Comparative Investigations of Combustion Emissions from Paper Briquettes

PacWaste
PACIFIC HAZARDOUS WASTE MANAGEMENT

SPREP
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EUROPEAN UNION

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Cover images: Briquette making in Majuro, Republic of the Marshall Islands.
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Table of Contents

Abbreviations

CO	Carbon Monoxide
CPC	Condensation Particle Counter
DustTrak	DustTrak Aerosol Monitor
EC	Electrostatic Classifier
EF	Emission Factors
EPA	Environmental Protection Agency
HEPA	High Efficiency Particulate Air Filter
ILAQH	International Laboratory for Air Quality and Health
NO	Nitric Oxide
NO_2	Nitrogen Dioxide
NO_X	Total Oxides of Nitrogen
PM	Mass concentration of particles
PNC	Total Particle Number Concentration
PSD	Particle Number Size Distribution
QUT	Queensland University of Technology
SMPS	Scanning Mobility Particle Sizer
SE	Standard Error of the Mean

1 Introduction

In the Pacific islands region the impacts of global climate change are becoming increasingly apparent, driving efforts to adapt and decrease the production of greenhouse gases (GHG) through combustion of fossil fuels.

On Majuro atoll in the Republic of the Marshall Islands (RMI), one initiative to mitigate the impact of climate change is the manufacturing of briquettes out of waste paper and cardboard, to replace the imported coal briquettes that are widely used for cooking.

From a climate perspective, the use of paper briquettes instead of coal provides a number of mitigation benefits, including:

- Diverting paper and cardboard from landfill, where they would rot and produce GHG;
- Reducing demand on the very limited local wood supply;
- Reducing the volume of GHG produced from the combustion of coal briquettes; and
- Reducing the volume of GHG produced in the extraction, production and lengthy transportation processes necessary to deliver coal briquettes to Majuro atoll.

Concerns have been raised however, about the health impacts of using paper briquettes for cooking. High emissions from incomplete biomass fuel combustion in small-scale appliances like woodstoves and fireplaces have been reported in literature (Vicente et al., 2015). In addition, emissions of gaseous pollutants, i.e. carbon monoxide (CO), nitrogen oxides (NOx) as well as of particulate matter are important parameters to consider, as they may pose an adverse health effect. Those pollutants are categorised as criteria pollutants that should be controlled to ensure air quality for the population (http://www.environment.gov.au/protection/air-quality/air-pollutants).

To our knowledge, there is currently no published literature detailing the concentrations of air pollutants from the combustion of recycled paper and cardboard briquettes.

AIM

In this study we undertook combustion testing of paper briquettes and other commercial fuels in laboratory conditions to determine the difference in concentration and characteristics of emission products (CO_2, CO, NO_X, PM, particle number concentration and particle size distributions) from the those fuels.

2 Materials and Methods

2.1 Stove

A wood stove, Scandia Warmbrite 140, was used in this experiment. The stove was connected with two metres of flue to establish convection and to host the laboratory instruments. The setup is shown in Figure 1.

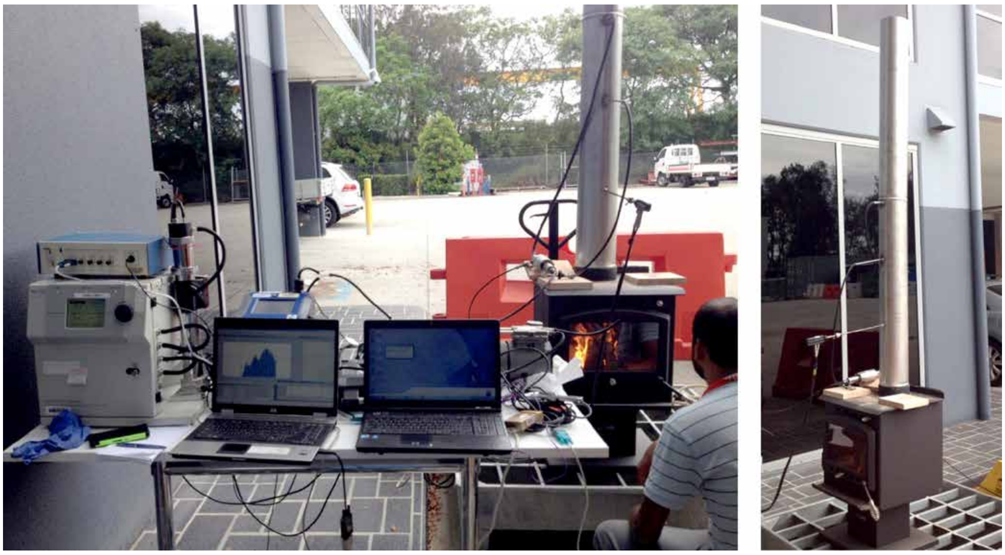


FIGURE 1 Stove and experiment set-up

2.2 Fuels for testing

Four different fuels were tested. As well as the paper briquettes obtained from Majuro atoll there were three commercial fuels purchased at Bunnings Warehouse (Rocklea, Qld):

- Paper briquettes (manufactured on Majuro atoll)
- Wood brick (Ekolog wood briquettes)
- Coal briquettes (BBQ fuel heat beads)
- Wood chips (kindling firewood)

A fire ignition product was used to start the fire as per common practice. Pictures of all products used in this experiment are presented in Appendix 1.

2.3 Measurement system

Gaseous and particulate emissions were continuously monitored throughout the combustion period. Measurements ceased once all the fuel was consumed. The process was repeated three times to provide more accurate emissions data.

Figure 2 displays the schematic diagram of the setup used to sample exhaust from the stove. The equipment consisted of:

- **Testo gas analyser**: connected directly to the flue, used to measure the gaseous emissions.
- **Dekati ejector diluter**: connected to the flue via steel tubing to dilute raw stove exhaust with HEPA filtered air for particle emissions measurement.

- **TSI DustTrak 8530 with Scanning Mobility Particle Sizer (SMPS)**: to continuously measure Particulate matter (PM) and Particle number (PN) emissions from the diluted exhaust. The SMPS system consisted of a:
  - **TSI 3080 classifier**, and
  - **TSI 3010 butanol base Condensation Particle Counter (CPC)**: with a sheath-to-aerosol flow ratio of around 10.
- Lastly a **SABLE CA-10 CO_2 analyser**: to record the CO_2 from the diluted exhaust. The dilution ratio was calculated from two CO_2 measurements by using the formula (Eq1) below. The measured PM and PN emissions were then corrected by the dilution factor to get actual PM and PN emissions.

Eq1: $$\text{Dilution ration (DR)} = \frac{CO_2\,(\text{Raw}) - CO_2\,(\text{Background})}{CO_2\,(\text{Diluted}) - CO_2\,(\text{Background})}$$

The temperature of the exhaust was monitored by the thermocouple sensor to evaluate the heating efficiency of the fuels for comparison purposes.

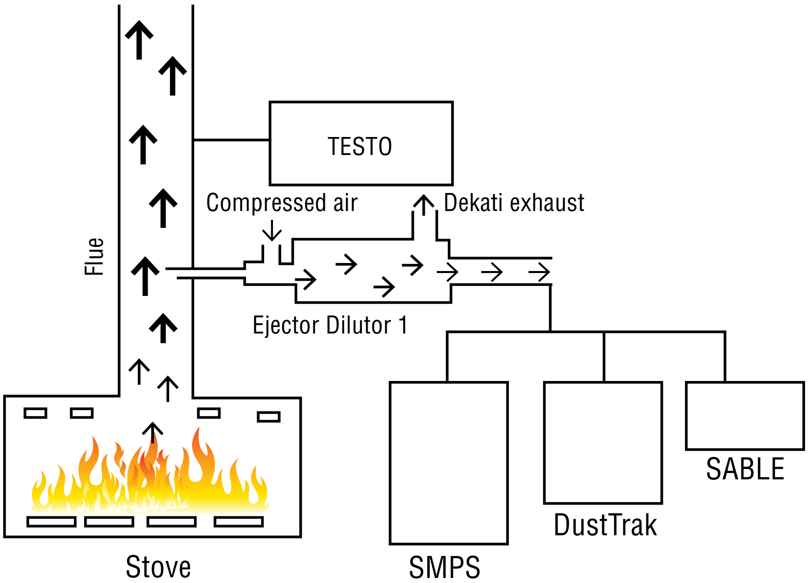


FIGURE 2 Schematic of experimental measurement system

2.4 Testing regime

For each of the solid fuels, an equal mass of fuel (~850g) was placed inside the stove. This amount of fuel was equivalent to six paper briquettes. Combustion was initiated with a small amount of fire lighter. The stove door was then closed immediately after igniting the fire lighter, and the air vent into the stove was kept wide open throughout the burning period to allow for the natural burning of each fuel. Each fuel was tested in three separate burning events.

To prevent contamination from the fuel used in previous tests, the stove was thoroughly cleaned after each burn. The full testing procedure for each fuel was as follows:

1. Weigh and prepare fuel for burning;
2. Start the burn with the same amount of fire lighter;
3. Perform measurements until the fuel burns out;
4. Clean the stove for the next burn;

2.5 Data analysis

A quality check was first conducted for all collected data to ensure it was valid for further analysis. In addition, the raw emission data was corrected with the calculated dilution rate. All valid data was then imported into a database. A Microsoft Excel 2007 pivot table was used to further analyse the data and present the results.

3 Results and Discussion

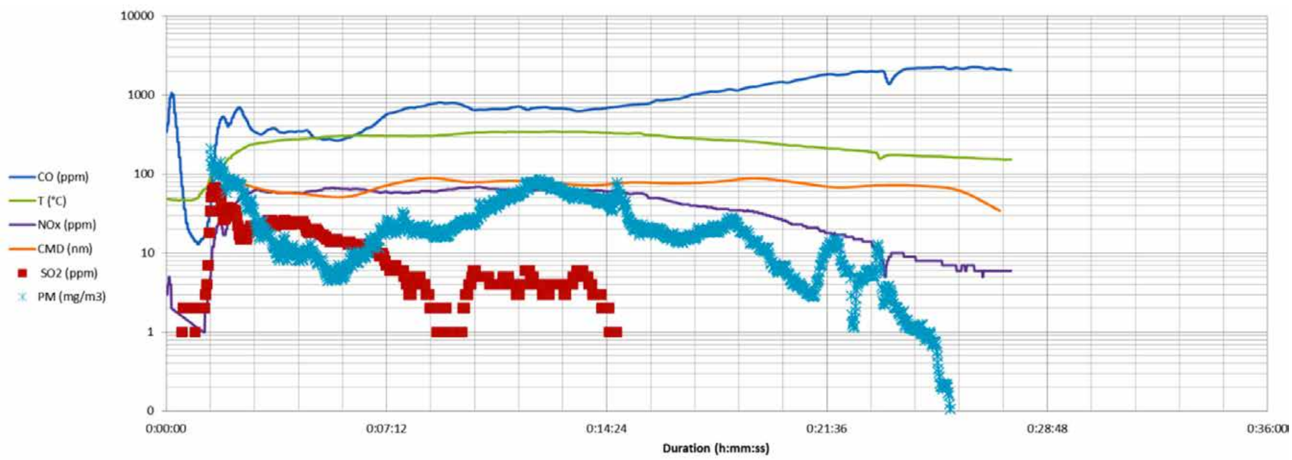
In this section, the data from the continuous monitoring of individual measurement parameters [$PM_{2.5}$, Count Median Diameter (CMD), CO, SO_2, NO_X, and temperature] is presented. The graphs provide a good way to quickly understand the emission differences between different fuel types. Next, the descriptive statistics of these burnings are summarised and compared to evaluate the emissions of paper briquettes.

3.1 Burning profile of different fuels

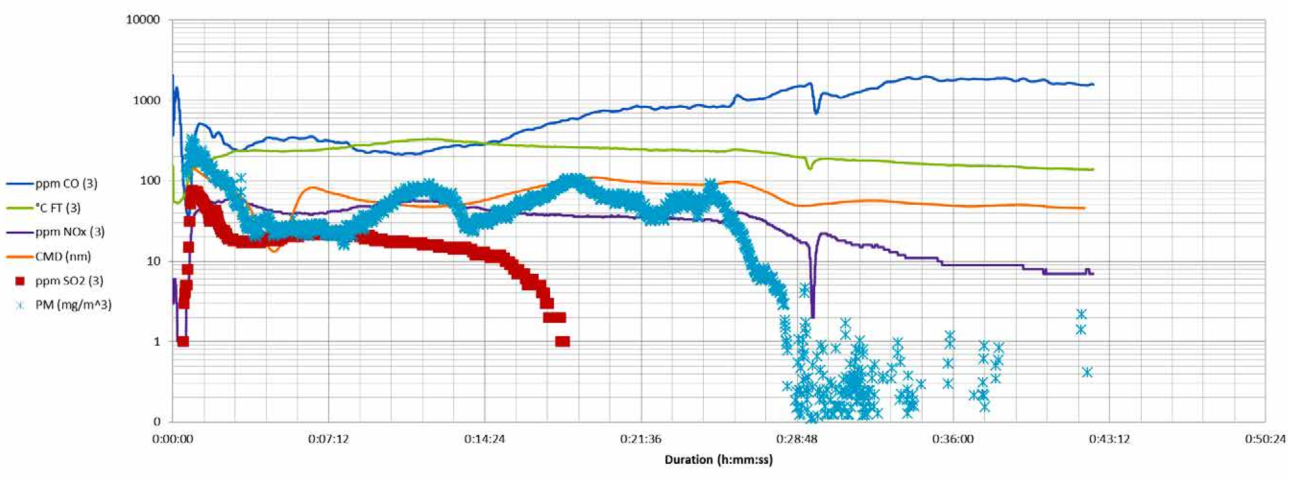
The burning profiles of all fuels are presented below. We can observe from those profiles that:

- The use of the fire lighter helped with combustion but contributed to the SO_2 emissions, thus it should be deducted from the fuel burning emissions;
- The paper briquettes burned quickly and generated high temperatures; and
- The emissions generated from paper briquettes are comparable with the other fuels tested.

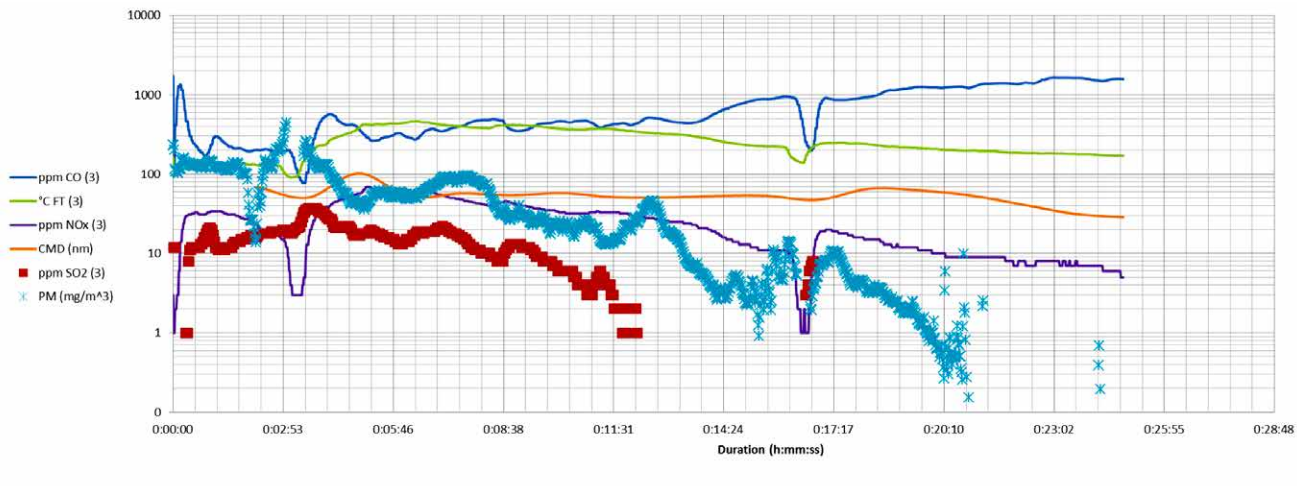
PAPER BRIQUETTES



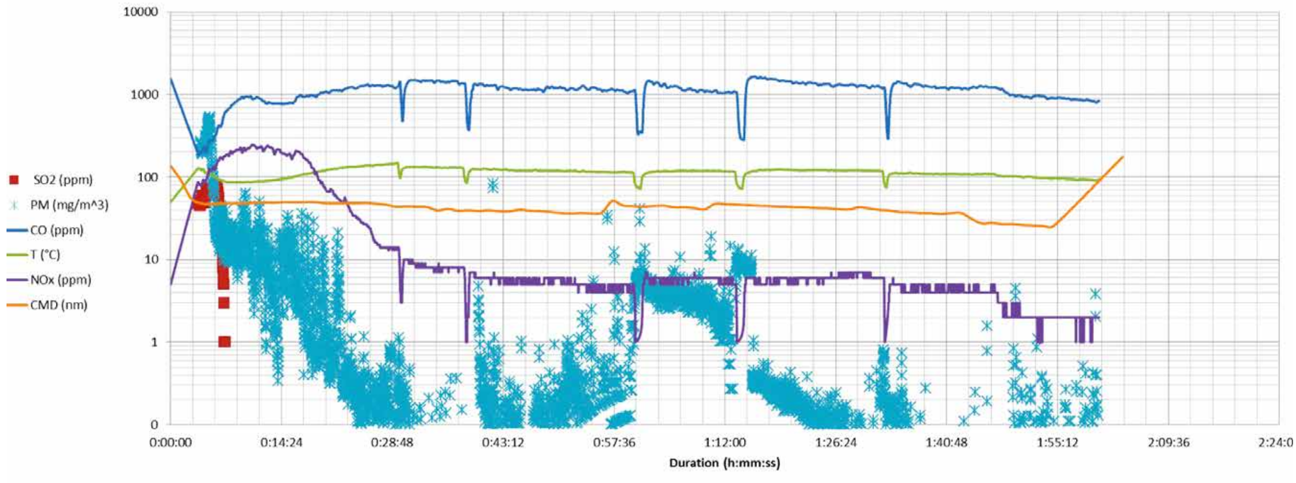
WOOD BRICK



WOOD CHIPS



COAL BRIQUETTES



FIRE STARTER

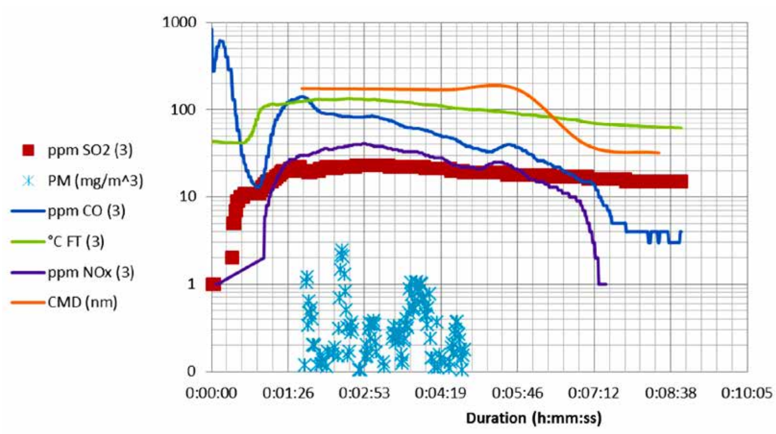


FIGURE 3 Burning profile of different fuels including the fire starter

3.2 Descriptive statistics of fuel emission

To evaluate the burning results, selected data is presented in Table 1 below.

TABLE 1 Descriptive statistics of the fuel emission.
The results are the mean values, with the standard deviation results presented in brackets.

Fuel	Time (min)	T (Celsius)	CO (ppm)	NO_X (ppm)	PM (mg/m^3)	CMD (nm)
Paper briquettes	30	262 (68)	1162 (627)	41 (23)	25 (21)	72 (14)
Wood brick	45	227 (56)	957 (595)	29 (15)	43 (25)	68 (28)
Wood chips	30	286 (94)	813 (446)	24 (17)	23 (25)	51 (10)
Coal briquettes	120	114 (14)	1163 (231)	26 (58)	1.8 (4.7)	45 (19)

We can see that the burning speed of different fuels varied. The paper briquettes and wood chips burned faster and hotter while coal briquettes burned very slowly. It should be noted that the coal briquette product used in this study was specifically manufactured to produce long lasting BBQ heat.

Paper briquettes and wood chips generated similar temperature levels (higher than the two other products) but the former emitted higher concentrations of CO and NO_X in particular than the latter.

The paper briquette exhaust gas recorded the highest concentration of CO (627 ppm), however because coal and wood briquettes burn longer (90 minutes and 15 minutes longer respectively), their total overall CO emissions would be higher.

The level of PM concentration emitted by paper briquettes (25 mg/m^3) was similar to that of wood chips (23 mg/m^3) and lower than that of wood brick (43 mg/m^3). This is probably due to the structure of the fuels. The slow combustion rate of the coal briquettes (120 minutes) is thought to be a contributing factor to their low concentrations of PM (1.8 mg/m^3).

Due to their longer combustion times and lower temperatures coal and wood briquettes would take longer to heat food or boil water.

3.3 Comparing emission factor estimates

To facilitate the comparison of performance among fuels, we have estimated the emission factors (EF) for the key pollutants included in Table 1, i.e. CO, NO_X and PM. The average EFs of those fuels were then compared, see Figure 4 below.

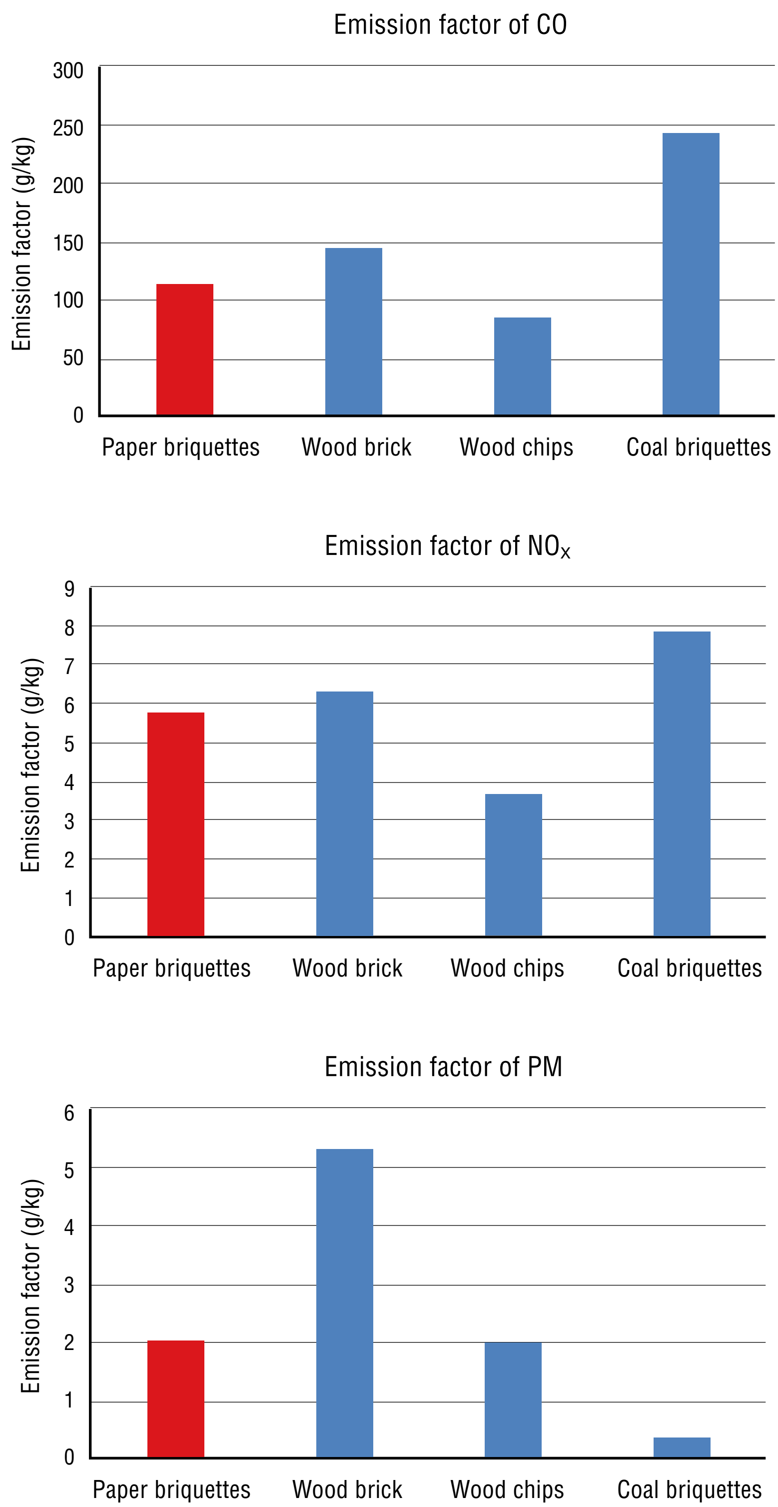


FIGURE 4 Emission factors of different pollutants

It can be observed from Figure 4 that, compared with other fuels which were tested in this study, the emissions of criteria pollutants of paper briquettes are comparable. The paper briquette emission factors of CO and PM are also well within the range reported in the literature for various types of fuels (Pettersson et al., 2011; Shen et al., 2014).

4 Conclusions

In short, this project produced some major findings as follows:

1. Paper briquettes burn at higher temperatures than the wood and coal briquettes, but for shorter durations;
2. Paper briquettes emissions are equal to or lower than the other non-fossil fuels tested in the experiment.

Important Note:

1. The World Health Organisation reports that exposure to household air pollution from cooking results in around 4 million premature deaths (WHO 2014). It is recommended to always cook in a well-ventilated location and preferably outdoors.
2. The composition of the tested fuels can change with different batch and can result in variations in the pollutant emissions. In addition the stove and instrumentation may change from one lab to another. Therefore, the results discussed above are only valid for the fuels provided and the conditions occurring during the test periods.

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Appendix 1 Test fuels

COAL BRIQUETTES

WOOD BRICK

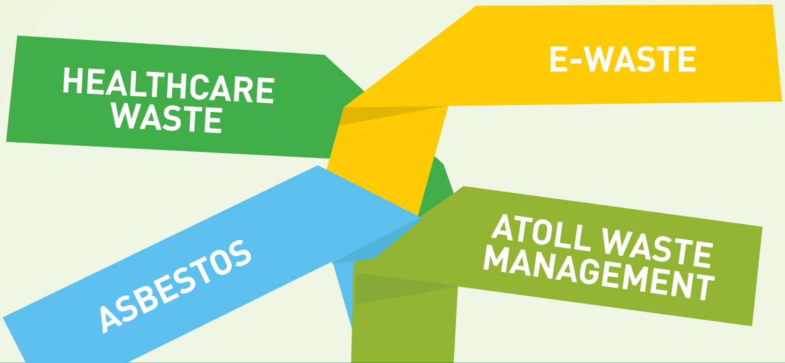
WOOD CHIPS

PAPER BRIQUETTES

Appendix 2 Burning conditions

ACTUAL STOVE IN THE FIELD

IN THIS STUDY



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