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CENTRE FOR RESEARCH IN ENERGY AND ENERGY CONSERVATION

Quad 2 Stove Performance Report

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Abstract

This report presents the findings from various tests on the Quad 2 stove. These tests were conducted from the Biomass Research Centre-CREEC, at the request of Dr. Paul Anderson.

The Quad 2 stove can use wood in various sizes. Two kilograms of cylindrical logs of diameter 6cm and length 18cm burn for 2 hours whereas 2kg of pieces of size 3x4x18 burn for 1 hour and 30 minutes and 1.2 kg of pieces of size 2x2x4 cm burn for 55 minutes.

Using wood of size 5x7x18cm, the Quad 2 stove boils 5L of water in 27 minutes, uses 636g of wood and 11713 KJ of energy to boil and simmer 5L of water which is less than the Aprovecho benchmark for improved wood stoves, i.e. 850g of wood and 15000KJ of energy. It has a thermal efficiency of 42% during the high power phase and 41% during low power. It has a turndown ratio of 1.43, an indication that the stove's firepower can be controlled for different cooking regimes.

According to the Tiers of stove performance, its fuel use lies in Tier 3 and is considered to achieve Significant, Measurable Health and /or Environmental Goals. With regards to safety, the stove scored 77.5% and is rated **Good.** It lies in Tier 2 and is considered to have Substantial Improvement over Minimum Best Practice according to the Lima Consensus tiers of stove ranking.

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1 About CREEC

The Centre for Research in Energy and Energy Conservation (CREEC) is a not-for-profit organization which works “to enhance access to modern types of energy through research, training and consultancy”. It is located at the College of Engineering, Design Art and Technology, Makerere University.

1.1 The Bio-energy Research Centre

The Bio-energy Research Centre laboratory was built in 2008 with support from GIZ. Among other activities, the Bioenergy Research Centre is concerned with Cookstove design and testing as well as training. It also works on Biogas, Gasification and Briquetting and other applied research in Bio-energy and Bio-fuels.

1.2 Stove Testing

An improved stove must meet the users' needs, decrease the amount of fuel used and make the cooking task easier. Therefore, improved stoves must be tested to ensure that they are safe, and represent an improvement over their predecessors. To address this, CREEC has developed into an independent **Regional Stove Testing Centre** that offers stove testing services to stove manufacturers and promoters, using globally accepted testing procedures.

1.3 Objective of the Test

The objective of the tests was to understand the performance of the Quad 2 stove using the Water Boiling Test, Safety Test and Fuel Size

2 Tests on Fuels

2.1 Different types of Eucalyptus

Test 2.1.1:

2kg of soft Eucalyptus sticks of diameter 6cm and length 18cm were put into the fuel chamber and ignited with 70g of woodchips soaked in kerosene. A pot containing 5 litres of water was put on the stove. Wood was allowed to pyrolyse completely. The experiment was repeated with harder eucalyptus wood

Cylinders of 6x18

Result: It was a slow start that took 30 minutes to boil 5 litres of water. The flames lasted for 2 hours in a stove, leaving 400g of charcoal (20%) at the end of pyrolysis. The harder eucalyptus wood boiled 5 litres of water in 40 minutes. The flames lasted for 2 hours and 5 minutes, leaving 389g of charcoal (19%) at the end of pyrolysis.

2.2 Different fuel sizes

Test 2.2.1:

2kg of smaller pieces of about 3x4x18 cm were put in the fuel chamber and ignited as above. A pot containing 5 litres of water was placed on the stove.

Logs of 3x4x18

Result: It was a faster start that took 19 minutes to boil 5litres of water. The flames lasted for 1 hour and 30 minutes, leaving charcoal equal to 19% by mass of the original wood

Test 2.2.2:

Wood was chopped into pieces of about 2x2x4 cm. The pieces were poured into the fuel chamber. 10 pieces were soaked in kerosene and were ignited on the top of the fuel chamber. A pot containing 5 L of water was put on the stove.

Logs of 2x2x4

Result: The fuel chamber was filled with just 1200g of such wood. It took 19 minutes to boil 5 litres of water. The flames lasted for 55 minutes in the stove, leaving charcoal equal to 18% by mass of the original wood.

3 Standard Water Boiling Test

The Quad 2 stove was subjected to a Version 4.1.2 of the Water Boiling Test. This test was carried out thrice to increase accuracy of the results. Eucalyptus wood of 5x7x18cm, at 16% moisture content was used for these tests.

3.1 WBT Results:

The results from the Water Boiling Test are shown below.

HIGH POWER	Units	Test 1	Test 2	Test 3	Mean	St Dev	COV
Time to boil	*Min*	22	27	32	27	5	19%
Burning rate	*g/min*	10.6	9.2	8.8	9.5	1	10%
Thermal efficiency	*%*	44%	42%	40%	42%	2%	5%
Specific consumption	*g/litre*	50	53	61	54.9	5.8	11%
Firepower	*Watts*	3,269	2,832	2,693	2932	300	10%

LOW POWER	Units	Test 1	Test 2	Test 3	Mean	St Dev	COV
Burning rate	*g/min*	6.7	6.8	6.6	6.7	0.1	1%
Thermal efficiency	*%*	40%	39%	43%	41%	2%	4%
Specific fuel consumption	*g/litre*	74	75	68	72.2	3.6	5%
Firepower	*Watts*	2,044	2,082	2,037	2054	24	1%
Turn down ratio	--	1.6	1.36	1.32	1.43	0.2	11%

BENCHMARK VALUES	units	Test 1	Test 2	Test 3	Mean	St Dev	COV
Fuel Use	*g*	619	641	647	636	14.9	2%
Fuel Use	*g/L*	123.8	128.2	129.4	127.1	2.9	2%
Energy Use	*kJ*	11,401	11,821	11,918	11,713	275	2%

The Quad 2 stove boils 5L of water in 27 minutes, uses 636 g of wood to boil and simmer (cook) 5L and has an energy use of 11713KJ. The results show that the Quad 2 stove meets the Aprovecho benchmarks for improved cook stoves, that is, 30 minutes to boil, 850g of wood to cook 5L and energy use of 15000kJ (Aprovecho, 2008). Having a turndown ratio above 1 is also an indication that the stove's firepower can be controlled to suit different cooking regimes.

3.2 Comparison to other cooking devices

This presents a comparison between the Quad 2, its larger predecessor, the Quad 1 and the three stone fire.

		3 Stone Fire		Quad 1		Quad 2	
HIGH POWER TEST	**units**	**Mean**	**St Dev**	**Mean**	**St Dev**	**Mean**	**St Dev**
Time to boil	*Min*	23.8	2.2	18	0.0	27	5
Burning rate	*g/min*	20.5	1.13	16.7	0.3	9.5	0.98
Thermal efficiency	*%*	22%	3%	33%	1%	42%	2%
Specific fuel consumption	*g/litre*	102.8	13.1	61.9	1.4	53	5.4
Firepower	*Watts*	6293	348	5125	85	2932	300

LOW POWER	**Units**	**Mean**	**St Dev**	**Mean**	**St Dev**	**Mean**	**St Dev**
Burning rate	*g/min*	12.2	2.9	11.6	0.5	6.7	0.1
Thermal efficiency	*%*	26%	2%	29%	3%	41%	2%
Specific fuel consumption	*g/litre*	147	36	144	17	72	4
Firepower	*Watts*	3623	739	3574	145	2054	24
Turn down ratio	--	2.13	0.04	1.44	0.08	1.43	0.15

BENCHMARK VALUES	**Units**	**Mean**	**St Dev**	**Mean**	**St Dev**	**Mean**	**St Dev**
Fuel Use for 5 litres	*g*	1247	249	1049	76	636	15
Energy Use for 5 litres	*kJ*	22985	4591	19337	1404	11713	275

The Quad 2 has an improved thermal efficiency and fuel use compared to the Quad 1 and the three stone fire. However, since it has the lowest burning rate, the cooking time is greater than that of the three stone fire and Quad 1.

4 Safety Evaluation

The Safety Test addresses the basic safety issues concerning stove. The IOWA Safety Test Protocol, designed by Nathan Johnson, is used.

The results for the Safety Test are shown below, based on the following key: **1= Poor; 2= Fair; 3= Good; 4= Best.**

Safety Tests		Score	Performance benchmarks for stove safety	Remarks
1	Sharp edges and points	2	**Fair:** Sharp edges present **Best:** Sharp edges absent	The stove has some sharp points on its corners that could cause cuts to the user, or get entangled to a cloth.
2	Cook stove tipping	4	Tipping ratio(R): **Poor:** R>0.978; **Fair:** 0.961<R<0.978 **Good:** 0.940<R<0.961; **Best:** R<0.940	The stove is very stable on the ground, with a tipping ratio of 0.84.The cook pot and its contents are not likely to spill if the stove is tipped.
3	Containment	3	Number of time (n) fuel falls out of the stove: **Poor**: n≥9; **Fair**: 6≤n≤8; **Good**: 3≤n≤5; **Best:** n≤2	The stove retains the fuel when it is tipped and allowed to fall over 4 times in each of the four directions. It is unlikely that nearby substances will catch fire in case it falls over.
4	Expulsion of ember	4	Distance (D) through which fuel can be seen: **Poor:** D>5; **Fair:** 3<D<5; **Good**: 1<D<3; **Best:** D<1	Burning fuel can hardly be seen when the stove is in operation. Burning embers have no chance of escaping out of the stove.
5	Obstructions near the cooking surface	4	Height difference (D) between the cooking surface and obstructions near cooking surface **Poor:** D>4; **Fair:** 2.5<D<4; **Good:** 1<D<2.5; **Best:** D<1	There are no obstructions near the cooking surface that would otherwise cause risks when placing or removing the pot from the stove.
6	Stove Surface temperatures	1	Surface temperature (T) above air temperature: **Poor:** T>50; **Fair**: 44<T<50; **Good**: 38<T44; **Best:** T<38	The stove surface temperature reaches a maximum of 150^{o}C. This high temperature may cause burns if touched by users.
7	Heat transmission to the surrounding	1	Floor Temperature (T) above air temperature: **Poor:** T>65; **Fair:** 55<T<65; **Good:** 45<T<55; **Best:** T<45. Wall Temperature (T) above air temperature: **Poor:** T>80; **Fair:** 70<T<80; **Good:** 60<T<70; **Best:** T<60	The temperature of the floor underneath the stove rose to 130^{o}C; and that of the wall at about 10 cm from the stove; rose to 40^{o}C. Substances underneath the stove could catch fire. In addition, users could be injured if they stepped on the place where the stove has been placed.
8	Handle temperatures	4	Handle temperature (T)above air temperature: **Poor:** T>32; **Fair:** 26<T<32; **Good:** 20<T<26; **Best:** T<20	Handle temperature rose by only 5^{o}C above room temperature. It is therefore very safe to handle.
9	Flames surrounding the cook pot	4	Uncovered flames touching the cooking pot: **Poor:** Entire cooking pot & handles; **Fair:** Most of cooking pot, not handles; **Good:** Less than 4cm up the sides, not handles; **Best:** None	Flames around the cooking pot depend on the air control mechanism of the stove. The stove has a good air control mechanism that controls flames around the cookpot. It therefore performs well.
10	Flames exit fuel magazine	4	**Poor:** Flames protrude; **Best:** Flames are contained	Since the stove has no fuel loading area (fuel magazine) while it is in operation, It is ranked best.
Sum of scores (S)/40		31	**Poor**: S ≤ 16; **Fair:** 17≤S≤25; **Good**: 26≤S≤34; **Best:** S≥35	Since the sum of scores is between 26 and 34, it is ranked **GOOD**; It therefore scored 77.5% in safety evaluation.

As per the Safety Test Protocol, the following multipliers were applied to the test scores. The multipliers give an indication of the importance of the parameter (4 is most important and 1 is least important).

Tests	Test1	Test2	Test3	Test4	Test5	Test6	Test7	Test8	Test9	Test10	Total
Score	2	4	3	4	4	1	1	4	4	4	31
Multiplier	1.5	3	2.5	2	2	2.5	2	2.5	3	4	
Results	3	12	7.5	8	8	2.5	2	10	12	16	81

4.1 Ranking Stove Results

The stove's performance was checked against the Lima Consensus (PCIA, 2011) with the following outcome (see appendix for detailed explanation of Tiers):

Parameter	Result	Tier
Fuel Use	127.1 g/L	Tier 3 (Can achieve Significant, Measurable Health and Environmental Goals)
Safety	81 Points	Tier 2 (Substantial Improvement over Minimum Best Practice.)

5 Conclusion

The Quad stove boils 5L of water in 27 minutes. To boil and simmer 5L of water, it uses 636g of dry wood and has an energy use of 11713kJ. It has a thermal efficiency of 42% during the high power phase and 41% during simmering. It has a turndown ratio of 1.4, an indication that the stove's firepower can be controlled for different cooking regimes. Its fuel use is considered to achieve significant, measurable health and environmental goals according to the Lima Consensus Tiers of stove ranking.

With regards to safety, the stove scored 77.5% and is rated **GOOD** and is considered a Substantial Improvement according to the Lima Consensus Tiers of stove ranking.

6 Appendix: Stove Ranking according to the Lima Consensus

Tier 0	Typical, Unimproved
Tier 1	Measureable Improvement using Minimum Best Practice
Tier 2	Substantial Improvement Over Minimum Best Practice
Tier 3	Stretch Goals which achieve Significant, Measurable Health and/or Environmental Goals

	Reduction	Efficiency (Wood)	Efficiency (Charcoal)
Tier 0	< 50%	> 170 g/L	> 60 g/L
Tier 1	> 50%	< 170 g/L	< 60 g/L
Tier 2	> 55%	< 153 g/L	< 50 g/L
Tier 3	> 60%	< 136 g/L	< 40 g/L

	Safety (Iowa State)
Tier 0	< 50 points
Tier 1	≥ 50 points
Tier 2	> 70 points
Tier 3	> 90 points