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Standards for Biomass Cookers in West Africa: Application on A Cooking Stove Used in Benin

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Abstract Nowadays, throughout the world, the sector of import, manufacture and use of cookers is governed by regulations. These regulations set criteria for counttry's import, manufacture and use of cookers. These regulations aim to reduce the anthropic pressure exerted by cooking stoves on forests due to the high consumption of wood energy as fuel for some of them. They also aim to reduce the footprint of cooking stoves on the climate and the well-being of users by limiting the emission factors of these stoves. Most Asian countries such as China and India are more advanced than West African countries in the field of cookers. These Asian countries have in most cases regulations governing the cooking equipment sector. In West Africa, only a few countries have such regulations. On the one hand, this article aims to list the standards of cooking equipment available in West Africa and test to assess a cooking stove following the test protocols provided for by these standards. On the other hand, the article aims to show the footprint of cooking stoves with regard to the well-being of users but also the environment. The adapted approach consists of carrying out in-depth documentary research through databases, personal exchanges with laboratories and research centers that work in the domestic energy sector. It appears that only 2/16 West African countries have standards on biomass cookers. These include the FDNIS 1000 standard of Nigeria and the GS ISO 19867-1 standard of Ghana. The thermal performances of the tested stove are : 11.48%; 0.64 kW for the GS ISO 19867-1 standard and 10.66% in HP, 9.33% in BP; 9.52 kW in HP 7.871 kW in BP for the FDNIS 1000 standard. Statistics show that countries which have standards are sometimes at the intermediate level and sometimes at the lower level in terms of exposure to problems related to the wood energy sector.

Keywords: *Standard, Test protocols, Cooking stove, Wood energy, West Africa*

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1. Introduction

The Around 18,600,000,000 m^3 of fuelwood, charcoal and other wood based energy sources are consumed each year around the world to meet the need for cooking energy [1]. Around 6,696 million m^3 volume are burned in Africa in poor-quality cooking stoves [1]. In Africa, forecasts have shown that, by 2030 if no measures are taken, the annual demand for wood energy will have to double [2]. In Africa and more particularly in West Africa, 50 to over 95% of households burn wood energy to meet their domestic energy needs. This has serious consequences on the well-being of these households, forests and the environment. The global cooking equipment industry is growing. Thus, the transaction of cooking equipment between countries continues to grow overnight. Therefore, it is imperative that cooking appliances from different countries are regulated by standards. Establishing standards is essential for developing and promoting high quality cook stoves within a country. Most Asian countries such as China, India, Mangolia have experienced significant progress in the field of cookers compared to West African countries. Each of these countries has individually developed and established its own regulations on the manufacture, use and importation of cooking stoves. However, in West Africa, only a few countries have such regulations.

Faced with the problems posed above, research is increasingly being conducted by pairs in order to develop standards and technologies of cooking equipment. Zhang et al. [3], examined systematic and conceptual errors in thermal performance standards and protocols for biomass stoves. They suggested that experts from less developed countries could actively participate in the development of international standards. The technical committee of the International Organization for Standardization has developed the ISO 19867-1 standard on cooking stoves [4]. Zhang et al. [5] used the water boiling protocol, the south African standard protocol (heterogeneous test), the Chinese standard protocol and the Indian standard protocol to highlight the influence of the lid and the amount of water for the test on the thermal efficiency of the cook stove. Arora et al. [6] tested two models of cook stoves using the Indian standard protocol and the water boiling protocol version 4.2.3. Francis Okafar [7] evaluated the thermal and emission performance of stoves using the Nigerian Standard protocol. Maman Nazifi et al. [8] used the water boiling protocol version 4.2.3 to demonstrate the effect of thermal mass on fuel consumption of solid biomass stoves. Lombardi et al. [9] proposed guidelines for the publication and analysis of laboratory test results of biomass cook stoves. SU Yunusa et al. [10] have developed a review of the progress of research on cook stove technologies. On the one hand, this study aims to list the standards of cooking equipment available in West Africa, test to assess a model of cooking stove following test protocols provided for by these standards. On the other hand, it aims to show the impact of cooking stoves on the well-being of users but also on the environment in West Africa.

2. Literature Review

2.1. Wood Energy Problem in West Africa

2.1.1. Wood Energy Consumption in the West African Countries

West African forest cover is estimated at around 72 million hectares, or 14% of the land area [11]. This forest resource is threatened by a combination of factors including increased demand for wood energy [11]. In fact, in each of the countries, the fraction of households that use wood energy as cooking fuel largely exceeds 50% with the exception of Cape Verde. Countries such as: Niger, Mali, Burkina Faso, Benin are those with the highest proportion (≥ 95%). The map below, drawn using QGIS version 3.36.0, shows the fractions of households that use wood and charcoal as cooking fuel in West Africa. The data used to develop this map come from a report by the World Health Organization (WHO) [12].

2.1.2. Proportions of Deaths Due to the Use of Poor Quality Cooking Equipment in the West African Region

As shown in the previous section, in West Africa, cooking fuel is mainly provided by wood and charcoal in most households. To cook, these households burn these fuels in inefficient cooking equipment that releases harmful particles during their operation, including carbon monoxide, carbon dioxide, nitrogen oxides, etc. There is strong evidence that exposure to these substances in the short and long term has health consequences including respiratory, eye, heart infections, cancer, etc., [13]. The distribution of deaths related to air pollution caused by the cooking sector in West Africa is presented in the map below that we have drawn with the QGIS software version 3.36.0. The data used to draw this map were taken from a report by the World Health Organization (WHO) [12].

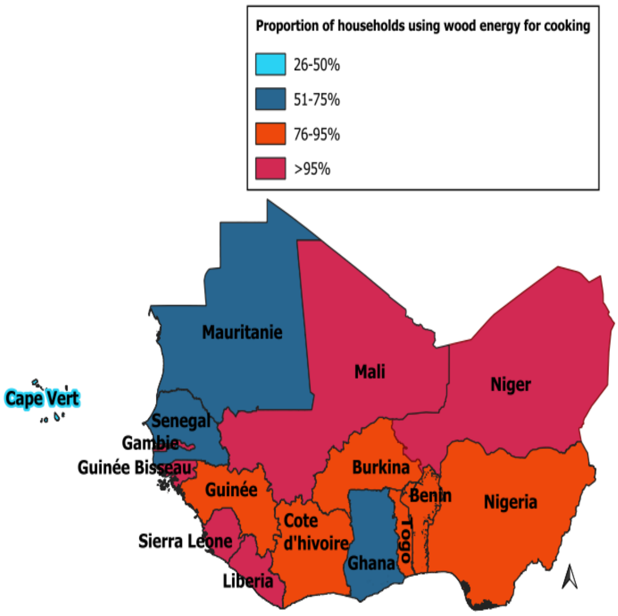


Figure 1. Proportion of households using wood energy for cooking

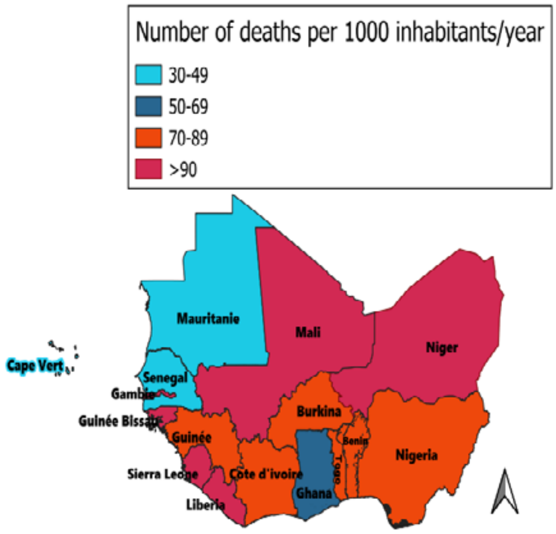


Figure 2. Deaths due to exposure to pollution caused by cooking equipment

2.1.3. Time Spent Collecting Firewood

The heavy burden of West African households' reliance on solid biomass for cooking fuel falls on children and women. Indeed, apart from the indoor air pollution to which they are exposed, in most West African countries, wood collection is often entrusted to women accompanied by their children. The latter spend hours of the day looking for firewood to the detriment of schooling and other more productive activities for children and women respectively. Worse still, in these situations, women can suffer serious physical harm in the long term due to this hard work without sufficient recovery. Added to this damage is the risk of falls, dead wood branches or attacks by wild animals. These risks are all the greater the further women and children move away from their homes. During this wood collection, women can also be victims of physical or sexual violence. Reducing this burden will probably allow women and children to have more time to rest, take care of other more productive activities and/or take care of their schooling. The figure below illustrates the number of hours per day devoted to wood collection in some West African countries [14].

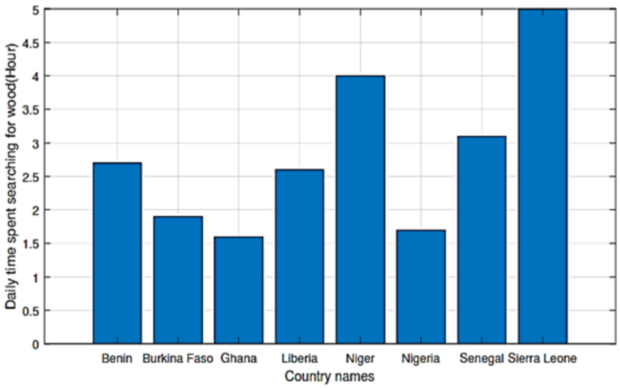


Figure 3. Daily time spent collecting firewood

3. Materials and Method

3.1. Material

3.1.1. Cooker Tested

The cooker on which the protocols of the listed standards have been carried out is a traditional stove used in Benin called a rim stove [15,16]. Its physical structure as well as its characteristics are presented respectively in the figure and table below.

Figure 4. Cooker tested

Table 1. Cooker characteristic

Combustion chamber height (cm)	Diameter of the combustion chamber (cm)	Mass (kg)
6	36	8.35

3.1.2. Scale

A KC AMMRY brand electronic balance with a precision of 20g and a capacity of 100kg is used to weigh the mass of: fuel, water at the beginning and at the end of the tests.

Figure 5. KC AMMRY electronic scale

3.1.3. Thermometer Support

A wooden board is used to hold the thermometer probe 5 cm from the bottom of the pot.

Figure 6. Thermometer support

3.1.4. Thermometer

Digital liquid immersion probe thermometers with an ac-curacy of 0.5°C and a range of -50 to 300°C are used for water temperature measurement during the test.

Figure 7. Cooker tested Digital thermometer with liquid immersion probe

3.1.5. Stopwatch

A stopwatch is used for time measurement during the test.

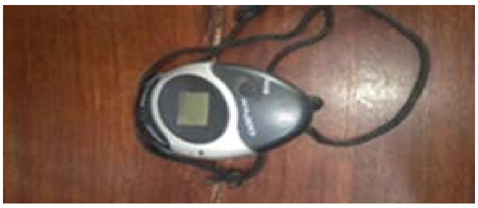


Figure 8. Stopwatch

3.1.6. Temperature and Humidity Sensor

For the Ghanaian standard, the testing protocol requires that the temperature and relative humidity be within a given range. The DHT11 is used to evaluate the evolution of these parameters in the test room.

Figure 9. Temperature and humidity sensor

3.1.7. Anemometer

According to the requirements of some of the protocols including the Ghanaian standard protocol, during testing, the wind speed within the test laboratory enclosure must be controlled. The KESTRE 4000 type anemometer is used to measure and control the wind speed.

Figure 10. Wind speed sensor

3.1.8. Personal Protective Equipment

In accordance with the test protocols of the listed standards (FDNIS 1000, ISO 19867), personal protective equipment must be used during the tests. These include: respiratory mask, safety glasses and heat resistant gloves.

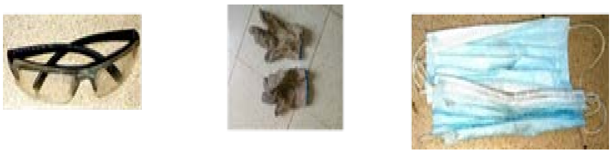


Figure 11. Personal protective equipment

3.2. Method

This study began with an in-depth documentary research in order to retrieve the available information and draw up a global vision of the problem. For this we conducted a documentary research through databases such as: Scopus, Chemical Abstracts Service (CAS), Google scholar, etc. The types of documents taken into account are: articles available in newspapers, West African and international standards on the performance of cooking stoves, conference proceedings, web pages and reports of research centers on cooking stoves. Personal exchanges with peers were also carried out in order to collect other complementary information. Geographic information system tools (QGIS software version 3.36.0) were used for: the materialization of the study area, the distribution of research institutions, the distribution of the need for wood energy, the number of deaths linked to the use of poor quality cooking equipment in the study area. These tools also made it possible to distribute the countries that have a standard in the study area. As for the test method used, these are those provided for by each of the listed standards.

3.2.1. Presentation of the Study Area

West Africa covers approximately 17% of the total surface area of the African continent (6.14 million m^2) [11]. It has 16 countries, which are: Benin, Burkina Faso, Ivory Coast, Cape Verde, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone and Togo [11]. Estimated at approximately 72 million hectares, West African forests are threatened by a combination of factors including the supply of wood energy [11].

Figure 12. Presentation of the study are

4. Results and Discussion

4.1. Results

4.1.1. Laboratory and Research Institutions

The domestic energy issue described in sections 2.2.1, 2.2.2 and 2.2.3 remains one of the greatest concerns of West African countries. This is why laboratories and research institutions working on cooking equipment, are increasingly being implemented in most West African countries. The map below was drawn with QGIS software (version 3.36.0), provides a list of laboratories and research institutions across West African countries. This list is not exhaustive; it only contains the research institutions that we were able to collect from the literature.

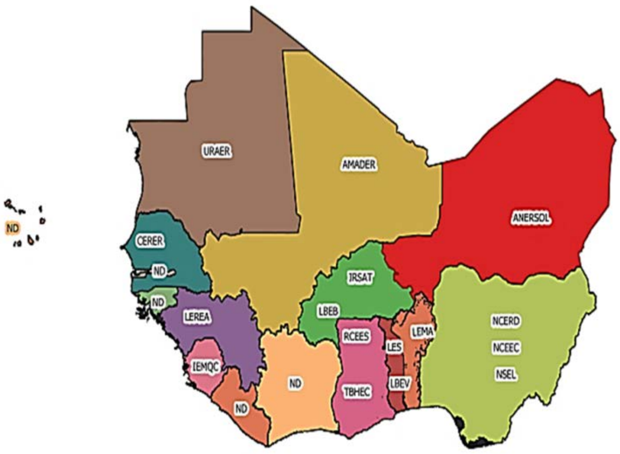


Figure 13. Distribution of laboratories and research centers according to country

The table above presents the address, the country of affiliation as well as some publications of the laboratories and research centers which work in the cooking equipment sector in the West African zone.

Table 2. Research Paper Structure

Research institutions				
Acronym	Designation	Address	Country	Some Publications affiliated with research institutions
AMADER	Malian Agency for the Development of Domestic Energy and Rural Electrification of Mali	Email(s): amader@amadermali.net	Mali	NA
ANERSOL	National Solar Energy Agency	TEL: + 227 20 72 39 23	Niger	[17]
NCERD	National Center for Energy Research and Development	University of Nigeria, Nsukka Enugu State SUCH : +234 42 771 853	Nigeria	[18]
NCEEC	National Center for Energy Efficiency and Conservation	enquiries@nceec.gov.ng TEL: +234 802 302 5053		[19]
NSEL	National Stove Eligibility Laboratory	Email: cosmas.anyanwu@unn.edu.ng TEL: +2347036706987		[7]
LEMA	Laboratory of applied energetics and mechanics	Email:lemaepacuac@gmail.com	Benin	[8], [15], [16],[20]
CERER	Center for studies and research on renewable energies	TEL: +221 33 832 37 79	Senegal	NA
IRSAT	the Institute of Applied Sciences and Technologies Research	TEL: 00 226 25356031 Email: dirsat@fasonet.fr	Burkina Faso	[21]
LBEB	Biomass energy laboratory, Biofuel from Burkina	Email :2ie@2ie-edu.org Tel: + 226 25 49 28 85		[22]
THE	Solar Energy Laboratory	NA	Togo	[23]
LBEV	Laboratory of Botany and Plant Ecology	NA		
NCEES	Regional Center for Energy and Environmental Sustainability	rcees@uenr.edu.gh TEL: +(233) 352291404	Ghana	[24]
TBHEC	Brew-Hammond Energy Center	keep@knust.edu.gh TEL: +233 322 49 2919		[25]
URAER	Applied research unit on renewable energies	BP 880- Route Nouadhibou-nouakchott, Mauritania	Mauritania	NA
IEMQC	Institute of Environmental Management and Quality Control	Email(s): registrar@njala.edu.sl TEL: +232 78 701222	Sierra Leone	[26]

NA: not available

4.1.2. Standards for Biomass Cookers Available in West

A standard is "a document that is developed and then validated by consensus by an institution recognized as competent in a specific field. It provides common and repeated use, rules, guidelines or characteristics for activities or their results, aimed at achieving an optimal level of order in a given context. Standards should be based on the consolidated results of science, technology and experience, and aim to promote optimal benefits for the community [27]. In principle, the development processes as well as the strict application of a standard are supported by a state. In a standard, the rules of characterization or assessment are set by a protocol. The latter can be defined as a set of sequential instructions allowing a scientific experiment to be carried out. Regarding the specific case of the domestic energy sector for cooking in West Africa, despite the research efforts of laboratories and research centers, only 2/16 countries have a standard governing the cooking sector. Domestic energy for cooking. Indeed, to the author's knowledge to date, only Ghana and Nigeria have a standard that governs the manufacture, importation and use of cooking stoves. For the case of Ghana, this is the GS ISO 19867-1 standard [28] while for the case of Nigeria, it is the FDNIS 1000 standard [29] as can be seen in the figure below:

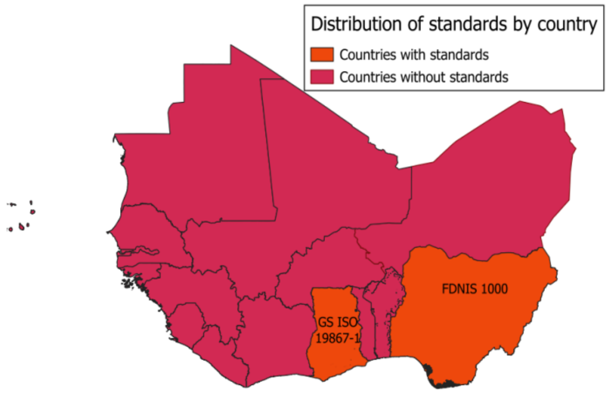


Figure 14. Biomass cooker standards and country of origin

Table 3. Overview of standards available in West Africa [28,29]

Standard acronym	country	Institution in charge of development	Title of the standard	Year of publication	Scope	Test protocol
GS ISO 19867-1	Ghana	Ghana Standards Authority	Energy performance and labelling of improved biomass waders	2019	Portable improved biomass cook stoves available in the market, manufactured in Ghana or imported for use in Ghana	. ISO 19867-1 test protocol
FDNIS 1000	Nigeria	Nigeria Standards Organization	Standard for Clean Cooking Systems Part 1: Type of Biomass	2017	Clean solid biomass cooking stoves	Boiling water protocol V 4.2.3

Table 3 above provides some information concerning: the title, the institution in charge of development, the year of publication, the scope and the test protocol for each of these standard.

4.1.3. Summary Presentation of the Test Protocols for the Standards Listed

4.1.3.1. Ghanaian Standard Protocol

The Ghanaian standard (GS 19867-1) uses the protocol of ISO 19867-1 which involves heating the water in two phases. The first consists of bringing or not bringing a quantity of water to a boil for a period of 30 or 60 minutes, respectively in the case of forced draft fireplaces and natural draft fireplaces. While the second consists of reducing the hot water from the first phase to less than 5 degrees compared to its final temperature. The test sequence is carried out with a pot without its lid. During the test, the water temperature is recorded every minute. In the test room, the following atmospheric parameters must be monitored: ambient temperature, wind speed and relative air humidity. The performance of the tested stove can be evaluated based on the parameters defined as follows [28]:

Useful energy :

$$Q_1 = C_p \times G_1 \times (T_1 - T_2) + (G_1 - G_2) \times \gamma \quad (1)$$

Thermal efficiency:

$$\eta_c = \frac{Q_1}{B \times PCI} \times 100 \quad (2)$$

Thermal power :

$$P_c = \frac{Q_1}{t_3 - t_1} \quad (3)$$

4.1.3.2. Nigerian Standard Protocol

The Nigerian FDNIS 1000 standard uses version 4.2.3 of the water boiling test protocol which consists of heating to boiling a quantity of water contained in a pot. The test is carried out in two main phases. The first, called the high power phase, consists of rapidly bringing the water initially introduced into the pot from its initial temperature to the boiling temperature (100°C). The second, called the low power phase, consists of simmering (maintaining at between 95 and 99.5°C) the hot water from the high power phase for a time interval of 45 minutes. The high power phase is itself subdivided into two sub-phases: cold start (bringing the water to the boil) when the burner is at room temperature and hot start (bringing the water to the boil) when the burner is still hot. However, the hot start sub-phase is optional. In this work, the latter is also not taken into account. The entire test procedure is carried out with the pot without its lid. During the entire test period, the water temperature is recorded every five (5) minutes. The performance of the tested stove is evaluated based on the parameters defined as follows:[24]:

High-power energy efficiency :

$$h_c = \frac{4{,}186\left(T_{1cf} - T_{1ci}\right)\left(P_{1ci} - P_1\right) + 2260 \times w_{cv}}{f_{cd} \times LHV} \quad (4)$$

Low-power energy efficiency :

$$h_s = \frac{4{,}186\left(T_{1sf} - T_{1si}\right)\left(P_{1si} - P_1 + w_{sr}\right)/2 + 2260 \times w_{sv}}{f_{sd} \times LHV} \quad (5)$$

Thermal power in the high-power phase :

$$FP_c = \frac{f_{cd}.\mathrm{LHV}}{60.\Delta t_c} \quad (6)$$

Thermal power in the low-power phase :

$$FP_s = \frac{f_{sd}.\mathrm{LHV}}{60.\Delta t_s} \quad (7)$$

4.1.4. Summary Presentation of the Experimental Devices

Table 4 and Table 5 show some of the steps involved in running the protocols. Figure 15 shows the humidity and temperature measurement setup.

4.1.4.1. Case of the GS ISO 19867-1 Standard Protocol

The following table illustrates some of the steps involved in implementing the Ghana standard protocol.

4.1.4.2. Case of the FDNIS 1000 Standard Protocol

The following table illustrates some of the steps involved in implementing the Nigeria standard protocol.

Table 4. A few steps in executing the GS ISO 19867-1 standard protocol

(A): Measurement of the initial water temperature: 31,8°C	(B): Measurement of the initial quantity of fuel for the test: 2kg
	
(C): The water temperature in the pot reaches 72.1°C	(D): 60 minutes have passed but the water has not reached boiling point, the temperature is 95.6°C
	

Table 5. A few steps in executing the FDNIS 1000 standard protocol

(A): Measuring the quantity of water required for the test: The total volume of the pot is 7 liters so 2/3 of the capacity of the pot is 4.6 liters	(B): Measuring the initial water temperature
	
(C): Loaded hearth put on the market then the water contained in the pot brought to the boil	(D): The water of the 1st phase is maintained at 99.6 and 95 for 45 min
	

4.1.4.3. Control of Ambient Atmospheric Parameters

The following assembly composed of a temperature and humidity sensor, an Arduino card and a computer made it possible to control the evolution of the temperature and humidity in the room where the test.

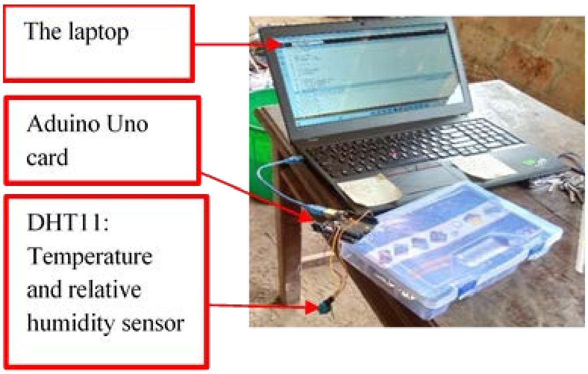


Figure 15. Temperature and humidity measurement setup in the test room

4.1.5. Thermal Performance of the Fireplace Following the Protocols of the Inventoried Standards

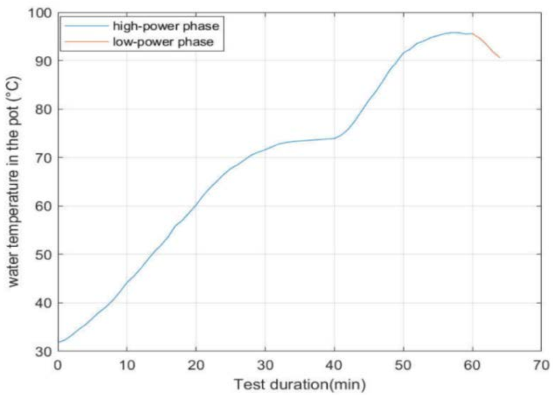
The execution of different test protocols of the listed standards allowed to obtain the results recorded in Table 6 and Table 7 below. These results are expressed in terms of a performance indicator allowing to evaluate and/or compare the assessment received by the household tested according to each of the protocols. Each protocol was run three times in a row. Figure 16.a and Figure 16.b show the evolution of the water temperature in the pot during the different phases of the two protocols test.

Table 6. Test results following the Ghanaian standard protocol

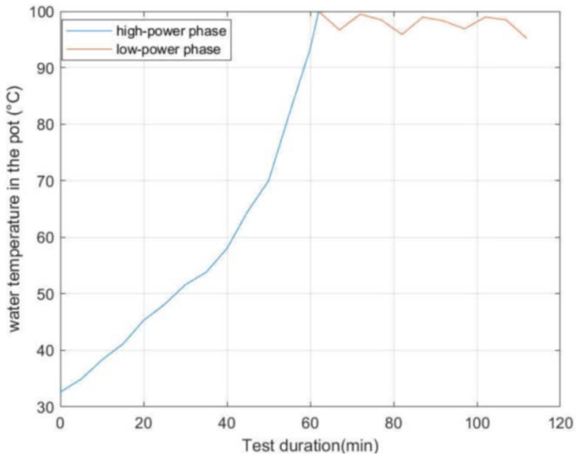
Performance indicators	1st test	2nd test	3rd test	average
Thermal efficiency (%)	11.2	12.2	10.9	11.4
Thermal power (kW)	0.7	0.5	0.5	0.6

Table 7. Test results following the Nigerian standard protocol

Performance indicators	1st test		2nd test		3d test		average	
	HP	BP	HP	BP	HP	BP	HP	BP
Thermal efficiency (%)	11	8	11	11	10	9	10.6	9.3
Thermal power (kW)	10.4	8.1	8.9	7.03	9.2	8.4	9.5	7.8



(a):GS ISO 19867-1 Protocol



(b):FDNIS 1000 Protocol

Figure 16. Evolution of the temperature of the water contained in the pot during the test

4.1.6. Minimum Performance of Inventoried Standards

It has been stipulated in the manuscript of each of the listed standards that any biomass cooking stove manufactured or imported into the territory of one or other of the standards in question, before any use, this stove must be subjected to a test following a very specific test method. Thus, for the use of this cooker to be legal, at the end of the test, the tested cooker must meet minimum performances. These minimum performances relate to energy performance, the safety score and/or the emission factor. In the context of this work, we are interested in the minimum energy performances only, which we present in Table 8 below.

Table 8. Minimum energy performance of the inventoried standards [28,29]

Standard	Scope	Energetic efficiency
GS ISO 19867-1	Any type of biomass fireplace	≥20%
FDNIS 1000	chimney cooker with natural draft	≥20% in HP
	stove without chimney with natural draft	≥25% in HP
	forced draft cooker	≥35% in HP

4.1.6.1. Application of Minimum Energy Performance to the Cooker Tested

In this section, the minimum energy performances provided by the two standards will be applied to the tested fireplace in order to see if it complies with both standards and if this fireplace is authorized to be used or not. To do this, we will compare in the table below, the minimum energy performances with the energy efficiency values of the fireplace obtained through the test protocol of each of the standards. From this table, it is clear that the tested fireplace does not meet any of the minimum energy performances of the listed standards. As a result, its use is prohibited in accordance with the GS ISO 19867-1 standard of Ghana and the FDNIS 1000 standard of Nigeria.

4.1.6.2. Classification Systems for Inventoried Standards

In order to guide users when choosing a fireplace model among the models available on the market, the standards have provided for a classification by level according to the energy efficiency obtained at the end of the stove test. The classification system facilitates policy makers and non-governmental organizations in choosing the type of cooking stove technology to popularize or subsidize in a country. The transaction of cooking equipment between countries can also be facilitated by the classification systems provided by the standards. The classification criteria provided by the listed standards are listed in Table 8 below. Thus, according to these classification criteria, the tested stove is at level zero (0) in both (2) cases.

Table 9. Comparison of energy efficiency values and minimum performances

		Energetic efficiency	
Standard	**Scope**	**Minimum performance [28,29]**	**Cook tested**
GS ISO 19867-1	Any type of biomass fireplace	≥20%	11.48%
FDNIS 1000	stove without chimney with natural draft	≥25% in HP	9.0% HP

Table 10. Classification of the Tested Cooker results

Standard	Ranking level	Equivalent thermal efficiency [28,29]	Ranking received by the tested cooker
GS ISO 19867-1	4	>50%	
	3	>40%	
	2	>30%	
	1	>20%	
	0	<18%	√
FDNIS 1000	4	≥45%	
	3	≥35%	
	2	≥25%	
	1	≥15%	
	0	<15%	√

4.2. Discussion and Validation of Results

4.2.1. Validation of Results

To start, the hearth on which the protocols of the standards were carried out is a traditional hearth. According to the literature, the thermal efficiency of the latter must therefore be between 8 and 13% [23]. This aspect emerged in our results. On the one hand, the stove that we tested in this work was studied by Ekouedjen [15] who tested it following the protocol of the ISO 19867-1 standard (the protocol of the Ghanaian standard in our case). Ekouedjen et al. found 10.58 ±0.013% and 0.43 ±0.027 kW respectively the efficiency and thermal power. While for the case of this study, following the GS ISO 19867-1 protocol, the efficiency and thermal power are respectively: 11.48% and 0.64 kW. It appears that apart from a slight difference, our results are very close to those obtained by Ekouedjen et al. This small difference is probably induced by the difference in the shapes of the pots used during the tests as well as the difference in mass of the hearths. Indeed, during the tests a pot with a rounded bottom was used in this study while Ekouedjen et al. used a pot with a flat bottom. Regarding the difference in mass, for the case of this study, the mass of the hearth is 8.35 kg while in the case of the works it is 12 kg. Figure 16.a shows that during the tests following the protocol of the GS ISO 19867-1 standard, the water could not reach boiling point, the same observation was made in the work of Ekouedjen et al. On the other hand, the tested hearth was studied by Anjorin et al. [16], who tested it following a version of the water boiling protocol (FDNIS 1000 standard protocol in our case). Anjorin et al., found 12.00% and 10.20 kW respectively the efficiency and the thermal power for the high power phase. While for the case of this study, in high power the efficiency and the thermal power are respectively equal to: 10.66% and 9.52 Kw. Although Anjorin et al., did not specify the version of the water boiling protocol that they used while in this study it is version 4.2.3 which is used, the results obtained are close to those obtained by Anjorin et al.

4.2.2. Discussion of Results

The results of the various tests show that the efficiencies of the hearth following the protocol of the GS ISO 19867-1 standard and the FDNIS 1000 standard are closer during the 1st phase of two protocols. This translates, on the one hand, into an identity between the equations (sum of sensible and latent heat of water divided by the heat released by the combustion of the fuel) of the calculation of the efficiency for these two protocols. On the other hand, this translates into the fact that the test procedure is more or less similar during the 1st phase for both protocols. This similarity can also be noticed in Figure 16.a and Figure 16.b which shows the evolution of the water temperature during the tests. However, regarding the thermal power, that calculated according to the FDNIS 1000 standard is 12.29 to 14.87 times higher (respectively BP and HP) than that calculated according to the GS ISO 19867-1 standard. This difference can be explained by the divergence of the equations used for the calculation of this power by each of the protocols. In fact, the equation for calculating the power of the FDNIS 1000 standard quantifies the thermal power released by the combustion of the fuel, while that of the GS ISO19867-1 standard quantifies the thermal power actually received by the water.

Figure 1, Figure 2 and Figure 3 presenting respectively: the proportions of households using wood energy for cooking, the death rate linked to pollution caused by cooking equipment and the time spent collecting firewood, show that Nigeria and Ghana, which have standards, are among the countries least affected by the problems linked to the use of poor quality cooking stoves. This state of affairs cannot be without cause and effect. Although the data that allowed us to develop these Figure 1, Figure 2 and Figure 3 come from an older source than the standards listed, these trends are probably the fruits of the efforts of these countries in the process of developing standards. In any case, it is easy to see from sections 4.1.6.1 and 4.1.6.2 that the establishment of a standard and strict compliance with its application will allow users to make a judicious choice of cooking equipment. Also, through the application of these standards, decision-makers in the energy sector can only authorize the use of cooking equipment with a given level of performance. All this will undoubtedly reduce the footprint of cooking stoves on the environment, the climate, but also improve the well-being of users.

The results of this study may encourage non-governmental organizations and policy makers in West Africa to adopt and subsidize more efficient cooking equipment. These results may also draw the attention of policy makers, international organizations and all stakeholders in the domestic energy sector to the need for other West African countries to establish standards in order to promote the said sector. The establishment of a standard in any country will force designers and importers to take into account the aspects of energy efficiency in their respective sectors of activity.

5. Conclusions

In this work, a review of the available standards on biomass cookers in West Africa was presented. Research institutions working in the domestic energy sector were also listed in this work. Despite these research efforts, only Ghana and Nigeria have standards on the performance of biomass cookers. While it is clearly demonstrated that the cookers that are in use in this West African zone have a significant negative impact on the environment, the climate but also on the well-being of users. It is therefore urgent that each country has a standard for cooking equipment. If possible, these standards should use a more or less similar test protocol and more identical performance indicators. This will harmonize and facilitate the comparison of the performance of stoves on the market at the sub-regional level.

In addition, the global market for cooking equipment is growing. In order for West African cooking stoves to be exported to other countries where the cooking equipment sector is regulated, these West African cooking stoves must meet a certain minimum performance. This involves the establishment of a standard by each of the countries in the said region.

ABBREVIATIONS

HP : High power

BP : Low power

Q_1 : Useful energy

C_p : Specific heat of water

G_1 : Initial water mass

T_1 : Initial water temperature

T_2 : Final water temperature

G_2 : Mass of water at the end of the fuel combustion period

γ : Latent heat of vaporization

B : Mass of the main fuel

PCI : Mass of the main fuel for the Ghanaian standard protocol

p_c : Thermal power

h_c : Thermal efficiency (efficiency) of the boiling phase

T_{1cf} : Water temperature at the end of the boiling phase

T_{1ci} : Water temperature at the start of the phase

P_{1ci} : Mass of the pot and water at the start of the phase (initial mass of pot+water)

P_1 : Dry mass (empty) of the pot

w_{cv} : Mass of water evaporated during the Boiling phase

f_{cd} : Equivalent of fuel consumed during the Boiling phase

LHV : Net lower heating value of fuel (coal)

h_s : Thermal yield (efficiency) of the simmering phase

T_{1sf} : Water temperature at the end of the simmering phase (final temperature)

T_{1si} : Water temperature at the start of the simmering phase (initial temperature)

P_{1si} : Mass of the pot and water at the start of the simmering phase

P_1 : Dry mass (empty) of the pot

w_{sv} : Mass of water evaporated during the simmering phase

f_{sd} : Equivalent of fuel consumed during the simmering phase

FP_c : Power of boiling phase

Δt_c : Duration of boiling phase

FP_s : Power for simmering phase

Δt_s : Duration of simmering phase

FP_s : Power for boiling phase

w_{sr} : Effective mass of simmered water (exact mass of water remaining at the end of the phase)

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