CENTRE FOR RESEARCH IN ENERGY AND ENERGY CONSERVATION

Energy for generations

Fuel Use and Emissions Report for Canarumwe and Canamake Iviguruye Stoves

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EXECUTIVE SUMMARY

The Regional Testing and Knowledge Centre (RTKC) at the Centre for Research in Energy and Energy Conservation (CREEC) conducted stove performance tests on two stoves from the Netherlands Development Organisation (SNV), Rwanda.

The stoves were Canamake Iviguruye, which uses charcoal as fuel and Canarumwe which uses wood as fuel. The Canarumwe stove was integrated in a mud hearth following the stove manufacturer's guidelines which were provided by SNV Rwanda before the tests were conducted.

The purpose of the tests was to ascertain their performance in terms of fuel use, emissions and indoor emissions.

Physical descriptions of the stoves were done to be able to understand the stove design and how various parts may affect the overall stove performance.

A Water Boiling Test (WBT) was conducted three times on each stove, concurrently with an emissions test using the Portable Emissions Measurement System (PEMS) following the Water Boiling Test Protocol 4.2.2 and the Guidelines for testing charcoal stoves with WBT 4.2.2.

Real time emissions and indoor emissions of Carbon monoxide and Particulate Matter produced during the standard cooking process were measured and logged by the Portable Emissions Measurement System. Fuel use and thermal efficiency were also determined during the Water Boiling Test.

The test results were evaluated based on only three IWA Metrics and Tiers of performance (Fuel use/Efficiency, Emissions and Indoor emissions) set by the Global Alliance for Clean Cookstoves and the Partnership for Clean Indoor Air. The stoves were assigned a Tier of one to four for fuel use and efficiency, emissions and indoor emissions with each tier representing a comparison to baseline or three-stone open fire. Tier 0 represents no improvement over traditional open fire/baseline, and Tier 4 represents stretch goals for improved cookstoves to target ambitious health and environmental outcomes. The remaining tiers fall on the spectrum between Tiers 0 and 4.

Canamake Iviguruye stove was placed in tier 3 for Efficiency/Fuel use which indicates the currently achievable technology for biomass cookstoves. For emissions the stove was put in tier 0 which indicates no improvement over the baseline. Indoor emissions also put the stove

in tier 0 which indicates no improvement over the base line.

High carbon monoxide emissions affected the overall performance of the stove in terms of emissions and indoor emissions. This is attributed to insufficient air supply to the charcoal in the combustion. Therefore there is a need to improve proper air supply to charcoal in the combustion chamber such that there is complete oxidation which will reduce high Carbon monoxide emissions. It should however be noted that most charcoal stoves fail to reduce carbon monoxide emissions. This calls for a wide research to find better ways of how carbon monoxide emissions from charcoal burning stoves can be reduced.

The Canarumwe stove was placed in tier 1 for fuel use which indicates a measurable improvement over the traditional open fire. High fuel use resulted from high mass earth body that surrounds the stove. During stove operation, significant energy is needed to warm the stove which wastes the energy that should have otherwise been used to cook.

For emissions the stove was put in tier 0 and this resulted from high emissions at low power phase. During the low power phase, less energy is needed to keep water a few degrees below the boiling point. This reduces temperatures in the combustion chamber affecting the combustion efficiency of the stove hence resulting to high emissions of carbon monoxide and particulate matter. The stove was put in tier 1 for indoor emissions which indicates a measurable improvement over the traditional open fire. This was due to high carbon monoxide emissions and Particulate matter which shows incomplete combustion of gases in the combustion chamber of the stove resulting from poor air supply.

There is a need to improve the insulation of Canarumwe stove in order to reduce the heat that is wasted heating the cold stove body. This would increase thermal efficiency as well as reducing fuel use. Using a grate under the fire would increase air supply to the wood and the charcoal in the combustion chamber hence increasing combustion efficiency reducing the particulate matter and carbon monoxide emissions.

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LIST OF ACRONYMS

Avg	Average
CEDAT	College of Engineering, Design, Art and Technology
CO	Carbon monoxide
CoV	Coefficient of Variation
CREEC	Centre for Research in Energy and Energy Conservation
IAP	Indoor Air Pollution
ISO	International Standards Organisation
IWA	International Workshop Agreement
PATS	Particle and Temperature Sensor
PEMS	Portable Emission Measurement System
PM	Particulate Matter
RTKC	Regional Testing and Knowledge Centre
SNV	Netherlands Development Organisation
SUMS	Stove Use Monitoring System
WBT	Water Boiling Test

1. INTRODUCTION

1.1 About CREEC

The Centre for Research in Energy and Energy Conservation (CREEC) is a not-for-profit organization whose mission is “to enhance access to modern types of energy in East Africa through research, training and consultancy. CREEC is located at the College of Engineering, Design, Art and Technology (CEDAT), Makerere University, Kampala Uganda. The centre focuses on the following thematic areas: i.e. Rural Electrification, Energy for Productive Use, Energy Efficiency, Energy for Household Use, Energy Testing Services and Energy Entrepreneurship.

CREEC is a partner to the Global Alliance for Clean Cookstoves (GACC), a “public-private partnership that seeks to save lives, improve livelihoods, empower women, and protect the environment by creating a thriving global market for clean and efficient household cooking solutions[1].”

CREEC has an independent **Regional Testing and Knowledge Centre** (RTKC)[2] for biomass cookstoves and fuels, offering stove and fuel testing services to stove manufacturers and promoters, using globally accepted testing procedures. The stove tests conducted at CREEC include: Water Boiling Tests, Controlled Cooking Tests, Stove Safety Tests, and Emission Tests for Indoor Air Pollution (IAP). Fuel tests include: Calorific Value or Energy content tests, moisture content, ash content.

The Regional Testing Centre and Knowledge Centre is equipped with a Portable Emission Measurement System (PEMS), equipment used to measure and analyze emissions from cookstoves. The PEMS measures real-time emissions of Carbon dioxide, Carbon monoxide, and Particulate matter. It also measures the flow rate of the diluted exhaust gases, enabling mass-based calculations of the emissions during the test, from which combustion efficiency can be deduced. The testing centre is equipped with other equipment to enable determination of stove performance and support of stove producers in designing better stoves. These include; Stove Use Monitoring System (SUMS), Particle and Temperature Sensors (PATS), Lascar Carbon Monoxide Sensor and other measurement equipment.

[1] www.cleancookstoves.org
[2] www.stovetestingafrica.com

1.2 Relevance of stove testing

Stove performance varies greatly between stoves, and the performance of a specific stove is often different in the laboratory and in the field. Testing gives the performance of the stove under controlled conditions which gives a potential performance for that stove under best practices. Testing stove performance allows implementers to learn how well stoves perform and to quantify improvements in fuel efficiency and emissions. Test results can be used to guide implementation decisions and to improve stove design and performance. Stove performance is evaluated using parameters like thermal efficiency, fuel consumption, time taken to perform a specific cooking task, emission of pollutants like carbon monoxide (CO) and particulate matter (PM), and safety to the user.

1.3 Standard procedures

CREEC tests stoves following procedures recognized by the Global Alliance for Clean Cooking (GACC). These procedures include: the Water Boiling Test protocol version 4.2.2, Guidelines for testing charcoal stoves with WBT 4.2.2, the Biomass Stove Safety Protocol, the Kitchen Performance Test Protocol and the Controlled Cooking Test Protocol.

1.4 Stove performance tests

Water Boiling Test (WBT): The WBT is a test in which the performance of a stove is evaluated through the heating of a known quantity of water across a specified range of temperature following a defined protocol. The following parameters are measured during a WBT: thermal efficiency, specific fuel consumption, time to boil, burning rate, turn-down ratio and fire power. The test reveals the technical performance of a stove, not necessarily what it can achieve in real households.

Controlled Cooking Test (CCT): The CCT is a field test that measures performance of an improved stove in comparison to the traditional stove that the improved stove is meant to replace. Stoves are evaluated based on a standard cooking task that is closer to the cooking that local people do every day (Bailis, 2004). The results relate to specific fuel consumption, speed of cooking and user satisfaction.

Kitchen Performance Test (KPT): The KPT is a field test used to evaluate stove performance in real-world settings. It is designed to assess actual impacts of an improved stove on household fuel consumption. KPTs are typically conducted in the course of an actual dissemination effort with real populations cooking normally, and it gives the best indication of real world changes.

Safety test: The safety test evaluates harmful factors that may result from cookstove use like burns, scalds, cuts and loss of property. A safety test encourages stove designers and manufacturers to consider safety concerns when designing a stove.

Emissions and indoor emissions test: An emissions test is intended to measure the total gases and particles that are emitted by the cookstove during a standard cooking task.The test helps to determine if the implementation of a specific type of improved stove might reduce harmful emissions and its impacts on the environment. Indoor emissions refer to the rate of gaseous and particulate emissions. Indoor emissions are related to the indoor air pollution that is caused by stove use. The test helps to determine if the implementation of a specific type of improved stove might reduce indoor air pollution and the impacts of the stove on the health of the users.

1.5 Task overview

Three cookstoves i.e. one Canamake Iviguruye charcoal stove and two Canarumwe firewood stoves were delivered at CREEC-RTKC by SNV Rwanda. Preliminary laboratory tests in terms of fuel use and emissions tests were conducted on only one Canarumwe firewood stove and the Canamake charcoal stove. The Canarumwe firewood stove was integrated in a mud hearth as requested by the SNV Rwanda following the guidelines *(Canarumwe Users Guide)* provided by SNV Rwanda before testing commenced.

2. MATERIALS AND METHODS

2.1 Laboratory conditions

The tests were performed at CREEC Regional Knowledge and Transfer Centre (RTKC) at an altitude of 1240m above sea level. The measured local boiling point was 95.1^{o} C

2.2 Materials

2.2.1 Pot

A flat-bottomed aluminium pot with capacity of 7L and a diameter of 27 cm with a height of 12 cm was used for all the tests.

2.2.2 Fuel

Firewood used consisted of sticks (3cm x 3 cm x 30 cm on average) of air-dried *Eucalyptus grandis* with measured14% moisture content and measured gross calorific value of 19,373.22 KJ/kg.

Lump wood charcoal produced from same species and sourced from one supplier with measured moisture content of 4.2% and measured gross calorific value of 30,759.45 KJ/kg was used.

2.2.3 Auxiliary equipment

The additional equipment used include: a 30kg capacity digital weighing scale and a wood moisture meter.

Figure 1: Auxiliary equipment used: Digital weighing scale (left) and Moisture Meter (right)

2.3 Stove description

Stove description makes it possible to understand well the physical design of the stove and how each part may affect the general stove performance. Also it allows identifying or classifying the stove at a later stage for re-testing. The stoves were described following a procedure developed at CREEC-RTKC.

The following parameters were measured or analyzed for each stove:

- Shape
- Fuel used
- Height above ground
- Diameter at the top and bottom
- Fuel inlet size
- Number, size and shape of stove supports
- Nature of pot stands
- Nature of stove insulation
- Combustion chamber size
- Grate material and description
- Any other features

2.4 Water Boiling Test (WBT)

Each stove was tested three times. The Canarumwe stove was tested following the Water Boiling Test (WBT) protocol version 4.2.2 (GACC, 2013)[3] whereas the Canamake Iviguruye was tested following the guidelines for testing charcoal stoves with WBT 4.2.2, released on June 14, 2013.The WBT has three phases described below:

1. High-power cold-start: Five litres of water were brought to a boil in a 7 litre pot using a stove at ambient temperature.
2. High-power hot-start: Five litres of water were brought to a boil in a 7 litre pot using a pre-heated stove.
3. Low-power simmering: The water temperature is kept at about 3° C below boiling point for 45 minutes.

2.5 Emissions test

The emissions test was done simultaneously with the Water Boiling Test (WBT). A Portable Emissions Measurement System (PEMS) was used to measure real-time emissions of carbon monoxide (CO) and total suspended particulate matter (PM) throughout the WBT.

The PEMS consists of a hood, a blower and flow measurement system, a sampling system for the emissions, a real-time data acquisition system, and a logging and analysis software (Aprovecho Research Centre, 2011). The PEMS measures real time emissions of carbon

[3] WBT 4.2.2 was released on 22nd April, 2013, and is available at: http://community.cleancookstoves.org/files/405

monoxide (CO) and the total suspended particulate matter (PM).

Figure 2: Canarumwe stove under the PEMS hood for WBT, Emissions and indoor emissions test.

2.6 Analysis of results

Of the four stove performance indicators developed by the International Standards Organization (ISO)/International Workshop Agreement (IWA) only three were used to summarize the results. The indicators, each derived from a set of metrics, include: fuel use and efficiency, emissions, indoor air emissions and safety (Table 1).

Table 1: Performance indicators and respective metrics

Performance indicator	**Metrics**	**Units**
Efficiency/Fuel Use	High power Thermal Efficiency	%
	Low power Specific Consumption	MJ/min/L
Emissions	High power CO	g/MJ_d
	Low power CO	g/min/L
	High power PM	mg/MJ_d
	Low power PM	mg/min/L
Indoor emissions	Indoor emissions CO	g/min
	Indoor emissions PM	mg/min

Basing on the results, the stoves were categorised under different tiers of performance according to ISO/IWA guidelines *(see Appendix 4)*, as follows:

For fuel use, emissions and indoor emissions, a rating (called a sub-tier) was assigned to each of the performance metrics under a given performance indicator. Based on the sub-tier values of the metrics under a given performance indicator, an overall Tier was assigned to that particular performance indicator. Tiers are determined using the lowest value of the sub-tiers. The Tiers are explained in Table 2 below.

Table 2: Tier levels and their explanations

Tier	Explanation
Tier 0	No improvement over open fire / baseline
Tier 1	Measurable improvement over baseline
Tier 2	Substantial improvement over baseline
Tier 3	Currently achievable technology for biomass stoves
Tier 4	Stretch goals for targeting ambitious health and environmental outcomes

(Source: PCIA/GACC, 2012)

3. RESULTS

3.1 CANAMAKE IVIGURUYE

3.1.1 Stove description for Canamake Iviguruye

Figure 3: Canamake Iviguruye

The Canamake Iviguruye stove shown in figure 3 above is metal cladded, hour glass in shape, has a ceramic liner surrounded by an insulation layer and uses charcoal as fuel. The stove has a hinged door which fits properly when closed and has nineteen air holes on the grate surface and two handles located on the upper part of the stove. The stove has three stands located on the bottom surface of the stove and three pot stands located on the top of the combustion chamber and they extend into the combustion chamber. Table 3 below shows the measurable physical dimensions of the stove.

Table 3: Measurable physical dimensions of Canamake Iviguruye stove

Parameters	**Value (Cm)**
Top diameter	31
Bottom diameter	32
Middle diameter	21
Thickness with insulation layer	4
Combustion chamber top diameter	23
Combustion chamber bottom diameter (grate)	17

Pot rest height	1
Pot rest extension to the stove	5
Air hole	1.5
Stove height above the ground	21.5
Stove stands	1
Height of air gap	8
Length of air gap	10.5
Length of door	15
Height of door	9
Width of handles	4
Length of handles	10.3

3.1.2 IWA performance results

Table 4: IWA performance results for Canamake Iviguruye stove

		Metric	Value	Unit	Sub-Tier
Efficiency/Fuel Use					
Tier	**3**	High power Thermal Efficiency	37.1	%	3
		Low power Specific Consumption	0.017	MJ/min/l	4
Emissions					
Tier	**0**	High power CO	27.93	g/MJ_d	0
		Low power CO	0.18	g/min/l	1
		High power PM	8.1	mg/MJ_d	4
		Low power PM	-0.01	mg/min/l	4
Indoor emissions					
Tier	**0**	Indoor emissions CO	2.05	g/min	0
		Indoor emissions PM	0.4	Mg/min	4

3.2 CANARUMWE

3.2.1 Stove description for Canarumwe

Figure 4: Canarumwe stove (left) before and after (right) it was integrated in the mud hearth

The Canarumwe is a ceramic stove which uses fuel as wood. The stove has three pot stands located on the top of the combustion chamber and they extend inside the combustion chamber. The stove was integrated in the mud hearth before testing commenced as recommended by the client (SNV Rwanda); however the stove was described before it was integrated in the mud hearth as shown in figure 4 above. Table 5 below shows the measurable parameters of the Canarumwe stove.

Table 5: Measurable physical dimensions for Canarumwe

Parameters	**Value (Cm)**
Top diameter	28
Bottom diameter	21.5
Combustion chamber top diameter	21.5
Combustion chamber bottom diameter	16
Pot rest height	2
Pot rest extension to the stove	10
Stove height above the ground	21.5
Height of wood inlet	11.5
Length of wood inlet	10

3.2.2 IWA performance results

Table 6: IWA performance results for Canarumwe

		Metric	Value	Unit	Sub-Tier
Efficiency/Fuel Use					
Tier	**1**	High power Thermal Efficiency	26.3	%	2
		Low power Specific Consumption	0.04	MJ/min/l	1
Emissions					
Tier	**0**	High power CO	10.82	g/MJ_d	2
		Low power CO	0.22	g/min/l	0
		High power PM	131.23	mg/MJ_d	3
		Low power PM	1.39	mg/min/l	3
Indoor emissions					
Tier	**1**	Indoor emissions CO	0.83	g/min	1
		Indoor emissions PM	8.16	Mg/min	2

4. DISCUSSION OF RESULTS

The measured data was checked, verified and the Coefficient of Variation (CoV) done across the three tests for each stove to make sure the results were consistent and were true results obtained from the stove performance tests. The recommended limit for CoV on fuel use/Efficiency and bench mark values is 25%. However, Variability in emissions may be higher. *(Reference: Water Boiling Test, version 4.2.2, page 57).* Most of the parameters showed no variations except on emissions and indoor emissions.

4.1 Canamake Iviguruye

4.1.1 Fuel use/efficiency

In terms of high power thermal efficiency, the canamake iviguruye stove was placed into sub tier 3 which indicates the currently achievable technology for biomass stoves. The stove's ability to have 37% high power thermal efficiency is attributed to good air supply facilitated by the air holes in the grate. The air holes have a good diameter which facilitates good air flow to the charcoal. The stove has good insulation which reduces heat loss before it makes it to the pot. The design of the pot rests which extend towards the combustion chamber leaves a good gap to pot distance which facilitates proper heat transfer from the combustion chamber to the pot.

The stove used 0.017MJ/min/L at Low power/simmering as the specific fuel consumption which placed it into tier 4 which is the stretch goals for targeting ambitious health and environmental outcomes. This indicates the stove's ability to use very little charcoal at simmering hence reducing fuel use as well as emissions. This performance is attributed to good insulation which reduces heat loss thus retaining some heat which is eventually used to keep water at 3^{o}C below the boiling point throughout the simmering phase thus reducing overall fuel consumption at low power phase. The combination of efficiency and fuel use therefore placed the stove in tier 3 which is the currently achievable technology for biomass stoves compared with the traditional stoves.

4.1.2 Emissions and indoor emissions

The stove was placed into tier 0 in terms of emissions which combine high power CO, low power CO, low power PM and high power PM indicating no improvement over the baseline.

Indoor emissions, both CO and PM put the stove in tier 0 indicating no improvement over the baseline.

Charcoal stoves' ability to reduce Carbon monoxide emissions and indoor emissions is still a very big challenge. In reference to most of the stoves tested at CREEC-RTKC, most of the charcoal stoves are usually between Tier 0 and Tier 1.

Carbon monoxide is produced as a result of partial oxidation of carbon containing compounds (charcoal) when there is limited supply of oxygen to produce carbon dioxide (CO_2). CO emissions in this case could be attributed to improper air mixing in the combustion chamber mostly at the top of charcoal hence emitting CO gas before it is completely combusted.

For PM emissions, charcoal stoves significantly reduce PM emissions except when the charcoal is not fully carbonized or during the lighting phase. Therefore most charcoal stoves are in sub tier 4 for both emissions and indoor emissions due to low emission levels or no emissions emitted during the cooking process.

4.2 Canarumwe

4.2.1 Fuel use/efficiency

In terms of high power thermal efficiency, the stove was placed into sub-tier 2 which indicates a substantial improvement over the baseline/traditional open fire. High power thermal efficiency of 26.3% implies that some heat produced by the stove is wasted before it makes it to the pot. This could be due to cold high mass mud hearth body surrounding the stove which consumes the heat before it goes to the pot. Poor insulation also contributes to heat loss to the stove body hence reducing thermal efficiency hence increasing fuel use.

The stove used 0.04 MJ/min/l as low power specific fuel consumption and thus was placed in sub-tier 1 which indicates a measurable improvement over the baseline. Usually the stoves with high mass body do well at simmering phase. However the results show that the stove consumed a lot of fuel at simmering phase and this is because the heat is lost to the cold body of the stove rather than retaining it in the combustion chamber thus using a lot of fuel. Heat loss is due to poor insulation of the stove.

The combination of efficiency and fuel use therefore placed the stove into tier 1 which indicates a measurable improvement over the baseline/traditional open fire.

4.2.2 Emissions and indoor emissions

The stove was placed into tier 0 in terms of emissions which combine high power CO, low power CO, low power PM and high power PM indicating no improvement over the baseline.

Indoor emissions, both CO and PM put the stove in tier 1 indicating a measurable improvement over the baseline/traditional open fire.

Improved wood stoves usually emit low levels of CO. According to results, the CO emissions were high especially at Low power and this could be attributed to poor air supply, poor-fuel air contact and reduced temperatures in the combustion chamber. However, for PM emissions the stove was placed in sub-tier 3 both at High power and Low power PM which indicates the currently achievable technology for biomass stoves as far as reducing PM emissions is concerned when compared with the baseline/traditional open fire.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

5.1.1 Canamake Iviguruye

According to the test results, the stove was placed in tier 3 for fuel use and efficiency indicating the currently achieved technology for biomass stoves. This was attributed to good insulation which reduces heat loss to the stove body but rather transfers it to the pot eventually reducing fuel use.

In regards to both emissions and indoor emissions the stove was placed in tier 0 which indicates no improvement over the baseline and the major reason is due to high CO emissions which are a typical characteristic of charcoal stoves. However for PM, the emissions were very low. PM emissions arose only at the lighting phase and no emissions were emitted throughout the testing process. However it should be noted that charcoal stoves do not emit PM unless the charcoal used is not fully carbonized.

Generally for Canamake stove, research aiming at the reduction of CO emissions would greatly improve the performance of the stove in terms of emissions and indoor emissions. More improvement on insulation is still necessary such that the efficiency of the stove can be improved up to tier 4. This would reduce heat loss to the stove body eventually reducing fuel use.

5.1.2 Canarumwe

The Canarumwe stove was placed in tier 1 for fuel use and efficiency which indicates a measurable improvement over the baseline. This low heat transfer is attributed to the mud hearth surrounding the stove which makes it cold that it takes too much fuel to first heat the stove body before it starts cooking. Poor air supply in the combustion chamber reduces the flame temperature hence reducing the heat transfer efficiency and combustion efficiency. This in turn contributed to high levels of CO and PM emissions which placed the stove in tier 0 for emissions and tier 1 for indoor emissions.

Improvements on Canarumwe should focus on insulation to prevent heat loss to the stove body and also an improvement on proper air supply to the burning wood in the combustion chamber would greatly improve the stove performance for efficiency/fuel use, emissions and indoor emissions.

5.2 RECOMMENDATIONS

5.2.1 Canamake Iviguruye charcoal stove

The stove's insulation should be improved. Better insulation would increase thermal efficiency /fuel use. Proper insulation also reduces heat transfer to the stove surface. This would reduce the risks of burns to the users.

Secondary air holes could be added on top of the combustion chamber to facilitate proper air mixing to the charcoal. This could reduce High CO emissions. Research should be carried out on the most efficient ways of reducing CO emissions since it is still a big challenge to most of the charcoal stoves.

The handles should be insulated to reduce the risk of burns to the user. Well insulated handles facilitate proper handling of the stove since the risk of burns is minimized.

5.2.2 Canarumwe wood stove

The stove should be well insulated. Proper insulation reduces heat loss to the stove body hence increasing thermal efficiency as well as reducing fuel use.

Whereas earth reduces heat transfer to the surrounding stove surface which is good for the safety of the stove user, the use of earth around the combustion chamber consumes most of the heat produced by the stove hence affecting the combustion. There is thus a need to strike a balance between safety, fuel use and emissions. Adding insulation between the liner and the earth could solve this issue.

The combustion chamber of the stove is wide and thus should be reduced. A big combustion chamber leads to accumulation of cold air reducing the draft which eventually lowers the temperature in the combustion chamber hence resulting in too much PM and CO emissions. A big combustion chamber also prompts the user to use too much fuel than required for a specific cooking task. A grate should be used to lift the burning sticks up off the ground so that air can pass under the sticks and through the charcoal. This increases combustion efficiency hence reducing PM and CO emissions as well as increasing the draft which also improves thermal efficiency.

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7. APPENDICES

Appendix 1: Glossary of terms

Charcoal—The black, porous material that contains mostly carbon that is produced by burning of wood or other biomass.

Combustion chamber—The region of the stove where the fuel is burned.

Combustion efficiency—The percentage of the fuel's heat energy that is released during combustion. Combustion efficiency refers to the amount of the energy from the biomass that is turned into heat energy.

Draft—The movement of air through a stove and up a chimney.

Emissions—The byproducts from the combustion process that are discharged into the air.

Grate—A framework of bars or mesh used to hold fuel or food in a stove, furnace, or fireplace.

High mass stove—A stove made of uninsulated earth, clay, cast iron, or other heavy material that requires significant energy to be warmed during stove operation.

High power—A mode of stove operation where the objective is to boil water as quickly as possible; the highest power at which a stove can operate.

Indoor emissions—The rate of gas and particle emissions produced by the cookstove during a specific standard cooking task that a user may be exposed to which may affect the users' health.

Low power—A mode of stove operation where the objective is to simmer the water or food product; the lowest power at which a stove can operate and still maintain a flame and simmer food.

Retained heat—Heat energy that warms the enclosures around the fire that does not escape to the surroundings.

Specific fuel consumption—The fuel required to produce a unit output. In this case, the low-power specific consumption is a measure of the amount of fuel required to simmer one liter (or one kilogram) of water**.**

Thermal efficiency—Thermal efficiency is a measure of the fraction of heat produced by the fuel that made it directly to the water in the pot. The remaining energy is lost to the environment.

Appendix 2: Combined IWA performance test results for Canamake Iviguruye

IWA Performance Metrics	units	Test 1	Test 2	Test 3	Avg	STDEV	CoV
High Power Thermal Efficiency	%	38.8%	35.2%	37.3%	**37.1%**	0.02	5%
Low Power Specific Consumption Rate	MJ/min/L	0.018	0.015	0.018	**0.02**	0.00	8%
High Power CO	g/MJ_d	25.77	27.10	30.91	**27.93**	2.67	10%
Low Power CO	g/min/L	0.18	0.18	0.17	**0.18**	0.01	4%
High Power PM	mg/MJ_d	10.6	9.1	4.6	**8.11**	3.10	38%
Low Power PM	mg/min/L	-0.01	-0.02	0.00	**-0.01**	0.01	-100%
Indoor Emissions CO	g/min	2.08	1.97	2.10	**2.05**	0.07	3%
Indoor Emissions PM	mg/min	0.6	0.5	0.2	**0.44**	0.19	43%

Appendix 3: Combined IWA performance test results for Canarumwe stove

IWA Performance Metrics	units	Test 1	Test 2	Test 3	Avg	STDEV	CoV
High Power Thermal Efficiency	%	27.5%	25.9%	25.3%	**26.3%**	0.01	4%
Low Power Specific Consumption Rate	MJ/min/L	0.041	0.036	0.042	**0.04**	0.003	9%
High Power CO	g/MJ_d	10.02	10.67	11.78	**10.82**	0.89	8%
Low Power CO	g/min/L	0.21	0.21	0.24	**0.22**	0.01	7%
High Power PM	mg/MJ_d	88.5	138.1	167.0	**131.23**	39.69	30%
Low Power PM	mg/min/L	1.25	1.10	1.83	**1.39**	0.38	28%
Indoor Emissions CO	g/min	0.79	0.82	0.89	**0.83**	0.06	7%
Indoor Emissions PM	mg/min	5.6	9.1	9.7	**8.16**	2.23	27%

Appendix 4: Values of performance metrics used to categorize stoves

Performance indicator	IWA VITA WBT Tiers	units	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4
Efficiency/Fuel Use	High Power Thermal Efficiency	%	<0.15	≥0.15	≥0.25	≥0.35	≥0.45
	Low Power Specific Consumption	MJ/min/L	>0.05	≤0.05	≤0.039	≤0.028	≤0.017
Emissions	High Power CO	g/MJd	>16	≤16	≤11	≤9	≤8
	Low Power CO	g/min/L	>0.2	≤0.2	≤0.13	≤0.1	≤0.09
	High Power PM	mg/MJd	>979	≤979	≤386	≤168	≤41
	Low Power PM	mg/min/L	>8	≤8	≤4	≤2	≤1
Indoor emissions	Indoor Emissions CO	g/min	>0.97	≤0.97	≤0.62	≤0.49	≤0.42
	Indoor Emissions PM	mg/min	>40	≤40	≤17	≤8	≤2
	Safety	Points	<45	≥45	≥75	≥88	≥95