Performance evaluation and emission characterisation of three kerosene stoves using a Heterogeneous Stove Testing Protocol (HTP)

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Abstract
The combustion of kerosene fuel in poorly designed cookstoves is a major domestic source of poor indoor air quality and burn injuries in the developing world. It is argued that these challenges are best addressed by the development and dissemination of clean, safe and efficient cookstoves. In this study, three kerosene stoves including two wick stoves and one pressurised stove were tested for thermal performance and CO gas emissions using the Heterogeneous stove Testing Protocol (HTP) developed at the SetAR Centre, University of Johannesburg. Results from the testing showed that the diameter of the pot had little effect on the performance of the tested kerosene stoves in terms of CO emissions, but it did have an effect on the thermal efficiency at the high power setting. Power setting was found to influence the thermal efficiency and combustion performance of all stoves tested, indicating the need for assessment of the appliances across the full range of power settings (where feasible). The pressurised stove had lower CO emissions compared with the wick stoves. Conversely, the wick stoves depicted lower specific times to boil water and higher fuel efficiencies. These results provide essential information to stove designers, regulators and authorities interested in the dissemination of improved kerosene stoves. The variation of emissions and performance across the power band may be useful for improving national standards by correctly characterising novel technologies and improving the design of existing appliances under different operating conditions. Implications of improved kerosene stoves are improved health, improved access to modern energy, reduced fuel consumption and a reduction in energy poverty.

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Introduction
An estimated 40–50% of the South African population rely on kerosene (illuminating paraffin) to meet part of their daily domestic energy needs (Kruger, 2006), with 21% using it for cooking, 14% for heating and 13% for lighting (Muller et al., 2003; SSA, 2000). In some parts of the developed world, kerosene has been mooted as a potential replacement for paraffin fuel. In South Africa, the use of kerosene and related appliances has been attributed to the use of non-durable and inefficient kerosene stoves that dominate the South African market. Of these stoves, 90% are non-pressurised (wick-based) (Truran, 2009) and the balance, pressurised stoves.

Due to frequent domestic fire disasters attributed to unsafe kerosene stoves, the South African Bureau of Standards (SABS) has developed stringent compulsory specifications for wick (non-pressure) kerosene stoves, heaters and pressurised stoves. The standards for wick stoves (SANS 1906, 2006) and that of pressurised stoves (SANS 1243, 2007) provide specifications for:

- Preventing incorrect assembly
- Safe ignition
- Preventing fuel leakage
- Preventing refuelling the stove while burning
- Effective control and extinguishing of the flame
- Self-extinguishing if stove is tilted or knocked over
- Ensuring the fuel in the tank remains below the flash point during and after stove use
- Limiting harmful emissions (e.g. CO:CO2 ratio<0.02)
- Ensuring the strength, durability and stability of the appliance
- Ensuring sustained power over time (Lloyd and Truran, 2008)

Keywords:
Heterogeneous Testing Protocol
Energy poverty
Indoor air quality
Kerosene
Paraffin
Stoves

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Following the homologation of the non-pressure kerosene appliances standards, a commonly used type of wick stove which we call here “the baseline kerosene wick stove” was ruled unsafe by the South African Bureau of Standards (SABS) and cannot be imported or marketed in that form (Cowan and Dieden, 2008; NRCS, 2009). A new type of non-pressurised kerosene stove which complies with the compulsory specifications (SANS 1906, 2006) of SABS has been put on the market. Although portions of SANS 1906:2006 were subsequently declared compulsory, its enforcement has proved difficult and illegal stoves continue to be sold, often to unsuspecting consumers.

The Sustainable Energy Technology and Research (SeTAR) Centre was formed as a joint venture between the University of Johannesburg and GIZ’s SADC-based Programme for Basic Energy Conservation (ProBEC) with a mandate to develop safer, cleaner burning and more energy efficient domestic stoves. The SeTAR Centre was commissioned by ProBEC to characterise the thermal efficiency and gaseous emissions of a number of solid fuel, kerosene and ethanol gel stoves. One of the ultimate goals of the centre is to replace the ubiquitous and highly polluting coal braziers and inexpensive but dangerous wick-type kerosene stoves. During the process of evaluation the SeTAR staff were engaged simultaneously in the development of appropriate test procedures and a MS Excel™ spreadsheet for producing chemically balanced emissions reports. These activities led to the development of what we term the Heterogeneous Testing Protocol (HTP) for stoves (Makonese, 2011).

Little data is reported in the literature on the thermal performance and emission characteristics of cooking appliances using kerosene in developing countries. Despite the obvious, that cooks use different pots and power settings, there are no reports of steady-state performance of kerosene stoves with different pot sizes and power settings. Studies of high-power kerosene stoves (Bussman et al., 1987) and the evaluation of thermal performance of kerosene stoves (Floor and van der Plas, 1991) were carried out using a Water Boiling Test (WBT). These tests involved determining the power rating of the stove without the pot on and were thus atypical of actual use. Stoves were lit and the wicks adjusted so that combustion took place with blue flames (Floor and van der Plas, 1991). The stoves were then operated for 30 minutes, after which the fuel consumption was established. The minimum power was also measured (without a pot) over a burn cycle of 30 minutes with the wicks in the minimum position flush with the top of the wick tubes according to EDP No. 27 (Floor and van der Plas, 1991). Prasad et al. (1983) suggested a different water boiling test for the evaluation of kerosene stoves. In their evaluation the actual WBTs were carried out by lighting the stove (at any chosen power setting) and waiting for a warm-up period. This was followed by weighing the stove, placing a pre-weighed pot of water (with known temperature) on the stove and starting the stop-watch. As soon as the water boiled, the pot was removed and replaced by a second pot with an identical quantity of cold water. This procedure was repeated until four pots were brought to a boil. The weight of the pot at the end of each boiling period and the times were recorded. All tests were performed using pots with their lids on. This method of stove performance evaluation has been suggested to minimise errors (Prasad et al., 1983).

The aim of this paper is to report the performance and CO emissions of three kerosene stoves (two wick stoves of markedly different designs and one pressurised stove) using the SeTAR Centre’s HTP for stoves.

Materials and methods

Experimental stoves tested

Stoves that were tested in this study are shown in Figs. 1, 2, and 3. The following are the descriptions of the stoves:

A. The baseline kerosene wick stove

This stove is of barrel-shaped sheet metal construction with a series of vertical slots on its sides and has a potholder with three pot rests mounted on top (Fig. 1). The stove has a wick configuration consisting of two woven fiberglass mats which are formed into crescent shapes and fitted into bent aluminum retainers. The retainers have tabs that allow them to be fitted to a base plate. The wick mechanism works with a single closed top inner diffuser and a double outer diffuser (Bradnum, 2007). This whole unit is then slotted into the wick housing.

The flame controller is held within the wick housing and has a toothed gear at its far end. The gear works in conjunction with a vertical rack that is attached to the moving wick sleeve and base plate mechanism. The movable rack on the wick mechanism is held in place by a wire which prevents it separating from the wick housing. On the wick housing, a set of bent sleeves allows the wick to slide up and down as the controller is adjusted. Spot-welding holds these components (top and base) the correct distance apart on the wick housing (Bradnum, 2007).

B. The new type kerosene wick stove

This stove evolved from the baseline wick stove model described above, incorporating additional safety elements required by the new SABS kerosene stove safety standard (SANS 1906: 2006). The stove has a double C-shaped wick configuration. Each of the two wicks is made from woven fibre glass. The stove has a tripod leg construction riveted at the base of the fuel tank (Fig. 2). The tripod structure holds the pot support structure away from the fuel tank.

The mesh around the diffuser allows for the free circulation of combustion air. The diffuser configuration of this stove includes a closed top with a small hole in the centre where a metal cup with circular holes protrudes, an inner diffuser and a double-walled outer diffuser. The gap created between the inner and the outer diffuser allows air to come into contact with the wick.

The controller is held in place within the wick housing. It has at its end a toothed gear. This gear works in conjunction with a vertical rack attached to the moveable wick and the top metal cap. When the wick moves up, the metal cap moves up leaving a gap allowing the diffusion of air into the combustion zone of the stove. Elevating the wick and the metal cap increases the size of the flame and the

Fig. 1. Baseline kerosene wick stove.
fire power of the stove. Both diffusers heat rapidly when the stove is ignited, pre-heating the combustion air before reaching the flame zone thereby increasing the combustion efficiency of the stove (Bradnum, 2007). The controller is also connected to an external auto-shutoff lever (Fig. 2). The lever relies on a friction mechanism to function properly. If the stove is tilted or moved slightly, the lever triggers a wick retraction mechanism. The wick and the top metal cap drop, closing the top of the stove, shutting off the flame instantly.

Compared with the baseline product, the increased distance between the combustion zone and the fuel tank intends that the temperature of the fuel in the tank does not reach the flash point even after prolonged use. The heating of the fuel was considered a critical design flaw in the baseline stove.

C. The pressurised kerosene stove

This stove uses a roarer type burner. The fuel tank has a filling port with a sealed fuel cap and next to it, a brass pressure release thumb-screw valve. The fuel tank has a hand operated air pump protruding from the side (Fig. 3). The pump has an integral non-return valve allowing the fuel bladder inside the fuel tank to be manually pressurised with air, forcing the fuel up to the burner head.

According to the manufacturer’s instructions, the stove should be ignited using methylated spirits to fill the pre-heating cup. This pre-heating flame raises the temperature of the fuel evaporator. In practise, most users burn kerosene from the tank instead of methylated spirits. The common practise is to pressurise the stove slightly and allowing kerosene to flow out the nozzle in the roarer head. In the absence of any flame, it runs down into the pre-heating cup. The tank pressure is released when the pre-heating cup is nearly full. An asbestos swab dipped in fuel is used to transfer a flame from a match to the kerosene in the pre-heating cup. Once the roarer head has been engulfed in a flame for about one minute, the pressure relief valve is closed and the tank is again pressurised using the hand pump until the required flame is obtained. The initial fire warms the inner and outer tubes of the evaporator of the roarer head. When this assembly becomes hot enough to start vapourising the kerosene as it passes through the evaporator, the nozzle sends a stream of this vapourised kerosene vertically to the chamfered underside of the copper head (Bradnum, 2007). This vapour mixes with air immediately below the flame allowing combustion to take place around the copper head. This keeps it hot enough for the vapourisation of fuel to continue as long as there is fuel and positive pressure in the tank.

The stove power is controlled by a combination of increasing or relieving the air pressure in the tank. The higher the pressure within the fuel vessel, the higher the fuel flow rate. The stronger the flame, the more heat is generated. To lower the fire power of the stove the user releases some air using the brass bleed screw. In order to extinguish the flame, the user releases all the pressure from the fuel vessel, thereby cutting completely the fuel supply to the burner head.

Sampling and analysis

The carbon mass balance and hood method were used for determining the emissions from the kerosene stoves. Gaseous emissions such as CO₂ and CO were measured continuously with a Testo® 350XL/454 flue gas analyser. The flue gas analyser was manufactured by Testo India Pvt Ltd. The analyser has an accuracy of ± 10 ppm CO (0 to 199 ppm CO) and ±5% of m.v. (200 to 2000 ppm CO). The resolution for CO detection is at 1 ppm CO (0 to 10000 ppm CO). The reaction time for the analyser is approximately 40s (http://www.testo.uk). The analyser is automatically calibrated daily at start-up through its zero calibration function.

The stove to be tested is placed under a natural draft ventilation hood and duct with the gas sample probe is placed inside a hood exhaust duct (Fig. 4). Since a high extraction rate may influence the combustion characteristics of the stove (Bhattacharya et al., 2002), an extractor fan was not used for drawing air through the hood and duct. We use a modified version of a commonly used carbon mass balance method (Smith et al., 1993) to determine emissions without the need to capture all emissions, requiring only the following: a well-mixed sample of the gases, a measure of the mass of fuel burned and the elemental fuel composition from which the stoichiometric air demand can be calculated. The sampling configuration for gases includes, in sequence, a stainless steel probe, a coalescing filter and a flue gas analyser with a moisture condensation chamber.

The hood method of determining emissions can be used simultaneously for the determination of thermal performance in a systematic and standard manner (Zhang et al., 1999). Fig. 4 shows the experimental
set-up for the analysis of combustion gases from fuel/stove/pot combinations.

Even though gases such as SO\textsubscript{2}, H\textsubscript{2}S, NO, NO\textsubscript{x}, and H\textsubscript{2} can be reported using the HTP, only carbon monoxide and carbon dioxide have been chosen as our indicator pollutants and are reported as such in this paper. Sulphur and nitrogen pollutants are omitted for the following reasons: in South Africa the kerosene available on the market has low sulphur content (< 0.1% v/v) (Dlamini and Gqaleni, 2006); very low emissions of SO\textsubscript{2} and H\textsubscript{2}S were observed for kerosene burning stoves; and the flame temperature does not approach the threshold (~1540°C) for NO\textsubscript{x} production so the NO\textsubscript{x} emissions are inconsequential.

Testing protocol

The Heterogeneous stove Testing Protocol (HTP), developed by the SeTAR Centre, University of Johannesburg was used for the evaluation of thermal and emissions performance of the three kerosene stoves. The essence of the HTP is to test the stove over the full range of power levels and tasks anticipated during domestic use including at least two widely used pot sizes. The HTP hypotheses that pot size may be an important performance metric for the evaluation of fuel/stove/pot combinations. The underlying proposition is that emissions might vary with power or because different pot sizes may alter the air and gas flow patterns (Bhattacharya et al., 2002; Makonese, 2011). Accordingly, the protocol requires that the device is operated, as per manufacturer’s instructions or local fire tending practices, over a nominal range of three power settings — high, medium, and low — to heat water in two significantly different pot sizes (typically containing 5 litres and 2 litres water). The large pot used in these tests was 255 mm in diameter and the small pot was 205 mm in diameter. Features of the test protocol require a minimum of three tests under each condition (stove/fuel/pot combination) to obtain standard deviations and quality-assured generalisations about performance. Prior to each series of tests, fuels were analysed for determination of their calorific values using a bomb calorimeter (CAL2\textsuperscript{®} ECO® calorimeter).

The procedure is divided into three phases, a high power, a medium power and a low power test which were separately evaluated. The high power test begins with the pot, stove and water at room temperature. The stove is operated at its highest power setting until the water reaches a rolling boil. To obtain the specific fuel consumption at the high power setting, this test is continued for a minimum of 10 minutes after reaching the local boiling point. The medium power phase begins immediately after the first phase. The stove is adjusted to a medium power setting and allowed to reach a steady state (indicated by a constant rate of fuel consumption) usually for five minutes after which an identical second pot of cold water is placed on the stove. Mass, time and temperature readings are recorded while the water temperature is allowed to rise from ambient to ~70°C, marking the end of medium power test. The stove is next adjusted to a low power setting (or to the lowest level that provides a stable flame). An identical third pot of cold water is placed on the stove and data recorded until the water temperature has increased to ~70°C, marking the end of low power test. The HTP requires performance testing across a range of power settings and pot sizes. This is different from making measurements of CO emissions and efficiency calculated during the completion of a boil and simmer with a single pot as is the case with a typical WBT. Note that the only cooking task performed was heating water. The metrics recorded relate to thermal efficiency and CO emissions at different power levels (high, medium and low, where such power variation is practical). A digital mass balance with a 32 kg range and a 0.001 kg resolution supports the entire stove, fuel and pot. Mass readings were recorded manually every 60 seconds for the whole system mass as well as the “pot lifted” state (mass readings without the pot on). From these readings the interim fuel use, thermal power and water mass change can be calculated.

Other calculated values are the amount of water evaporated and mass of fuel burned. These are necessary to determine thermal parameters such as burn rate and the overall thermal efficiency of each fuel/stove/pot combination. The thermal efficiency of the fuel/stove/pot combination is reported as a percentage. The test calculates this as the ratio of enthalpy change of the water in the pot to the maximum energy theoretically available from combustion, assuming no condensation of moisture in the product gases (Taylor, 2009). Thermal efficiency is calculated using the formula given below:

$$\eta = \frac{[4.186(P_0-P)(T_i-T_f) + 2257(W_{ov})/(f_{cd} \times \text{LHV})]}{1}$$

where \(P_0-P\) is the initial mass of water in the pot, 4.186 Jg\textsuperscript{-1}°C is the specific heat of water, \((T_i-T_f)\) is the change in water temperature,
compound in the exhaust (CO₂, CO, HC), the mass of fuel burned pounds. By carefully measuring the ratio of each carbon containing exhaust gas volume. The method assumes that all carbon in the fuel is taken. This method obviates the need to guarantee the capture of (pot/stove/fuel). A change in mass (fuel burned) is used to infer the of it. A high resolution mass balance is placed under the whole system volume can be calculated without having to capture and measure all of it. A high resolution mass balance is placed under the whole system (pot/stove/fuel). A change in mass (fuel burned) is used to infer the volume of all gases in the hood from which a representative sample is taken. This method obviates the need to guarantee the capture of 100% of all emissions and avoids the complexities of quantifying the exhaust gas volume. The method assumes that all carbon in the fuel is consumed by the fire and released as measurable carbon compounds. By carefully measuring the ratio of each carbon containing compound in the exhaust (CO₂, CO, HC), the mass of fuel burned and the fuel composition, the total volume of gases emitted can be calculated. The emissions factors are then calculated using a total carbon balance. According to Smith et al. (1993), the following assumptions are made using such a test protocol:

- Samples are representative of the emission ratios throughout the burn.
- The fuel is the only source of the net carbon measured in the grab samples.
- The carbon-containing gaseous species other than those measured contain a negligible fraction of the carbon

Emission factors are calculated as follows:

$$EF = \frac{C_{\text{pollutant}}}{C_{\text{carbon}} + F_{\text{carbon}}}$$

where $C_{\text{pollutant}}$ is the average pollutant concentration in the exhaust gas (gm$^{-3}$), $C_{\text{carbon}}$ is the average carbon concentration in the exhaust gas (gm$^{-3}$), and $F_{\text{carbon}}$ is the mass fraction of carbon in the fuel (The Water Boiling Test, 2012).

Results and discussion

CO emissions per task accomplished

The CO emissions per standard task accomplished (bringing water to the boil) were investigated for the three kerosene stoves using the Heterogeneous Stove Testing Protocol and the results are shown in Fig. 5. Error bars show the standard deviation ($\sigma$) for the three replicate tests that were performed. Error bars for the precision of the equipment are not indicated. A two tailed Student t-test at the 95% confidence level ($p = 0.05$) was used for all statistical analyses in this study.

The difference between the emissions of CO for small and large pots for all three stoves tested was not statistically significant (Fig. 5). The baseline kerosene wick stove gave a task specific CO emission of 0.83 ± 0.17gL$^{-1}$ (mean ± SD) when using a small pot, and 0.78 ± 0.24gL$^{-1}$ when using a large pot (Fig. 5). The new type kerosene wick stove showed a task specific CO emission of 0.94 ± 0.20gL$^{-1}$ (for small pot) and 0.76 ± 0.10gL$^{-1}$ when using the large pot. However, for each stove type the difference between the two pot sizes is not statistically significant.

The pressurised kerosene stove showed significantly lower task specific CO emissions of 0.03 ± 0.02gL$^{-1}$ using a small pot, compared to the two wick stoves (Fig. 5). This can be attributed to the nature of the burner which has a much higher flame temperature in a confined space. The nozzle sends a stream of vapourised kerosene vertically to the chamfered underside of the copper head. The vapour mixes well with air allowing for more complete combustion. Further, when the burner on the pressurised stove indents air into the fuel jet area it is less influenced by air flow around the bottom of the pot than is the case with wick stoves. This induction results in a low level of products of incomplete combustion (PIC). CO is formed when the fuel and air are not completely burned. Good mixing and complete combustion do not usually occur in stoves without a controlled air supply. An uncontrolled and excessive air supply is a well-known performance problem for wick type stoves.

Task-based performance comparison

Task-based performance measurements will inform the customer what compromises may be necessary when selecting appliances for fuel efficiency and cooking performance. Task-based results from the three kerosene stoves evaluated are presented in Table 1. In all cases the fuel used and emissions produced to bring water to a boil are normalised to an equivalent 80°C rise. After normalisation, specific fuel consumption and emission factors can be fairly compared between tests.

Results show that the specific time to boil water (time per unit volume water boiled and normalised to 80°C) is shorter for both pot sizes for the baseline kerosene stove than for the new type kerosene stove or the pressurised kerosene stove. This is due to higher average fire power of the baseline stove. The pressurised kerosene stove gave the lowest fire power at a high power setting mainly due to the gradual blocking of the nozzle by the accumulation of elemental carbon which reduced the fuel flow. The nozzles were unblocked and cleaned at the beginning of each test and no effort was made to clear them during the definitive tests. The manufacturer of the stove, in further discussions, indicated that the issue of nozzle blocking had been
addressed in subsequent designs. However, the improved version of the stove was not available in time to be re-evaluated for this paper. Compared with the baseline stove, the pressurised stove took twice as much time to boil both pot sizes. The baseline kerosene stove has a lower specific fuel consumption compared with both the new wick stove and pressurised kerosene stove (Table 1). At any given power setting, one would expect a stove with a higher specific fuel consumption to give an increased fire power, but this was not the case.

For all the stoves tested, the specific fuel consumption and the specific time to boil increased with a reduction in the pot size (Table 1). This is due to an increase in heat transfer efficiency when using a larger pot.

It has to be noted that there is a price to pay if one chooses the pressurised kerosene stove on the basis of low emissions and good combustion efficiency. Clearly the stove fails to perform the basic function of continuous heating due to the gradual blocking of nozzles and the consequent reduction in power. The direct cause of the blocking is overheating of the fuel during vaporisation creating excessive ionised elemental carbon inside the evaporator which rapidly accumulates on sharp edges, especially on the jet. The pressurised stove will take twice as long as the baseline kerosene wick stove to boil 5 litres of water — a difference sufficiently large for users to complain about.

**Thermal efficiency and fire power comparison**

A fuel/stove combination can be characterised by a thermal efficiency versus fire power graph. The purpose of the graph is to be able to assess the stove across a range of power settings and to distinguish between good and poor performance. Fig. 6 graphs the thermal efficiency versus fire power for the three kerosene stoves using a small pot. It should be noted that the pressurised kerosene stove was evaluated at only two power settings (high and low). It was difficult to standardise the medium power setting as the stove uses a hand pump and a pressure release valve to control the firepower.

When cooking with a small pot (Fig. 6) the pressurised kerosene stove performance profile shows that the thermal efficiency does not change with an increase in the fire power. Although the stove shows a stable thermal efficiency to fire power relationship, it is far from ideal because the fire power only varies from 550 to 750 Watts — falling far short of the 1000W target (SANS 1906, 2006) with a thermal efficiency of only 35%. This highlights the need for design changes to the stove to meet the thermal requirements. The fire power of pressurised stoves can be increased by increasing the diameter of the nozzle orifice.

The baseline kerosene wick stove (P1) showed a more optimal performance curve than the new-type kerosene wick stove (P3) (Fig. 6), with higher fire power and better thermal efficiency. This was unexpected as the new-type kerosene wick stove design was intended to be safer and more efficient than the baseline product.

The baseline kerosene wick stove (P1) generated 1400W on high with a thermal efficiency of 55% and 560W on low with a thermal efficiency of 36%. The new type kerosene wick stove has a fire power of 1100W with a thermal efficiency of 46% on high and 300W on low with a thermal efficiency of only 20%. As a result the fire power of the new-type kerosene wick stove on high setting is reduced by 21% while the thermal efficiency drops by 10% compared with the baseline stove.

When cooking with the large pot (Fig. 7) the baseline kerosene wick stove and the new type kerosene stove gave results similar to the small pot case (Fig. 7). The pressurised kerosene stove shows an efficiency range of 30—44%. Thermal efficiency increases with a large pot.

When plotting the stoves’ thermal efficiency vs. fire power curves, it is seen that the baseline kerosene wick stove performs best followed by the pressurised kerosene stove and then the new type kerosene wick stove. In terms of safety, the pressurised kerosene stove is ranked higher than the new type kerosene stove and much higher than the baseline kerosene stove because it has more safety features compared with the two wick stoves. These safety related evaluations are not reported in this study but are mentioned here to highlight the need for optimisation of domestic cooking appliances both in terms of efficiency and safety.

**Comparison with previous work**

This section seeks to analyse present results against work done in previous studies. Although it is difficult to compare results from different investigations due to incomplete data, different products and the use of different test procedures, such comparisons are important in identifying improvements in test methodologies and reported data. Our results showed a thermal efficiency range of 20—60% for kerosene wick stoves which compares well with and partly overlaps with the 45—60% range obtained by Floor and van der Plas (1991).

![Fig. 6. Thermal efficiency versus fire power of: baseline kerosene wick stove (P1), new-type kerosene wick stove (P2), and pressurised kerosene stove (P3) using a small pot.](image)

**Table 1**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Baseline kerosene wick stove</th>
<th>New type kerosene wick stove</th>
<th>Pressurised kerosene stove</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Large pot (Mean±SD)</td>
<td>Small pot (Mean±SD)</td>
<td>Large pot (Mean±SD)</td>
</tr>
<tr>
<td>Time to boil [min]</td>
<td>37.2±3.50</td>
<td>12.8±1.40</td>
<td>53.0±0.70</td>
</tr>
<tr>
<td>Specific time to boil [min·L⁻¹]</td>
<td>7.4±0.70</td>
<td>8.5±0.90</td>
<td>10.6±0.10</td>
</tr>
<tr>
<td>Specific fuel consumption [g fuel L⁻¹]</td>
<td>11.7±0.30</td>
<td>16.7±0.80</td>
<td>14.6±0.10</td>
</tr>
<tr>
<td>Specific CO emission [g CO L⁻¹]</td>
<td>0.76±0.24</td>
<td>0.81±0.17</td>
<td>0.76±0.10</td>
</tr>
<tr>
<td>CO [g/MJ]</td>
<td>1.59±0.57</td>
<td>1.29±0.48</td>
<td>1.96±0.77</td>
</tr>
<tr>
<td>Thermal efficiency at high setting [%]</td>
<td>50±2</td>
<td>61±1</td>
<td>53±1</td>
</tr>
</tbody>
</table>

* All data normalised to an 80°C temperature rise save for CO g/MJ.
Generally, all three stoves had significantly different thermal efficiencies which explain why there is a significant difference in the specific time to boil a litre of water. The performance of the pressurised kerosene stove was substantially reduced by the progressive blocking of the nozzle with carbon particles. The drop-off in performance resulted in the stove having a maximum fire power of 800–850 W which falls short of the SABS standard for kerosene fuelled cooking stoves. Despite these shortcomings, the pressurised stove gave a substantially better emissions performance compared with both un-pressurised wick stoves.

All the stoves exhibited a significant difference in specific fuel consumption between large and small pots. The power setting significantly affected the overall performance of the stoves highlighting the need for assessments of fuel/stove combinations to be made across the full power range from high to low.

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References


