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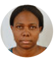

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Thermal Performance of Improved Charcoal Stove as a Clean Development Mechanism Project – A Case Sudy of Bauchi

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Abstract- Improved cook stoves (ICS) are known to ensure efficiency in the use of traditional fuels, reduce smoke emission and associated health hazards during cooking and reduce cooking time. Another benefit of ICS is in mitigating the effects of climate change. This paper presents the thermal performance and achievable emission reductions by ICS for daily cooking in households around Bauchi. It evaluates an ICS using the International Workshop Agreement (IWA) which rates cook stoves on four indicators (Indoor emission, total emission, efficiency/fuel use and safety) each indicator is rated along five tiers (0: lowest performing to 4: highest performing).The evaluation focused on efficiency/fuel use. The benchmark values for thermal efficiency, fuel use and energy use are 35%, 0.310kg and 7928kJ respectively. This shows that the ICS offers modest improvements in fuel use and it is rated as a tier 3 ICS. A carbon savings of 0.9 x $10^6 tCO_{2}e$can be achieved on an annual basis assuming all rural and urban households in Bauchi employ ICS for their daily cooking.

Keywords- Improved charcoal stove (ICS), Water Boiling Test (WBT), climate change, Clean Development Mechanism (CDM), Thermal efficiency.

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1 INTRODUCTION

Every day, three billion people in the world cook their food on open fires or traditional cookstoves. They burn solid fuels such as wood, crop residues, dung, coal, and charcoal, producing smoke that kills more than four million people annually and sickens millions more (Barnes et al, 2009). In addition to the enormous health toll, this cooking method carries an enormous environmental burden; the emissions from the combustion of unsustainably harvested wood fuel alone accounts for roughly 2% of global greenhouse gas emissions (IPCC 5th assessment report, 2014). The result is that one of our most fundamental activities – cooking a meal – is a major global health and environmental issue, as well as a significant barrier to sustainable economic development. Though cleaner, more efficient cooking technologies have been developed, they are often out of reach for families in developing countries due to cost or lack of availability in their local marketplace.

Over 95,000 Nigerians, mostly women and children die annually from smoke from the kitchen (Osita et al, 2013). This is Nigeria's third highest killer after Malaria and HIV/AIDS (WHO, 2012). In addition, Nigeria loses 3% of its forests annually partly as result of the cutting of trees for firewood (Al-Amin, 2014). Clean Development Mechanism (CDM) projects aims to assist developing countries in achieving sustainable development and to help developed countries fulfil their commitments to reduce emissions by investing in climate change mitigation projects in developing countries (CDM Benefits, 2012)

2 THEORETICAL BACKGROUND

The stove performances with respect to the type of fuel used can be analysed using energy audit method. It is assumed that no heat is lost from the stove combustion chamber to the outside, and with this assumption, the result is compared to the benchmark values from the same fuel utilized in simmer tests. Default heating values of charcoal are given as 31,000kJ/kg for Higher Heating Value (HHV), 29,800kJ/kg for Lower Heating Value (LHV),and charcoal carbon content Cc =95%. However, due to the presence of some water content in the charcoal, the accessible heating values are lowered to an effective heating value (EHV) which is given with reference to the moisture content as (Morgan et. Al, 2010).

$$EHV = LHV * (1 - MC) - MC * [(T_a - T_b) * 4.2 + 2260] \quad (1)$$

Where LHV is the Net calorific value,
MC is the moisture content,
T_b is the local boiling temperature and
T_a is the reference air temperature.

The total heat extracted from the charcoal is the product of the EHV and the quantity of charcoal consumed f_m measured in grams, obtained as the difference between the initial weight f_i and final weight $f_m$of the charcoal:

$$f_m = f_i - f_f \quad (2)$$

In addition to changes in weight of charcoal, there is also net change in weight of the charcoal ΔC_cgiven as

$$\Delta C_c = C_c - K \quad (3)$$

WhereC_c is the weight of container plus charcoal and
K is the weight of dry container.

The equivalent dry charcoal consumedf_d is given as(Morgan et. Al, 2010)

$$f_d = \{f_m[LHV * (1 - MC) - MC * (4.186 * (T_a - T_b) + 2257)] - \Delta C_c * CCV\}/LHV \quad (4)$$

Where f_m is the quantity of charcoal consumed in grams,
LHV is the lower heating value of charcoal
MC is the moisture content,
T_b is the local boiling temperature and

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T_a is the reference air temperature
ΔC_c is the net change in weight of charcoal, and
CCV is the char calorific value

The effective mass of water boiled w_b is given as (Morgan et. al, 2010):
$w_b = \sum_{i=1}^{n}\{(P_{w.i} - P_{d.i}) * [(T_{f.i} - T_{i.i})/(T_b - T_{i.i})]\}$ (5)
Where $P_{w,i}$ is the weight of pot + water;
$P_{d,i}$ is the weight of empty pot
$T_{f,i}$ is the temperature at finish
$T_{i,i}$ is the temperature at start, and
T_b is the local boiling temperature.

During heating, the weight of evaporation w_v, which takes place is given as (Morgan et. al, 2010):
$w_v = \sum_{i=1}^{n} P_{w.i} - \sum_{i=1}^{n} P_{d.i}$ (6)
Where w_v is the weight of water evaporated,
$P_{w,i}$ is the weight of pot with water and
$P_{d,i}$ is the weight of dry pot.

The required time Δt to boil the water in the pot is given as the difference between the start time t_i and the stop time t_f defined as:
$\Delta t = t_f - t_i$ (7)
Where Δt is the time required to boil water in the pots,
t_f is the stop or finish time, and
t_i is the start or initial time

With reference to normal boiling condition from a temperature of $25\ {}^oC$ to $100\ {}^oC$, temperature correction factor is (Morgan et. Al, 2010):
$\Delta t^T \Delta t * 75/(T_b - T_{i.i})$ (8)
Where Δt^T is the temperature correlation time to boil water in the pots,
$T_{i.i}$ is the water temperature in the pot before commencing boiling.

Thus the thermal efficiency of the stove is obtained from(Morgan et. Al, 2010):

$$h_{th} = \frac{4.186 * \{\sum_{i=1}^{n}[(P_{w,i} - P_{d,i}) * (T_{f,i} - T_{i,i})] + 2260 * w_v}{f_d * LHV} \qquad (9)$$

Where h_{th} is the thermal efficiency,
$P_{w,i}$ is the weight of pot + water;
$P_{d,i}$ is the weight of empty pot
$T_{f,i}$ is the temperature at finish
$T_{i,i}$ is the temperature at start,
w_v is the weight of water vaporized from the pots,
f_d is the mass of equivalent dry fuel consumed, and
LHV is the lower heating value of charcoal.
The thermal efficiency above is used for the high power phase (cold and hot start) with the following (Morgan et. al, 2010):

$$h_{th,hp} = \begin{cases} h_{th},c & \text{for} \Delta t_h = 0 \\ \frac{h_{th,c} + h_{th,,h}}{2} & \text{for} \Delta t_h > 0 \end{cases} \qquad (10)$$

Where $h_{th,hp}$ is the thermal efficiency of the simmer test,
$h_{th,c}$ is the thermal efficiency for cold start test,
$h_{th,h}$ is the thermal efficiency for hot start test.
Δt_h is the difference between start and finish for hot start test.

The rate of burning the fuel over the test period is:
$r_b = f_d/\Delta t$ (11)
Where r_b is the burning rate,
f_d is the mass of dry fuel consumed,
Δt is the duration for boiling water in the pots.

The theoretical specific fuel consumption is given as:
$SC = 1000 * f_d/w_b$
Where SC is the theoretical specific fuel consumption,
f_d is the mass of equivalent dry fuel consumed, and
w_b is the equivalent mass of water boiled.

This value is normalized by temperature correction factor to give the effective specific consumption as:
$SC_T = SC * 75/(T_b - T_{i.i})$ (12)
Where SC_T is the effective specific consumption,
SC is the theoretical specific fuel consumption,
T_b is the local boiling temperature, and
$T_{i.i}$ is the water temperature in the pot before commencing boiling.

Corresponding specific energy consumption is:
$SE_T = SC_T/1000 * LHV$ (13)
Where SE_T is the specific energy consumption,and
SC_T is the effective specific consumption.

The fire power of charcoal is defined as (Morgan et. al, 2010):
$FP = f_d * LHV/(\Delta t * 60)$ (14)
Where FP is the fire power of charcoal,
f_d is the mass of equivalent dry fuel consumed, and
Δt is the duration for boiling water in the pots.

The energy turn down ratio is given as the ratio of the fire power for cold start to fire power for simmer test:
$TDR = FP_C/FP_S$ (15)
Where TDR is the energy turn down ratio,
FP_C is the fire power of charcoal in cold start test,
FP_S is the fire power of charcoal in Simmer test.

Low power specific consumption based on simmer test values is defined as(Morgan et. al, 2010):
$SC_{LP} = (f_{d.S} * LHV)/(w_{b.S} * \Delta t * 1000)$ (16)
Where SC_{LP} is the low power specific consumption,
$f_{d.S}$ is the mass of equivalent dry fuel consumed in Simmer test,

$w_{b,s}$ is the equivalent mass of water boiled in Simmer test.

The fuel consumption bench mark is based on the utilization of 5 litres of water and is given by(Morgan et. Al, 2010):

$$BF = 5 * SC_{T,C} + SC_{T,s} \; for SC_{T,h} = 0 \tag{17}$$

$$BF = 5 * \frac{SC_{T,C} + SC_{T,h}}{2} + SC_{T,S} \; for SC_{T,h} > 0 \tag{18}$$

Where *BF* is the fuel consumption benchmark,

$SC_{T,C}$ is the temperature correlation specific consumption for cold start,

$SC_{T,h}$ is the temperature correlation specific consumption for hot start,

$SC_{T,s}$ is the temperature correlation specific consumption for simmer test,

The corresponding energy benchmark to complete 5 litres is(Morgan et. Al, 2010):

$$BE = BF * LHV/1000 \tag{19}$$

Where *BE* is the energy benchmark,

BF is the fuel consumption benchmark, and

3 METHODOLOGY

The Water Boiling Test (WBT) protocol developed by the Global Alliance for Clean Cooking (GACC) has been adopted. The WBT consists of three phases.

3.1Cold start high power phase

Water at room temperature is poured in a sauce pan (three quarters full) and weighed.Charcoal pieces (of uniform size) completely filling the combustion chamber of the ICS but not touching the base of the sauce pan was weighed and put into the combustion chamber. The insulation foam was placed on the sauce pan and the thermocouple/thermocouple holder was passed through an opening on the foam into the sauce pan allowing a gap of about 5cm from the base of the sauce pan and the tip of the thermocouple. The stove was lit by using a kindler and the sauce pan placed on the ICS. The starting time was immediately recordedusing a digital timer. Time at the pre-determined local boiling point was recorded,the remaining charcoal was removed from the ICS and weighed (separate from the ash). The weight of the sauce pan plus water was also recorded.

3.2 Hot start high power phase

This phase begins immediately after the cold start high power phase. With the stove still hot, the hot saucepan was refilled with the same quantity of water as in the first phase. The saucepan containing the water was weighed and the weight recorded in the calculation sheet. The foam insulation was placed on the surface of the water and the thermocouple holder placed in the sauce pan. The thermocouple was placed in the saucepan by passing it through a small opening on the insulation foam leaving a gap of 5cm between the tip of the thermocouple and the base of the sauce pan.Temperature of water was measured and recorded in the calculation sheet. Quantity of charcoal that can fill the combustion chamber of the ICS was put in a weighing containerand weighed. The weight of the charcoalwas recorded in the calculation sheet. The charcoal was poured into the combustion chamber and the stove was lit. The saucepan containing water and covered with insulation foam (thermocouple inserted) was placed on the ICS. The time was noted on the digital timer and recorded on the calculation sheet. At thepre-determinedlocal boiling point, the time and temperature was recorded. The weight of the saucepan and boiling water was also recorded (this is also the starting weight in phase 3), the charcoal in the combustion chamber was removed, weighedand recorded in the calculation sheet.

3.3 Simmering phase

The saucepan containing the hot water was immediately placed back on the ICS after the remaining hot charcoal in phase 2 has been poured back into the combustion chamber of the ICS. The water temperature did not drop 6 degrees Celsius below the local boiling point during the transition from phase 2 to phase 3 and also during the simmering process (this would have rendered the test results invalid). The temperature at the start of simmering was recorded as well as the weight of saucepan and boiling water. Simmering was carried out for forty five (45) minutes with the heat from the charcoal able to keep the water at the pre-determined local boiling point. At the end of 45 minutes, the temperature of water, weight of saucepan and the weight of charcoal remaining in the combustion chamber were recorded.WBT protocol version 4.2.2 was used to determine the efficiency of the ICS (GACC, 2013).

3.4 Drawing of ICS

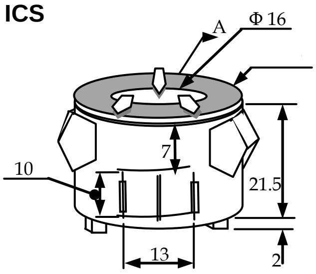
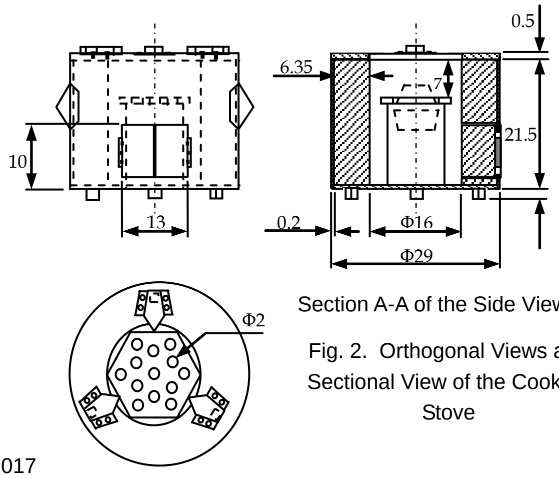


Fig. 1. Oblique Projection of the Cooking Stove



Section A-A of the Side View

Fig. 2. Orthogonal Views and Sectional View of the Cooking Stove

4 RESULT AND ANALYSIS

The result is split into three components: cold start, hot start and simmer test.

Table 4.1 High Power Test Result for Cold Start

Cold Start Performance	units	Test 1	Test 2	Test 3	…	Test 9	Test 10	Test 11	Average	St. Dev	COV
Time to boil Pot # 1	min	27	31	39	…	35	33	33	38.64	7.27	0.188
Temp-corrected time to boil Pot # 1	min	30.09	34.39	43.85	…	35.67	32.40	33.54	40.96	7.85	0.19
Burning rate	g/min	5.78	5.55	3.69	…	4.12	5.50	4.23	4.20	1.00	0.24
Thermal efficiency	%	28.7%	26.2%	30.9%	…	32.6%	29.0%	33.9%	31.8%	4.8%	0.15
Specific fuel consumption	g/liter	39.17	42.97	36.27	…	36.21	46.11	35.03	39.57	4.21	0.11
Temp-corrected specific consumption	g/liter	43.65	47.67	40.78	…	36.90	45.27	35.60	41.97	4.71	0.11
Temp-corrected specific energy cons.	kJ/liter	1124	1228	1050	…	987	1211	952	1074	121	0.11
Firepower	watts	2483	2383	1585	…	1839	2451	1886	1798	461	0.26

Table 4.2 High Power Test Result for Hot Start

Hot Start Performance	units	Test 1	Test 2	Test 3	…	Test 9	Test 10	Test 11	Average	St Dev	COV
Time to boil Pot # 1	min	28	24	38	…	21	21	23	29.55	6.35	0.215
Temp-corrected time to boil Pot # 1	min	31.34	26.83	42.47	…	21.55	21.84	23.41	31.75	7.27	0.23
Burning rate	g/min	4.51	5.38	2.93	…	4.79	7.28	4.25	4.43	1.14	0.26
Thermal efficiency	%	35.2%	34.6%	40.8%	…	47.0%	33.0%	48.4%	39.0%	5.9%	0.15
Specific fuel consumption	g/liter	31.60	32.38	27.93	…	25.30	38.93	24.55	31.72	4.62	0.15
Temp-corrected specific consumption	g/liter	35.38	36.19	31.22	…	25.95	40.50	24.98	34.03	5.25	0.15
Temp-corrected specific energy cons.	kJ/liter	911	932	804	…	694	1083	668	870	131	0.15
Firepower	watts	1936	2309	1257	…	2137	3246	1896	1898	540	0.28

Table 4.3 Simmer Test Result for Imput Variables

Low Power Simmer Performance	units	Test 1	Test 2	Test 3	…	Test 9	Test 10	Test 11	Average	St Dev	COV
Burning rate	g/min	30	30	30	…	30	30	30	30	7E-14	2E-15
Thermal efficiency	%	46.5%	49.3%	49.0%	…	52.6%	60.9%	54.6%	51.9%	4.4%	0.084
Specific fuel consumption	g/liter	27.66	25.13	17.47	…	18.05	28.58	17.81	24.04	5.517	0.23
Temp-corrected specific energy cons.	kJ/liter	712.4	647.3	449.9	…	483.0	764.6	476.4	613.7	134.1	0.219
Firepower	watts	1378.4	1258.0	910.0	…	959.8	1383.1	945.6	1181.0	220.9	0.187
Turn down ratio	--	1.80	1.89	1.74	…	1.92	1.77	1.99	1.55	0.402	0.258

Table 4.4 Benchmark Values for 5 Liters IWA Performance Result in Metric

	Units	Test 1	Test 2	Test 3	…	Test 9	Test 10	Test 11	Average	St Dev	COV
Fuel Use Benchmark Value	g	335.9	335.3	267.3	…	247.4	357.3	240.5	310.2	45.5	0.147
Energy Use Benchmark Value	kJ	8651	8637	6886	…	6619	9560	6434	7928	1113	0.14

Table 4.5 IWA Performance Comparative Result in Metric

IWA Metrics Values	Units	Test 1	Test 2	Test 3	…	Test 9	Test 10	Test 11	Average	St Dev	COV
High Power Thermal Efficiency	%	31.9%	30.4%	35.8%	…	39.8%	31.0%	41.1%	35.4%	4.7%	0.132
Low Power Specific Fuel Consumption	MJ/(min·L)	0	0	0	…	0	0	0	0.02	0.005	0.225

4.1 Carbon Savings

Possiblecarbon savings that can be achievedwith the use of an ICS is calculated fromdefault values of parameters published by the United Nations Framework Convention on Climate Change, thermal efficiency of ICS andstatistical data obtained from study area as shown in the table below.

Table 4.6: Parameters and their Values

Paramters	Desciption of Quantity	Value	Source
$F_{NRB,v}$	Fraction of non-renewable biomass for Nigeria	93%	https://cdm.unfccc.int/Panels/ssc_wg/meetings/037/ssc_37_an14.pdf [11]
$NCV_{Biom.}$	Net Calorific Value of Biomass	15MJ/kg	https://cdm.unfccc.int/methodologies/DB [12]
EF_{Pff}	Emission factor of projected fossil fuel	81.6 tCO2/TJ	https://cdm.unfccc.int/methodologies/DB
B_{old}	Average charcoal consumption	Calculated	Survey data
η_{old}	Thermal efficiency of traditional charcoal stove	11.46%	Adeyemi (2010)
η_{New}	Thermal efficiency of improved charcoal stove	35%	WBT results

The population of Bauchi State is 4,653,066 (NPC, 2006 census)and with a growth rate of 3.2%, population is estimated at 5,931,594 in 2015. Total number of regular households is 847,731. More than 90% of the household depend on biomass for their daily cooking. Average daily charcoal consumption per household is 0.64kg in urban areas and 4.353kg in the rural areas (Adeyemi and Asere, 2007). Annual average charcoal consumption per household is estimated as 1.588tonnes per charcoal stove. The baseline consumption for charcoal, B_{old}, therefore becomes::

B_{old} =Number of appliance x estimated average annual consumption of charcoal per appliance

= 762,958 x 1,588

=1.21Million tonnes of charcoal

Biomass saved from the use of improved charcoal stove

$$B_{v.Savinas} = B_{old} * (1 - \eta_{old}/\eta_{New}) = 0.83 \text{ Millions tonnes of Biuomas}$$

$$B_{v.Savinas} = B_{y.Savings} * (F_{NRB.v} * NCV_{Biom.} * EF_{Pff}) = 0.94 * 10^{06}\ tCO_2e$$

5 CONCLUSION

This research work has looked into the biomass that can be saved by the use of ICS. The Biomass saved translates directly to carbon savings that can mitigate the effects of climate change. The thermal analysis was aimed at determining the thermal efficiency of the ICS as compared to the traditional charcoal stove as indicated in Table 4.6. The thermal efficiency of 35% (as analysed in the equations and tables above) showspossible reduction in the quantity of charcoal consumed for daily cooking. This is in comparison to the traditional stove with efficiency of 11.46% which was determined in previous work. The importance of this analysis is that the thermal performance of ICS is related to climate change mitigation.Sustainable development in the domestic energy sector by the use of ICS in households can be achieved if the biomass savings is converted to emission reductions. These reductions can be traded in what can be referred to as the carbon market as a CDM project. This would generate additional income and benefits for households and also mitigate the effects of climate change.

REFERENCES

Adeyemi, Kafayat (2010): Thermal Efficiency and Specific Fuel Consumption of Common Household Cookstoves in Bauchi. *Journal of Engineeringand Technology,*Vol 5 No 2.

Adeyemi, Kafayat&Asere, Abraham (2007): Domestic Energy Use Pattern in the North East. *Nigerian Journal of Solar Energy*, Vol 19 No 1 pp 68-73.

Al-Amin, Mohammed (2014): Domestic Energy Crisis and Deforestation Challenges in Nigeria. *Journal of Environment and Science.* www.iiste.org

Aprovecho Research Centre retrieved 12 Jan 2013 from www.aprovecho.org/lab/pubs/testing

Brendon et Al (2009): Household energy, indoor air pollution andchild respiratory health in South Africa, *Journal of Energy in Southern Africa*, Vol 20 No 1

CDM Benefits (2012) https://cdm.unfccc.int/about/dev_ben/index.html

IPCC fifth assessment Report, Climate Change 2014: Mitigation of Climate Change. http://www.ipcc.ch/report/ar5/wg3/

Keith Openshaw(2014), Energy Values of Unprocessed Biomass, Charcoal and other Biomass Fuels and their role in Greenhouse Gas Mitigation and Energy Use. *Advances in Environmental Science and Energy Planning. Pp 30 – 40.*

Morgan et al (2010): Stove Manufacturers Emissions and Performance Test Protocol (EPTP). Retrieved 10 Jan 2013 from https://cleancookstoves.org/binary-ata/DOCUMENT/file/000/000/73-1.pdf

Nigeria Over 167 Million Population: Implications and Challenges http://www.population.gov.ng/index.php/component/content/article/84-news/latest/106-nigeria-over-167-million-population-implications-and-challenges

Osita et al (2014**):** The effect of solid fuel use on childhood mortality in Nigeria: evidence from the 2013 cross-sectional household survey. http://www.ehjournal.net/content/13/1/113

UNFCCC: Default values of fraction of non-renewable biomassretrieved 17 Jan 2013 fromhttp://cdm.unfccc.int/DNA/fNRB/index.html

UNFCCC: Energy efficiency measures in thermal applications of non renewable biomass (AMS II.G version 4.0) Retrieved 2 Dec 2012 fromhttp://cdm.unfccc.int/methodologies/DB/REQC2MYZJJ6I7BC9SKCS32T2K87AOW.

2006 Population and Housing Census of the Federal Republic of Nigeria.http://www.population.gov.ng/images/Priority%20Tables%20Volume%20I-update.pdf

WHO (2012) Study Report

Definition of Terms/Symbols

BE	Energy benchmark
CCV	Char calorific value
C_C	Weight of container plus charcoal
FPc	Fire power of charcoal in cold start test
FPs	Fire power of charcoal in Simmer test
f_m	Quantity of charcoal consumed
f_i	Initial quantity of charcoal
f_f	Final quantity of charcoal
FP	Fire power of charcoal
f_d	Mass of equivalent dry fuel consumed
$f_{d,s}$	Mass of equivalent dry fuel consumed in Simmer test
f_b	Mass of dry fuel consumed
h_{th}	Thermal efficiency
$h_{th,hv}$	Thermal efficiency of the simmer test
$h_{th,c}$	Thermal efficiency for cold start test
$h_{th,hh}$	Thermal efficiency for hot start test
K	Weight of dry container
LHV	Lower heating value of charcoal
MC	Moisture content
$P_{w,i}$	Weight of pot + water;
$P_{d,i}$	Weight of empty pot
r_b	Burning rate

SE_r	Specific energy consumption
SC	Theoretical specific fuel consumption
SC_e	Effective specific consumption
$SC_{T,C}$	Temperature correlation specific consumption for cold start,
$SC_{T,h}$	Temperature correlation specific consumption for hot start,
$SC_{T,s}$	Temperature correlation specific consumption for simmer test,
SC_{LP}	Low power specific consumption,
T_b	Local boiling temperature
T_a	Reference air temperature
$T_{f,i}$	Temperature at finish
$T_{i,i}$	Temperature at start
T_b	Local boiling temperature
TDR	Energy turns down ratio
t_f	Stop or finish time
t_i	Start or initial time
$w_{b,s}$	Equivalent mass of water boiled in Simmer test.
w_v	Weight of water vaporized from all the pots
Δt	Time required toboil water in the pots
ΔC_c	Change in weight of container plus charcoal
Δt^T	Temperature correlation time to boil water in the pots
Δt_h	Duration of heating in hot start