Energy Efficiency and Emissions of a Natural-Draft Wood Pellets Gasifier Compared to Charcoal Cookstoves in Kenya

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Abstract

The conversion of biomass to make charcoal fuel is an inefficient process that leads to immense energy losses along the value chain. We compared the energy efficiency and emissions of Gastov206, a natural draft TLUD gasifier cookstove using two sizes of wood pellets, as an alternative to two contemporary charcoal stoves in Kenya.

A laboratory test showed that more energy in the fuel was lost by the charcoal cookstoves (69%) compared to the pellet gasifier cookstove (31%). The pellet gasifier cookstove had high thermal efficiency and cooking power (65–73%, 0.95–1.13 kW) compared to the charcoal cookstoves (27–35%, 0.68–0.89 kW). During the test, Gastov206 converted pellets-to-char at a ratio of 25% and a rate of 3 g/min. These findings indicate that when biomass is converted to pellets rather than charcoal, and cooking continues over the burning char generated by the gasifier cookstove, energy currently being wasted converting wood-to-charcoal can be avoided.

Gastov206 using pellets showed lower CO emission (4.46–5.47 g/MJ_d and 0.27–0.39 g/min) compared to charcoal cookstoves (20.82–24.36 g/MJ_d and 0.89–1.35 g/min). PM2.5 emission by Gastov206 (52.35–61.50 mg/MJ_d and 3.21–4.37 mg/min) was not significant different compared to charcoal stoves (40.81–41.13 mg/MJ_d and 1.69–2.35 mg/min).

Laboratory results show that natural-draft gasifier cookstoves using pellets can be studied further in kitchens as an alternative to charcoal cookstoves since they are potentially more energy-efficient.

Introduction

1.1 Background

Biomass is the largest energy source in Kenya and provides 69% of the Country's overall energy requirements, petroleum and electricity accounting for about 22% and 9% respectively. About 55% of this is from farmlands as woody biomass, crop residue, and animal waste, and the remaining 45% is from forests [1]. A national household budget survey [2] carried out from September 2015 to August 2016 showed that most households use this biomass as fuel. In the 11.4 million households surveyed, the primary source of cooking fuel was firewood (54.6%), charcoal (14.6%), kerosene (14%), and liquefied petroleum gas (LPG) (13.4%). In the urban areas, households mainly used kerosene (29%), LPG (27.6), charcoal (21.9%), and firewood (16.1%). A study done in 2018 showed that Kenyan households using LPG as their primary cooking option also use one or more traditional fuels like charcoal (47%), wood (17%), and kerosene (18%) [3].

Arid and semi-arid lands (ASALs) cover more than 80% of the land and are a major source of woodfuel. However, the woodfuel is extracted in an uncontrolled and unmanaged manner, with natural regeneration as the way of recovery [4, 5]. To mitigate climate change, and provide sustainable energy for all, Kenya has developed policies to promote a transition to clean cooking fuels. These include promoting LPG and ethanol in urban areas, clean biomass cookstoves in rural areas, and alternative fuels such as compressed biomass and biogas [6, 1]. There is also recent legislation [7] that seeks to promote efficient and sustainable production (e.g. growing fast-maturing trees for energy production and biofuels), distribution, and marketing of biomass energy resources.

There is a growing demand for charcoal in Kenya caused mainly by population growth and urbanization, and about 2.5 million tonnes are produced annually [8]. Several advantages make charcoal as a fuel attractive for cooking compared to un-carbonized biomass. Its calorific value is roughly double that of un-carbonized material (its higher heating value per unit mass is approximately 30 MJ/kg with 5% moisture content compared to approximately 15 MJ/kg of firewood with 15% moisture content). Charcoal can be stored for long periods because it cannot get damaged by rain or moisture, it is available in the local market in small quantities, and it can be burned in inexpensive stoves [9]. The cost per kg (and per megajoule) of LPG, charcoal, and wood pellets is about US$ 1.50 (US$ 0.03), US$ 0.47 (US$ 0.02), and US$ 0.38 (US$ 0.02) respectively [3, 10-12].

The artisanal Kenya ceramic jiko (KCJ) cookstove, developed in 1984, has been widely accepted. 34% of all households in Kenya own it (40% urban and 31% rural), and about 343,000 units are sold each year with an annual market value of US$ 1.3 million. Households that use charcoal primarily use approximately 395 kg of charcoal per year [3]. The thermal efficiency of KCJ and similar stoves is below 27% [13, 14]. Factory-assembled modern charcoal cookstoves e.g. Jikokoa, JikoFresh, and SuperSaver, are increasingly being introduced [3].

The most widely used method for converting wood to charcoal in Kenya is the earth-mound and pit kilns with 10-14% wood-to-charcoal conversion efficiency. Although kilns with efficiencies of up to 30% have been promoted, e.g. improved earth Kiln, Casamance, and Brazillian masonry (or "beehive") kiln, their actual use in charcoal production is very minimal [8]. The conversion of 1 kg of wood, therefore, yields only 0.1 – 0.3 kg of charcoal. In other words, to produce 1 kg of charcoal with a specific energy content of 30 MJ/kg, 3.3 - 10 kg of firewood is required, which would otherwise have a total energy content of 53 - 160 MJ [9, 15].

To save the energy currently being lost when converting wood to charcoal, technologies e.g top-lit-up-draft (TLUD) gasifier cookstoves, that provide clean cooking energy from biomass pellets at thermal efficiencies greater than 50% [16, 17] are available. Compared with the direct combustion of solid biomass, gasifier cookstoves have higher thermal efficiency and fewer pollutant emissions since the syngas created from solid biomass is easily mixed with air to generate heat [18].

To densify lignocellulosic biomass, the first machine in the process line is a chipper. The wood chips are dried to about 10% (wet basis) in a rotary drum dryer that can use woodfuel. After drying, hammer mills are used to grind the chips to a screen size of 3.2 to 6.4 mm, a particle size suitable for pelleting. The ground biomass is then compacted using a ring or flat die pelletizer. Pellet density ranges from 1000 to 1200 kg/m^3. Pellets are then sifted over a screen to remove fines and weighed before storage [19, 20]. Various factors that affect the economic viability of pellet production have been studied [21-23].

Pellets production in Kenya is still in its nascent stages. To promote pellets as a cooking fuel, SNV and EcoZoom undertook pilot studies in 2014 - 2015, aiming at increasing access and use of pellet stoves in urban and peri-urban markets. Pellets were tested on both locally manufactured gasifier stoves (WISDOM and SCODE) and imported ones (Philips and TERI). A key challenge observed in the adoption of pellet-cookstoves was the high upfront cost of the stoves (e.g. a WISDOM gasifier stove costed US$ 34) [3]. Other factors also affect the adoption of pellet gasifier cookstoves, and households will generally adopt a fuel stacking model [24-30, 12]. Ongoing pellet production and gasifier cookstoves initiatives in Kenya include: Lean Energy Solutions Ltd., Iko Briq Ltd., Power Spot Ltd., Wisdom Innovations Ltd., and KIRDI [3, 10, 31, 32].

This study compared the energy efficiency and emissions of a natural-draft gasifier cookstove using wood pellets to contemporary charcoal cookstoves in Kenya.

1.2 Limitations of the study

Field tests to determine performance of cookstoves in kitchens were not conducted.

It was beyond the scope of the study to determine to what extent the targeted communities would adopt the pellet cookstoves if promoted. Adoption of cookstoves is dependent on many factors, including availability and affordability of high-quality cookstoves, reliability and accessibility of fuel supply, safety and usefulness of the cookstove in application, technical/industrial support for stove manufacturers, innovative funding mechanisms for consumers, awareness, and post-sales interventions, and multi-stakeholder collaboration [25-30].

A few firms are already manufacturing biomass briquettes and pellets in Kenya from industrial wastes like sugarcane bagasse and sawdust, although at a small scale [3, 10]. However, we did not investigate their experiences, especially regarding biomass availability, cost of investment, operation and maintenance, location and plant capacity, logistics, and energy costs [20, 21].

Materials And Methods

2.1 Cookstoves tested

We tested the three cookstoves shown in **Fig. 1**. The natural-draft gasifier cookstove (Gastov206) was fabricated at Kenya Industrial Research and Development Institute (KIRDI). Its weight was 9.46 kg, height 37 cm, and diameter 24 cm. The main features, illustrated in **Fig. 2**, were:

- A metal casing insulated with Rockwool and fireclay insulation;
- removable stainless steel fuel canister, of diameter 13cm and depth 21cm, in which the pellets were placed;
- removable fuel platform of height 11.5cm, placed inside the fuel canister;
- a removable nozzle on the burner that ensures mixing of combustible gases and heated secondary air;
- damper used to control primary airflow;
- fuel canister handler; and
- snuffer for extinguishing the fuel in the fuel canister.

We obtained the charcoal cookstoves, a modern charcoal jiko (MCJ), and Kenya ceramic jiko (KCJ), from distributors in Nairobi. The outer body of the MCJ was made from mild steel and ceramic wool. It weighed 3.88 kg and had a height of 25 cm. Its top diameter was 26 cm. The fuel chamber, made of alloy steel, had a diameter of 13.5 cm and a depth of 8 cm.

The metal cladding of the KCJ was made from mild steel sheets that held a ceramic fuel chamber (liner). It weighed 3.70 kg and had a height of 20 cm. The top-diameter was 28 cm. Its ceramic fuel chamber had a diameter of 21.5 - 16 cm, a depth of 8 cm, and had 14 holes.

Fig. 1 Gastov206, MCJ and KCJ test cookstoves

Fig. 2 Exploded view of the main components of Gastov206

2.2 Cookstove Test Method

We used ISO 19867-1 laboratory testing method [33] to determine the cookstoves' thermal efficiency (%), fire-power (kW), cooking-power (kW), emission of carbon monoxide (g/MJ_d and g/min of CO), and emission of particulate matter less than 2.5 μm (mg/MJ_d and mg/min of PM2.5). The Appendix shows how we computed these performance parameters.

Table 1 and **Fig. 3** show the laboratory conditions and equipment that we used [34]. Five liters of water were heated on the cookstoves for 30 min at both high and medium power levels. There were five replicates for each power level. We did all tests under the hood of the Laboratory Emissions Measurement System (LEMS). We used one Whatman GF/C filter for PM2.5 gravimetric measurements during an entire test that consisted of a high power (cold start) phase, and medium power (hot start) phase, each 30 min long. The LEMS acquired real-time data and saved it as MS Excel CSV files.

Table 1: Test conditions

Test dates and lab. location	Sept 10, 2019 to Sept 30, 2019, Nairobi, Kenya
Altitude	1655 m
Air temperature	18 – 21^{o}C
Humidity	50 - 70%
Wind condition	No wind
Laboratory Emissions Measurement System (LEMS) components	· The emissions collection hood had a 15.2cm ducting connected to an exhaust blower (open flow rate of 1200 cubic feet per minute). Dilution valves were adjusted to provide a differential pressure of 1.07 cm H_20 (i.e. a gas flow of 550 m^3/hr). K-type thermocouple measured exhaust gas temperature. An amplified pitot tube measured flow grid pressure drop within ducting for calculation of mass flow rate of gases in ducting. Gas samples were collected, at a flow rate of 4.4 L/min, from the ducting by sampling tubes connected to a sensor box fitted with a suction pump. In the sensor box, the exhaust gas sampled passed through a PM (light scattering photometer) sensor, CO (electrochemical) sensor, and CO_2 (NDIR) sensor before exiting the box. Water temperature was measured by a bead probe thermocouple (-4 to 260 ^{o}C)). The sensor box had a real time data acquisition system. · The PM2.5 gravimetric system consisted of tubing connected to hood ducting, vacuum pump (16.7 L/min), PM2.5 cyclone separator, filter housing for Whatman GF/C - glass fiber filters, and an analytical balance (0.01 mg resolution).
Other equipment used	30 kg capacity weighing scale, bomb calorimeter, drying oven and 2 desiccators
Pot used (no lid)	aluminum, height 23 cm, diameter 12.5 cm, weight 401 g,

Fig. 3 Set-up of test equipment

2.3 Fuels used

We obtained pellets having a diameter of 6mm (size 6 pellets) from Iko Briq Ltd., and those having a diameter of 8mm (size 8 pellets) from EcoZoom. The pellets were made from sawdust, an industrial waste product. *Prosopis juliflora* charcoal was from a vendor in Nairobi. We used standard laboratory methods to determine the fuels' calorific value (ASTM D5865), moisture content (ASTM D3302), ash content (ASTM D3174), bulk density, and size.

We used 600 g of pellets as fuel to test Gastov206. To light the cookstove, we soaked 120 g of pellets with 30 g of bioethanol in a beaker. The soaked pellets were placed on top of the other pellets in the fuel canister and ignited using a match stick.

For MCJ and KCJ, we used 370 g and 409 g respectively of charcoal fuel. A few charcoal pieces, soaked with 20 - 22 g of kerosene in a beaker, were placed in the middle of the charcoal fuel and ignited.

To operate the cookstoves at ‘high power’, we allowed maximum entry of primary under-grate air. To test at ‘medium power’, we reduced by half the primary air entry by adjusting the damper of Gastov206, the ashtray of MCJ, and the door of KCJ.

The pellet fuel and pellet char remaining after testing Gastov206 were weighed after removing the nozzle from the burner and lifting the fuel canister using a handler. We used a snuffer to suffocate the remaining pellets until they had cooled enough for separating the unburnt and carbonized portions. To determine the weight of the charcoal remaining after testing charcoal stoves, we weighed the cookstove together with the remaining charcoal and deducted the initial weight of the empty cookstove.

2.4 Experimental design

There were four independent variables: Gastov206 using size 6 pellets, Gastov206 using size 8 pellets, MCJ using charcoal, and KCJ using charcoal. The dependent variables were five: thermal efficiency (%), fire-power (kW), cooking-power (kW), emission of carbon monoxide (g/MJ_d and g/min of CO), and emission of particulate matter less than 2.5 μm (mg/MJ_d and mg/min of PM2.5. The Appendix shows how we computed the performance parameters.

We carried out Analysis of variance (ANOVA) and Tukey Honestly Significant Difference (HSD) tests at a 95% level of confidence [35]. We used the Tukey HSD test to group means that had no significant differences. We were then able to determine significant differences in performance between Gastov206 using pellets and charcoal cookstoves, and between Gastov206 using size 6 pellets and size 8 pellets.

Results And Discussion

3.1 Fuel characteristics

Table 2 shows the properties of fuels used to test the cookstoves. Compared to size 6 pellets, size 8 pellets had higher calorific value, lower ash content, lower moisture content, and lower bulk density. These results compare well with Gorzelanya et al. [36], who showed that pellets of diameter 6mm and 8mm from coniferous and deciduous sawdust had moisture content of 6.8 – 7.5%, ash content of 0.3 – 0.6%, and calorific value of 17.7 – 19.2 MJ/kg. Oduor and Githiomi [37] showed that *Prosorpis juliflora* charcoal had calorific value, moisture content and ash content of 32,861 kJ/kg, 4.6% and 2.3% respectively.

In addition to industrial wastes, there is a potential of manufacturing pellets from rotational woodlots in ASALs [38], plantation forestry [39], and C_4 energy crops [40-42].

Table 2: Properties of fuels used to test cookstoves

Fuel	calorific value (kJ/kg)	Moisture content (%)	Ash content (%)	Bulk density (kg/m^3)	Average Dimensions (mm)
Size 6 pellets	18,416 ± 774	8.0 ± 0.1	0.96 ± 0.03	640 ± 5	28.9 ± 7
Size 8 pellets	19,581 ± 1221	7.4 ± 0.2	0.39 ± 0.04	600 ± 7	19.4 ± 8
Charcoal	31,706 ± 1122	4.6 ± 0.1	3.2 ± 0.3	290 ± 4	41 x 24 x 66

3.2 Fuel consumption

During the 30 min test (average of high and medium power tests), Gastov206 consumed 359 ± 18 g of size 6 pellets and 363 ± 35 g of size 8 pellets. Char remaining was 97 ± 4 g (size 6) and 81 ± 6 g (size 8). MCJ and KCJ consumed an average of 174 ± 18 g and 171 ± 13 g of charcoal respectively.

Gastov206 consumed pellets at a rate of 12 g/min, and char formed at a rate of 3 g/min, a pellet-to-char conversion ratio of 25%. Therefore, approximately 50 min is required to turn the 600g of pellets into 150g of charcoal. When 600g of size 6 pellets were allowed to burn longer than the 30 min test, Gastov206 ‘switched’ from gasifying pellets to burning charcoal with a flame after approximately 57 min. The charcoal kept the water temperature above 85.5 ^{o}C for a further 30 min as the charcoal slowly turned to ash. Therefore, Gastov206 using 600g of pellets can provide cooking power for more than 1.5 hours.

Gastov206 having a batch of 600g of pellets, can therefore be ‘stacked’ with an LPG cookstove to cook meals like boiling a mixture of maize and beans, a common meal in Kenya. In urban areas, Ochieng et al. [43] showed that fuel stacking of LPG with charcoal was the norm to overcome the supply, cost, and practical challenges of relying on LPG. Using LPG to boil a mixture of maize and beans was considered impractical.

3.3 Performance of cookstoves

The cookstoves performed as shown in Table 3. ANOVA and Tukey HSD test (Table 4) showed that there were significant differences ($p < 0.05$) between Gastov206 using pellets and charcoal stoves in all performance variables except for PM2.5 (mg/MJ_d and mg/min) emission.

On average, when using both size 6 and size 8 pellets, the thermal efficiency of Gastov206 were significantly higher compared to charcoal cookstoves. This shows that more energy in the fuel is lost by charcoal cookstoves (69%), compared to pellet gasifier cookstoves (31%), during cooking operations.

Gastov206 using size 6 pellets showed a thermal efficiency higher than that reported for forced-draft pellet gasifier cookstoves [44, 13]. Jetter et al. [13] showed a natural-draft pellet gasifier cookstove (StoveTec TLUD) had a higher overall thermal efficiency of 53%, compared to a forced-draft pellet gasifier cookstove (Oorja stove) that had 32%. Still, Bentson, and Li [45] showed a natural draft TLUD pellet cookstove (ND TLUD 4) had a thermal efficiency greater than 50%, higher than that of forced-draft TLUD cookstoves.

As shown by **Fig. 4**, Gastov206 showed significantly higher fire-power and cooking-power using size 8 pellets compared with size 6 pellets. Size 8 pellets took approximately 26 min to boil 5 liters of water during the 'cold start' high power phase, the quickest compared to all the other cookstoves. The significantly higher fire-power of Size 8 pellets, compared to size 6 pellets, can be attributed to their higher calorific value, lower bulk density, lower moisture content, and lower ash content, which caused a higher combustion reactivity and burn rate.

Although charcoal cookstoves had the highest fire-power, they showed the lowest cooking-power because of their low thermal efficiencies (**Fig. 4)**. We observed that the charcoal cookstoves could not boil 5 litres of water (in a pot without a lid) within 30 min. Studies have shown that KCJ (known as Gyapa in Ghana) and other modern charcoal cookstoves, take 30 – 60 min to boil 5 litres of water [14, 13].

As shown by Table 4 and **Fig. 5**, compared to Gastov206, the charcoal cookstoves had significantly higher CO emission. Emission of PM2.5 from Gastov206 was higher compared to charcoal cookstoves. However, the difference was not significant ($p > 0.05$). Emissions of CO and CO_2 from charcoal cookstoves increased with time, as burning rate of charcoal increased (**Fig. 6**).

The natural-draft Gastov206 has high PM2.5 and CO emissions compared to Mimimoto, a forced-draft TLUD gasfier cookstove, reported to have PM2.5 and CO emissions of 13.94 mg/MJ_d and 0.154 g/MJ_d respectively [44]. Air supply to force draft TLUD gasifiers is by axial fans powered by electricity to favor a good mixture between producer gas and secondary air in the combustion zone [17, 46, 47].

Table 3: Cookstoves performance results

Performance variable	Gastov 206 with Pellets		Charcoal	
	Size 6 pellets	Size 8 pellets	MCJ	KCJ
Thermal efficiency (%)	73±7	65±8	35±8	27±6
Fire-power (kW)	1.41±0.15	1.87±0.31	2.79±0.45	2.61±0.39
Cooking-power (kW)	0.95±0.05	1.13±0.07	0.89±0.18	0.68±0.22
PM2.5 mass per useful energy delivered (mg/MJ_d)	52.35±33.12	61.5±48.47	40.81±32.03	41.13±19.07
CO mass per useful energy delivered (g/MJ_d)	4.46±0.92	5.47±1.31	24.36±10.69	20.82±4.36
PM2.5 mass per time (mg/min)	3.21±2.03	4.37±3.44	2.35±2.04	1.69±0.76
CO mass per time (g/min)	0.27±0.06	0.39±0.10	1.35±0.52	0.89±0.27

Table 4: Tukey Honestly Significant Difference (HSD) test results

Performance Variable	Cookstove type	N	Comparison of means [a] (alpha = 0.05)		
			1	2	3
Thermal efficiency (%)	KCJ	10	27.30		
	MCJ	10	34.80		
	Gastov 206 with size 8 pellets	10	65.30		
	Gastov 206 with size 6 pellets	10	72.60		
	Sig.	0.108	0.123		
Fire-power (kW)	Gastov 206 with size 6 pellets	10	1.4130		
	Gastov 206 with size 8 pellets	10	1.8740		
	KCJ	10	2.6120		
	MCJ	10	2.7870		
	Sig.	1.000	1.000	0.665	
Cooking-power (kW)	KCJ	10	0.6803		
	MCJ	10	0.8926		
	Gastov 206 with size 6 pellets	10	0.9511	0.9511	
	Gastov 206 with size 8 pellets	10	1.1307		
	Sig.	1.000	0.817	0.050	
CO mass per useful energy delivered (g/MJ_d)	Gastov 206 with size 6 pellets	10	4.4560		
	Gastov 206 with size 8 pellets	10	5.4720		
	KCJ	10	20.8180		
	MCJ	10	24.3550		
	Sig.	0.980	0.534		
CO mass per useful energy delivered (g/min)	Gastov 206 with size 6 pellets	10	0.2720		
	Gastov 206 with size 8 pellets	10	0.3940		
	KCJ	10	0.8860		
	MCJ	10	1.3470		
	Sig.	0.812	1.000	1.000	
PM2.5 mass per time (mg/min)	KCJ	10	1.6880		
	MCJ	10	2.3500		
	Gastov 206 with size 6 pellets	10	3.2050		
	Gastov 206 with size 8 pellets	10	4.3720		
	Sig.	0.057			

[a] The Tukey HSD test checks pairs of means of all independent variables using the HSD statistic ( ). If q > , the two means are significantly different and are not grouped together (not homogeneous). This enables pairwise comparisons ([35]).

Conclusion

Gastov206 using pellets is more energy-efficient compared to KCJ and MCJ charcoal cookstoves. More energy in the fuel was lost by charcoal cookstoves, compared to pellet gasifier cookstoves, during the test. Although the emission of CO was significantly lower in Gastov206, further improvements are needed to reduce PM2.5 emissions. Controlled cooking and kitchen performance tests can provide actual fuel usage when cooking typical foods.

The gasifier cookstove can make charcoal from biomass during cooking, at a pellet-to-char ratio of 25%. This ratio is higher than the wood-to-charcoal conversion ratios of earth-mound and pit kilns widely used in Kenya. This charcoal, when left to burn in the cookstove, provides additional fuel for cooking. Therefore, using pellet gasifier cookstoves instead of charcoal cookstoves, energy in the original biomass will not be lost during charcoal burning.

Considering that wood-to-charcoal conversion efficiencies are low and charcoal cookstoves have low thermal efficiencies, a substantial amount of energy can be saved by switching from charcoal to using pellets. We recommend kitchen trials to investigate actual fuel usage, user acceptance, and fuel stacking models that communities can adopt with the pellet cookstove. For example, the pellet gasifier cookstove can be used for operations like heating water and cooking local foods requiring high cooking-power (e.g. boiling maize and bean grains). Fossil fuels, e.g. LPG, can be used sparingly to cook vegetables and other dishes requiring low cooking-power.

Wood pellets of diameter 6mm and 8mm, or a mixture of both, can be used with natural-draft gasifier cookstoves. However, the larger pellets (diameter 8 mm) provided higher fire-power because they had a higher calorific value, lower moisture content, and lower ash content. The lower bulk density caused more air spaces within the pellets, leading to more airflow and a higher burning rate.

The pellets used in this study were made from sawdust, an industrial waste product. To increase adoption of pellet cookstoves, we recommend further multi-stakeholder collaborative research to examine the potential of a sustainable wood pellet supply chain in Kenya and solutions to the other barriers that hinder the widespread adoption of efficient cookstoves.

Declarations

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Availability of data and material: Raw data and materials used are available

Code availability: Not applicable

Abbreviations

Top-lit up-draft (TLUD), carbon monoxide (CO), particulate matter less than 2.5 µm (PM2.5), mega joule delivered to water in cooking pot (MJ_d), modern charcoal jiko (MCJ) and Kenya ceramic jiko (KCJ)

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Figures

Figure 1

Gastov206, MCJ and KCJ test cookstoves

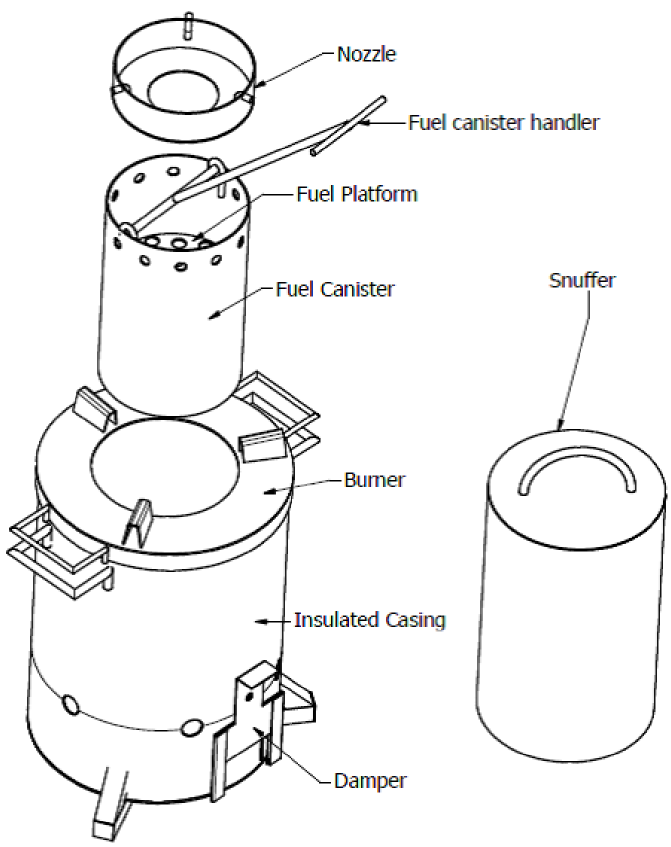

Figure 2

Exploded view of the main components of Gastov206

Figure 3

Set-up of test equipment

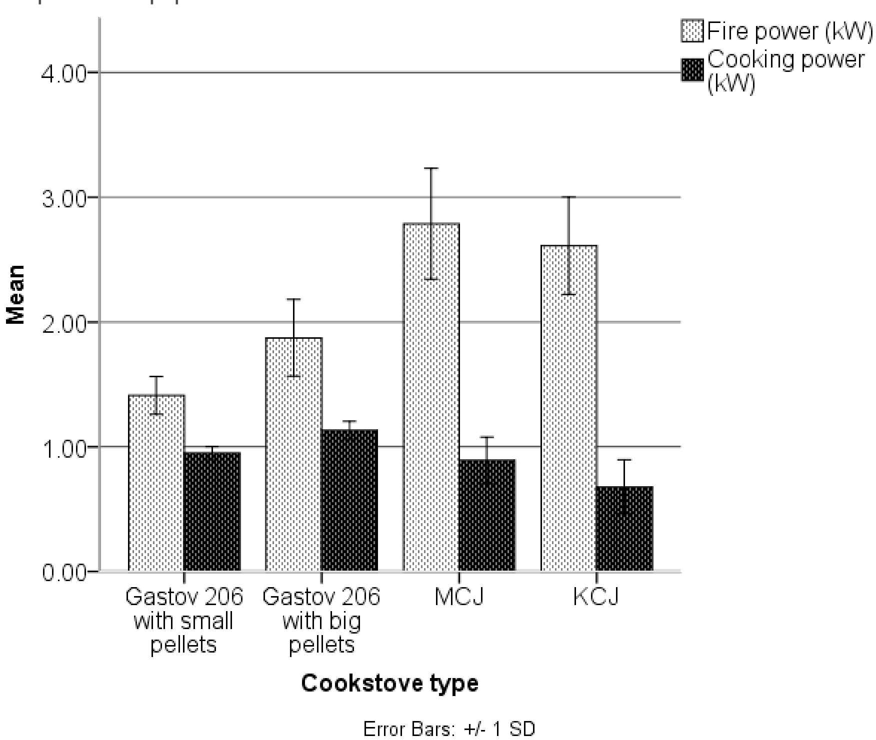

Figure 4

Comparison of mean fire-power and cooking-power of cookstoves

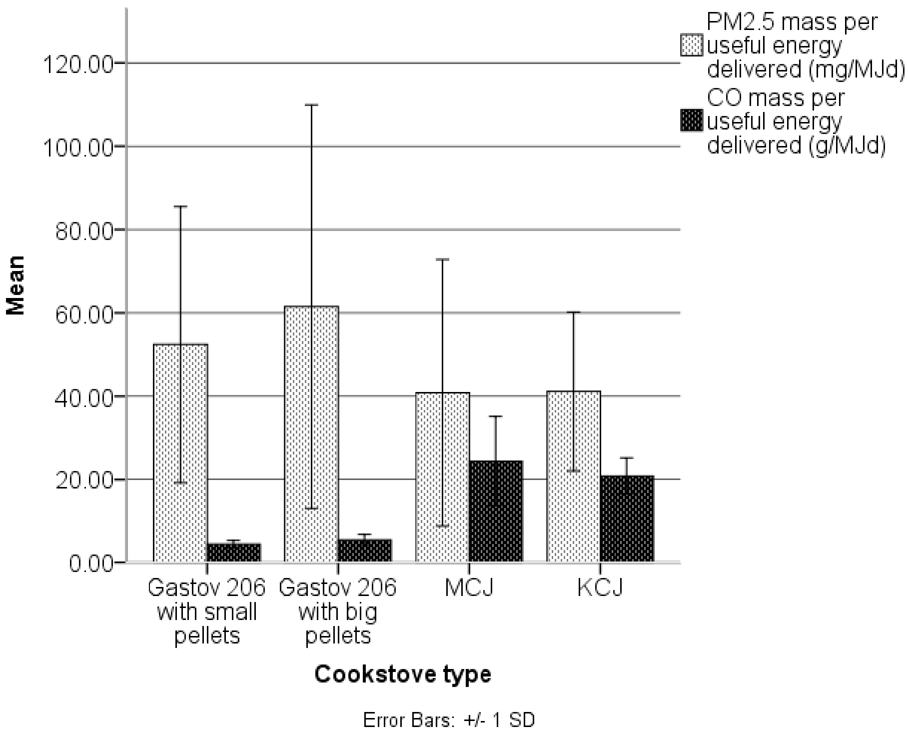

Figure 5

Comparison of mean PM2.5 and CO emissions of cookstoves

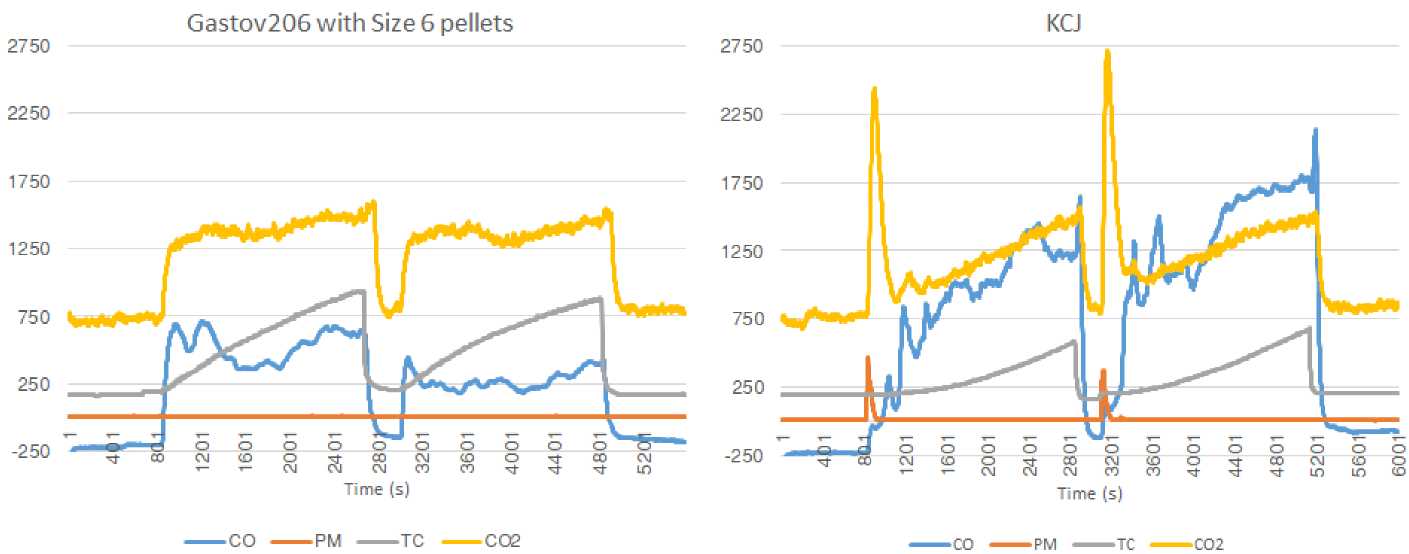

Figure 6

Variation of temperature of water (TC) and emissions of CO, CO2 and PM2.5 relative to ambient background

Supplementary Files

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