$
- The firepower
  It's the fuel energy consumed to boil the water divided by the time to boil. It tells the average power output of the stove in Watts during the high-power test:
  $$FP_j = \frac{f_{jd}.LHV}{\Delta t_j.60} \quad (3)$$
- The time to boil is the difference between start and finish times:
  $$\Delta t = T1_{jf} - T1_{ji} \quad (4)$$

Results And Discussions:-

About ten tests for each cooking stove took place during the month of September 2021. The behavior of the new model is studied and compared with the two other models adopted by households in the Kara region. The tests were carried out at the laboratory in a hall reflecting a kitchen used in households. The boiling temperature in the region is 98.1 degrees, there was hardly any wind, and the humidity of the ambientairwas65% in average while that of the charcoal was 10%. The pre-weighed bundle of charcoal with size 1.5 cm x 1.5 cm was 400 grams. According to the pot selected for the study, 1.5 liters of water were used for tests conducted. The results for the three phases for each cookestove are given not only in terms of characteristics parameters but also in terms of performances parameters. The evolution of water temperature is shown in figure 2. It is observed that the three phases immediately follow each other.

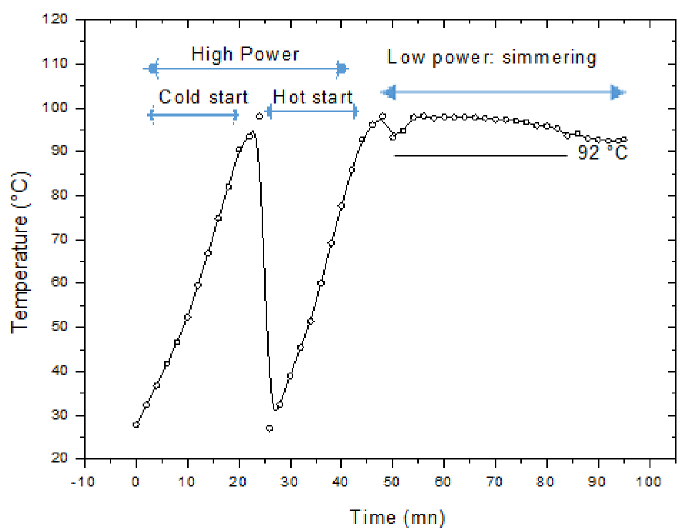

Fig. 2:- Temperature during the three phases of the water boiling test.

The behavior of a cooking stove depends not only on it design but also in part on the operator performing the test. The firepower is a parameter which allows to follow the influence of the characteristics of the cooking stove but also of the tester on the behavior of the stove. Indeed, it's a measure of how quickly fuel was burning, reported in Watts. In figure 3 is shown the firepower of the three cooking stoves studied. It can reaches 7.24 kW and 6.11 kW respectively for the conical and modified conical cooking stoves in hot start high power phase while for clay cooking stove the value is closed to 4.96 kW. The conical and modified conical cooking stoves haves almost similar combustion chamber and opening dimension for the air admission chamber. The slight decrease observed for modified model can be explained by the additional thermal mass. In low power, the maximum value of firepower (3.3 kW) is obtained in case of conical cooking stove.

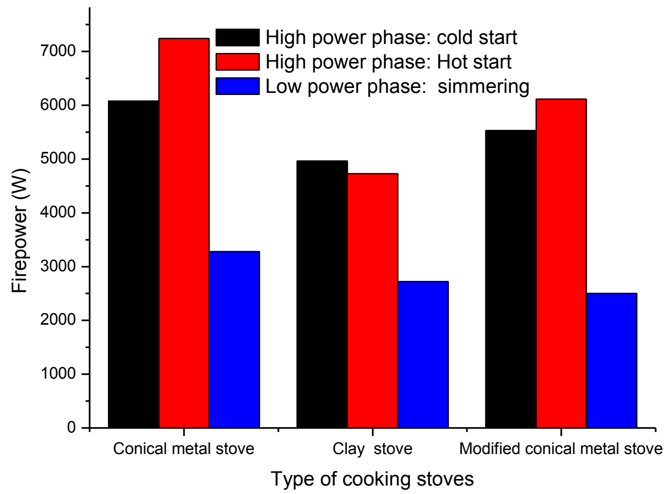

Fig. 3:- Average firepower for different cooking stoves during the three phases.

It's correlated to the average grams of charcoal burned per minute during the test and consequently impacts the fuel consumption. Considering the firepower of different cooking stoves and the fact that the standard deviation is not exceeding 18.5 W, one can get an indicator on how consistently the operator ran the stove over multiple tests.A higher or lower value of firepoweris not necessarilypreferable, but ratherispartillyanindicator of the size of the cookestove.Measures that most stove programs use include also efficiency and performance measures such as specific fuel consumption, thermal efficiency and the time to boil.Specific fuel consumption can be defined for given cooking task as the fuel required to produce a unit output whether the output is boiled water, cooked rice or potatoes etc. In the case of the cold-start high-power, it is a measure of the amount of charcoal required to produce one liter of boiling water starting with cold stove.

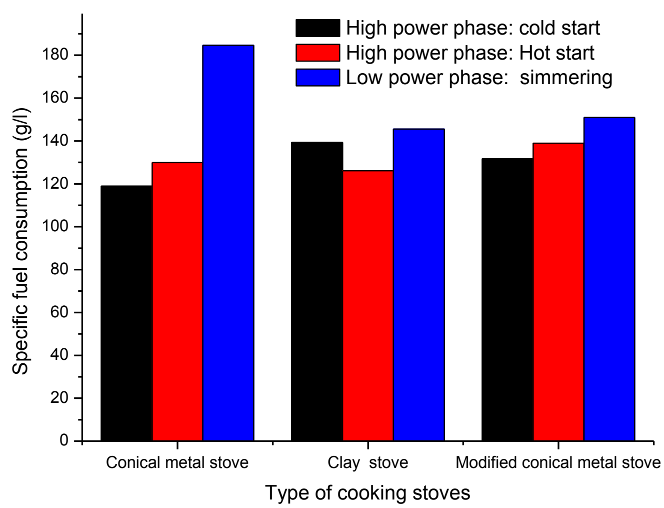

Fig. 4:- Specific fuel consumption for different cooking stoves during the three phases in average.

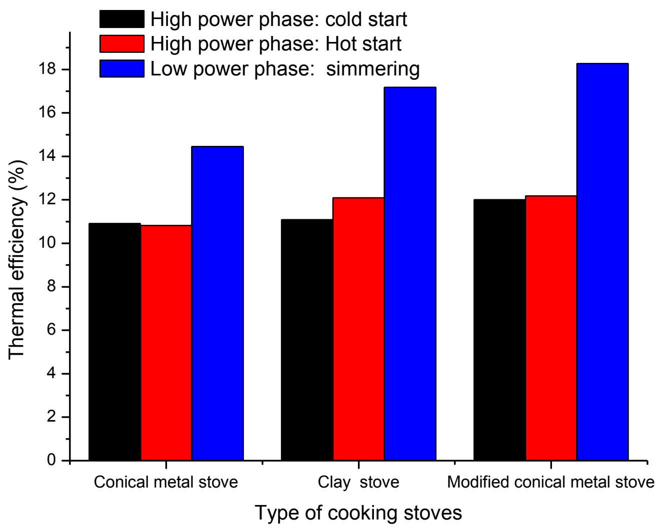

Fig. 5:- Thermal efficiency for different cooking stoves during the three phases in average.

In figure 4 is presented specific charcoal consumption of the studied stoves during the three phases. The analysis of the results in high power phase showed that, the conical cooking stove save better fuel. Compare to the modified conical cookestove, 13 g/l of the fuel can be save; but compare to clay cookestove, 20 g/l of the fuel can be save. A similar analysis in low power revels an over consumption of the conical model. Compare to the modified conical stove, 34 g/l of the fuel is lost; but compare to clay cookestove, 39 g/l of the fuel is lost. It's clearer that, for long cooking, the modified conical stove and the clay cooking stove save better fuel.The fuel consumed produces heat to be transferred to the pot. Thermal efficiency is a measure of the fraction of heat produced by the fuel that made it directly to the water in the pot. The remaining energy is lost to the environment. So a higher thermal efficiency indicates a greater ability to transfer the heat produced into the pot. As shown in figure 5, the thermal efficiency in high power phase of the conical cooking stove is closed to 11% against 12% for ceramic cooking stoves. Moreover,in low power phase, the conical stove's thermal efficiency is grown to 14% against 18% for modified conical cookestove and 17% for the clay cookestove. This interesting performance of the ceramic cooking stoves can be explained by the thermal inertia due to the clay.While thermal efficiency is a well-known measure of stove performance, a better indicator may be specific consumption, especially during the low power phase.

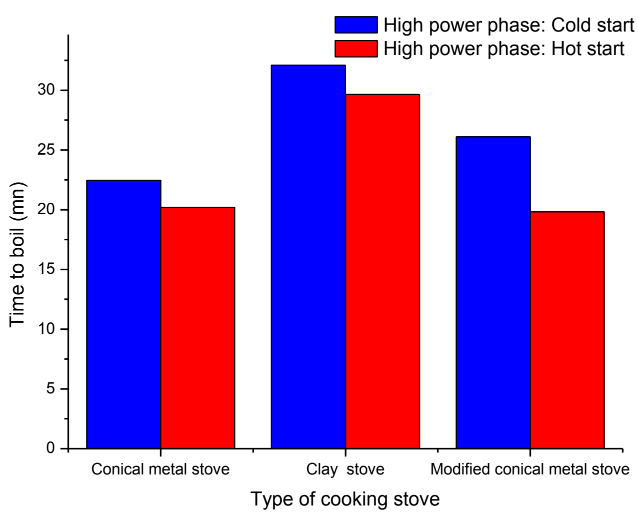

Fig. 6:- Required time to boil for different cooking stoves in average.

Figure 6 reported the required time to boil for different stoves. The conical cookestove has taken about 21 minutes to boil 1.5 liters of water from the room temperature. It's followed by the modified conical cookestove with 23 minutes. The clay cookestove has taken more time until 31 minutes to boil the same quantity of water. It seem, the time to boil grows with the importance of the thermal mass. In table 3 are summarized the average performances over all phases of each cooking stove. Compared to conical cookestove, the modified conical cookestove is improved relatively about 17.35% in terms of thermal efficiency, but compared to the clay stove, relative performance is only 5.18%. When considering specific consumption, the modified conical cookestove save 2.76% of charcoal relatively to conical cookestove, but over consumed 2.62% of charcoal relatively to the clay cooking stove. According to this result, globally, the both two cooking stoves with ceramic are very interesting in saving fuel in daily cooking.

	Units	Conicalmetalicstove (1)		Clay cooking stove (3)		Modifiedconicalmetalicstove (2)		Difference (%)	
		Average	SD	Average	SD	Average	SD	(1) And (2)	(3) And (2)
TE	%	12.1	0.8	13.5	1.4	14.2	1.5	17.35	5.18
SC	g/liter	144.5	19.2	136.9	23.6	140.5	19.9	-2.76	2.62
FP	W	5533.2	15.6	4138.8	14.8	4715.3	18.5	-14.78	13.92
Δt	mn	21.3	2.6	30.8	5.4	22.9	4.5	7.51	-25.64

Table 3:- Studied cooking stoves performances.

Conclusion And Recommendation:-

Two cooking stoves particularly the conical metallic and clay cookestoves widely used in Kara region have been investigated and a new model of stove is proposed to combine the advantages of the both two existing cookestoves. Tests are carried out to compare the proposed model to the both two cookestoves and provide information relating to the operating performance of these stoves. The tests have been done at the Laboratory Materials Renewable Energy and Environment at the University of Kara. The procedure used is similar to that proposed by a group of experts for the Household Energy and Health Program of the Shell Foundation. The main results are as follows:

1. Thermal efficiency of modified conical cookestove is improved about 17.35% relatively to conical cooking stove and about 5.18% relatively to the clay stove cooking stove;
2. The modified conical cookestove save 2.76% of charcoal relatively to conical stovewith regard to specific consumption;
3. However, modified conical cookestove over consumed 2.62% of charcoal relatively to the clay cooking stove.
4. The conical stove takes about 21 minutes to boil 1.5 liters of water against 23 minutes and 31 minutes respectively for the modified conical and the clay cooking stoves.

Recommendation:-

1. Considering the performance of the modified conical cookestove, it offer an alternative to replace the clay cookestove and solve the problem of maintenance which can affect negatively the longevity of this cookestove;
2. For long cooking, modified conical cookestove(or clay cookestove with maintenance)is recommended;
3. For short cooking, the conical cookestove is recommended.

Nomenclature:-

FP_j Firepower (W)
f_{jd} Equivalent dry fuel consumed (grams)
Δt Time to boil (min)
LHV Lower heating value or Net calorific value (kJ/kg)
$T1_{jf}$ Water temperature at end of test (ºC)
$T1_{ji}$ Water temperature at start of test (ºC)
$P1_{ji}$ Mass of pot of water before test (grams)
$P1$ Weight of the pot (grams)

w_{jv} Water vaporized (grams)
SC_j Specific fuel consumption (grams/liter water)
w_{jr} Effective mass of water boiled (grams)
ET Thermal efficiency (%)
SD Standard Deviation

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