Cooking Sequences: The Realistic Utilization of Fuel/Stove Combinations in Standardised Experiments

T. Makonese, and J. Meyer

Abstract— The development of stove performance evaluation standards and protocols has received significant attention in the past decade. This was given the impetus by the advent of the Global Alliance for Clean Cookstove (GACC). Currently, there is a huge drive to developing an international stove-testing standard that addresses real-world uses of fuel/stove combinations. The study was conducted to evaluate the performance of a biomass pellet cookstove using uncontrolled cooking test (UCT) with cooking sequences derived from food dishes prepared in the low-income stratum of Johannesburg. Results show that cooking sequences, when incorporated in standardised stove testing protocols, offer the potential to correlate better the laboratory and field performances of fuel/stove combinations. This is because cookstoves are operated, during technical test experiments, the way they would in real world-uses by mimicking the preparation of specific food dishes. Results from this study have implications for the development of future stove testing protocols.

***Index Terms*— Cooking sequence, solid fuels, stove testing standards, culturally appropriate, emissions, thermal efficiency**

1 INTRODUCTION

Biomass fuels are used in the developing world as energy carriers for cooking and heating, leading to household air pollution and health consequences [1]. It is arguable that in countries like South Africa, improved biomass cookstoves and clean biomass fuels such as biomass pellets can be a direct replacement of paraffin and related cooking devices. In South Africa, paraffin accidents including fires, burns, and ingestion poisoning lead to about 200 000 injuries annually [2]. Ingestion poisoning in children leads to over 800 000 cases per annum [3]. Faulty and sub-standard paraffin appliances have been pointed out as the primary cause of uncontrolled fires in low-income households and informal settlements [4]. Recent trends emphasise the need to identify cost-effective emission reduction opportunities aimed at reducing health impacts of indoor air pollution resulting from unvented stoves [5]. In light of this, the South African government is looking for sustainable energy solutions for marginalised and poor communities to provide them with a healthy and sustainable lifestyle [6].

It has been argued that improved cookstoves have the potential to address a comprehensive set of issues ranging from local health [7],[8] and environmental implications to global impacts associated with greenhouse gas (GHG) emissions [9]. However, experiences from past fuel/stove campaigns have shown that a successful cookstove program is more than just building or disseminating novel design cookstoves [5]. Masera *et al.* [10] contended that before rolling out cookstoves *en masse*, the whole 'cooking system' (fuel/stove/pot combination) needs to be considered through integrated approaches that work simultaneously with technology innovation, creative financing and market development, and the monitoring of actual health and environmental benefits. Such programmes encourage bottom-up participatory approaches [11] that seek to involve end users, including women, to address issues of priority and preference correctly [10].

In South Africa, several "improved" domestic combustion devices used for cooking and heating, which are readily available on the market do not show satisfactory improvements regarding emissions and thermal parameters compared to the baseline. Selected studies have indicated that these stoves have basic and unsafe designs that burn fuel poorly and emit harmful gases and copious amounts of toxic emissions (PM) into the immediate environment [4],[12],[13]. These devices are exacerbating the problem that they are intended to alleviate - that of indoor pollution - partly because the new stoves are not properly tested against known baseline criteria [14].

Central to the issue of access to clean and safe cooking energy fuels is the performance evaluation of fuel/stove combinations. The performance evaluation of cookstoves is an important step in all fuel/stove campaigns and dissemination programmes [6]. In the past decade, there has been growing interest for specifying performance of stoves powered by solid and liquid fuels, given an impetus by the advent of the Global Alliance for Clean Cookstoves (GACC) whose mandate is to disseminate to the developing world over 200 million improved cookstoves and clean fuels by the year 2020.

The development of stove performance evaluation standards and protocols has received significant attention in the past decade. This was given the impetus by the advent of the Global Alliance for Clean Cookstove (GACC). Several of the more widely used protocols for solid fuel stoves (wood, charcoal, coal) including the Water Boiling Test (WBT) are prescriptive in the type of fuel used, to derive a standardised test. However, the introduction of standardised fuels imposes conditions that are often not representative of real-world uses or likely combinations of the manner in which fuels, stoves and pots may be used [5],[15]. When assessing the types of stoves used in the developing world, there is, to date, no agreed set of stove testing protocols that have been devised under the guidance of a professional standards setting agency. Consequently, the majority of these protocols are not validated and certified by professional standards-certifying bodies. This results in *ad*

Financial assistance by the University of Johannesburg through a University Research Committee (URC) post-doctoral fellowship grant to T.M

T. Makonese is with the SeTAR Centre, Faculty of Engineering & the Built Environment, University of Johannesburg, P. Bag 4524, Johannesburg 2006, South Africa (E-mail: tmakonese@uj.ac.za).

J. Meyer is with the department of Electrical and Electronic Sciences, Faculty of Engineering & the Built Environment, University of Johannesburg, P. Bag 4524, Johannesburg 2006, South Africa (E-mail: johanm@uj.ac.za).

hoc protocols that are designed for a specific stove testing community or stove programme. This often leads to non-uniformity of the testing regimen, which makes it difficult to compare between stoves tested in different areas [5].

Currently, there is a huge drive to developing an international stove-testing standard. The international standards organisation (ISO) is spearheading this development with the support of the GACC. Standards-setting bodies and research institutes in various countries have been involved in this process. Although this process is a welcome move, some researchers feel that the proposed standard does not capture the contextual uses of fuel/stove combinations in different parts of the world. Such evaluations of stoves have been reported to be flawed because they do not reflect conditions under which the stove is used in the field. Thus, emission measurements from such tests do not reflect typical domestic emissions during daily activities. As such, these standards or evaluation methods do not provide an accurate assessment of the performance of the stoves under real-world conditions and, therefore, cannot be used to make informed decisions about which fuel/stove combination to promote. An important aspect that has been ignored in the ISO standard is the provision of cooking sequences.

Further complexities are realised from changing stove testing protocols on the testing of emissions and thermal efficiency of a variety of stoves to meet the demand for quality. For example, there has been a great international debate regarding the relevance of laboratory situations versus practical situations (controlled cooking test – CCT and kitchen performance test – KPT developed under the Household Environment and Health (HEH) Project) [6]. The difference between the two situations has often been posed in such a manner as to suggest that laboratory work cannot provide any guidelines for the development of efficient stoves [16-18]. The Engineers in Technical and Humanitarian Opportunities of Service (ETHOS) technical committee on stove testing methods was set up by specialists in both the laboratory and the field to develop, refine and update laboratory-testing protocols that are robust and can simulate real-world cooking practices [19]. This came in the realisation that both laboratory and field-testing have their valued places in the overall assessment of global cookstove emissions [5].

Therefore, there is an urgent need for robust testing protocols that allow for representative and reproducible testing and inter-comparison of the thermal performance and emissions from a diverse range of fuel/stove/pot combinations [20]. Such standardised protocols should be representative of either the stove design parameters or contextual uses of the fuel/stove/pot combination. Region-specific cooking regimes/ *cooking sequences* are an important part of a cookstove testing regimen [6],[21]. The concept of ‘burn sequences’ or ‘cooking sequences’ was first introduced by Johnson *et al*. [18] and later adopted and adapted by the SeTAR Centre, the University of Johannesburg during the clean Stove Initiative (CSI) stove programme in Indonesia. Cooking sequences have been considered a critical factor in assessing the actual performance of cookstoves. Uncontrolled cooking testing (UCT) [20] has the potential to be a better method for testing cookstoves as it can easily capture the intricate details of cooking sequences, which can help both stove designers and researchers engaged in the development of cookstove testing protocols [6].

To date, there is a paucity of information in the open and grey literature concerning the evaluation of fuel/stove combination using cooking sequences developed for the South African households, except for work done by Arora *et al*. [6]. In this study, cooking sequences are proposed for the laboratory assessment of stoves in a versatile but internally self-consistent manner that can provide a meaningful and representative evaluation of a wide range of stove and fuel types. A biomass pellet stove was assessed for emissions, and thermal performance using an improved UCT protocol that incorporates cooking sequences based on food dishes commonly prepared in South Africa.

2 MATERIALS AND METHODOLOGY

2.1 Experimental stoves

The cookstove selected for the experiments is an innovative biomass pellet stove, designed and developed in South Africa by a local artisan (Fig. 1). All tests were conducted using biomass pellets made from rice husks. The size of the biomass pellets used in the cookstove was 20 mm long and 5 mm wide. The pellets were tested for moisture content before performing the definitive experiments using the formula described in Makonese *et al.* [22]. The calorific value of the fuel was determined using a bomb calorimeter and was found to be 18.11 MJ/kg.

The biomass pellet stove comprises of an inner cylinder and an outer cylinder, which hosts the combustion chamber. The stove requires a 12V battery to power the fan. By adjusting the speed of the fan, the flame can be set to low, medium or high power settings depending on the level of heat required for the cooking or heating task.

Fig. 1. Photograph of the biomass pellet forced draft cookstove and pellet fuels used.
(Photograph: Marian Brown)

2.2 Survey of food dishes and cooking sequences

The number of food items/ dishes were set according to the most widely cooked meals in the low-income stratum of Johannesburg, South Africa, which involved a staple dish and relish. With the help of a questionnaire, the survey identified the cooking patterns and food dishes including the recipes [6]. The survey was administered in the Alexandra Township. The sampling was carried out using a stratified random sampling of 100 households in the case study area. A semi-structured questionnaire was employed during the survey and comprised questions relating to the primary food items, quantities, the frequencies, and cooking sequences of each food item [6].

We have termed the protocol used in this study for the development of cooking sequences – contextual testing. This is a form of uncontrolled cooking tests (UCT) [20]. The UCT differs from the conventional CCT [23] in that the meal is not controlled and the cook is free to prepare the dishes the way they prefer. The only measurements taken include the fuel used, how the stove is operated during the cooking sequence and the final mass of food cooked as part of an actual household meal [20].

2.3 Contextual testing protocol – observation tests

Female cooks who were residents of Alexandra Township prepared the meals, while the SeTAR stove testing team recorded the activities. The contextual testing was conducted during the cooking of some everyday household meals as suggested in Robinson *et al*. [20]. The cooks were asked to identify the utensils (pots, lids, cooking spoon/ stick etc.) to be used during the meal. All cooking utensils were cleaned, dried, weighed and the measurements were recorded in a logbook. Sufficient fuel was provided for the preparation of the meal and any follow-up dishes. The amount of fuel and lighting material needed to prepare the meal was weighed on a mass balance. Each food item (mealie meal, rice, water, salt, cooking oil, onion, tomatoes, meat etc.) was weighed before it was cooked.

The test began with the cook being asked to make and light a fire as they normally would, with the method and start time noted. The ignition method was kept constant for all the tests [6]. The cook was then recorded preparing the meal. The cooking observation test involved recording the time taken to cook each meal from start to finish, noting the time of changes between the two power levels as required by the recipes. The observed cooking sequence was dictated by the cook, type of food being prepared, recipe and the design capacity of the stove, rather than by the technician. The technician's job was to observe and record the happenings, specifically the time of operation at each power level and to assist in changing the power levels. When they had finished preparing the meal, the time was noted. The food was then weighed, photographed, and removed from the cooking area [20]. The cook was free to start serving the food. The fire was then extinguished, and all char (no ash) was put in a heatproof container, before weighing. Unburned biomass pellets and marginally burnt and torrefied biomass pellets were also weighed. Questions on cooking, fire management practice and socio-economic issues were asked during the cooking observation exercises.

2.4 Selection of cooking sequences in the lab

After the field observation exercise, and back at the SeTAR laboratory, a cook was chosen from among the team members to mimic the cooking sequences as learnt from field experiences. The cooking at the laboratory followed a similar cooking style as observed within the study area.

Cooking sequences were selected from a suite of previously determined cooking tests derived using different power settings and time durations. Three standard meals were cooked on the biomass pellet stove. The first meal consisted of samp (dry maize and beans) and beef tripe, while the second meal was made up of pap (thick maize-meal porridge) and cabbage. The third meal comprised of rice and chicken. These meals are chosen from common menus of low-income urban households in the Townships of Gauteng. The foods were cooked across the power range of the stove (low to high power settings). Adjustments to the power level settings were made at the discretion of the cook. Six-litre aluminium pots were used for the cooking sequences, with the amount of food cooked enough for seven adults.

The observed cooking sequences (duration of operation at each power level from ignition to completion of the cooking) for the two meals were combined into a technical burn sequence, intended to represent the typical use of the stove by the target user communities.

2.5 Technical tests and sampling regimen

The technical burn sequences for the fuel/stove combination were replicated on the testing rig (under an emissions collection hood) with a pot of water to be heated as a surrogate for a pot of food. The test under the emissions collection hood is referred to as a 'technical test'. The test was carried out to determine the thermal and emissions performance of the devices.

Technical tests were done as per the Heterogeneous Testing Protocol (HTP protocol, downloadable from www.setarstoves.org), which refers to testing a device at multiple power levels with 5-L or 2-L pots of water. The tests are based on a technical burn sequence, derived from culturally appropriate cooking observation tests. In the HTP, the pot of water was substituted with a fresh pot of water at room temperature upon reaching 70ºC to avoid complexities brought about by water evaporation. The water temperature was monitored with a thermocouple placed inside the pot. Gas probes placed in the emissions hood and channelled to flue gas analysers sampled combustion products. Two Testo™ flue gas analysers model 350 XL were used – one for diluted and the other for the undiluted gas stream. A DRX DustTrak™ was used for in-situ monitoring of particulate emissions. The stove and pot combination was placed on a mass balance and remained there from ignition to completion of the test. The readings for fuel burnt, trace gases and particulate matter emissions were logged at 10 s intervals. The technical test provided important information on gaseous emissions (e.g. CO, CO/CO_2 and PM2.5) and thermal performance (e.g. fuel burn-rate, firepower, cooking power, and cooking efficiency) of the test stove. The sampling set-up is described in detail in Makonese *et al.* [22].

3 RESULTS AND DISCUSSION

3.1 Cooking sequences

Given that cooking sequences are derived from UCTs where cooks could prepare any meal they wanted according to local practices, the time that was taken to prepare each dish varied between cooks. As such, there was a great need to average the data between cooks and develop a single averaged cooking sequence specific to each dish. For example, the cooking observations tests done on the device were with a large pot (5 L), meant to feed seven people. The three dishes were cooked at different times. The average of cooking durations at each power level formed the cooking sequence for the technical tests. Results showed that the biomass pellet stove had a cooking sequence of 134 minutes, distributed as follows: 55 minutes for the first high power phase; 19 minutes for the initial medium power phase; and 39 minutes for the second high-power phase. Details on the derivation of the cooking sequence are depicted in Table 1. The same cooking sequence was derived for the small pot experiments, to compare the effect of pot size on the emissions performance of the fuel/stove combination.

Table 1: Cooking sequence for the biomass pellet stove

Meals	Cooking time (minutes) at different firepower levels					
	High	Medium	Low	High	Medium	Low
Pap and cabbage	44	0	0	26	0	0
Samp and tripe	85	30	0	58	20	0
Rice and chicken	36	27	0	34	0	43
Average cooking sequence	55	19	Nil	39	7	14

3.2 Thermal performance

The averaged cooking sequence was used in the technical tests determine the thermal and emissions performance of the cooking device. The stove was operated as it would under normal cooking conditions. Instead of using food items for the experiments, water was used as surrogated for the food. Results of the water heating tests using the HTP, based on the derived cooking sequence, showed that the average fuel burn-rate for the stove when using 5 L water was 0.42 kg/h with an average firepower output of 2.1 kW and cooking power of 0.67 kW (Table 2). The fuel burn rate while heating a 2 L pot of water was 0.36 kg/h with a firepower of 1.83 kW. These results are averages for three tests and are based on a calorific value of 18.11 MJ/kg. A t-test at 95% confidence level was used to test the hypothesis that there is no significant statistical difference between the 5 L and 2 L pot results; rejected if the p-values were greater than 0.05 ($p>0.05$). Based on this significance test, the thermal performance results were found to be statistically similar except for cooking efficiency and heat (MJ) into pots. As such, the presence and size of the pot significantly influenced the performance of the stove concerning the thermal efficiency and heat delivered to the pot numbers (Table 2).

The thermal efficiency results presented in this study are comparable to those reported in Raman *et al.* [24]. However, the biomass pellet stove employed in our experiments used 65% less fuel per minute compared to the forced draft stove reported in Raman *et al.* [24]. The difference can be attributed to the dissimilar design parameters in the forced draft stoves used.

Table 2: Thermal performance results for the biomass pellet cookstove (complete cooking-sequence) – Mean ±SD

Pot size	FBR (kg/h)	FP (kW)	CP (kW)	HE (MJ)	TE (%)	SH (kW)
5 L	0.4 ± 0.0	2.1 ± 0.0	0.7 ± 0.1	5.3 ± 1.3	32 ± 6.0	2.4 ± 0.1
2 L	0.4 ± 0.0	1.8 ± 0.2	0.5 ± 0.1	1.8 ± 0.3	26 ± 1.0	2.7 ± 0.2
p-values	0.00	0.01	0.01	0.14	0.26	0.01

FBR = fuel burn rate; FP = firepower; CP = cooking power; HE = heating energy in the pots; TE = thermal efficiency; SH = space heating

Considering power settings, results further indicated that switching the stove from high power to medium or low power settings did not appreciably affect the firepower and the fuel burn rate. The firepower of the stove is changed by varying the speed of the fan on the forced draft stoves – the higher the speeds, the greater the firepower and vice versa. However, the thermal efficiency was lowered with each turndown. The largest reduction of about 25% was recorded between the high and low power settings (Table 3). This result is dissimilar to findings in Arora *et al.* [6] who found that when operating the forced draft stove at low air supply the thermal efficiency increased by up to 15%. The CO results reported in this study are in agreement with the results presented in Arora *et al.* [6] who indicated that when the air supply is reduced, CO emission factors decreased by up to 42%. Our results indicated that at low fan speeds (low power setting), CO emission factors are reduced by ~70% and by ~39% when the fan speeds are set at medium power setting. The adjustment of the fan speed is always at the discretion of the cook and is dependent on the food dish being prepared. These factors need to be considered when developing standardised stove testing protocols. The integration of cooking sequences in standard test experiments has the potential to give laboratory results that are comparable to field obtained results. Such cooking sequences can be incorporated into standard tests such as the heterogeneous stove testing protocol (HTP) and the water boiling test (WBT), to mention a few.

Table 3: Averaged performance parameters at different power level settings

Power level setting	FBR (kg/h)	FP (kW)	CE (%)	TE (%)	CO (g/h)	$PM_{2.5}$ (mg/MJ)
High	0.42	2.1	1.02	32	4.4	7.2
Medium	0.37	1.9	0.45	30	2.7	0.1
Low	0.43	2.1	0.30	24	1.3	2.7

FBR = fuel burn rate; FP = firepower; CP = cooking power; HE = heating energy in the pots; TE = thermal efficiency; SH = space heating

3.3 Emissions performance

The biomass pellet stove was evaluated for emissions performance using the cooking sequence derived in 3.1. The CO emissions were relatively low throughout the technical tests, with spikes only recorded when the stove was refuelled (usually after 40 – 50-minute intervals). Emissions of CO and $PM_{2.5}$ and the combustion efficiency (CO/CO_2 ratio) were higher at the high power settings of the cooking sequence. Results showed that the biomass pellet stove depicted good combustion efficiency (99%) with an average CO/CO_2 ratio of 0.87% with 5 L water and 1.13% with 2 L water in a 3 L pot (Table 4). These ratios are well below the 2% limit that is recommended for domestic paraffin and ethanol gel stoves by the South African Bureau of Standards (SANS 1906:2006). The biomass pellet stove converted about 99% of the fuel carbon into CO_2. Ideally, there should be no CO emissions in a very clean burn (all fuel carbon is converted to CO_2). Such performance is a rare feat for a domestic biomass combustion device.

Table 4: Averaged emissions performance results for the biomass pellet stove (complete burn-sequence) – Mean ±SD

Pot size	CO (g)	$PM_{2.5}$ (mg)	CO (g/hr)	$PM_{2.5}$ (mg/h)	CE (%)	CO (g/MJ)	$PM_{2.5}$ (mg/MJ)
5 L	7.8 ± 0.3	90 ± 0.0	3.6 ± 0.2	43 ± 3	0.9 ± 0.1	0.5 ± 0.0	5.7 ± 0.3
2 L	5.7 ± 1.9	40 ± 0.0	4.1 ± 1.4	28 ± 9	1.1 ± 0.5	0.6 ± 0.3	4.1 ± 1.5
p-value	0.08	1.97	0.06	0.63	0.02	0.01	0.14

CE = combustion efficiency (CO/CO_2)

Comparisons between the emissions performance with 5 L and 2 L pots of water show significant differences regarding total CO and $PM_{2.5}$ emissions for the entire cooking sequence - the emissions being higher with the bigger pot size. Results show that there is no statistically significant difference in the combustion efficiency and CO emission factors between the pot sizes.

3.4 Application of cooking sequences in standardised tests

Task-based tests such as the Water Boiling Test, although desirable for a quick assessment of the performance of a cooking device, may not necessarily reflect how the stove will behave in realistic/ real-world uses of the fuel/stove combination. Although the Kitchen Performance Test (KPT) is argued to provide a realistic view of the performance a fuel/stove combination in real-world scenarios, aggregating the results leads to an inherent bias in the findings with a coefficient of variation up to 50% [23]. On the other hand, the Controlled Cooking Test (CCT), although being representative of the actual food prepared in the target communities presents only a 'snap-shot' of system performance. As such, may omit key system behaviour that has the potential to affect the overall assessment of the fuel/stove combination [16],[20].

Incorporating cooking sequences into the HTP offers a potential to give a stronger and more representative data set with a better measure of the inherent variability as one would experience in real-world scenarios including cooking practices, meals cooked, user behaviour, local fuels etc. An HTP with cooking sequences addresses the context of use of cooking systems and is fundamentally different from other task-based assessments that analyse single tasks [20]. Although this method is being developed further, it is envisaged that by studying the context of use of a variety of cooking systems and developing technical tests based on cooking sequences, a better picture can be gained of the way the cookstove performs in real-world scenarios. Again, it will be possible to carry out test experiments in the lab, obtaining test results that are comparable with field results.

4 CONCLUSION

The study aimed to evaluate cooking sequences and their use in the performance evaluation and realistic utilisation of biomass pellets in a forced draft stove. The method advocated in this study is a revised in-situ testing protocol based on the Uncontrolled Cooking Test (UCT). It seeks to assess the task-based performance of the system (fuel/pot/stove/meal/user) when preparing any meal and when the cookstove is operated according to local conditions and practices. Cooking sequences were integrated into the overall assessment of the stove using a heterogeneous stove testing protocol. The incorporation of cooking sequences in standardised stove testing protocols offers the potential to correlate better the laboratory and field performances of fuel/stove combinations as the cookstoves are operated, during technical test experiments, the way they would in real world-uses by mimicking the preparation of specific food dishes.

It is recommended for future studies to compare the performances of the UCT, CCT and KPT using derived cooking sequences.

REFERENCES

[1] A. P. Grieshop, J. D. Marshall, M. Kandlikar (2011). "Health and climate benefits of cookstove replacement options". *Energy Policy, 39(12)*, pp. 7530 – 7542.

[2] D. K. Kimemia, C. Vermaak, S. Pachauri, B. Rhodes, (2014). "Burns, scalds and poisonings from household energy use in South Africa: Are the energy poor at greater risk?" *Energy for Sustainable Development 18*, pp. 1–8.

[3] E. Mills, (2012). "Health impacts of fuel-based lighting". The Lumina project, Technical Report No. 10; 2012. http://light.lbl.gov Accessed on 01 February 2018.

[4] G. Truran, (2009). "Household energy poverty and paraffin consumption in South Africa", *Boiling Point, 56*, pp. 1-6.

[5] T. Makonese, (2011). "Protocols for thermal and emissions Performance testing of domestic fuels and stoves". MSC Thesis, Dept. Geo. Env. Mngt & Energ. Studies, Univ. Johannesburg, Johannesburg, South Africa, 2011.

[6] P. Arora, S. Jain, K. Sachdeva, (2014). "Laboratory-based assessment of cookstove performance using energy and emission parameters for North Indian cooking cycle". *Biomass and Bioenergy, 69*, pp. 211 – 221.

[7] B. Barnes, A. Mathee, E. Thomas, N. Bruce, (2009). "Household energy, indoor air pollution, and child respiratory health in South Africa". *Journal of Energy in Southern Africa, 20(1)*, pp. 4 – 13.

[8] N. Bruce, R. Perez-Padilla, R. Albalak, (2000). "Indoor air pollution in developing countries: A major environmental and public health challenge". *Bulletin of the World Health Organization 78*, pp. 1078 – 1092.

[9] S. Solomon, G. Platther, R. Knutti, P. Friedlingstein, (2009). "Irreversible climate change due to carbon dioxide emissions". *Proceedings of the National Academy of Sciences of the United States of America (PNAS), 10(6)*, pp. 1704 – 1709.

[10] O. R. Masera, R. Diaz, V. Berrueta, (2005). "From Cookstoves to Cooking Systems: the integrated program on sustainable household energy use in Mexico". *Energy for Sustainable Development, XI(1)*, pp. 25 – 36.

[11] T. Makonese, C. Bradnum, (2017). "Public participation in technological innovation: The case of the Tshulu stove development programme". *Journal of Energy in Southern Africa, 28(1)*, pp.13 – 24.

[12] T. Makonese, J. Robinson, C. Pemberton-Pigott, V. Molapo, H. Annegarn, (2010). “A heterogeneous testing protocol for certifying stove thermal and emissions performance for GHG and air quality management accounting purposes.” *In A&WMA Conference,* Xian, China. pp. 10 – 14.

[13] P. Lloyd, (2002). “The safety of paraffin and LPG appliances for domestic use”. *Energy Management Use, 8(2),* pp. 1 – 6.

[14] P. R. Taylor, (2009). “The uses of laboratory testing of biomass cookstoves and the shortcomings of the dominant U.S. protocol”. MSc thesis, Dept. Mech. Eng., Iowa State Univ., Ames, Iowa, 2009.

[15] T. Makonese, C. Pemberton-Pigott, J. Robinson, Kimemia, D, H. Annegarn, (2012). “Performance evaluation and emission characterisation of three kerosene stoves using a Heterogeneous Stove Testing Protocol (HTP)”. *Energy for Sustainable Development, 16(3)*, pp. 344 – 351.

[16] M. Johnson, R. Edwards, V. Berrueta, O. Masera, (2010). “New approaches to performance testing of improved cook-stoves”. *Environmental Science and Technology, 44*, pp. 368 – 374.

[17] C. A. Roden, T. C. Bond, S. Conway, A. B. O. Pinel, N. MacCarty, D. Still, (2009). “Laboratory and field investigations of particulate and carbon dioxide emissions from traditional and improved cookstoves”. *Atmospheric Environment, 43*, pp. 1170 – 1181.

[18] M. Johnson, R. Edwards, C. A. Frenk, O. Masera, (2008). “In-field greenhouse gas emissions from cookstoves in rural Mexican households”. *Atmospheric Environment, 42*, pp. 1206 – 1222.

[19] T. Bond, (2007). Proposal for ETHOS Technical Committee on Stove Testing Methods. www.bioenergylists.org/ethos (accessed November 29, 2010).

[20] J. Robinson, M. Ibraimo, C. Pemberton-Pigott, (2011). “The uncontrolled cooking test: measuring three-stone fire performance in northern Mozambique”. *Proceedings of the DUE (Domestic Use of Energy) Conference*, Cape Peninsula University, Cape Town, South Africa.

[21] F. Lambe, A. Atteridge, (2012). “Putting the cook before the stove: A user-centred approach to understanding household energy decision-making”. Working paper No. 2012-03, Stockholm Environment Institute, Sweden. pp. 27.

[22] T. Makonese, D. M. Masekameni, H. J. Annegarn, P. B. Forbes, (2017). “Emission factors of domestic coal-burning braziers”. *South African Journal of Science, 113(3-4)*, pp.1 – 11.

[23] R. Bailis, K. R. Smith, R. Edwards, (2004). “The kitchen performance test Version 1.5, Technical Report”, Household Energy and Health Programme, Shell Foundation, London.

[24] P. Raman, J. Murali, D. Sakthivadivel, V. S. Vigneswaran, (2013). “Performance evaluation of three types of forced draft cookstoves using fuelwood and coconut shell”. *Biomass Bioenergy, 49*, pp. 333 – 340.

[25] R. Bailis, D. Ogle, N. MacCarty, D. Still, R. Edwards, K. R. Smith, (2007). “The Water Boiling Test Version 3.0: Cookstove emissions and efficiency in a controlled laboratory”. Technical Report, Univ. Calif. Berk., California Berkeley, USA.

AUTHORS BIOS AND PHOTOGRAPHS

Tafadzwa Makonese is an energy and air quality specialist with the SeTAR Centre, University of Johannesburg. He holds a PhD in Energy Studies from the University of Johannesburg. His current research interests are in air pollution and related health effects. He has researched the development of culturally appropriate stove performance testing protocols, and their usefulness in wider stove dissemination programmes funded the World Bank, the Global Alliance for Clean Cookstoves (GACC) and others. taffywandi@gmail.com

Johan Meyer is an associate professor in the Department of Electrical Engineering at the University of Johannesburg. He has a D.Ing in electrical engineering from the Randse Afrikaanse Universiteit. He worked in the aviation industry before returning to academia. His research interest is in renewable energy, rural development and systems engineering. He is a senior member of IEEE and SAIEE. johanm@uj.ac.za

Presenting author: T. Makonese will present the paper