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► **To cite this version:**

Alexis Dzokom. Ecological Modeling, Fuel Economy, Energy Autonomy and Community Acceptability of Improved Stove-Ovens. Elsevier Procedia, In press, 1 (4), pp.146-179. <10.1023/a:1014843004627.PMID:14617973>. <hal-04673146>

HAL Id: hal-04673146

<https://hal.science/hal-04673146v1>

Submitted on 26 Aug 2024

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Ecological Modeling, Fuel Economy, Energy Autonomy and Community Acceptability of Improved Stove-Ovens

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ABSTRACT

In this work, the objective is to propose conceptual models of improved stoves capable of saving fuels and increasing the energy autonomy of cooking stoves. The stove construction technique has made it possible to manufacture ecological and sustainable improved cooking stoves. The Active Method of Research and Participatory Planning (MARPP) was used in the surveys. The ASTM E711-87 method (2004) and the MA protocol, 108-P. Cal. 1.0 helped to obtain an average calorific value of 28.15 ± 0.53 MJ/kg, a maximum calorific and energy efficiency expected from combustion stoves of 50%. The average humidity rate in the combustion chamber is $23.08 \pm 0.52\%$ governed by an average temperature before ignition of $33.85 \pm 0.86^\circ\text{C}$ with an average heating time of the combustion chambers of 12.48 ± 0.96 min. The protocol for measuring the collection efficiency and the performance of the fibrous media in filtration made it possible to determine a direct interception ratio of fine particles of 0.561 ± 0.051 with a total average quantity of fluorescent particles injected of 13.92 ± 0.74 L/min. When evaluating the performance of the fibrous media in filtration, the collection efficiency is 0.21 ± 0.08 L/min while the pressure drop 0.023 ± 0.005 L/min. When analyzing the particles collected by the smoke filters of the improved stoves, the evaluation of the collection efficiency with the acid gas treatment filter indicates that CO_2 ($67.10 \pm 0.63\%$) and $(\text{NH}_4) \text{HCO}_3$ ($16.33 \pm 0.21\%$) were better filtered with the SAHEL NATURE CONSULTING stove. The highest fuel economy is $61.07 \pm 0.309\%$ with an average of 0.716 ± 0.093 kg of charcoal produced. The energy autonomy of improved stoves has made it possible to observe that the maximum heat ($871.02 \pm 58.32^\circ\text{C}$) obtained in the combustion chamber. The analysis of the socio-economic impacts of improved stoves in households, it appears that the most used heat in households is that of traditional African three-legged stoves due to its high accessibility rate and the weight of culinary habits although users have noted a high emission of smoke ($80.1 \pm 0.5\%$).

Keywords: Improved culinary stoves, energy autonomy, fuel economy, community accessibility

INTRODUCTION

The study of hearths can be considered as a means of approaching the behavior of prehistoric men in relation to the use of fire (March, 1992). The hearth represents a technology that is as old as the discovery of fire and the civilization of man. The oldest known hearths date from approximately 400,000 years BC found in China (Sharma, 1993; Beatrix, 1995) to 500,000 BC (Europe) (Bonifay, 1976; Beatrix, 1995). Man (homo erectus, lower Paleolithic) lived mainly in caves and made fire in a circle of stones. In Africa, although there are some clues about ceramic hearths (1000 BC – 16th century), it is noted that there remains a significant amount of research and documentation to be done to trace their history and find their presence in the ancient cultures of the South (Dorst, 1960; Beatrix, 1995). The technical development of the hearth, the oven and the cooker only began with the industrial revolution in the 19th century. From the 19th century in Europe, the developments in technology and the most influential factors are (Beatrix, 1995): the overexploitation of forests followed by a shortage leading to a high price of firewood; the discovery and introduction of other fuels and energies, first in industry and then in households (coal, gas, oil, electricity, etc.); the development of new industrial technologies (cast iron, steam engine, light, steel, aluminum, etc.) and the growing need for a practical and efficient organization of the household and the kitchen. In Africa, in the Sahel, they started after the great drought of the end of 1970. In Central America, it was after the earthquake in Guatemala in 1976. These first waves, more or less at the initiative of Westerners, correspond to massive stoves with chimneys, with two or three pots or pans. They are generally complicated, expensive or difficult to obtain compared to traditional local stoves. In 1985, the improved stove project was requested by the State of Cameroon and it was not until 1989 that the pilot phase began. The motivations for such a request were due to the fact that programs concerning domestic energy, mostly in the form of stove projects using fuel efficiently, have been implemented for several decades. However, it is only in the last decades that significant technical and financial assistance has been provided, but in no case sufficient aid that would correspond to the importance of the sector (Klingshirn, 1995).

Nevertheless, the support given to the various projects and programs by governmental and non-governmental organizations has been sufficient to prove, over time, that programs, properly planned and implemented with the involvement and participation of users, producers and development managers, can have a significant impact at different levels and be among the most effective development efforts (Klingshirn, 1995). "Thanks to their integrated and

interdisciplinary nature, combined with a participatory approach, household energy projects can be considered socially, economically and ecologically beneficial; they are also sustainable when properly managed" (Klingshirn, 1995).

Wood represents only 5.4% of the total energy consumed in the world, but it constitutes for 2/3 of humanity the main, if not almost exclusive, domestic energy resource (Doat, 1982). Stoves that have had incomplete combustion produce more charcoal than those that have gone all the way with this combustion (March, 1992).

In the context of this work, the objective is to propose conceptual models of improved stoves capable of saving fuels and increasing the energy autonomy of culinary stoves. The idea is to conduct a reflection in the direction of the design of a stove-oven, capable of consuming less wood while having a high energy efficiency and whose maximum temperature is maintained for a long time to not only ensure culinary requests, but also to allow the continuous production of heat energy transformable into electrical energy.

1- MATERIAL AND METHOD

1-1 Study sites

The study sites were identified in the Far North and North regions of Cameroon, Sahelian zone, in ten localities, with women's associative movements and common initiative groups (GIC). These are the localities of Mokolo, Maroua, Mora, Garoua, Guider (for the semi-arid Sahelian zone) and Waza, Makari, Lagdo, Yagoua and Maga (for the Sahelian humid zone).

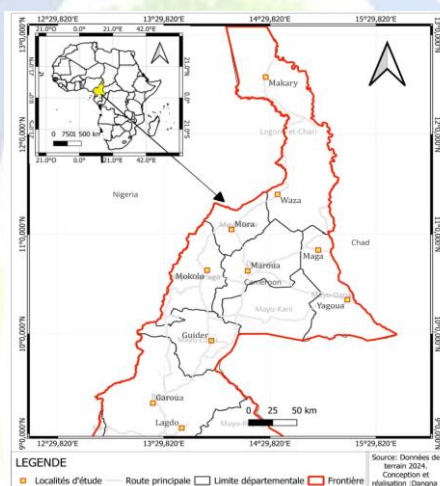


Figure 1: Localities sites of the study area in the Sahelian regions of the Far North and North Cameroon

Three localities in the North region were chosen for the study while the other seven localities belong to the Far North region. These localities were chosen because they are part of the wetlands and semi-arid zones and the different methods of using traditional stoves and ovens for culinary purposes.

1-2- Design and dimensioning of the structure of some improved stoves used in the Far North Cameroon

The stove construction technique developed in the workshop of the NGO SAHEL NATURE CONSULTING FOR COMMUNITIES (2023) consisted of cutting, folding, assembling and riveting using templates adapted to each model to be made. Production was carried out by technicians trained by the NGO SAHEL NATURE CONSULTING FOR COMMUNITIES (2023), and sales are left to women's associations after the project.

1-3- Materials for manufacturing the internal components of the hearths

From the point of view of their materials, the different types of known hearth-ovens can be classified into four classes:

1-3-1- Hearth-ovens made of earth and/or ceramic

In many cases, this category is made with a mixture of sand and clay. These hearth-ovens have a high thermal inertia, and the heating time as well as the cooling time is long. Hence the interest in dishes with a long cooking and simmering time.

1-3-2- Metal hearth-ovens

They can range from simple to complex. The simplest to make can be made from old cans and thus give rise to rustic, economical but not very resistant material. The coating that will be used is a mild steel sheet (sheet metal), with a minimum thickness of 0.6 mm.

1-3-3- Brick and cement hearth-ovens

Hearth-ovens made of cement, briquettes or hearth-ovens that, in manufacturing, require the mixing of cement, brick and metal generally have a significantly longer lifespan than large earthen ovens, and generally do not have cracks. They often heat up quickly, compared to the heating of three-stone hearths and have a better known cooking method. Their only major drawback is their fairly high price (Doat, 1982).

1-4- Expected calorific and energy yield of combustion chambers.

Combustion is the most widespread process for the energy recovery of biomass with a contribution corresponding to 97% in the overall production of bioenergy. (Takali, 2015)

1-4-1- Factors entering into the overall expected calorific production of the combustion chamber.

a) Moisture content

In the context of this work, the determination of the moisture content was inspired by the methodological measurement procedures developed by Tobiasson *et al.*, (1991). The moisture content expresses the water content and strongly influences the calorific value and the ignition capacity of the briquettes. The moisture content is obtained by the following formula:

$$W(\%) = \frac{(\text{Wet matter} - \text{Dry matter})}{(\text{Wet matter})} \times 100 \quad (1)$$

With: W: moisture content; Wet M: mass of the sample; Dry M: mass obtained after heating to 105°C in an oven.

b) Calorific value

The ASTM E711-87 method (2004) and the MA protocol, 108-P.Cal. 1.0 helped to measure and calculate the calorific value. The heat capacity of the bomb and the tank was calculated from a test done with benzoic acid. The calorific value of the samples is measured by the following equation:

$$P.C. = \frac{[1000 \times (T_f - T_i) \times W - (H_h \times a)]}{b} \quad (2)$$

Where P.C.: calorific value of the sample (kJ/kg); T_f: maximum final temperature of the water in the tank after ignition (°C); T_i: initial temperature of the water in the tank before ignition (°C); W: calorific capacity of the calorimeter [constant of the device determined with benzoic acid (kJ/°C)]; H_h: calorific value of the mineral oil (kJ/kg); b: weight of the sample (g); a: weight of the oil (g).

c) Expected combustion tests in the combustion chamber

The combustion test allowed us to determine:

- The combustion time of each combustible briquette;
- The mass of the fuel (ash) post-combustion;
- Mass losses

d) Determination of the ease of ignition of the fuels in the combustion chamber

The ignition test consists of determining the ease of ignition of the fuels in 5 minutes. It consists of measuring, using a thermocouple, the fire temperature of an incandescent sample (T_{al}). The ignition of the fuel lasts 1 minute and the measurement of the temperature of the incandescent part of the fuel is done at 25 s (T_{er}) and at 300 s (T_{er'}). The ease of ignition is written by Formula 1 (Souleymane *et al.*, 2020).

$$T_{al} = T_{er} - T_{er'} \quad (3)$$

T_{al}: ignition temperature, T_{er}: temperature at t equal to 5 min, T_{er'}: temperature at t equal to 25 s.

e) Determination of the combustion time of fuels in the combustion chamber

The combustion time (CD) test consists of determining the total combustion time of 600 g of fuels introduced into an improved fireplace with a clay combustion chamber. It begins with ignition until the ash is obtained. The combustion time is written according to Formula 2.

$$\Delta t = t_f - t_i \quad (4)$$

Δt: time for the fuels to burn; t_f: end of combustion time of the fuels; t_i: start of combustion time of the samples

f) Determination of the energy efficiency of the combustion chambers

The study on the energy efficiency of the fuels lasts 2 hours. It is determined from the start and duration of boiling of the water, the quantities of remaining and evaporated water and then the temperature of the fuel fire. The results are obtained according to the relations below:

- Start of heating of the combustion chambers

The start of boiling of the water corresponds to the time it takes for the water to boil. It is expressed as follows

$$t_{eb} = t_{deb} - t_p \quad (5)$$

t_{eb} : start of boiling of the water; t_{deb} : time from which the water boils; t_p : time from which the pan is placed on the fire.

➤ Heating time of the combustion chambers

This corresponds to the boiling time of the water. To do this, we take the difference between the time when the water stops boiling and the time when boiling begins. The expression is as follows

$$\Delta t = t_{feb} - t_{deb} \quad (6)$$

Δt : boiling time of the water (min); t_{feb} : end of boiling of the water; t_{deb} : start of boiling of the water.

1-4-2- Decontamination of fumes and toxic pollutants in the air

As part of this work, purifying the fumes that could be emitted by the hearth-oven means designing a small absorbent filter that will have the capacity to retain all the acidic, basic or simply toxic pollutants resulting from the combustion of fuels.

1-4-2-1- Manufacturing materials of the "pleated cartridge filter" for fumes

According to Laurence (2006), filter cartridges are made up of pleated fibrous media placed under

1-4-2-2- Manufacturing materials of the "pleated cartridge filter" of fumes

According to Laurence (2006), filter cartridges are made of pleated fibrous media placed in a cylindrical shape, while cassettes are flat pleated filters. Although there are other types of filters based on non-woven fibrous media ("depth" cartridge filters, flat filters), pleated filters are by far the most used (Colin, 2013).

According to this author (Colin, 2013), for an equivalent size, pleating makes it possible to obtain filtration surfaces more than 10 times greater than flat filters and two geometric quantities are generally used to characterize them. Collection efficiency measurement protocol

According to Galbrun, (2007), the main air flow is generated by creating a depression downstream of the collection system using a venturi pump operating on compressed air, whose flow rate can reach 30L/min. A fraction χ of the injected air is taken upstream of the collection system using a vane pump and passes through a bag filter, which provides access to the total quantity of fluorescent particles injected which is equal to

$$n_1 = \left[\frac{1-\chi}{\chi} \right] n_0 \quad (7)$$

n_0 being the total quantity of fluorescent particles collected on the filter.

The collection efficiency is then calculated by taking the ratio of the amount of particles collected divided by the amount of particles introduced into the collection cell:

$$\eta = \frac{n_2 + n_3}{n_1} \quad (8)$$

1-4-2-3- Sizing and permeability models of fibrous media

From Darcy's law, modeling the flow of a gas in a porous medium amounts to determining an expression for the permeability (Colin, 2013). In the case of a monomodal fiber size distribution, k is a function of the solid volume fraction of the media, α , and the fiber radius r as deduced by the formula:

$$k = r^2 \cdot f(\alpha) \quad (9)$$

$f(\alpha)$, called dimensionless permeability, can be calculated from considerations on an arrangement of fibers, subjected to the drag force resulting from a fluid flow (Thomas, 2001; Colin, 2013).

1-4-2-4- Performance of fibrous media in filtration

When used as a filtration system, the performance of fibrous media is assessed by its collection efficiency (E) and its pressure drop (ΔP). A "good filter" must have a low pressure drop and a high efficiency. This characteristic can be assessed by a quality factor, called figure of merit (Colin, 2013):

$$FOM = \frac{-\ln(1-E)}{\Delta P} \quad (10)$$

1-4-2-5- Collection efficiency

The efficiency is determined experimentally ($1 - (C_p \text{ downstream} / C_p \text{ upstream})$); however, it is possible, under certain conditions, to calculate it from the expressions of unit collection efficiency of a fiber and the structural parameters of the filter.

The unit collection efficiency of a fiber is a function of several collection mechanisms that intervene more or less significantly depending on the particle size:

- Brownian diffusion for $d_p < 1 \mu\text{m}$ (figure 20),
- Direct interception for $d_p > 0.1 \mu\text{m}$ (figure 21),
- Inertial impaction for $d_p > 1 \mu\text{m}$ (figure 22),
- Sedimentation, generally neglected for particles with a diameter of less than $10 \mu\text{m}$,
- Possible electrostatic effects.

1-4-2-5-1- Collection by Brownian diffusion.

Due to collisions with gas molecules, particles of dimensions smaller than or equivalent to the mean free path of gas molecules ($\lambda=0.067 \mu\text{m}$ for air) travel a random oscillating trajectory which considerably increases the probability of interception by the fibers (Laurence, 2006). Particle capture by Brownian diffusion is characterized by the Peclet number (Pe) which describes the relationship between particle transport by convection and transport by diffusion:

$$Pe = \frac{d_p U_0}{D_{diff}} \quad (11)$$

With U_0 = superficial velocity of the fluid ($\text{m}\cdot\text{s}^{-1}$)

D_{diff} = Brownian diffusion coefficient ($\text{m}^2\cdot\text{s}^{-1}$)

For a spherical particle, this coefficient is written as: $D_{diff} = \frac{kTCu}{3\pi\mu d_p}$ (12)

With k Boltzmann constant [$k= 1,380\ 658 \cdot 10^{-23} \text{J}\cdot\text{K}^{-1}$],

T temperature (K),

μ dynamic viscosity of the gas ($\text{Pa}\cdot\text{s}$),

Cu Cunningham correction coefficient.

The Cunningham correction coefficient (Cu) is a factor that takes into account the discontinuities of the medium when the particle size is close to the mean free path of the gas molecules (Laurence, 2006).

$$C_u = 1 + Kn_p \left[1,207 + 0,44 \exp\left(\frac{-0,78}{Kn_p}\right) \right] \quad (13)$$

With Kn_p Knudsen number relative to the particle:

$$Kn_p = \frac{2\lambda}{d_p} \quad (14)$$

In the flow, small diameter particles ($d_p < 1 \mu\text{m}$) are not subject to any interaction other than collisions with the carrier gas molecules. They follow random trajectories, independent of the streamlines (Colin, 2013).



Figure 2: Schematic of the Brownian diffusion collection mechanism (Bémer *et al.*, 2006, and Colin, 2013).

1-4-2-5-2- Collection by interception.

Particles that follow the streamlines of the carrier gas ($d_p > 0.1 \mu\text{m}$) can be intercepted by a fiber if the distance between them becomes smaller than their radius. The interception collection mechanism is independent of the velocity; it depends only on the geometry of the particles and is described by the ratio between the particle diameter and the fiber diameter (Colin, 2013):

$$R = \frac{d_p}{d_f} \quad (15)$$

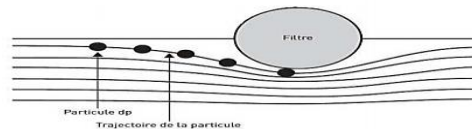


Figure 3: Schematic of the interception collection mechanism (Bémer *et al.*, 2006 and Colin, 2013)

1-4-2-5-3- Collection by inertial impaction.

Large particles ($d_p > 1 \mu\text{m}$), under the effect of their inertia, tend to leave the streamlines of the carrier gas and follow rectilinear trajectories (Colin, 2013).

$$St = \frac{\rho_p \times d_p^2 \times v_i}{\mu \times d} \quad (16)$$

Collection by inertial impaction is characterized by the Stokes number (St), which expresses the ratio between the kinetic energy of the particle and the energy dissipated by friction with the fluid (Laurence, 2006).

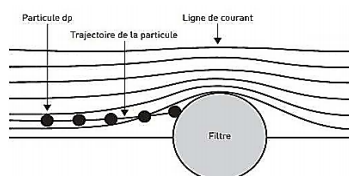


Figure 4: Schematic of the inertial impaction collection mechanism (Bémer et al., 2006; Colin, 2013).

1-4-2-5-4- Sieving.

Sedimentation (sieving), generally neglected for particles with a diameter of less than 10 μm , is the predominant capture mechanism when the particles have a size greater than or equal to the characteristic dimension of the pores of the fibrous media (Colin, (2013))



Figure 5: Mechanisms of particle capture on a collector fiber by sieving (Laurence, 2006)

1-4-2-5-5- Collection by electrostatic effects.

Some electrostatic filters are composed of polarized fibers. Under the effect of electrostatic forces, the trajectory of a charged particle can be deflected in the vicinity of a fiber and the particle can attach itself to it (Bémer et al., 2006, ; Colin, 2013).



Figure 6: Particle capture mechanisms on a collector fiber by electrostatic effects (Laurence, 2006)

1-5- Fuel economy and energy autonomy of improved stoves

The Active Research and Participatory Planning Method (MARPP) used in this work consisted of more or less structured interviews. This socio-economic data collection tool aims to obtain information in person, individually or in small groups, through a series of questions asked (Dzokom, 2021). The information collected is recorded in a sheet serving as a conversation guide with the possibility of readjusting the questions during the interview. This data collection method was carried out mainly during the intense activities of using improved stoves in households in the Sahelian zone of Cameroon.

2- RESULT AND DISCUSSION

2-1- Design and dimensioning of the structure of some improved stoves used in the Far North of Cameroon

In the Far North of Cameroon, the cities that have benefited greatly from the projects related to improved stoves are Maroua, Mokolo, Mora, Yagoua, Kaélé, Maga and Kousseri. Popularized under the popular name of Katindé Njamndi (Multi pot), the stoves made from recovered sheet metal (200 l drums, vehicle carcasses) were intended for the use of wood fuel by women in households. The diameters of the stoves vary between 300 and 600 mm for respective prices between 1300 and 5500 FCFA in 1993.

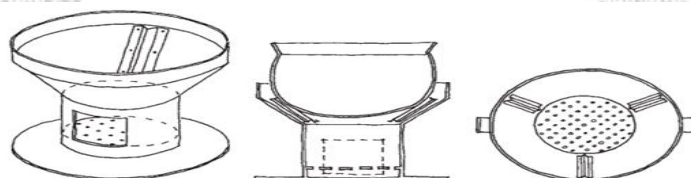


Figure 7: Improved stoves in Maroua-Cameroon

An improved stove is a stove that is built to use the same local materials as the traditional stove but with the aim of reducing smoke emissions, common diseases and infections that these smokes cause, reducing deforestation and making traditional stoves efficient by improving them. (Akouehou et al., 2012). Designing ecological improved stoves-ovens must be able to ensure energy efficiency that can produce significant energy output while minimizing fuel consumption. Its sizing depends on the shape and size of the pots.

As part of our study, we aim to design an ecological improved stove-oven whose shape and bottom should have the following characteristics:

- Lower fuel consumption than the traditional three-legged stove;
- Higher energy efficiency than the traditional three-legged stove;
- The production of fumes and dirt is lower than that of the traditional three-legged hearth.

The dimensional characteristics of the ecological hearth-oven that we aspire to set up, taking into account socio-economic and environmental realities, aims to make viable a system that, until recently, was not very important and did not attract much interest. In other words, the ecological hearth-oven that we size must provide electrical energy.

2-2- Characteristics of improved hearths

From the point of view of their materials, the different types of known hearth-ovens can be classified into four classes:

2-3- Earth and/or ceramic hearth-ovens

In many cases, this category is made with a mixture of sand and clay. These hearth-ovens have a high thermal inertia, and the heating time as well as the cooling time is long. Hence the interest in dishes with a long cooking and simmering time.

Their construction techniques are simple because they are similar to traditional masonry and the construction materials needed for their construction are shovels, trowels, sieves, briquette molds, etc. (depending on the various unlisted literature) (Doat, 1982)

Table 1: Different materials for manufacturing improved earthenware (clay) hearth-ovens

CHARACTERISTICS		MEDIUM MODEL			LARGE MODEL	
Type of hearth:		Ecological clay hearth-oven (or ALZO cement)				
Number of households		One hearth	Two hearths	Three hearths	Four hearths	Five hearths
Type of clay		Earthenware clays, refractory clays, stoneware clays, raku clays, etc.				
Manufacturing temperature (resistance)		950° to 1100° approximately				
Material	Clay		*			*
	Straw		**			**
	Ash		***			***
	Manure		Animal dung			Animal dung
	Water		5 to 10 (liters)			15 to 40 (liters)

* any type of clay that can meet the requirement of pottery

** straw from plant debris

*** ash from the incineration of dry plants

For Doat, 1982, these are hearth-ovens made of pottery built in fired clay, are light and heat much more quickly than the previous one while retaining heat moderately. According to Mbaye (2011), the ceramic insert with a clay grain size should preferably not exceed 0.5 mm.

2-4- Metal hearth-ovens

They can range from simple to complex. The simplest to make can be made from old drums and thus give rise to rustic, economical but not very resistant material. The covering that will be used is a mild steel sheet (sheet metal), with a minimum thickness of 0.6 mm.

Table 2: Different materials for manufacturing improved hearth-ovens (in metal)

CHARACTERISTICS		MEDIUM MODEL			LARGE MODEL	
Type of hearth:		Ecological metal fireplace oven (ALZO)				
Number of households		One hearth	Two hearths	Tree hearths	Four hearths	Five hearths
Type of metal		Steel, aluminum, iron, stainless steel,...				
Welding alloy		Tin, copper,...				
Matériaux de fabrication	Steel		*			*
	Stainless steel		***			**
	Iron		***			***
	Aluminium		**			***

* any type of pure metal

** scrap metal

*** any type of scrap metal or alloy

Unlike earthen stoves, metal hearths with a chimney, a grate, holes and lids are efficient cookers whose costs are often incompatible with local purchasing power and possibilities (Doat, 1982).

2-4- Brick and cement hearths

Hearths made of cement, briquettes or hearths that, in their manufacture, require a mixture of cement, brick and metal generally have a much longer lifespan than large earthen stoves and generally do not have cracks. They often heat up quickly, compared to the heating of three-stone hearths and have a better-known cooking method. Their only major drawback is their relatively high price (Doat, 1982).

Furthermore, for Mbaye (2011), the thickness of the sheet metal must not exceed 1.2 mm. If the coating used is that of a recovered sheet, direct exposure to fire (under high temperature) for about an hour improves the resistance and

finish of the hearth. The ceramic insert used in the manufacture of the hearth must be made from suitable clay and fired uniformly between 700°C and 900°C in a kiln. The grid (base of the ceramic insert), according to Mbaye (2011), must have small holes separated by at least 15 mm by material. The holes must measure from 10 to 20 mm.

Table 3: Different materials for manufacturing improved earthenware (clay) hearths-ovens

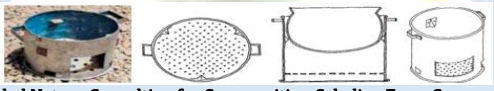


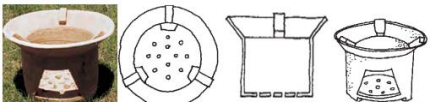
Characteristics	MEDIUM MODEL		LARGE MODEL		
Type of hearth:	Ecological clay (or cement) hearth-oven				
Number of households	One hearth	Two hearths	Tree hearths	Four hearths	Five hearths
Cement type	Earthenware clays, refractory clays, stoneware clays, raku clays, etc.				
Manufacturing method	(resistance) Cement-sand-water dosage				
Material quantity	Cement				*
	Sand	Fine ± semi coarse		Fine + semi-coarse + coarse	
	Water	5 to 10 (liters)		15 to 40 (liters)	
Material content	Depends on the texture of the materials and the size of the pots				

* any type of cement that can meet the requirement of solidity

2-5- The mixed clay-metal hearth-ovens of SAHEL NATURE CONSULTING

The metal hearth-oven that we designed is made from old sheets and thus gives rise to rustic, economical and more or less resistant material. The coating that is used is a mild steel sheet (sheet), with a minimum thickness of 0.6 mm. The combustion chamber is made with a mixture of sand (03%) and clay (97%)

Table 4: Some prototypes of improved hearths studied in Maroua-Cameroon

Origin	Name of the hearth	Materials	Size (mm ø)	Thermal efficiency in the laboratory	Fuel economy (in the field)	Unit cost
Mali, Niger	Mali: Téliman Niger: Mai Sauki	Recycled sheet metal, barrels, black sheet metal	210- 650	26 à 30 %	30 à 40 %	550- 950
ONG S.N.C. C. (2023)	ALZO	Recycled sheet metal	210- 650	26 à 30 %	30 à 40 %	550- 950
 <p>Source: Sahel Nature Consulting for Communities, Sahelian Zone_Cameroon (2023)</p>						
Mali, Niger	Cameroon: Katindé Njamndi Mali: Nafacaman, Multi mixed pot Niger: Multi pot	Drums, black sheet metal, salvaged sheet metal, etc.	180- 220	27 to 32% (in laboratory) in Mali and 23% (Burkina and Niger)	40 à 50 % au Mali et 25 % (Burkina and Niger)	1.800- 2.300
 <p>Source : DNAS-GTZ, Anke Weymann</p>						
Burkina Faso Cameroun	Cameroon : Katindé loppé	Red clay	190- 240	27 à 32 % (en laboratoire) au Cameroun et 23 % (Burkina)	40 à 50 % au Cameroun et 25 % (Burkina)	2000- 3000
						
Bolivie: La Paz	Foyer Amélioré	Argile rouge, céramique, argile	270	19% (aluminum pot, ø 200 mm) 24% (aluminum pot, ø 260 mm)	20 %	2000- 3000
 <p>Source : Augusto Rocha, AMCPP</p>						

The dimensional characteristics of the ecological hearth-oven that we aspire to set up, taking into account socio-economic and even environmental realities, aims to make viable a system that, until recently, did not have great importance and did not attract great interest. In other words, the ecological hearth-oven that we aim to size must meet the need to provide electrical energy. Thus, the various dimensions of the components of the hearth are found in the following tables:

Table 5: Different dimensions of improved ecological hearth-ovens made of clay

Characteristics	MEDIUM MODEL	LARGE MODEL
Exterior dimension	55-65 cm	70-75 cm
Interior dimension	30-50 cm	40-60 cm
Combustion chamber dimension	15-25 cm	20-30 cm
Firebox section	30x50 cm	40x60 cm

Dimensions :	Door (combustible entrance)	Circular shape	20×20 cm	25×25 cm
		Rectangular shape	20×25 cm	20×30 cm
	Height		25-30 cm	45-50 cm
	Built-in height		15-20 cm	20-25 cm
	Boiler (capacity)		15 000 à 18 000 cm ³	19 000 à 20 000 cm ³
	Fume cooler (L×W×H)		30×17×38 cm ³	30×17×38 cm ³
	Chimney	Luminous surface* (h x w)	40 x 35 cm	60 x 45 cm
		Conduit section (Ø)	20 cm	30cm
		Conduit volume	63 000-95 000 cm ³	354 000- 495 000 cm ³
		Conduit height	200-300 cm	500-700 cm

* The luminous surface is the open surface of the hearth and which is a function of the volume of the combustion chamber to be heated

2-6- Expected calorific and energy efficiency of combustion hearths.

The average humidity rate in the combustion chamber is 23.08±02.52% and the calorific value measured in the combustion chamber is 28.15±02.53MJ/kg. During the expected combustion tests in the combustion chamber, the average mass of the fuel before combustion was observed to be 12.71±08.55 gr, with an average mass of the post-combustion fuel of 01.77±00.58 gr and mass losses of 86.07±07.97% for an average combustion time of 15.24 ± 1.66 minutes.

Table 6: Calorific value and expected combustion tests in the combustion chamber

Humidity level in the combustion chamber (%)	Calorific value measured in the combustion chamber (MJ/kg)	Expected combustion tests in the combustion chamber			
		Burn time (minutes)	Mass of fuel before combustion (grams)	Post-combustion fuel mass (grams)	Mass losses (%)
23.08±02.52	28.15±02.53	15.24 ± 01.66	12.71±08.55	01.77±00.58	86.07±07.97

The thermal efficiency in terms of smoke emission, fuel economy and energy production capacity is presented in the following table:

Table 7: Qualitative characteristics of the product efficiency of improved ecological hearth-ovens

CARACTERISTICS	ELEMENTS OF PERFORMANCE	MEDIUM FIREPLACE MODEL	LARGE FIREPLACE MODEL
Fuel used		Combustible waste, wood, coal	
Fuel economy*for	Boiling for liquid (e.g. water)	22% - 49%	35 % - 40 %
	Controlled cooking 1*	20% - 55%	35 % - 40 %
	Controlled cooking 2*	25% - 45%	25 % - 40 %
	Energy efficiency (effective use of heat)	20% - 30%	35 % - 40 %
Thermal efficiency		35% - 50%	35% - 45 %
Smoke emission (CO/CO2)		0,04	0,04
Savings through time saving and compared to the 3-stone hearth used for cooking:		10% - 25%	10% - 25%
Speed of production		Excellent	Very good
Ability to control the intensity of the fire using all types of solid fuels		Excellent	Very good
Easy ignition using:	Combustible waste	Very good	Very good
	Wood	Good	Good
	Coal	Very good	Very good
Versatility	Combustible waste	Very good	Very good
	Wood	Very good	Very good
	Coal	Very good	Very good
Easy extinguishing using	Combustible waste	Very good	Good
	Wood	Good	Very good
	Coal	Good	Good
Cleanliness using:	Combustible waste	Very good	Very good
	Wood	Very good	Very good
	Coal	Very good	Very good
Sustainability		Excellent	Excellent
Expected production location		Far North, North Cameroon Other Sub-Saharan African countries	
Production capacity (Households / month / craftsman)		25-30	30-50
Price	Simple, without air pollution control chimney but without integrated electricity production system	3,500 à 4,000 F.CFA	5,500 à 10,000 F.CFA
	With air purification chimney but without integrated electricity production system	5,500 à 10,000 F.CFA	15,500 à 50,000 F.CFA
	With air purification chimney and integrated electricity production system	25,500 à 50,000 F.CFA	75,500 à 250,000 F.CFA

(*) Fuel savings compared to the 3-stone hearth

(1*) Controlled cooking for foods requiring short and medium cooking times

(2*) Controlled cooking for foods requiring long simmering times

To maintain a stable and continuous flame, the humidity level must be less than or equal to 65% while the typical combustion temperature for fixed bed technological processes is between 850 and 1400 °C (Jenkins et al., 1998; Sjaak van, 2002; Takali, 2015). Furthermore, Takali (2015) indicates that in fluidized beds, the heat output can be higher and suitable for large installations. Thus, in order not to vitrify the bed material, it is necessary to reduce and maintain the temperature at a lower level by constituting the bed with silica sand, limestone grains or dolomite. For the combustion chamber of our device, we hope to proceed to place in turn:

- ✓ the ash pan (10 cm high);
- ✓ the sand 3 to 5 cm thick (silica);
- ✓ the gravel 3 to 5 cm thick (limestone);
- ✓ the stack of fuels 25 to 30 cm high (combustible waste, wood, coals, etc.)

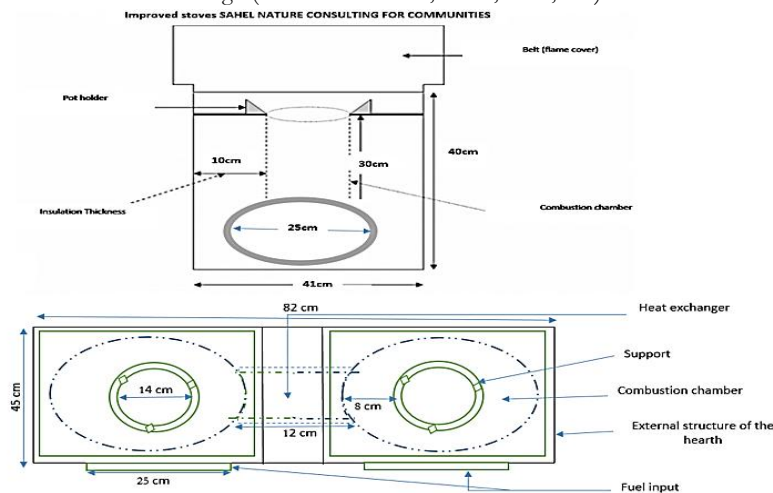


Figure 8: Dimensions of improved stoves produced by SAHEL NATURE CONSULTING FOR COMMUNITIES

Thus, the relatively expected overall combustion temperature in the combustion chamber would be lower and between 300 and 700 °C

The ease of ignition of fuels in the combustion chamber is governed by an average ignition temperature of $(33.85 \pm 05.86^\circ\text{C})$ and an average temperature at $t=25$ min of $(498 \pm 46.61^\circ\text{C})$.

Table 8: Ease of ignition and energy efficiency of combustion chambers

Ease of ignition of fuels in the combustion chamber			Energy efficiency of combustion chambers	
Ignition temperature (°C)	Temperature at t=5 min (°C)	Temperature at t=25 min (°C)	Start of heating of the combustion chambers after ignition (min)	Combustion chamber warm-up time (min)
33.85 ± 05.86	58.95 ± 04.76	498 ± 46.61	02.61 ± 00.64	12.48 ± 01.96

The energy efficiency of the combustion chambers is governed by an average start of heating of the combustion chambers after ignition of 02.61 ± 00.64 minutes and an average heating time of the combustion chambers 12.48 ± 01.96 min.

But, at the time when the start of combustion in the combustion chamber would be difficult, due to exogenous factors to the hearth-furnace, we will adopt the co-combustion of waste-based fuels with coal, because the co-combustion of biomass with coal is the most economical method for their energy recovery because it requires minimal modifications (Dzokom et al., 2024 a and b; Dzokom et al., 2022; Veringa and Takali, 2015). According to the arrangement of fuels in the carbonization stack, in the combustion chamber for better efficiency, the fuels can be arranged in three types of stacks, namely: vertical stack, horizontal stack and improved stack (Schenkel et al., 1997). The average usable energy yield when arranging wood in an improved carbonization stack is lower ($60.32 \pm 0.04\%$) while the usable energy yield when arranging ecological charcoal based on *Eichhornia crassipes*, arranged in an improved carbonization stack ($99.92 \pm 0.13\%$) after using 1 mg of fuel. Generally, ecological charcoal wastes less energy than wood if the usable energy obtained from a quantity of wood used directly is lower than the usable energy obtained from the same quantity of biomass transformed into charcoal. The useful thermal efficiency of wood is on average 8% and can even drop to 5% with the very widespread African three-stone hearth, while that of charcoal reaches an average of 28% (Keita, 1983; Keita, 1987).

Table 9: Expected energy yields from the arrangement of fuels in a carbonization pile

	Expected energy yields from the arrangement of wood in carbonization mills				Expected energy yields from the disposal of ecological charcoal based on <i>Eichhornia crassipes</i> , arranged in a carbonization mill			
	Calorific value inferieur (kWh.kg ⁻¹)	Initial mass (kg)	Ash mass (kg)	Usable energy yield (%)	Calorific value inferieur (kWh.kg ⁻¹)	Initial mass (kg)	Ash mass (kg)	Usable energy yield (%)
Vertical grinding wheel	5.93±0.06	1	0.284±0.016	47.44±0.65	5.84±0.72	1	0.555±0.062	96.35±0.25
Horizontal grinding wheel	4.53±0.69	1	0.288±0.084	36.24±0.92	4.25±0.83	1	0.325±0.042	91.19 ±0.05
Improved grinding wheel	7.54±0.22	1	0.305±0.032	60.32±0.04	6.79±0.54	1	0.859±0.091	99.92 ±0.13

1 kWh.kg⁻¹=3. 6 MJ.kg⁻¹ =3600 kJ.kg⁻¹

The average mass of ash when placing wood in an improved carbonization pile is lower (305±32 mg) while the average mass of ash when placing ecological charcoal based on *Eichhornia crassipes*, placed in an improved carbonization pile (859±91 mg) after the combustion of 1000 mg of fuel.

A cooking test with 1 kg of ecological charcoal based on *Eichhornia crassipes* produces a post-combustion mass (ash) of 14.36±0.22 milligrams/kilogram, i.e. an average mass loss of 86.75±0.01% (DZOKOM et al., 2024a)

NB: We are using the notion of pile here because we believe that the arrangement of fuels in the combustion chamber must comply with that of the carbonization piles for a good start of combustion and optimal efficiency of the system. In this work, we will adopt the improved stack fuel arrangement which consists of arranging large-caliber fuels in the center of the combustion chamber, surrounding it with medium- and then small-caliber fuels. By definition, the P.C.S. as well as the P.C.I. can be related to the green matter by the formula (Doat and Valette, 1981). :

The moisture content in the combustion chamber before ignition, the calorific value of the dry matter and the moisture uptake rate of the ash in the combustion chamber after 24 hours are higher in the other improved hearths_furnaces than in the hearth_furnace of SAHEL NATURE CONSULTING FOR COMMUNITIES while the moisture content of the dry matter and the calorific value of the dry matter at 30% humidity are higher in the hearth_furnace of SAHEL NATURE CONSULTING FOR COMMUNITIES than in the other Hearths_furnaces

Table 10: Calorific value of the material according to the water content

		Moisture content in the combustion chamber before ignition (%)	Ash humidity recovery in the combustion chamber after 24 hours (%)	Moisture content of dry material (%)	Calorific value of dry matter (kwh.kg ⁻¹)	Calorific value of the dry material at 30% humidity (kwh.kg ⁻¹)
Improved fireplace SAHEL NATURE CONSULTING FOR COMMUNITIES	Charcoal	25.66±0.13	11.53±0.66	18.21±0.43	4.034±0.101	2.634±0.541
	Ecological Charcoal	21.31±0.36	09.44±0.54	15.85±0.12	6.265±0.425	5.626±0.115
	Ecological Briquette	20.52±0.24	10.43±0.44	16.31±0.55	6.143±0.133	4.653±0.765
Improved fireplace_oven	Charcoal	26.29±0.87	16.77±0.32	15.85±0.12	5.248±0.559	2.548±0.219
	Ecological Charcoal	25.62±0.59	15.54±0.32	15.33±0.67	5.895±0.524	5.504±0.901
	Ecological Briquette	20.02±0.64	10.92±0.64	17.38±0.02	5.635±0.234	3.575±0.125

Following studies conducted on a series of forest species from the South and East of the USA, a classification of forest fuels into four categories according to their higher calorific value has been proposed (Hough, 1969 and Valette, 1981):

- o P.C. less than 4,000 cal/g (16.7 kJ/g);
- o P.C.S. between 4,000 and 4,500 cal/g (16.7 and 18.8 kJ/g);
- o P.C.S. between 4,500 and 5,000 cal/g (18.8 and 20.9 kJ/g);
- o P.C.S. greater than 5,000 cal/g (20.9 kJ/g).

2-7- Decontamination of fumes and toxic pollutants in the air

As part of this work, purifying the fumes that could be emitted by the hearth-furnace involves designing a small absorbent filter that will have the capacity to retain all acidic, basic or simply toxic pollutants from the combustion of fuels.

2-7-1- Characteristics of the manufacturing materials of the “pleated cartridge filter” of fumes

The average pitch between the two peaks is 0.22±0.04 μm, and the average pleat height is 0.29±0.03 μm. From Darcy's law, gas flow modeling has determined that the average solid volume fraction of the media is 0.29±0.02 μm³, and the average fiber radius is 0.052±0.002 μm.

Table 12: Sizing and permeability models (empirical model, flow through a random arrangement of fibers

Distance between two neighboring fold peaks	Sizing and permeability models (empirical model, flow through a random arrangement of fibers, α < 0.25)
---------------------------------------------	---------------------------------------------------------------------------------------------------------

Pitch (μm)	Ply height (μm)	Solid volume fraction of the media (μm^3)	Fiber radius (μm)
0.22 ± 0.04	0.29 ± 0.03	0.29 ± 0.02	0.052 ± 0.002

According to Laurence (2006), filter cartridges are made of pleated fibrous media placed in a cylindrical shape, while cassettes are flat pleated filters. Although there are other types of filters based on non-woven fibrous media ("depth" cartridge filters, flat filters), pleated filters are by far the most used (Colin, 2013).

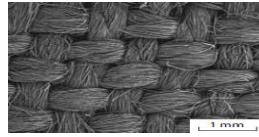


Photo 1: Woven fibrous media observed by scanning electron microscopy (Laurence, 2006)

According to this author (Colin, 2013), for equivalent space requirements, pleating makes it possible to obtain filtration surfaces more than 10 times greater than flat filters and two geometric quantities are generally used to characterize them: the distance between two neighboring pleat peaks: the pitch, p and the pleat height, h .

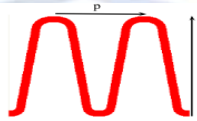


Figure 9: Geometric characterization of pleated filters by pitch and pleat height (Colin, 2013).

During Brownian diffusion, the average particle transport speed by convection is $0.057 \pm 0.008 \text{ m}\cdot\text{s}^{-1}$, the average transport speed by diffusion is $0.0041 \pm 0.0007 \text{ m}^2\cdot\text{s}^{-1}$ with a Peclet number of 0.931 ± 0.064 . During diffusion by direct interception, the particle diameter is $0.138 \pm 0.092 \mu\text{m}$, the fiber diameter is $0.246 \pm 0.062 \mu\text{m}$ with a direct interception ratio of 0.561 ± 0.051 .

Table 13: Brownian diffusion and direct interception diffusion

Brownian diffusion for particle size $d_p < 1 \mu\text{m}$			Direct interception scattering for $d_p > 0.1 \mu\text{m}$		
Convection particle transport velocity U_0 ($\text{m}\cdot\text{s}^{-1}$)	Diffusion transport velocity d_p ($\text{m}^2\cdot\text{s}^{-1}$)	Peclet number (Pe)	Particle diameter (μm)	Fiber diameter (μm)	Direct Interception Report
0.057 ± 0.008	0.0041 ± 0.0007	0.931 ± 0.064	0.138 ± 0.092	0.246 ± 0.062	0.561 ± 0.051

Due to collisions with gas molecules, particles of dimensions smaller than or equivalent to the mean free path of gas molecules ($\lambda = 0.067 \mu\text{m}$ for air) travel a random oscillating trajectory which considerably increases the probability of interception by the fibers (Laurence, 2006). The interception collection mechanism is independent of speed; it depends only on the geometry of the particles and is described by the ratio between the particle diameter and the fiber diameter (Colin, 2013)

During diffusion by inertial impaction, the kinetic energy of the particles is $0.0104 \pm 0.0003 \text{ m}\cdot\text{s}^{-1}$, the energy dissipated by friction with the fluid is $0.0458 \pm 0.0033 \text{ m}\cdot\text{s}^{-1}$ with the Stokes Number of 0.986 ± 0.022 , while the sedimentation of particles with a diameter of less than $10 \mu\text{m}$ is $0.057 \pm 0.008 \text{ mg}/\mu\text{m}$

Table 14: Diffusion by inertial impaction and sedimentation of particles

Inertial impaction diffusion for $d_p > 1 \mu\text{m}$			Sedimentation (sieving) for particles with a diameter of less than $10 \mu\text{m}$
Kinetic energy of the particle ($\text{m}\cdot\text{s}^{-1}$)	Energy dissipated by friction with the fluid ($\text{m}\cdot\text{s}^{-1}$)	Stokes number (St)	($\text{mg}/\mu\text{m}$)
0.0104 ± 0.0003	0.0458 ± 0.0033	0.986 ± 0.022	0.057 ± 0.008

Large particles ($d_p > 1 \mu\text{m}$), due to their inertia, tend to leave the carrier gas flow lines and follow straight trajectories (Colin, 2013).

Sedimentation (sieving), generally neglected for particles with a diameter of less than $10 \mu\text{m}$, is the predominant capture mechanism when the particles have a size greater than or equal to the characteristic pore size of the fibrous media (Colin, (2013)). When evaluating particle collection efficiency, the average fraction of injected air is $20.36 \pm 2.82 \text{ L}/\text{min}$ with a total average quantity of injected fluorescent particles of $13.92 \pm 0.74 \text{ L}/\text{min}$.

Table 15: Particle collection efficiency and performance of fibrous media in filtration

Fraction of injected air (L/min)	Collection yield	Performance of fibrous media in filtration	
	Total quantity of fluorescent particles injected (L/min)	Collection efficiency (E) (L/min)	Pressure loss (ΔP) (L/min)
20.36 ± 2.82	13.92 ± 0.74	20.01 ± 0.08	0.23 ± 0.05

A "good filter" must have a low pressure drop and high efficiency (Colin, 2013). When evaluating the performance of fibrous media in filtration, the collection efficiency is 0.21 ± 0.08 L/min while the pressure drop 0.023 ± 0.005 L/min.

2-7-2- Analysis of particles collected by smoke filters of improved stoves

When analyzing the particles collected by smoke filters of improved stoves, the evaluation of the collection efficiency with the acid gas treatment filter indicates that CO_2 ($67.10 \pm 0.63\%$) and $(\text{NH}_4) \text{HCO}_3$ ($16.33 \pm 0.12\%$) were better filtered with the SAHEL NATURE stove. Na_2CO ($09.77 \pm 0.27\%$) was better filtered with the improved ceramic stove while water vapor (H_2O , $14.54 \pm 0.54\%$) was better filtered with the Malagasy/Nigerian stove.

Table 16: Analysis of particles collected by smoke filters of improved stoves

Type of fireplace	Collection efficiency with acid gas treatment filter (%)				Collection efficiency with the alkaline gas treatment filter (%)			
	CO_2	$(\text{NH}_4)\text{HCO}_3$	Na_2CO	H_2O	CO_2	NaCO_3	N_2	H_2O
Improved fireplace SAHEL NATURE CONSULTING FOR COMMUNITIES	67.10 ± 0.63^a	16.33 ± 0.12^a	06.75 ± 0.07^b	09.82 ± 0.32^a	71.91 ± 0.13^a	07.16 ± 0.03^c	07.61 ± 0.03^a	13.32 ± 0.03^b
Malagasy/Nigerian Fireplace	65.32 ± 0.16^a	11.43 ± 0.29^b	08.71 ± 0.63^a	14.54 ± 0.54^d	62.76 ± 0.54^c	07.32 ± 0.16^a	10.42 ± 0.54^a	19.65 ± 0.13^a
Improved Metal Fireplace	65.01 ± 0.39^a	14.54 ± 0.29^b	07.62 ± 0.138^c	12.83 ± 0.72^a	68.05 ± 0.69^b	07.01 ± 0.39^a	13.00 ± 0.04^a	11.94 ± 0.17^a
Improved Ceramic Fireplace	66.06 ± 0.04^a	15.37 ± 0.54^b	09.77 ± 0.27^a	08.80 ± 0.54^a	69.13 ± 0.25^a	07.06 ± 0.48^b	15.23 ± 0.08^a	8.58 ± 0.64^c

The evaluation of the collection efficiency with the alkaline gas treatment filter indicates that CO_2 ($71.91 \pm 0.13\%$) was better filtered with the SAHEL NATURE hearth and $07.32 \pm 0.16\%$ of NaCO_3 was better filtered with the Malagasy/Nigerian hearth. $15.23 \pm 0.08\%$ of N_2 was better filtered with the improved ceramic hearth while $19.65 \pm 0.13\%$ of water vapor (H_2O) was better filtered with the Malagasy/Nigerian hearth.

2-8- Fuel economy and energy autonomy of improved stoves

Of the five types of stove, the highest fuel economy is that of the SAHEL NATURE CONSULTING stove ($61.07 \pm 0.39\%$) with 0.716 ± 0.093 kg of charcoal produced, while the lowest is that of the three-legged stove ($10.02 \pm 0.31\%$) with 0.327 ± 0.136 kg of charcoal produced.

Table 17: Energy efficiency of carbonization in the combustion chamber

Type of fireplace	Fuel economy of improved stoves			Energy autonomy of improved stoves		
	Initial mass of wood (kg)	Mass of charcoal produced Mba (kg)	Wood saving (%)	Maximum heat obtained in the combustion chamber ($^\circ\text{C}$)	Heat retention time $\geq 100^\circ\text{C}$ (minutes)	Heat used (%)
Improved fireplace SAHEL NATURE CONSULTING FOR COMMUNITIES	$01 \pm 0.32^{a,d}$	0.716 ± 0.093^a	61.07 ± 0.39^a	761.31 ± 30.66^a	29.76 ± 0.22^a	31.91 ± 0.13^a
Three stone fireplace	01 ± 0.51^a	0.327 ± 0.136^b	10.02 ± 0.316^a	480.11 ± 13.54^a	11.07 ± 0.37^d	12.76 ± 0.54^b
Malagasy/Nigerian Fireplace	01 ± 0.02^a	0.701 ± 0.390^b	30.01 ± 0.39^a	750.43 ± 11.76^b	28.07 ± 0.85^a	18.05 ± 0.69^a
Improved Metal Fireplace	01 ± 0.04^c	0.706 ± 0.048^c	55.06 ± 0.48^c	779.54 ± 64.71^a	28.05 ± 0.41^a	29.13 ± 0.25^c
Improved Ceramic Fireplace	01 ± 0.53^b	0.712 ± 0.014^a	60.02 ± 0.104^a	871.02 ± 58.32^a	28.07 ± 0.06^c	31.85 ± 0.44^a

The observation of the energy autonomy of improved stoves made it possible to observe that the maximum heat obtained in the combustion chamber ($871.02 \pm 58.32^\circ\text{C}$) was observed in the ceramic stove, improved the maximum heat retention time greater than 100°C in the combustion chamber was observed with the SAHEL NATURE CONSULTING stove (29.76 ± 0.22 minutes) with a maximum heat used of $31.91 \pm 0.13\%$.

2-8-1- Socio-economic impact and acceptability of improved stoves in households

During the analysis of the socio-economic impacts of improved stoves in households, it appears that users noted a high smoke emission with the three-legged stove ($80.1 \pm 0.5\%$) while low smoke emission was noted with the SAHEL NATURE CONSULTING stove ($30.1 \pm 0.2\%$). At the end of the survey, $99.37 \pm 0.16\%$ of respondents say that the traditional three-legged stove is more accessible than improved stoves, but among the improved stoves studied, the SAHEL NATURE CONSULTING stove is more accessible at $71.06 \pm 0.93\%$. Fuel savings were better observed on the SAHEL NATURE CONSULTING stove ($76.01 \pm 0.23\%$) with the best saving in cooking time ($85.54 \pm 0.48\%$) The observation and analysis of the energy autonomy of improved stoves by users allowed their responses concerning the maximum heat obtained in the combustion chamber which is better with the SAHEL NATURE CONSULTING stove ($87.71 \pm 0.356\%$) which also has a better heat retention time ($95.55 \pm 0.677\%$). However, the most used heat in households is that of traditional African three-legged stoves due to its high accessibility rate and the weight of cooking habits.

Table 18: Acceptability rate of improved stoves in households

Type of fireplace	Fuel economy of improved stoves				Energy autonomy of improved stoves		
	Smoke emission (%)	Affordability (%)	Fuel savings (%)	Cooking time savings (%)	Maximum heat obtained in the combustion chamber (%)	Heat retention time (%)	Heat used (%)
Improved fireplace SAHEL NATURE CONSULTING FOR COMMUNITIES	30.1±0.2 ^a	71.06±0.93 ^a	76.01±02.33 ^a	85.54±01.48 ^a	87.71±03.56 ^a	95.55±06.77 ^a	91.87±03.13 ^a
Three stone fireplace	80.1±0.5 ^a	99.37±0.16 ^d	10.52±04.62 ^b	13.43±02.11 ^c	80.41±03.54 ^a	51.08±02.84 ^b	98.76±07.54 ^b
Malagasy/Nigerian Fireplace	40.1±0.2 ^b	70.01±0.39 ^c	70.31±02.86 ^c	80.76±03.44 ^a	82.23±01.88 ^b	88.27±05.85 ^a	88.05±0.69 ^a
Improved Metal Fireplace	34.1±0.4 ^d	70.06±0.68 ^b	72.59±02.59 ^a	82.43±01.33 ^b	83.65±02.67 ^c	87.55±06.74 ^c	90.99±01.44 ^c
Improved Ceramic Fireplace	38.6±0.3 ^c	70.12±0.94 ^a	75.43±05.66 ^b	83.43±01.34 ^d	83.72±03.58 ^a	87.87±06.06 ^d	91.68±03.65 ^a

At the beginning, for the popularization of improved stoves, the dissemination system set up by SAHEL NATURE CONSULTING FOR COMMUNITIES consisted of opening a store for the project, which should be run by a facilitator designated by the promoters of the project. In addition, it was integrated with advertising programs (radio, billboards, etc.). Then, cooking demonstrations in the neighborhoods, in associations and health centers and meetings, sketches in high schools and training centers, street and market animations, reinforced this popularization program. Quality control and training in the management of facilitators and artisans were ensured and, to encourage producers of improved stoves, initially, the purchase of the majority of the production was carried out by the project in line with the project's subsidy policy.



Photo 2: Project for the dissemination of improved stoves in Maroua-Cameroon

Completed around mid-2022, the first phase of the project planned for the production and marketing system to be autonomous from the project. This type of stove is being disseminated in other African countries. This was followed by waves of improved stoves from various other countries and various other projects.

CONCLUSION

The objective here is to propose conceptual models of improved stoves capable of saving fuels and increasing the energy autonomy of culinary stoves. In the Far North of Cameroon, the cities that have benefited greatly from projects related to improved stoves are Maroua, Mokolo, Mora, Yagoua, Kaélé, Maga and Kousseri. The average humidity rate in the combustion chamber is $23.08 \pm 0.52\%$ and the calorific value measured in the combustion chamber is $28.15 \pm 0.53 \text{ MJ/kg}$. During the expected combustion tests in the combustion chamber, the average mass of the fuel before combustion was observed to be $12.71 \pm 0.55 \text{ gr}$, with an average mass of the post-combustion fuel of $01.77 \pm 0.058 \text{ gr}$ and mass losses of $86.07 \pm 0.97\%$ during an average combustion time of $15.24 \pm 1.66 \text{ minutes}$. The ease of ignition of fuels in the combustion chamber is governed by an average ignition temperature of $(33.85 \pm 05.86^\circ\text{C})$ and an average temperature at $t=25 \text{ min}$ of $(498 \pm 46.61^\circ\text{C})$. The energy efficiency of the combustion chambers is governed by an average start of heating of the combustion chambers after ignition of $02.61 \pm 0.064 \text{ minutes}$ and an average heating time of the combustion chambers $12.48 \pm 0.96 \text{ min}$. The average mass of ash when placing wood in an improved carbonization pile is lower ($305 \pm 32 \text{ mg}$) while the average mass of ash when placing ecological charcoal based on *Eichhornia crassipes*, placed in an improved carbonization pile ($859 \pm 91 \text{ mg}$) after the combustion of 1000 mg of fuel.

The average particle transport velocity by convection from the combustion chambers to the filters is $0.057 \pm 0.008 \text{ m}\cdot\text{s}^{-1}$ and the average diffusion transport velocity from the combustion chambers to the filters is $0.0041 \pm 0.0007 \text{ m}^2\cdot\text{s}^{-1}$ with a direct particle interception ratio by the filters of 0.561 ± 0.051 . The kinetic energy of the particles is $0.0104 \pm 0.0003 \text{ m}\cdot\text{s}^{-1}$, the energy dissipated by friction with the fluids is $0.0458 \pm 0.0033 \text{ m}\cdot\text{s}^{-1}$ with the Stokes number of 0.986 ± 0.022 , while the sedimentation of particles with a diameter of less than $10 \mu\text{m}$ is $0.057 \pm 0.008 \text{ mg}/\mu\text{m}$. When

evaluating the particle collection efficiency, the average fraction of injected air is 20.36 ± 2.82 L/min with an average total amount of injected fluorescent particles of 13.92 ± 0.74 L/min while the collection efficiency is 0.21 ± 0.08 L/min while the pressure drop 0.023 ± 0.005 L/min. When analyzing the particles collected by the smoke filters of the improved stoves, the evaluation of the collection efficiency with the acid gas treatment filter indicates that CO_2 ($67.10 \pm 0.63\%$) and $(\text{NH}_4) \text{HCO}_3$ ($16.33 \pm 0.21\%$) were better filtered with the SAHEL NATURE stove. Na_2CO ($09.77 \pm 0.27\%$) was better filtered with the improved ceramic hearth while water vapor (H_2O , $14.54 \pm 0.54\%$) was better filtered with the Malagasy/Nigerian hearth while the collection efficiency with the alkaline gas treatment filter indicates that CO_2 ($71.91 \pm 0.13\%$) was better filtered with the SAHEL NATURE Hearth and $07.32 \pm 0.16\%$ of NaCO_3 was better filtered with the Malagasy/Nigerian hearth. $15.23 \pm 0.08\%$ of N_2 was better filtered with the improved ceramic hearth while $19.65 \pm 0.13\%$ of water vapor (H_2O) was better filtered with the Malagasy/Nigerian hearth. Of the five types of stoves, the highest fuel economy is that of the SAHEL NATURE CONSULTING stove ($61.07 \pm 0.09\%$) with 0.716 ± 0.093 kg of charcoal produced, while the lowest is that of the three-legged stove ($10.02 \pm 0.16\%$) with 0.327 ± 0.136 kg of charcoal produced, while the observation of the energy autonomy of the improved stoves allowed us to observe that the maximum heat obtained in the combustion chamber ($871.02 \pm 58.32^\circ\text{C}$) was observed in the ceramic stove, improved the maximum heat retention time greater than 100°C in the combustion chamber was observed with the SAHEL NATURE CONSULTING stove (29.76 ± 0.22 minutes) with a maximum heat used of $31.91 \pm 0.13\%$. When analyzing the socio-economic impacts of improved stoves in households, it appears that users noted a high smoke emission with the three-legged stove ($80.1 \pm 0.5\%$) while low smoke emission was noted with the SAHEL NATURE CONSULTING stove ($30.1 \pm 0.2\%$). At the end of the survey, $99.37 \pm 0.16\%$ of respondents say that the traditional three-legged stove is more accessible than improved stoves, but among the improved stoves studied, the SAHEL NATURE CONSULTING stove is more accessible at $71.06 \pm 0.93\%$. Fuel economy was better observed on the SAHEL NATURE CONSULTING stove ($76.01 \pm 0.23\%$) with the best saving in cooking time ($85.54 \pm 0.148\%$)

The observation and analysis of the energy autonomy of the improved stoves by the users allowed their responses concerning the maximum heat obtained in the combustion chamber which is better with the SAHEL NATURE CONSULTING stove ($87.71 \pm 0.56\%$) which also has a better heat retention time ($95.55 \pm 0.67\%$). However, the most used heat in households is that of traditional African three-legged stoves because of its high accessibility rate and the weight of culinary habits.

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