



INSTITUTE OF INDUSTRIAL RESEARCH (CSIR)

COOKMATE STOVE PERFORMANCE REPORT

REQUESTING INSTITUTION:	COOKCLEAN (GHANA) LTD.
NAME OF EQUIPMENT:	COOKMATE CHARCOAL STOVE
TEST NUMBER OR CODE	CSIR-RTKC/2015/003
FUEL TYPE:	CHARCOAL
MANUFACTURER:	COOKCLEAN GHANA LIMITED
AMBIENT CONDITIONS:	<i>Air Temperature: 31.2°C</i> <i>Relative Humidity: <68.2%RH</i> <i>Local boiling point 100 °C</i>
TEST METHOD USED:	<i>Water Boiling Test Method</i> Version 4.2.3

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January, 2015

**PERFORMANCE TESTS EVALUATION OF
COOKMATE CHARCOAL STOVE**

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JANUARY, 2015

Executive Summary

This report presents Water Boiling Tests (WBT) on CookMate improved charcoal cookstove. The test was carried out at CSIR - Institute of Industrial Research Regional Testing and Knowledge Centre at the request of COOKCLEAN Ghana Limited. The WBT involved heating water to boiling point at high power test, for cold and hot start then simmering for 45 min where emissions (CO_2 , CO and $\text{PM}_{2.5}$) were simultaneously measured using the Laboratory Emissions Monitoring System (LEMS).

A newly manufactured charcoal cookstove by COOKCLEAN Ghana Limited was tested in the hood under standard protocol. The raw data obtained was from the Sensor Box and calculations based on the WBT version 4.2.3 software.

The average time to boil 5L water was 46.7 and 35.7 min for high power cold start and high power hot start respectively. Average burning rates for cold start, hot start and simmer were 5.09, 5.56 and 1.48 g/min respectively with corresponding average thermal efficiencies of 24.4, 26.99 and 24.8%. The average specific fuel consumptions for cold start, hot start and simmer were 49.1, 40.8 and 14.7 g/litre respectively with corresponding average fire powers of 2380.9, 2604 and 694.8 watts given a turn down ratio of 4.64.

Under the IWA metrics, the high power thermal efficiency and low power specific fuel consumption rate were determined to be 25.7% and 9.2 kJ/min/L respectively. High power and low power COs were 31.68 g/MJ_d and 0.106 g/min/L respectively while high power and low power $\text{PM}_{2.5}$ were 440337 mg/MJ_d and 1219.3 mg/min/L respectively.

The energy consumption rates at cold start, hot start and simmer were 142.9, 156.2 and 41.7 kJ/min respectively with corresponding specific energy consumption rates of 29.6, 32.2 and 9.2 kJ/min/L. The total energy consumed at cold start, hot start and simmer were 6589.6, 5594.2 and 1289.4 kJ respectively with corresponding energy delivered to the pot to be 1623.9, 1495.7 and 614.1 kJ. The average cooking power for cold start, hot start and simmer were 0.567, 0.665 and 0.228 kW respectively.

The average global warming impact was 980.34 gCO₂e and results for the Efficiency/Fuel and Emissions use in terms of Tiers was 2.0 and 1 respectively. This showed an improvement in the stove efficiency design as compared to the traditional coal pot.

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1.0 Introduction

1.1 About CSIR

The Council for Scientific and Industrial Research (CSIR) is a semi-autonomous Organisation with the mandate to pursue the implementation of government policies on scientific research and development, encourage coordination of scientific research for the management, utilization and conservation of the natural resources of Ghana; and to advise Government on scientific and technological advances likely to be of importance to national development.

Established in its present form in October 1968 as Ghana's premier S & T Research and Development organization, the CSIR now operates under the mandate of CSIR Act 521 of 1996, which among other things, empowers it to commercialize its research activities. The mission of CSIR as stated in its Strategic Plan is to become the force of accelerated social and economic development of Ghana through examining, exploring and creating science and technology catalysts for public and private wealth creation. The CSIR oversees 13 research institutes of which Institute of Industrial Research (IIR) is one.

1.2 The Institute of Industrial Research (IIR)

The Institute of Industrial Research among its duties assists in poverty reduction through the creation of opportunities for generating and increasing incomes within industries, contribute towards food security, generate foreign exchange earnings and apply cost-effective industrial technologies that are both environmentally friendly and commercially viable. The Regional and Knowledge Testing Centre (Ghana) has been established at the Institute where cookstoves are tested in the Laboratory Emission Monitoring Systems (LEMS).

The Institute of Industrial Research projects include the following:

- Mitigation of the global warming problem (CO₂), reduction of atmospheric load including NO_x and SO_x
- Higher efficiency of Ghana's energy utilization and to reduce energy waste in institutions

1.3 Description of Improve Stove:

Stove Name	:	CookMate Improve Charcoal Stove
Designer	:	CookClean Ghana Limited
Age at time of testing	:	Brand New
Material of construction	:	Mild steel
Material and shape of combustion chamber	:	Mild steel and conical
Volume of combustion chamber	:	2114.4 cm ³
Average weights	:	5640 g

The cookstove of cylindrical shape was fabricated using mild steel plate with fabricated conical shape (fire grate) for the combustion chamber with series of perforated cylindrical holes at different pitch circle diameters. The charcoal is top-loaded onto the fire grate to fill the combustion chamber whose nominal diameter is 280 mm and cone height of 103 mm. Air is supplied to the combustion chamber through the front damper of the stove. The overall dimension (D x H) of the stove is 293 mm x 243 mm. The stove is presented in Figure 1.



Figure 1 CookMate Improved Charcoal Stove

1.4 Objective of the Test

The objective was to carry out Water Boiling Test (WBT) for the stove.

2.0 Materials and Methods

2.1 Materials

2.1.1 Fuel used

A biomass (charcoal produced from a neem tree (*Azadirachta indica*)) chopped in average dimensions of 5.4 cm x 3.8 cm x 2.9 cm, with a net calorific value of 28200 kJ/kg was used for the test.

2.1.2 Moisture content

The moisture content of the fuel was determined by pre-weighing samples and placing in an open air oven at 105°C for 2 hours. Samples were allowed to cool to room temperature in a desiccator and re-weighed. The percentage moisture content was determined as a ratio of the weight loss and the weight of the fuel when moist expresses as a percentage. The moisture content of the charcoal was determined to be 9.1%.

2.2 Methods

2.2.1 Ambient conditions

The stoves were tested in the LEMS which is well ventilated with no wind. The ambient conditions (room temperature and humidity) were determined with a digital hygroscopic meter HTC-2 and the average room temperature of 32.1 °C and relative humidity of 68.2% were recorded.

2.2.2 Experimental procedures

The testing methods followed the Water Boiling Test version 4.2.3 by boiling 5L of water a stainless steel pot with a capacity of 7 litres which weighed 1030g. As a standard testing protocol, three (3) replicate tests were conducted and the results generated from LEMS in-built software with WBT data calculation sheet were recorded and analysed.

3.0 Results and Discussions

The statistical average and summary of the CookMate stove test results have been presented in Appendix I and Appendix II depicts sample of live graphs for the stove.

3.1 Time to Boil

The results showed that the average time to boil 5L water using a 7 litre stainless steel pot was 46.7 and 35.7 min for high power cold start and high power hot start respectively.

3.2 Burning Rate

The average burning rates determined for high power cold start, high power hot start and simmering were 5.09, 5.56 and 1.48 g/min respectively.

3.3 Thermal Efficiency

The average thermal efficiencies determined for high power cold start, high power hot start and simmering were 24.4, 26.99 and 24.8% respectively.

3.4 Specific Fuel Consumption

The average specific fuel consumptions determined for high power cold start, high power hot start and simmering were 49.1, 40.8 and 14.7 g/litre respectively.

3.5 Firepower

The average fire powers of the stove determined for high power cold start, high power hot start and simmering were 2380.9, 2604 and 694.8 watts respectively with a corresponding turn down ratio of 4.64.

3.6 Equivalent of Dry Fuel Consumed

The equivalent of dry fuel consumed by the stove was determined to be 237.5, 197.4 and 66.8 g for high power cold start, high power hot start and simmering respectively.

3.7 Standard Performance Measures

For the standard performance measurement, it was determined that the fuel and energy used benchmark values for the stove were 307.3 g and 8627.9 kJ respectively. The CO, CO₂ and PM_{2.5} benchmark values were determined to be 74.6, 838.6 and 1000 g respectively with a time to boil to be 42.78 min.

3.8 IWA Performance Metrics

From the International Workshop Agreement metrics, the determined high power thermal efficiency and low power specific fuel consumption rate were 25.7% and 9.2 kJ/min/L respectively. High power and low power COs were determined to be 31.68 g/MJ_d and 0.106 g/min/L respectively while high power and low power PM_{2.5} were 440337 mg/MJ_d and 1219.3 mg/min/L respectively.

3.9 Energy Consumption

The energy consumption rates at cold start, hot start and simmer were 142.9, 156.2 and 41.7 kJ/min respectively with corresponding specific energy consumption rates of 29.6, 32.2 and 9.2 kJ/min/L. The total energy consumed at cold start, hot start and simmer were 6589.6, 5594.2 and 1289.4 kJ respectively with a corresponding energy delivered to the pot determined to be 1623.9, 1495.7 and 614.1 kJ. The average cooking power determined for cold start, hot start and simmering were 0.567, 0.665 and 0.228 kW respectively.

The average global warming impact was 980.34 gCO₂e and results for the Efficiency/Fuel and Emissions

used in terms of Tiers was 2.0 and 1 respectively. This means the stove efficiency has been improved as compared to the traditional coal pot.

4.0 Conclusions

The average time to boil 5L water was 46.7 and 35.7 min for high power cold start and high power hot start respectively. The average burning rates for cold start, hot start and simmer were 5.09, 5.56 and 1.48 g/min for respectively with corresponding average thermal efficiencies of 24.4, 26.99 and 24.8%. The average specific fuel consumptions determined for high power cold start, high power hot start and simmer were 49.1, 40.8 and 14.7 g/litre respectively with corresponding average fire powers of 2380.9, 2604 and 694.8 watts given a turn down ratio of 4.64.

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APPENDIX – I (Processed data for the stove)

Basic Operation	units	TEST 1	TEST 2	TEST 3	Ave	SD	COV (%)
COLD START							
Time to boil Pot # 1	min	47	46	47	46.667	0.5774	1.2372
Burning rate	g/min	5.6541	4.8071	4.8008	5.0873	0.4908	9.6477
Thermal efficiency	–	0.2351	0.2558	0.2413	0.2441	0.0106	4.3451
Specific fuel consumption	g/liter	55.231	45.587	46.603	49.141	5.2992	10.784
Temp-corrected specific consumption	g/liter	56.512	46.329	48.011	50.284	5.459	10.856
Firepower	watts	2646.1	2249.7	2246.8	2380.9	229.7	9.6477
Equivalent Dry Fuel Consumed	g	265.74	221.13	225.64	237.5	24.559	10.341
HOT START							
Time to boil Pot # 1	min	33	38	36	35.667	2.5166	7.0559
Burning rate	g/min	6.2511	5.0369	5.4045	5.5642	0.6226	11.19
Thermal efficiency	--	0.2688	0.2867	0.2543	0.2699	0.0163	6.0216
Specific fuel consumption	g/liter	42.377	39.426	40.435	40.746	1.4997	3.6805
Temp-corrected specific consumption	g/liter	43.717	40.506	45.331	43.185	2.4562	5.6876
Firepower	watts	2925.5	2357.3	2529.3	2604	291.4	11.19
Equivalent Dry Fuel Consumed	g	206.29	191.4	194.56	197.42	7.8418	3.9722
SIMMER							
Burning rate	g/min	2.7325	0.7706	0.9508	1.4846	1.0844	73.043
Thermal efficiency	--	0.4374	0.1628	0.1446	0.2483	0.164	66.072
Specific fuel consumption 45 min	g/liter	28.404	7.0613	8.6883	14.718	11.881	80.721
Firepower	watts	1278.8	360.65	444.97	694.81	507.51	73.043
Turn down ratio	--	2.1785	6.3871	5.3667	4.6441	2.1954	47.273
Equivalent Dry Fuel Consumed	g	122.96	34.678	42.786	66.808	48.799	73.043
IWA Performance Metrics							
High Power Thermal Efficiency	%	0.2519	0.2713	0.2478	0.257	0.0125	4.8686
Low Power Specific Consumption Rate	MJ/min/L	0.0177	0.0044	0.0054	0.0092	0.0074	80.721
High Power CO	g/MJ _d	32.732	25.783	36.531	31.682	5.4503	17.203
Low Power CO	g/min/L	0.2431	0.0422	0.0326	0.106	0.1188	112.14
High Power PM	mg/MJ _d	744081	301635	275297	440337	263379	59.813
Low Power PM	mg/min/L	1707.1	851.83	1098.8	1219.3	440.19	36.103
Indoor Emissions CO	g/min	1.3881	0.977	1.3164	1.2272	0.2196	17.894
Indoor Emissions PM	mg/min	30526	11270	9661.3	17152	11609	67.684
Standard Performance Measures							
Fuel to Cook 5L (850/1500)	g	392.59	252.39	276.8	307.26	74.901	24.377
CO to Cook 5L (20)	g	110.59	50.994	62.159	74.58	31.68	42.477
PM to Cook 5L (1500)	mg	2E+06	678369	666197	1E+06	580699	57.636
Energy to Cook 5L (15,000/25,000)	kJ	11024	7087.2	7772.5	8627.9	2103.2	24.377
Time to Boil	min	41.067	42.895	44.39	42.784	1.664	3.8894
CO ₂ to Cook 5L	g	1633.7	544.32	337.9	838.64	696.23	83.019

Energy Consumption

Net Calorific Value (dry)	kJ/kg	28080					
Moisture Content	%	0.091					

COLD START

Temp-Corrected Time to Boil	min	48.09	46.748	48.42	47.753	0.8857	1.8548
Energy Consumption Rate	kJ/min	158.77	134.98	134.81	142.85	13.782	9.6477
Temp-Corr Specific Energy Consumption	kJ/liter	1586.9	1300.9	1348.2	1412	153.29	10.856
Specific Energy Consumption Rate	MJ/min/L	0.033	0.0278	0.0278	0.0296	0.003	10.084
Dry Fuel Consumed		260.66	223.16	220.2	234.67	22.55	9.6089
Total Energy Consumed	kJ	7319.2	6266.3	6183.3	6589.6	633.19	9.6089
Energy Delivered to the Cooking Pot	MJ	1.7543	1.5882	1.5292	1.6239	0.1167	7.188
Average Cooking Power	kW	0.608	0.5662	0.5263	0.5668	0.0408	7.2011

HOT START

Temp-Corrected Time to Boil	min	34.044	39.041	40.359	37.815	3.3312	8.8094
Energy Consumption Rate	kJ/min	175.53	141.44	151.76	156.24	17.484	11.19
Temp-Corr Specific Energy Consumption	kJ/liter	1227.6	1137.4	1272.9	1212.6	68.97	5.6876
Specific Energy Consumption Rate	MJ/min/L	0.0361	0.0291	0.0315	0.0322	0.0035	10.904
Dry Fuel Consumed		208.16	193.16	196.34	199.22	7.9027	3.9668
Total Energy Consumed	kJ	5845.2	5424	5513.3	5594.2	221.91	3.9668
Energy Delivered to the Cooking Pot	MJ	1.5569	1.5411	1.3892	1.4957	0.0926	6.1887
Average Cooking Power	kW	0.7622	0.6579	0.5737	0.6646	0.0944	14.208

SIMMER

Energy Consumption Rate	kJ/min	76.728	21.639	26.698	41.688	30.45	73.043
Time-Corr Specific Energy Consumption	kJ/liter	797.59	198.28	243.97	413.28	333.6	80.721
Specific Energy Consumption Rate	MJ/min/L	0.0177	0.0044	0.0054	0.0092	0.0074	80.721
Dry Fuel Consumed	g	96.329	10.997	30.428	45.918	44.725	97.403
Total Energy Consumed	kJ	2704.9	308.78	854.4	1289.4	1255.9	97.403
Energy Delivered to the Cooking Pot	MJ	1.5101	0.1586	0.1737	0.6141	0.776	126.36
Average Cooking Power	kW	0.5593	0.0587	0.0643	0.2275	0.2874	126.36

Total Emissions**COLD START**

CO	grams	55.609	36.146	47.119	46.291	9.7581	21.08
CO ₂	grams	655.5	450.46	332.14	479.36	163.61	34.13
PM _{2.5}	mg	2E+06	506998	486112	874510	654720	74.867

HOT START

CO	grams	52.568	44.393	58.692	51.884	7.1742	13.827
CO ₂	grams	725.4	440.96	447.19	537.85	162.45	30.204
PM _{2.5}	mg	869921	437711	323272	543635	288307	53.033

SIMMER

CO	grams	47.357	9.3347	7.224	21.305	22.586	106.01
CO ₂	grams	797.02	83.563	-64.94	271.88	460.81	169.49
PM _{2.5}	mg	332559	188249	243501	254770	72612	28.58

High Power Average

These work only for Full WBTs

Time to Boil (temp-corrected)	min	41.067	42.895	44.39	42.784	1.664	3.8894
Temp-Corrected Specific Consumption	g/L	50.115	43.417	46.671	46.734	3.3491	7.1663
Temp-Corr Specific Energy Consumption	kJ/L	1407.2	1219.2	1310.5	1312.3	94.044	7.1663
Firepower	W	2785.8	2303.5	2388	2492.5	257.55	10.333
Thermal Efficiency	%	0.2519	0.2713	0.2478	0.257	0.0125	4.8686
Cooking Power	kW	0.6851	0.612	0.55	0.6157	0.0676	10.98
CO per MJ delivered to pot	g/MJ	32.732	25.783	36.531	31.682	5.4503	17.203
CO ₂ per MJ delivered to pot	g/MJ	419.8	284.89	269.55	324.75	82.673	25.458
PM _{2.5} per MJ delivered to pot	mg/MJ	744081	301635	275297	440337	263379	59.813
TOTAL GLOBAL WARMING IMPACT	g CO₂e	1843.8	641.21	456.01	980.34	753.5	76.861

APPENDIX V – Sample of live graphs for the stove

