HETEROGENEOUS STOVE TESTING PROTOCOLS FOR EMISSIONS AND THERMAL PERFORMANCE♣

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ABSTRACT

A growing interest in accurately specifying domestic cooking and heating stove performance stems from increasing concern for women and children exposed to unhealthy levels of gaseous and particulate emissions, and for certifying and rating stove-fuel combinations for the mitigation of greenhouse gases. Popular flame-based stove testing protocols show inadequacies in the outputs as they do not represent real-world uses or likely combinations of fuels, stoves, and pots. The Sustainable Energy Technology Testing and Research Centre (SeTAR Centre), University of Johannesburg is developing *heterogeneous emissions and thermal performance protocols* for a range of stoves and fuels including paraffin, ethanol, wood, charcoal and bituminous coal - all fuels in widespread use in Southern Africa. The new protocol requires each appliance to perform realistic tasks (boiling water in two litre and six litre pots) at three different power levels; and that stoves be tested using the range of fuels and pots for which they were designed. The composition and heat content of each fuel used must be routinely determined. We present sample test results illustrating how we obtain insightful design information and robust evaluations. These protocols will be published, providing improved practices for stove development, efficiency rating and product certification.

1. MEASURING STOVE PERFORMANCE

Project managers and funding agencies often select a stove type by reviewing laboratory test results, especially comparative tests of a range of stove designs. The numbers reported by such comparisons are therefore important to stove developers who want to sell products or design services, or have stoves introduced as part of development aid or climate protection initiatives.

When industrial equipment is rated for performance there are standard approaches taken to the testing and standard formats for the outputs. Heating appliances are usually rated by calculating work done per unit of heat used. Combustion might be 'emissions per unit of heat produced' or 'per kilogram of fuel burned'. Using these metrics the efficiency or emissions or fuel used to perform any given task can be estimated, with laboratory or field tests conducted for confirmation. Efficiencies of various parts of the combustion and heat transfer processes may be used to calculate an overall task performance. However, tasks, being combinations of efficiencies, cannot be deconstructed to reveal the underlying efficiency numbers.

To date, standard performance figures for improved stoves have not been readily available, because the *Improved Cooking Stove* sector has not had an agreed set of testing criteria and protocols, devised under the guidance of a professional standards setting agency. Many developers feel historically constrained to conduct all testing in terms of a standardised task. This presentation will present a set of *heterogeneous testing protocols* for emissions and thermal performance from domestic cooing stoves, developed as part of a South African stove testing programme. Through presentation and discussion of representative results, we illustrate how a heterogeneous set of tests can provide essential information for the rating, comparison and ranking of a stove's performance. By implication, we illustrate why task-based evaluations, often used heretofore, are inadequate for performance evaluation of domestic and institutional flame-based cooking devices.

2. COMPULSORY STOVE STANDARDS

The American Environmental Protection Agency (US-EPA) provides a number of methods for testing heating and cooking appliances. Their compulsory certification test for free standing space-heating wood stoves is typical of early efforts to produce a compulsory national standard testing procedure. It prescribes the fuel, its method of use, the test conditions and the method of operating the stove. However, it has proven to be controversial, disappointing testers and manufacturers alike.

The South African (SA) government has passed compulsory paraffin stove performance and safety standards, prepared by the SA Bureau of Standards (SABS). It allows new products to be operated in new ways, but still prescribes the fuel and the test conditions which include among other things, a full power burn under a hood to test the CO/CO_2 ratio as the core test.

New Zealand has regulations that permit any stove and most fuels to be operated according to the manufacturer's recommendations, as long as they meet certain emission and durability standards. This has permitted clean-burning wood pellet space-heating stoves to enter a market where previously all wood fuel had been banned. The New Zealand technical advisors realised that the fuel alone is not the cause of air pollution, but that the stove/fuel combination need to be optimised.

New test protocols are required to deal with this more realistic approach to testing and certification of cooking stoves.

♣ An earlier version of this paper was presented to an invited workshop as: Pemberton-Pigott C., J. Robinson, H.J. Annegarn (2009), Stove testing in South Africa: heterogeneous testing protocols for emissions and thermal performance, *Asean-US Next-Generation Cook Stove Workshop*, Bangkok, Thailand, 16-20 November 2009. The paper appeared in the un-refereed workshop proceedings, distributed only to the participants.

3. STANDARD METRICS –SETAR CENTRE ACTIVITIES

As part of a national project to develop safer, cleaner burning and more energy efficient domestic flame stoves to replace the ubiquitous and highly polluting coal braziers, South Africa is engaged in assisting industry to design and evaluate new ethanol gel and paraffin stoves. The recently formed Sustainable Energy Technology Testing and Research (SeTAR) Centre at the University of Johannesburg was commissioned to determine the thermal efficiency and gaseous emissions of several stoves, including new prototypes or products recently made available on the market. (Our competence excludes testing of product safety, which is properly the domain of the South African Bureau of Standards.)

Eight different designs were provided for testing. In the process of evaluating these stoves for thermal and emissions performance, SeTAR staff was engaged simultaneously in the development of written procedures for testing and development of spreadsheet calculations that included both primary and secondary combustion effects. Importantly, these calculations take into account fuel moisture and oxygen content of the fuel. The protocols required operation of the devices at a range of power levels, using two different pot sizes.

The sections that follow illustrate some of the aspects of the test protocols and results from the more than one hundred individual tests conducted as part of this project.

4. TEST RESULTS – BASELINE PARAFFIN WICK STOVE

Figure 1 shows the carbon monoxide emissions factor, CO(EF) (Lambda corrected for Excess Air), from a paraffin wick stove, from ignition of the fuel through a boiling episode, and includes tests at three different power levels with the pot in place.

This stove has a CO level that increases with time on *High*, drops with time on *Low*, and stabilises on *Medium* power. It also indicates that on *Low* there is a significant variation in the combustion efficiency, the result of a wavering flame. The data used to generate charts, such as shown Figure 1, can be used to make direct comparisons with other stoves, provided the CO values are corrected for *Excess Air*. Together with the measurements of the CO_2 emitted and simultaneous measurement of the mass of fuel burned, and considering the elemental composition of the fuel, Figure 2 shows the derived parameters that can be calculated for the different phases of the test.

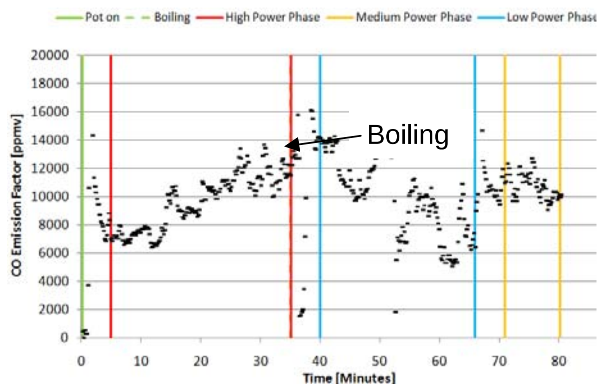


Figure 1 CO emission profile for a wick type paraffin stove, plotting the carbon monoxide emission factor (emissions corrected for *Excess Air*) over time (Stove 3, Test 7). Pot size is 6.8 litres. The regions between pairs of similarly coloured vertical lines indicate periods of stable flame at different power settings. The dotted green line (boiling point) is indicated by an arrow.

SeTAR CENTRE TEST RESULTS Single Test Analysis Paraffin Stove 3 Liquid Fuels, v1.52

Single pot Wick stove Report		Date	Time	Fuel	LHV, MJ/kg	Analysed by		
		9/15/2009	09:42 AM	Paraffin	44.0	C Pemberton-Pigott		
	Event Occurs on Line Number:	Stove Power Watts	Hart Big % Eff	Average CO/CO2 ratio	CO2 Emitted /kg burned g	CO Emitted /kg burned g	CO emitted during this portion, g	Delta T during this section
Pot on,	6	1,347	58.1%	5.2%	3,049	56	3.6	73.1
Boiling	206	Minutes of burn	34.83	VALID	This section is analysed separately			
High power start	35	1,288	58.7%	5.1%	3,050	55	2.9	60.5
High power end	207	Minutes of burn	30.17	VALID				
Medium power start	407	1,200	55.4%	5.7%	3,040	61	0.9	0
Medium power end	459	Minutes of burn	9.17	VALID				
Low power start	235	903	47.5%	5.2%	3,049	56	1.8	0.2
Low power end	380	Minutes of burn	26.00	VALID				
						Whole Test	Beginning line	35
Initial Mass of Water Boiled, g	**5,085**	Adjusted to 80 deg					Ending line	459
Time to Boil, minutes	34.83	**38.12**	**7.50**	minutes/Litre			Fuel burned, g	114.0
Fuel used to Boil, g	64.00	**70.04**	**1.84**	g/minute			Minutes of test	75.2
Sp Fuel Consumption to boil, g/litre	12.6	**13.77**	**0.36**	g/minute/litre			Avg g/minute	1.52
Energy to boil 1 litre, MJ	0.55	**0.61**	**55.3%**	Eff v.s. theoretical need			Turn down ratio	1.43
CO emitted to boil 1 litre, g	0.69	**0.75**						

Stage	CO, g Per hour	CO, g/MJ	CO2 g/MJ	CO g/kg	CO2 g/kg	CO/CO2	Fuel, g/hr	Watts
Boiling	**6.12**	**1.26**	**69.29**	**55.53**	**3,048.73**	**5.22%**	**110**	**1,347**
High Power	**5.76**	**1.24**	**69.32**	**54.62**	**3,050.27**	**5.13%**	**105**	**1,288**
Medium Power	**5.97**	**1.38**	**69.08**	**60.86**	**3,039.71**	**5.73%**	**98**	**1,200**
LowPower	**4.10**	**1.26**	**69.29**	**55.50**	**3,048.77**	**5.21%**	**74**	**903**
Whole Test	**5.33**	**1.33**	**69.17**	**58.52**	**3,043.67**	**5.51%**	**91**	**1,112**

Figure 2 Test results from Paraffin Stove 3 showing discrete power and emissions for each test segment.

This profile is typical of the old type of paraffin burning wick stove. The emissions are what we have come to expect, or more correctly, *what we usually think is going on in a stove*. The *turn down ratio* is modest, the CO/CO_2 ratio is high, slightly higher when the power is turned up, but quite stable throughout the whole test. Tested in *High* power alone, it would give a clear indication of the expected performance at any other power setting.

5. NEW TYPE PARAFFIN STOVE

In order to provide safer and cleaner paraffin stoves, many new products are entering the market with numerous novel features. Let us now look at a new type of single-pot portable stove with very low CO emissions when operated at full power. As *High* power operation is usually the worst case scenario for emissions, the South African Bureau of Standards (SABS) testing protocol requires that the stove be run at this maximum setting, predicting a consistent CO/CO_2 result similar to that observed in Figure 2.

However, looking at the test results for this stove (Figure 3), there is obviously a very large variation in the CO(EF) depending on the power setting. A standard water boiling test would not reveal this variation if, for instance, *Medium* power was required for simmering, a common occurrence. However paraffin stoves are often used on *Low* power setting for space heating at night and the emissions should be quantified also for this condition.

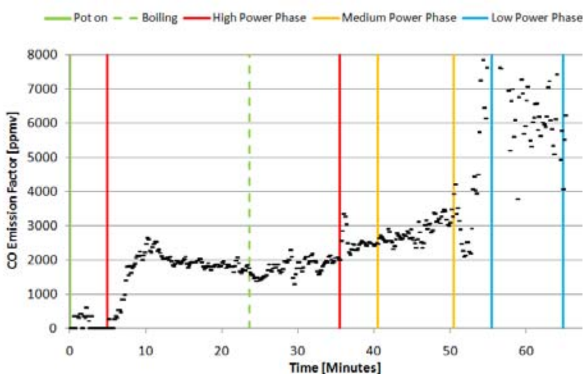


Figure 3 Paraffin Stove 1 (single pot) operated at three different power levels

The initial jumpy nature of the line in the first few minutes is caused by a very high *Excess Air* ratio. As soon as the fire is well established and the fumes are collecting under the hood, the line stabilises. If the CO_2 is calculated from the *Excess Air* figure, richer gas samples are required, above 2% CO_2 and preferably above 4%.

The delay between lighting and the beginning of the *High* power phase (left Red line) is 5 minutes. A similar delay is used for any change in power during which emissions are ignored save when calculating the overall values. Note the interesting drop in the CO(EF) concentration when switching from *Medium* (orange) to *Low* (blue) power - this is caused by the mechanical device that changes the fuel burn rate. After the flame stabilises, the combustion efficiency becomes much worse.

The erratic measurements when the stove is on *Low* are because of an unstable flame, not from the *Excess Air* being too high, i.e. it is not an instrument error. As can clearly be seen, the CO(EF) rises as the power level of the stove is gradually turned down.

This profile would be missed during a standard water boiling test which does not include testing over a range of power settings. If the test was conducted using a pot with no lid, it is unlikely to maintain a simmer or rolling boil on low power, so the test would miss the dramatic change in performance. For meaningful design feedback (performance and efficiency) the stove must be tested across its full power range. The green lines indicate the emissions starting when the pot was first put on the lit stove until the the water boiled.

The hydrogen in the exhaust is also an indicator of incomplete combustion. The H_2(EF) (Figure 4) has a profile very similar to the CO(EF) chart (Figure 3). H_2 is consistently about one sixth of the CO concentration. However, it cannot be assumed that the ratio of CO to H_2 is the same with all stoves – in other cases the H_2 concentration is equal to or greater than that of the CO.

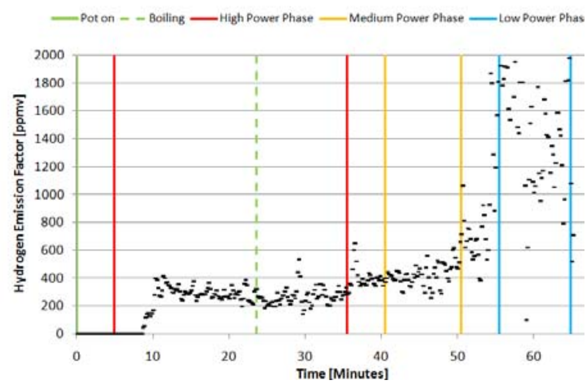


Figure 4 Hydrogen emission factor over time: H_2(EF) - unburned hydrogen corrected for *Excess Air*. (Paraffin Stove 1, single pot)

The combustion efficiency is normally taken to mean the ratio of partially burned carbon (CO) to fully burned carbon (CO_2). The CO/CO_2 ratio is used, because with most fuels, the majority of the energy comes from burning carbon. The H_2/H_2O ratio might also be used to measure combustion efficiency.

The CO/CO_2 ratio chart (Figure 5) is often clearer than the CO(EF) or CO_2(EF) measures alone. Measuring the CO and CO_2 at 10 second intervals and plotting their ratio gives a clear indication to us that the combustion efficiency varies with power (Figure 5).

The horizontal grey line shows the common standard (maximum allowable limit for indoor combustion devices) of most national regulations for flame-based domestic cooking appliances. The CO/CO_2 ratio on *Low* power is significantly higher than the permitted 2%.

As a quality control measure, total carbon, total oxygen and instrument checks (pump flow) are monitored and recorded (Figure 6). Any significant deviations are indicators to discontinue the test or discard a single data set. On the left axis is the sum of all the oxygen and carbon contained in all gases detected by all the cells. In theory it could equal the background O_2 level. However if there is oxygen present in the fuel, the total can rise above ambient especially when combustion is poor. Wet fuel burning badly, for example wet coal, can also produce an O_2 total that is above ambient because of the *Water Gas Shift Reaction.*

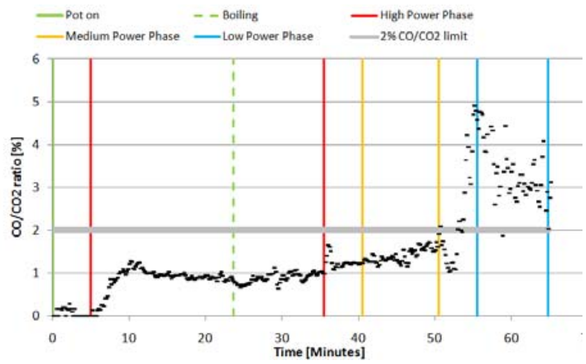


Figure 5 Combustion efficiency: the ratio of CO to CO_2 measured every 10 seconds. (Paraffin Stove 1, small pot)

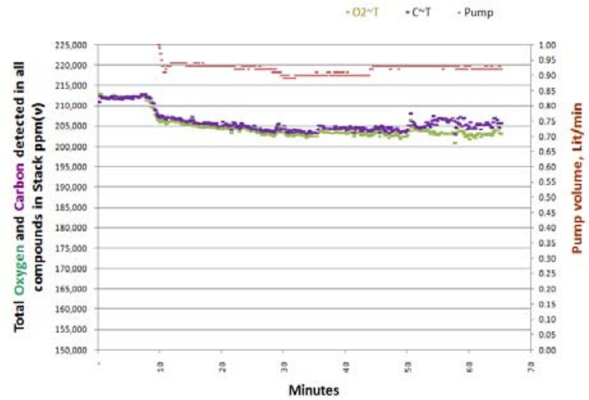


Figure 6 Data quality check: total oxygen, total carbon, and pump volume (instrument check)

Each set of measurements, typically several hundred, is analysed and plotted separately so that performance during different intervals can be observed (Figure 7). The Green cells are the Task: **boiling water**. The others are *High*, *Medium* and *Low* power tests with an aggregate at the end. The aggregate includes the five minute transition periods and is performance indicative, not definitive. It is ignored for the plots of performance but available to the reviewer on this chart. If the water cannot be maintained at a boil at any particular power level, the test is done with a cooler pot.

SeTAR CENTRE TEST RESULTS Single Test Analysis Paraffin stove 1 Protocol: Liquid Fuels, v1.52

Single pot Report		Date	Time	Fuel	LHV, MJ/kg	Analysed by		
		7/7/2009	10:53 AM	Paraffin	44.0	C Pemberton-Pigott		
	Event Occurs on Line Number:	Stove Power Watts	Hart Medium Pot % Eff	Average CO/CO2 ratio	CO2 Emitted /kg burned g	CO Emitted /kg burned g	CO emitted during this portion, g	Delta T during this section
Pot on,	5	1,332	55.0%	0.7%	3,130	8	0.3	80.2
Boiling	147	Minutes of burn	23.67	VALID				
High power start	35	1,250	59.2%	0.9%	3,127	9	0.5	66.1
High power end	218	Minutes of burn	30.50	VALID				
Medium power start	248	1,320	50.0%	1.4%	3,116	16	0.3	0.1
Medium power end	308	Minutes of burn	10.00	VALID				
Low power start	338	1,100	39.4%	3.3%	3,082	36	0.5	0
Low power end	388	Minutes of burn	9.33	VALID				

				Whole Test	Beginning line	35
Initial Mass of Water Boiled, g	2,998	Adjusted to 80 deg			Ending line	388
Time to Boil, minutes	23.67	23.61	7.87	minutes/Litre	Fuel burned, g	99.0
Fuel used to Boil, g	43.00	42.89	1.82	g/minute	Minutes of test	59.8
Sp Fuel Consumption to boil, g/litre	14.3	14.31	0.61	g/minute/litre	Avg g/minute	1.65
Energy to boil 1 litre, MJ	0.63	0.63	53.2%	Eff v.s. theoretical need	Turn down ratio	1.20
CO emitted to boil 1 litre, g	0.13	0.13				

Stage	CO, g Per hour	CO, g/MJ	CO2 g/MJ	CO g/kg	CO2 g/kg	CO/CO2	Fuel, g/hr	Watts
Boiling	0.82	0.17	71.13	7.55	3,129.93	0.69%	109	1,332
High Power	0.96	0.21	71.06	9.40	3,126.80	0.86%	102	1,250
Medium Power	1.68	0.35	70.83	15.55	3,116.38	1.43%	108	1,320
LowPower	3.23	0.81	70.05	35.85	3,082.02	3.33%	90	1,100
Whole Test	1.59	0.36	70.81	16.05	3,115.55	1.47%	99	1,213

Figure 7 Test outputs for paraffin stove 1

Note that the CO/CO_2 ratio increases from 0.86% to 3.3% while the power level (Watts) drops only 11.5%. Combining these two changes shows that the CO mass emitted per MJ increases by 390% as the heat drops by only 150 Watts. This is significantly different from the wick stove (See Figures 1 & 2) and is not what one expects.

Also note that the thermal efficiency drops from 59% to 39% as the power level decreases. This drop, combined with the actual power decrease of 11.5%, combine to give the user the impression that the fuel consumption rate has dropped because the quantity of heat getting into the pot has diminished. It is often the case that the thermal efficiency on *Low* is higher than on *High* power, but it can only be determined if they are calculated separately. Sometimes when turning a stove down from *High* to *Medium*, the power output actually rises. Some stoves may not drop in power when switched from *Medium* to *Low*.

6. ETHANOL GEL STOVES

The *gel fuel* stove tests also produced some interesting results. In Figure 8, there is a slight rise in CO as the *High* power test continues, possibly because the fuel in the reservoir is heating up or because it is emptying the reservoir. There is a dramatic drop in CO when the stove is turned down to *Low*, indicating excellent combustion. A standard water boiling test conducted on *High* and *Medium* might never reveal this remarkably clean burn.

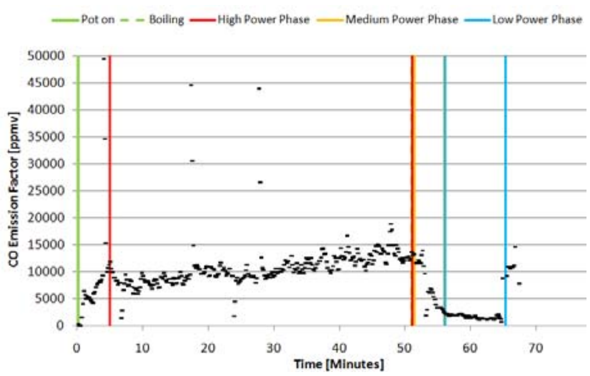


Figure 8 The CO(EF) for ethanol gel stove 2 indicates a high turn down ratio.

Note: there is no *Medium* test performed here. The gap between *High* and *Low* is denoted '*Medium*' but the numbers are ignored because the flame and power level are in transition. Once the water had boiled, the power was turned down so the boiling test and the *High* power test end at the same time.

When looking at the performance of the stove during the whole test (Figure 9) the CO/CO_2 ratio is initially high, and then drops by a factor of more than 5 when switched to *Low*. The 'Watts' column on the far right the power level shows a 60% drop.

This profile of emissions is completely at variance with Paraffin Stove 1 (Figure 7). This is an unexpected result quite unlike the normal profile. Paraffin Stove 1 (PS1) operated for a 10 minute *High* and 10 minute *Low* power burn will emit a total of 0.7 g of CO. Ethanol gel stove 2 (EGS2) will emit 1.15g, a factor of 1.64 times as high.

Their average CO/CO_2 ratios are PS1=2.1 and EGS2=3.3. The EGS2 ratio is higher by a factor of 1.6, very close to the results based on a 10 minute *High*-*Low* burn. Although the EGS2 has a 57% higher CO/CO2 ratio on *High*, the lower *Low* nearly compensates for it. An EGS2 water boiling test (WBT = boil on *High* + 45 minutes simmering on *Low*) shows CO emissions of 1.2 g/litre, only 30% higher than a WBT on the PS1: 0.93 g.

On *Medium* power the ethanol gel stove 2, instead of emitting 1.10 g/litre of water boiled, might be significantly lower because of a higher thermal efficiency, a higher power, and a lower CO/CO_2 ratio.

Doing a "*Medium power boil*" calculation for Paraffin Stove 1 determines that it would take 9 minutes longer than on *High*, at a lower thermal efficiency, with a higher CO/CO_2 ratio. The CO emitted per litre boiled, corrected for temperature, would double from 0.63 to 1.30 merely by operating the stove on *Medium* instead of *High*. This is a significant and unexpected result.

SeTAR CENTRE TEST RESULTS Single Test Analysis Gel Stove 2 Protocol: Liquid Fuels, v1.52

Local	Report	Date	Time	Fuel	LHV, MJ/kg	Analysed by		
		9/7/2009	11:30 AM	Gel	19.3	C Pemberton-Pigott		
	Event Occurs on Line Number:	Stove Power Watts	Hart Medium % Eff	Average CO/CO2 ratio	CO2 Emitted /kg burned g	CO Emitted /kg burned g	CO emitted during this portion, g	Delta T during this section
Pot on,	6	1,191	44.4%	5.6%	1,385	27	5.1	73.4
Boiling	302	Minutes of burn	50.77	VALID				
High power start	35	1,221	44.4%	5.7%	1,384	28	4.8	67.8
High power end	303	Minutes of burn	46.10	VALID				
Medium power start	304	786	57.8%	3.4%	1,403	17	0.2	0
Medium power end	331	Minutes of burn	4.50	INVALID				
Low power start	332	491	24.3%	1.0%	1,423	5	0.1	0.1
Low power end	383	Minutes of burn	9.17	VALID				

		Adjusted to 80 deg		
Initial Mass of Water Boiled, g	5,156			
Time to Boil, minutes	50.77	55.33	10.73	minutes/Litre
Fuel used to Boil, g	188.00	204.90	3.70	g/minute
Sp Fuel Consumption to boil, g/litre	36.5	39.74	0.72	g/minute/litre
Energy to boil 1 litre, MJ	0.70	0.77	43.7%	Eff v.s. theoretical need
CO emitted to boil 1 litre, g	1.01	1.10		

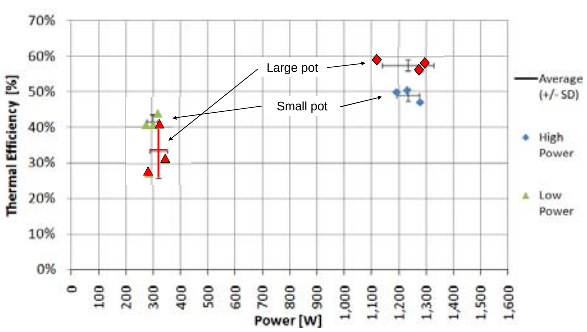
Whole Test		
	Beginning line	35
	Ending line	383
	Fuel burned, g	200.0
	Minutes of test	60.3
	Avg g/minute	3.32
	Turn down ratio	2.49

Stage	CO, g Per hour	CO, g/MJ	CO2 g/MJ	CO g/kg	CO2 g/kg	CO/CO2	Fuel, g/hr	Watts
Boiling	6.02	1.40	71.77	27.10	1,385.10	5.60%	222	1,191
High Power	6.29	1.43	71.72	27.60	1,384.25	5.71%	228	1,221
Medium Power	2.44	0.86	72.68	16.65	1,402.78	3.40%	147	786
LowPower	0.43	0.25	73.73	4.74	1,422.94	0.95%	92	491
Whole Test	4.63	1.21	72.10	23.26	1,391.60	4.79%	199	1,067

Figure 9 Ethanol Gel Stove 2 test results

7. THE EFFECT OF THE POT ON THERMAL AND EMISSIONS PERFORMANCE

Emissions of a stove can be affected by the size of the pot, and whether there is a pot present at all, as the pot can dramatically affect the quality of combustion and the air movements through the stove. Figure 10 illustrates the effects on power and thermal efficiency of substituting a large pot with a smaller one.



Note: For each power level three tests are shown with averages and standard deviations.

Figure 10 The relationship between power and thermal effciency for a small pot (2 litre) and a large pot (6.5 litre)

With a small pot on the stove, the power is 1250 Watts on *High*, and 300 Watts on *Low*. The thermal efficiency is 48% on *High* and 42% on *Low*. With a large pot on the stove, the power is somewhat reduced to 1 120 Watts on *High* and remains the same as previously with 300 Watts on *Low*. The thermal efficiency on *High* increases by one fifth to 58% but drops a little, to about 35% on *Low*. Similar changes occur with regard to the CO emitted. Figure 11 shows the temperature corrected specific CO emission per litre boiled.

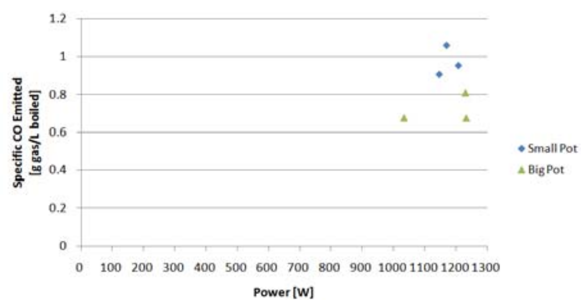


Figure 11 Relationship between power and CO emitted per litre boiled at high power, bringing water to the boil (temperature corrected)

There is a significant increase in the CO emitted per litre boiled if the cook chooses a small pot instead of a large one because the thermal efficiency is lower (Figure 12), so it takes more fuel to bring each litre to a boil.

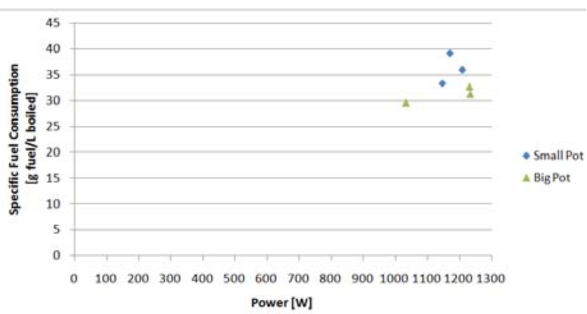


Figure 12 Specific fuel consumption (grams of fuel per litre boiled) on *High* Power

In cases where the thermal efficiency increases with pot size the emissions per litre boiled decrease even if the water volume and the power setting are the same for both pots. In other cases the thermal efficiency on *Medium* is highest for smaller pots and the specific fuel consumption is minimized, avoiding both extremes.

8. CONCLUSION

Over one hundred sets of data have been collected, burning standardised fuels in eight paraffin and ethanol stoves, each operated at three power levels and cooking two sizes of pot. We found that power and pot size can significantly affect the *Specific Fuel Consumption* (efficiency) and gas *Emission Factors*. Select data are presented demonstrating that the ***heterogeneous testing protocols*** provide an informative assessment of a stove's thermal performance and characteristic emissions under realistic operating conditions.

It has been demonstrated that testing at multiple power levels with multiple pot sizes provides an improved assessment of a stove's thermal performance and its characteristic emissions over ranges of likely realistic uses. Such tests can reveal the optimum operation conditions as well as expose shortcomings of a stove design. Rigid task-based protocols with standard pots and pot-loads can hide a number of defects or erroneously rate as inherently poor, a fuel or stove technology with good potential. Task-based testing neither approximates cooking nor can it provide the important information revealed in the above charts.

Our conclusion is that no single-task stove testing regimen can provide a meaningful performance evaluation of a flame-based cooking appliance. Our results indicate that a ***heterogeneous test protocol***, as developed at the SeTAR Center, incorporating a range of power settings, and various pot and load sizes, is more diagnostic, and hence more useful for stove designers and stove programme managers.

Extrapolations of total CO_2 emissions based on the common water boiling test protocols may also lead to overoptimistic projections of gross emissions reductions from stove replacement programmes – this is a cautionary note for carbon traders, CDM project developers and stove manufacturing and dissemination programmes.

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