Comparative Evaluation of Emissions from Selected Paraffin Lamps and a Paraffin Thermoelectric Generator

David Kimemia\textsuperscript{1*}, Tafadzwa Makonese\textsuperscript{1}, Harold Annegarn\textsuperscript{2}

1. SeTAR Centre, University of Johannesburg
   2. Energy Institute, Cape Peninsula University of Technology

Domestic Use of Energy Conference,
30 March – 2 April 2015, CPUT, Cape Town
• Introduction
• Materials and test procedures
  • Experimental lighting devices
  • Test procedures
• Results
• Discussion and conclusion
Introduction

- Energy services for cooking and lighting a necessity
- Energy poverty afflicts many households in dev countries
- Energy-poor rely on traditional biomass and paraffin lamps
- Products of incomplete combustion (McCarty et al., 2008)
- CO, PM$_{2.5}$ - cause of health losses (Lim et al., 2012)
- Black carbon (BC) - forcing mechanism in global warming (Bond et al., 2013)
- We focus on PM emissions from paraffin lamps
Introduction, cont’d

• About 620 million people in sub-Saharan Africa lack electricity (IEA, 2014)
• PM emissions from paraffin lamps underestimated (Arne et al., 2013)
• Lamps emit 20 times more PM (BC) than previously thought
• Even with adoption of clean stoves, households still exposed (WHO, 2014) (Lam et al., 2012)
• Mitigation – LED lamps by solar or thermoelectric generator
• Paper addresses knowledge gap on domestic lighting services
• Reports on evaluation of CO and PM$_{2.5}$ for two paraffin lamps and prototype thermoelectric generator
• Thermoelectric gen/LED (iHarvey™) designed to provide higher light intensity
• ...also has a USB plug point for media power
• We compare fuel consumption and emission rates of the 3 devices
• Tests conducted at SeTAR Centre stove-testing laboratory, UJ
Materials and test procedures

Experimental lighting devices

• Two paraffin wick lamps: a) standard lantern and b) glass lamp
• c) iHarvey™ thermoelectric generator

Source: SeTAR photos 2014
Materials and Test Procedures, cont’d

Testing rig: Emissions collection hood; flue gas analyser (Testo™), particle counter (Dust trak™), computer, mass balance

Test procedure:
• Device fuelled, weighed and ignited under the hood
• Left on mass balance to track fuel consumption
• Gas sample collected by two probes and channelled to flue gas analyser and particle counter
• Data logged every 10 seconds; Test duration 25 minutes
• SeTAR HTP adapted for the suite of tests (www.setarstoves.org)
Test equipment set-up at SeTAR lab: 
a) Combustion room; b) data capture room

Source: SeTAR photos 2014
Calculation and determination of CO and PM$_{2.5}$ emission factors

Calculation of the emission factors is made in this manner:

\[
CO_{EF} = \frac{CO[g]}{H_{NET}[MJ]}
\]

\[
PM 2.5_{EF} = \frac{PM 2.5[mg]}{H_{NET}[MJ]}
\]

% reduction = \( 100 \cdot \frac{(H_r-L_r)}{L_r} \)
Results

Emissions

• iHarvey has 83% less PM$_{2.5}$ emissions compared to p-lamps
• 90% of iHarvey PM emissions produced in first five minutes
• CO and CO/CO$_2$ ratio for the 3 devices have no statistical diff

Fuel consumption and illumination

• iHarvey and glass lamp similar fuel consumption rate (~30g/h)
• Manufacturer data – iHarvey has light output of 5 lanterns
• Implies iHarvey provides better illumination for less fuel consumption, with lower PM$_{2.5}$ emissions, lower risks of injury
PM$_{2.5}$ emissions profile for the paraffin lantern, glass lamp, and thermoelectric gen.
## Pair-wise comparisons

<table>
<thead>
<tr>
<th>Test Device</th>
<th>Fuel cons. (g/h)</th>
<th>COEF (g/MJ)</th>
<th>PM2.5 EF (mg/MJ)</th>
<th>CO (g/h)</th>
<th>PM2.5 (mg/h)</th>
<th>CO/CO2 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paraffin thermoelectric generator</td>
<td>30 ± 3</td>
<td>0.17 ± 0.02</td>
<td>48 ± 0.25</td>
<td>0.18 ± 0.01</td>
<td>21 ± 0.27</td>
<td>0.41 ± 0.02</td>
</tr>
<tr>
<td>Paraffin lantern</td>
<td>40 ± 0.58</td>
<td>0.14 ± 0.02</td>
<td>85 ± 0.26</td>
<td>0.16 ± 0.02</td>
<td>127 ± 0.29</td>
<td>0.34 ± 0.04</td>
</tr>
<tr>
<td>% reduction</td>
<td>-25%</td>
<td>27%</td>
<td>-44%</td>
<td>13%</td>
<td>-83%</td>
<td>21%</td>
</tr>
<tr>
<td>p-value</td>
<td>0.01</td>
<td>0.10</td>
<td>0.00</td>
<td>0.06</td>
<td>0.00</td>
<td>0.09</td>
</tr>
<tr>
<td>Sig. at 95% confidence (p&lt;0.05)</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test Device</th>
<th>Fuel cons. (g/h)</th>
<th>COEF (g/MJ)</th>
<th>PM2.5 EF (mg/MJ)</th>
<th>CO (g/h)</th>
<th>PM2.5 (mg/h)</th>
<th>CO/CO2 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paraffin thermoelectric generator</td>
<td>30 ± 3</td>
<td>0.17 ± 0.02</td>
<td>48 ± 0.25</td>
<td>0.18 ± 0.01</td>
<td>21 ± 0.27</td>
<td>0.41 ± 0.02</td>
</tr>
<tr>
<td>Paraffin glass lamp</td>
<td>30 ± 2</td>
<td>0.15 ± 0.01</td>
<td>212 ± 13</td>
<td>0.16 ± 0.01</td>
<td>127 ± 1.0</td>
<td>0.23 ± 0.12</td>
</tr>
<tr>
<td>% reduction</td>
<td>0%</td>
<td>16%</td>
<td>-77%</td>
<td>13%</td>
<td>-83%</td>
<td>78%</td>
</tr>
<tr>
<td>p-value</td>
<td>1.00</td>
<td>0.21</td>
<td>0.00</td>
<td>0.07</td>
<td>0.00</td>
<td>0.07</td>
</tr>
<tr>
<td>Sig. at 95% confidence (p&lt;0.05)</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>
Discussion and conclusion

• PM emissions still significant in households with clean stoves
• Remaining source of the PM emissions is paraffin lamps
• Paraffin thermoelectric gen/LED a suitable intervention
• ...iHarvey provides 5 times better light than lanterns and powers media
• ...demonstrates 83% reduction on PM$_{2.5}$ emissions, safer.
• Unlike solar, iHarvey thermoelectric gen provides power on demand – irrespective of time of day or night.
Images of iHarvey and Glass Lamp lighting a shack

iHarvey in a room

Glass lamp in a room
References


Acknowledgements

Global Alliance for Clean Cookstoves (GACC), for supporting the SeTAR Centre as a Regional Centre for Stove Testing and Development
University of Johannesburg for financial support for the SeTAR Centre
TEQDAS Ltd (iHarvey developers)
SeTAR Centre lab team