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Performance and emissions characteristics of a lighting cone for charcoal stoves

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ABSTRACT

A lighting cone is a simple metal cone placed on the charcoal bed during ignition to increase draft. Many traditional charcoal-burning stoves are difficult to light due to poor draft through the fuel bed, so lighting cones are used as an inexpensive accessory to help with charcoal ignition. The goal of this work was to determine the validity of using a lighting cone to decrease the ignition time of traditional Haitian charcoal stoves, and evaluate its impact on stove emissions and fuel consumption during the typically inefficient and slow ignition phase. We found that the lighting cone successfully reduced ignition time by over 50%. Due to a more efficient, shorter ignition stage, charcoal consumption during ignition was reduced by over 40% and carbon monoxide was reduced by over 50%. This suggests that lighting cones are a viable and beneficial accessory for aiding ignition in shallow-bed charcoal stoves.

Introduction

In the developing world, close to 3 billion people cook and heat their homes with biomass fuels including charcoal (World Health Organization, WHO, 2014). Emissions from these biomass fires can be quite harmful to both environment and human health; such emissions cause 4.3 million premature deaths a year, affecting primarily women and children, and are the largest environmental threat to health in the world (World Health Organization, WHO, 2014; Lim et al., 2012). Cooking with biomass fuels also contributes to adverse environmental effects such as climate change and deforestation (Bond et al., 2013).

Typically, charcoal-burning stoves have relatively shallow and exposed charcoal beds. The combustion rate and efficiency of charcoal is heavily dependent on the extent to which oxygen can reach the surface of the charcoal (Shelton, 1983). The charcoal beds in traditional stoves commonly ignite slowly due to interference from the wind and the initial lack of draft (upward air flow) through the stove body and charcoal bed. In shallow charcoal beds, it is initially difficult to achieve the draft required to create a self-sustaining flow of oxygen through the charcoal, so the combustion processes are stifled and inefficient due to an inadequate supply of oxygen. Therefore, devices that increase the amount of oxygen reaching the surface of the charcoal can greatly speed its ignition, reducing the amount of time needed to begin cooking.

Many devices and techniques exist to decrease the amount of time needed for a charcoal bed to be well lit, such as charcoal chimneys and lighter fluid. These products, however, can be expensive and toxic and are not well-suited for developing economies with low incomes where cooking with charcoal is a daily necessity. A straightforward and inexpensive accessory used to reduce ignition time, referred to in this paper as a "lighting cone", is already in use by some local populations in countries such as China, Zaire, and Mozambique but little research on lighting cones exists in literature (Lask and Gadgil, 2015).

This paper aims to evaluate the effectiveness of a lighting cone, not only on the immediate concern of a reduced ignition time, but also its impacts on fuel consumption and emissions from a charcoal-burning stove during its ignition phase.

Experimental system and protocol

Lighting cone

A lighting cone (Fig. 1) is a conical tube of sheet metal open at both ends. It is placed with the larger end down on the charcoal bed after the kindling (e.g., sappy wood or newspaper) has been lit, and is removed once the charcoal is considered lit enough to sustain its combustion even if a pot is placed on the stove.

The slightly conical shape allows for improved mechanical stability in placing the cone on the somewhat uneven charcoal-bed, and reduces the likelihood of wind-driven downdrafts of ambient air entering the

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Fig. 1. Lighting cone on the traditional Haitian stove used for experiments. A lighting cone is a metal cone intended to reduce the time necessary for ignition.

top of the cone. A lighting cone can provide additional usability benefits for the cooks by protecting the ignition process from the wind and directing smoky emissions away from the cooks and their children standing near the stove (Personal communication with Haitian NGO staff).

After building and testing several lighting cones, the lighting cone used in the experiments reported in this paper has a bottom diameter of 200 mm to adequately encompass the fuel bed of a traditional Haitian stove and a top diameter of 100 mm to achieve a slight taper. The cone is made from 0.3 mm thick stainless steel sheet and is 610 mm tall to produce adequate draft.

Fig. 2. Traditional Haitian stove used for experiments. Traditionally, Haitian stoves are made from scrap metal and feature a round or a square shallow charcoal chamber with several holes.

Traditional Haitian Stove

The lighting cone was tested using a traditional Haitian stove (Fig. 2). A Haitian stove was chosen because most of the 10 million Haitian people cook with charcoal and wood, which totals over 70% of Haiti's energy consumption, even though the country is heavily deforested (Nexant, Inc., 2010; International Energy Agency, IEA, 2004; Van der Plas, 2007). The traditional stove design features a shallow and exposed charcoal bed as described in the "Introduction" section.

Haitians typically use simple stoves made locally from scrap sheet metal. These stoves are widely available and have either a square or a circular charcoal chamber. The stove tested in this study has a square charcoal chamber with evenly distributed holes along the sides and bottom. The pot sits directly on the charcoal bed, which is approximately 110 mm square. The ash falls through to a tray underneath which is emptied by turning the stove over.

Laboratory and equipment setup

All testing was performed in the cookstove lab at Lawrence Berkeley National Laboratory (LBNL). The test system consisted of a stove platform under a ventilation hood that drew gases upward through an aluminum duct (150 mm diameter) using two blowers. Sampling ports in the duct led to several instruments for measurement of emitted gases in real time (1 Hz). These instruments included: a CAI NDIR gas analyzer for carbon dioxide and carbon monoxide measurements, a McGee Scientific Aetholameter for black carbon measurements, and for particulate size distribution measurements, a TSI Fast Mobility Particle Sizer spectrometer (diameter range 5–500 nm), and a TSI Aerodynamic Particle Sizer spectrometer (diameter range 500 nm–20 μm). A DustTrak DRX Model 8534 was used to measure the total mass of particles with diameters <2.5 μm; the DustTrak measurements reported in this paper have been calibrated using a gravimetric filter system. The total assembly of the stove, fuel and lighting cone were placed on a high-resolution (64 kg $\pm$ 0.1 g) precision platform scale to record real-time (1 Hz) fuel consumption.

The fuel used in the experiments was Grillmark© all-natural lump charcoal, which is produced in a fashion similar to Haitian charcoal. The rectangular lump charcoal was broken into pieces similar in size to Haitian charcoal (no larger than 80 mm by 50 mm by 25 mm). The charcoal samples were measured to have a moisture content of 5.9%, analyzed using standard oven-drying procedures (ASTM International, 2007).

Protocol

Each test was performed by loading the fuel bed of the traditional stove with 475 g of charcoal. The charcoal was arranged in a toroidal bed of approximately 200 mm outer diameter and 60 mm inner diameter. High resin pine (total mass 5 $\pm$ 0.2 g) was broken into 3 to 5 thin pieces and arranged in a pyramid-like structure in the center of the charcoal toroid to act as a fire starter. This fuel bed setup is similar to that observed from Haitian cooks. If the test included a lighting cone, the cone was placed on the charcoal bed immediately after the high resin pine was first lit.

Ignition time was recorded from when the high resin pine was first lit until the charcoal bed was considered well lit. Based on conversations with and observations of Haitian cooks, the bed was considered well-lit when at least an estimated 70% of the charcoal pieces were observed to be red, which occurred at a thermal power of approximately 2.4 kW.

The thermal power was estimated from the measured CO_2 release rate from the stove as shown in Eq. 1.

$$P_{th} = CO_{2,rate}\left(\frac{MW_C}{MW_{CO_2}}\right)e_C \quad (1)$$

where P_{th} is the thermal power, MW_C and MW_{CO2} are the molecular weights of carbon and carbon dioxide, respectively, e_C is the specific energy of carbon, and $CO_{2,rate}$ is the rate of CO_2 emitted in grams per second. Fuel consumption was recorded on the platform scale in real time as well as weighing the charcoal before and after each test.

Ten baseline (without cone) tests and eleven lighting cone tests were conducted to obtain adequately tight confidence intervals in the reported results. Statistical significance was determined for all tests by applying the Student's t-test as the sample size is small ($n < 30$) (Taylor, 1997; Spiegel et al., 2008). All error bars on the graphs represent a 95% confidence interval.

Results and discussion

Ignition time and fuel consumption

Fig. 3 compares the ignition time and fuel consumption with and without a lighting cone. As shown in Fig. 3, using a lighting cone decreases ignition time by over 50%, reducing the lighting time from 414 s to 193 s (or from about 7 to 3 min), on average. This indicates that the lighting cone works as expected, increasing the draft through the charcoal bed to speed ignition by accelerating the burn rate (grams of fuel combusted per second) and promoting higher temperatures in the charcoal bed. Although the burn rate for the lighting cone was found to be greater than the baseline, the significant decrease in ignition time counteracted the effect of a higher burn rate on total fuel consumption. As can be seen in Fig. 3, the time necessary to light the cone was short enough that the lighting cone still significantly reduced the fuel consumption needed for ignition.

Emissions

Fig. 4 shows the total grams of carbon monoxide (CO), particulate matter of size smaller than 2.5 μm ($PM_{2.5}$), and black carbon (BC) emitted from the baseline and lighting cone cases. Almost 3 times more mass of CO is emitted than particulates ($PM_{2.5}$ and BC) because charcoal combustion produces more CO due to its smoldering combustion conditions and releases less particulate matter than other biomass fuels such as wood, because the volatiles which typically form particulates have been driven off in the charcoal production process (Ward and Radke, 1993; Shelton, 1983). As shown in Fig. 4, the lighting cone reduced carbon monoxide by over 50% (statistically significant at $p = 0.05$); however, the reductions in particulate ($PM_{2.5}$ and black carbon) emissions were not statistically significant ($p = 0.05$).

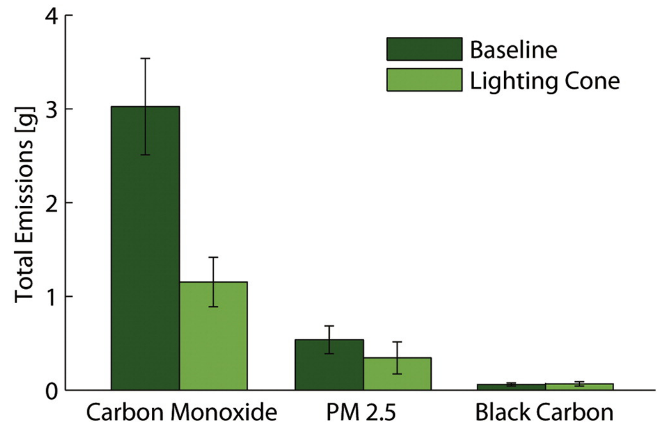

Fig. 4. Total mass emissions of carbon monoxide, black carbon, and $PM_{2.5}$ during ignition of the charcoal bed with and without (baseline) the lighting cone. The lighting cone more than halved the CO emitted during ignition, but did not have a statistically significant effect on the particulate emissions. Error bars represent a 95% confidence interval.

Particulate size distribution

The distribution of ultrafine particle concentration with and without the lighting cone is shown in Fig. 5. The results show that most of the particles generated are quite small (less than 1 μm), and a large difference is seen in the particle size distributions of the baseline (no cone) and cone cases. Additionally, the lighting cone greatly reduces the number of ultrafine (less than 100 nm) particles compared to the baseline. While the fine particles (less than 2.5 μm) emitted in combustion are harmful to human health, recent research indicates that the ultrafine particles are particularly detrimental (Oberdörster et al., 2005; MacNee and Donaldson, 2003). Therefore, the results suggest that in addition to user convenience and comfort, the lighting cone could also be better for human health than traditional lighting practices.

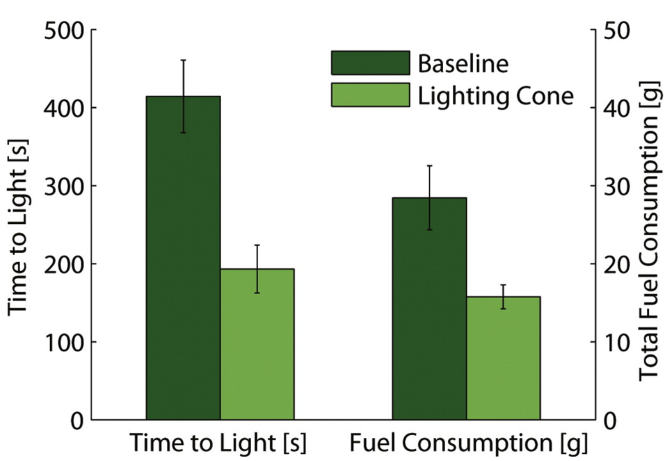

Fig. 3. Time to light and fuel consumption with and without (baseline) a lighting cone. The lighting cone decreased ignition time by over 50% and fuel consumption by over 40%. For both time to light and fuel consumption, the differences are significant at $p = 0.05$; the error bars show a 95% confidence interval.

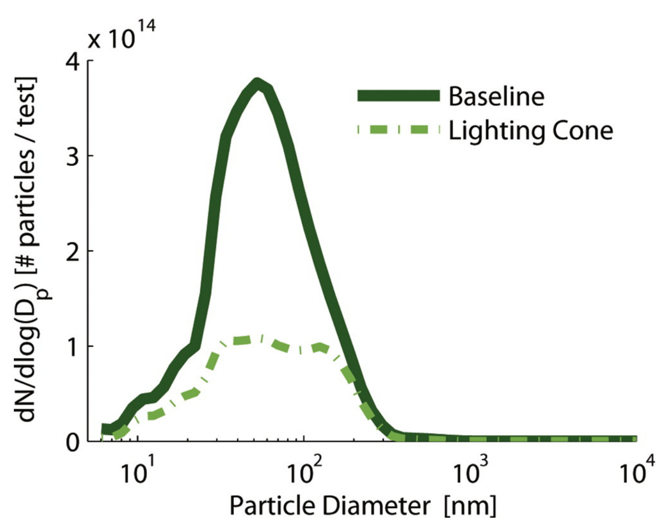

Fig. 5. The average particle size distribution for baseline and lighting cone cases. The lighting cone greatly reduces the number of ultrafine (less than 100 nm) particles compared to the baseline (no cone). Relatively few particles larger than 1 μm are released from either the baseline or lighting cone cases.

Conclusions

This research investigated the impacts of a lighting cone, a relatively easy-to-build and inexpensive accessory, on the ignition time, fuel consumption, and emissions during the lighting of a traditional Haitian charcoal stove. The results show that the lighting cone decreased ignition time by over 50%. User convenience is a well-known crucial consideration in stove use and adoption. Therefore, a device that reduces the amount of time and effort needed to light a stove could be useful not only for lighting current traditional stoves, but also as an accompaniment for promoting more efficient stoves, especially if the stove has difficulties with ignition. A lighting cone also improves the ignition stage of charcoal stoves for both the environment and human health by reducing the number of ultrafine particles emitted, reducing charcoal consumption by over 40%, and reducing carbon monoxide emissions by over 50% during this stage. Therefore, the application of lighting cones for assisting ignition of charcoal stoves in countries and communities where they are not in use is worth further exploration.

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References

ASTM International. Standard test methods for direct moisture content measurement of wood and wood-base materials. ASTM 2007;D4442-07.

Bond TC, Doherty SJ, Fahey DW, Forster PM, Berntsen T, DeAngelo BJ, et al. Bounding the role of black carbon in the climate system: a scientific assessment. J Geophys Res Atmos 2013;118:5380–552.

International Energy Agency (IEA). World energy outlook 2004: energy and development. IEA Publications; 2004.

Lask K, Gadgil A. Simplified model for lighting cone design. Lawrence Berkeley National Laboratory, Technical Report LBNL-6965E; 2015.

Lim SS, Vos T, Flaxman AD, Danaei G, Shibuya K, Adair-Rohani H, et al. A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the global burden of disease study 2010. Lancet 2012;380:2224–60.

MacNee W, Donaldson K. Mechanism of lung injury caused by PM10 and ultrafine particles with special reference to COPD. European Respiratory Journal 2003; 21(Suppl. 40):47s–51s.

Nexant, Inc. Final report: assessment of Haiti Alternative Cooking Technologies Program. United States Agency for International Development; 2010. [Accessed May 2013: pdf.usaid.gov/pdf_docs/PNADX776.pdf].

Oberdörster G, Oberdörster E, Oberdörster J. Nanotoxicology: an emerging discipline evolving from studies of ultrafine particles. Environ Health Perspect 2005;113(7): 823–39.

Shelton JW. Solid fuels encyclopedia. Garden Way Publishing; 1983.

Spiegel MR, Lipschutz S, Liu J. Mathematical handbook of formulas and tables. 3rd ed. McGraw-Hill; 2008.

Taylor JR. An introduction to error analysis: the study of uncertainties in physical measurements. 2nd ed. University Science Books; 1997.

Van der Plas R. Haiti: strategy to alleviate the pressure of fuel demand on national woodfuel resources. Republic of Haiti Ministry of Environment, Bureau of Mines and Energy, Energy Sector Management Assistance Program technical paper no. 112/07; 2007.

Ward DE, Radke LF. Emissions measurements from vegetation fires: a comparative evaluation of methods and results. In: Crutzen PJ, Goldammer JG, editors. Fire in the environment: the ecological, atmospheric, and climatic importance of vegetation fires. John Wiley & Sons, Inc.; 1993. p. 53–76.

World Health Organization (WHO). Indoor air quality guidelines: household fuel combustion. Geneva: World Health Organization; 2014.

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