Measuring Cookstove Emissions Using the Emissions Measurement Pod in Ghana

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Background

Like most developing countries in Sub-Saharan Africa, many people in Ghana rely on biomass as their main source of energy for cooking. Funded by NSF and EPA, the REACCTING study (Research of Emissions, Air Climate, and Cooking Technologies in Northern Ghana) will study the impact of human activities on air quality in rural Ghana. Specifically, its main objective is to study how the social, physical, and climatological determinants of regional emissions and air quality are related to cooking practices in the northern Ghana.

Introduction

The goal of this study is to provide quantitative data about the overall efficiency of three types of stoves: one traditional stove and two improved cookstoves by studying the combustion efficiency and emissions of each stove.

To measure cookstove emissions in the field, the emission measurement pod is used. This device was developed at University of Colorado and it uses low-cost sensors to measure real-time emissions of carbon monoxide (CO), carbon dioxide (CO2), NOx (nitric oxide and nitrogen dioxide), volatile organic compounds (VOCs), and other parameters such as temperature and humidity during the cooking process.

Figure 1. The Portable Emissions Monitoring System (PEMS) set-up in the field in Ghana and Inside the emission pod box with sensors .

Materials & Methods

The data collection is performed in real time during the entire cooking process at selected-randomized households in Ghana. Typically, each sampling trial takes between 2 to 3 hours from the beginning to the end of cooking during all the solid fuel combustion phases of ignition, flaming, and smoldering.

Figure 2. Improved Cookstoves used in our study: Gyapa stoves (left) and Philips stoves (middle), and a Traditional stove or 3-stone open-fire (right)

Solid fuel combustion phases

Ignition is defined as the act of setting the firewood on fire or simply starting the fire. Our estimation shows that it lasts between five to seven minutes.

Flaming is the phase that comes after the ignition. It is the period of burning fiercely the wood. This phase consists of adding more wood in order to keep the fire going. It is also takes longer than any other phase.

Smoldering is the last phase of combustion. It consists of burning slowly with smoke, but with little flame. We estimate this process to last from seven to ten minutes.

Results and Discussion

In order to quantify emissions, real-time emissions are measured by the emissions pod. The following plots show carbon monoxide (CO) , and nitric oxide (NO) measured during each cooking process using 3 different stoves in 3 different phases of combustion (ignition, flaming, and smoldering). These pollutants were measured while cooking regular meals by the local people.

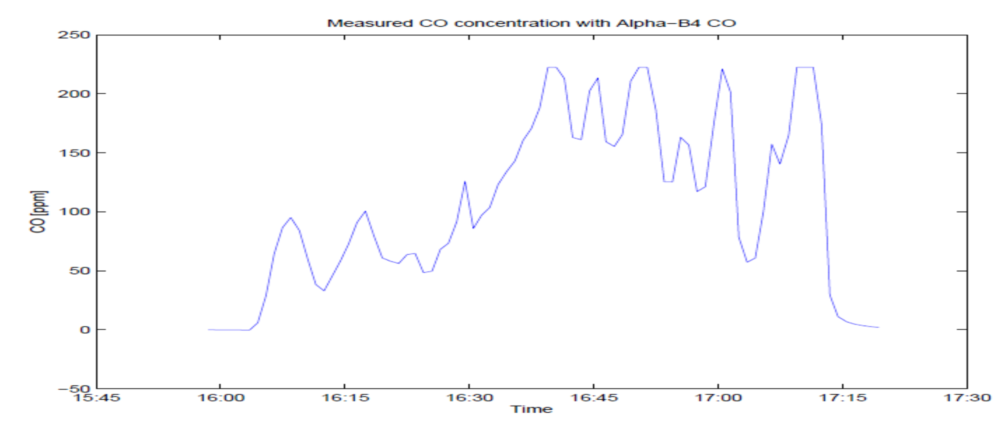

Figure 3. Time Series of CO concentration for a cooking event

Results and Discussion

Figures 4 and 5 show the box plots of CO and NO concentrations during a cooking event on a Gyapa Stove

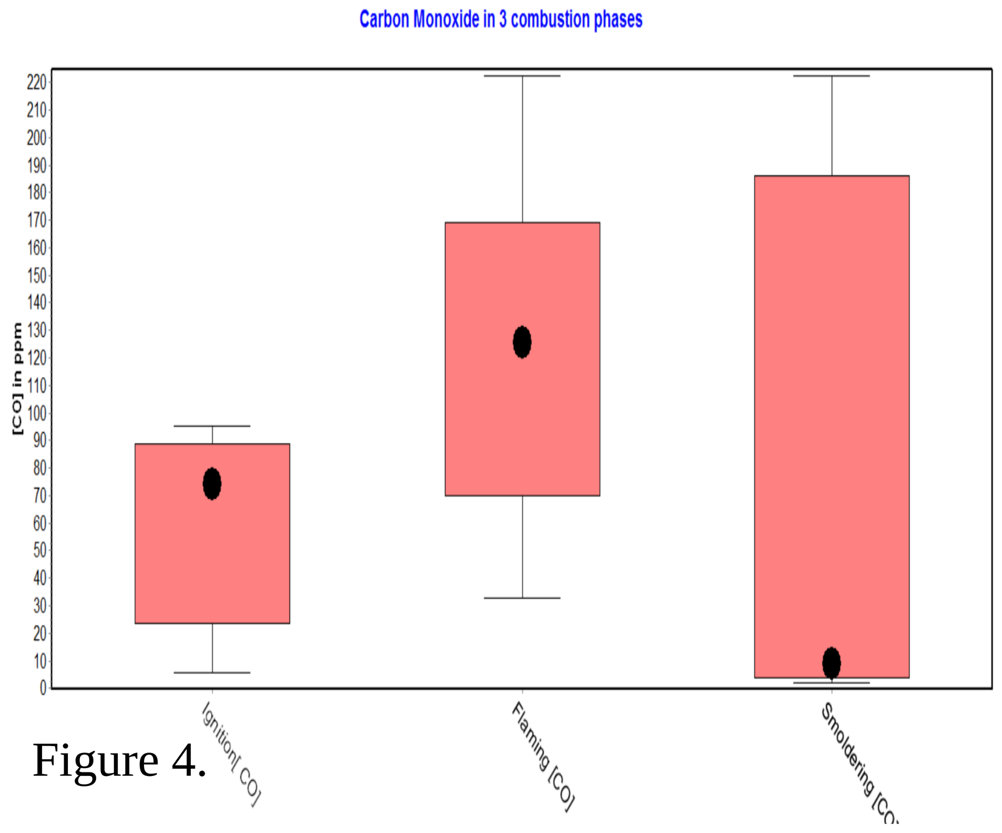

Figure 4.

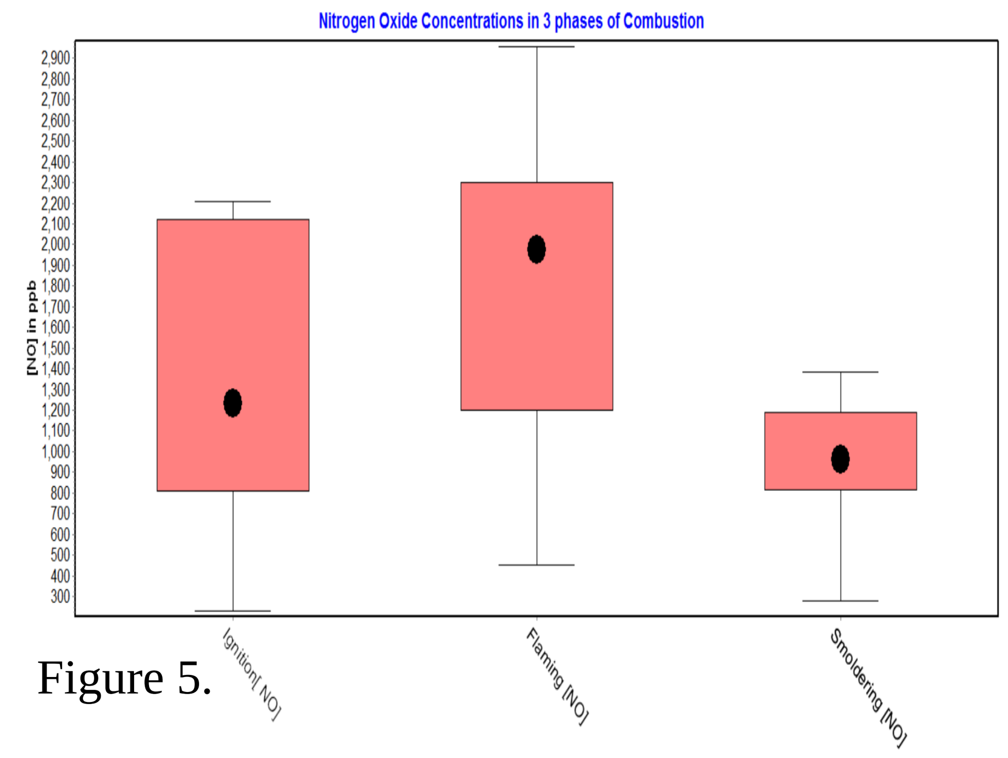

Figure 5.

During this cooking event on a Gyapa, the average CO concentrations were approximately 61 ppm in ignition, 128 ppm in flaming, 33 ppm in smoldering phases.
For the NO concentrations, the averages were 1331 ppb, 1787 ppb, 955 ppb in ignition, flaming, and smoldering respectively.
The concentrations in the flaming phases are generally higher than other concentrations in other phases. This is the phase that the cooks are constantly feeding and adding wood into the fire, which explains a larger variance of values in this phase due to different cooking behaviors such as constantly pushing the wood back into the fire.

Figures 6 and 7 show the box plots of CO and NO concentrations during a cooking event on a 3-Stone Stove

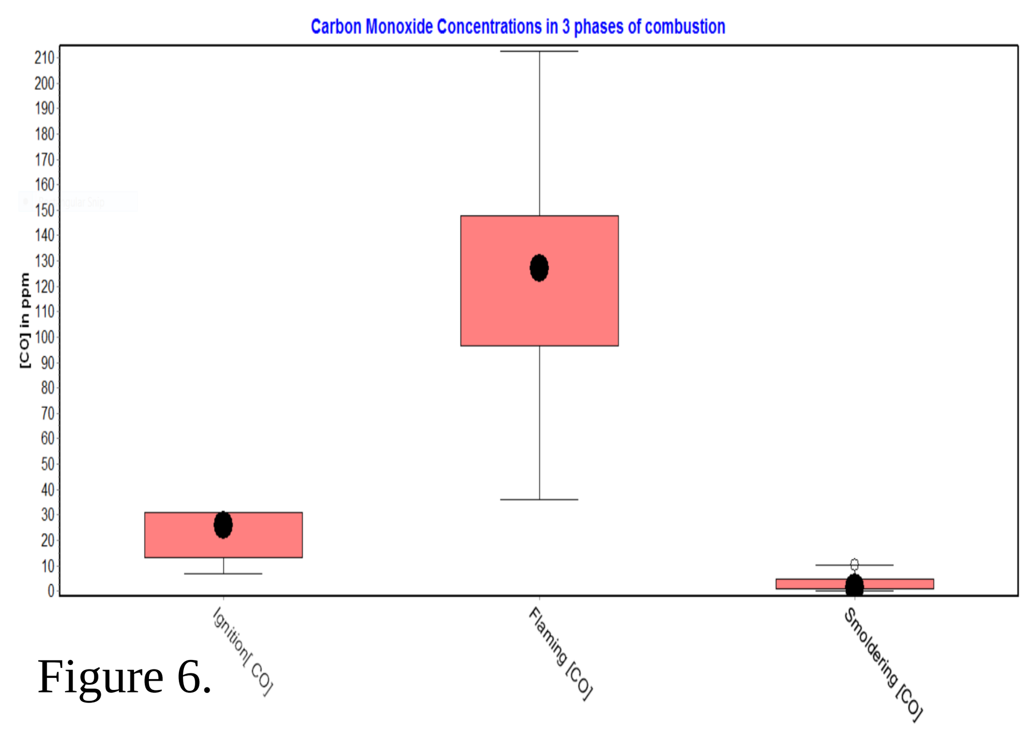

Figure 6.

Results and Discussion

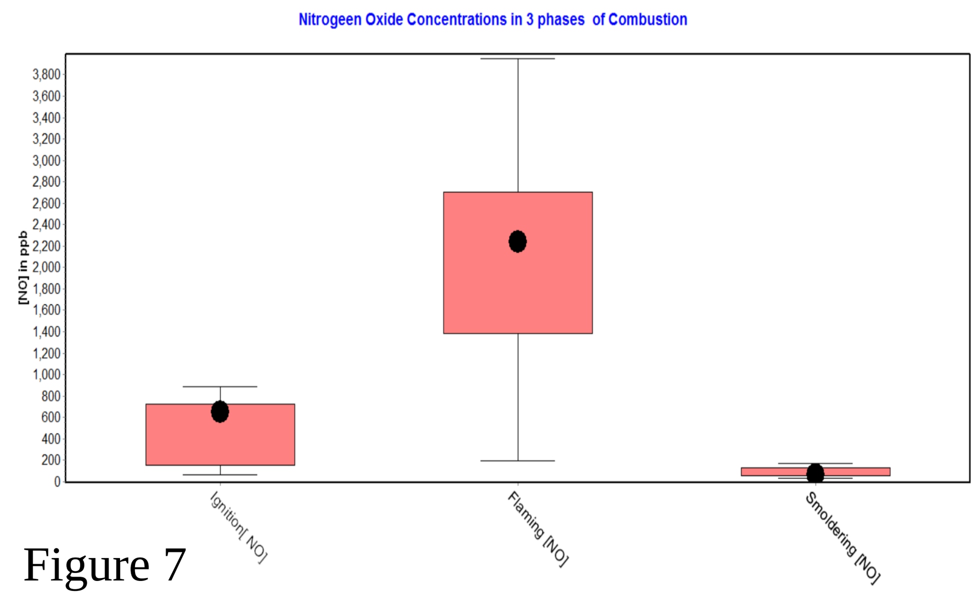

Figure 7

For the 3-stone stove, the CO and NO concentrations in flaming phases are also higher than in ignition, and smoldering phases. The average CO concentrations are 22 ppm, 122 ppm, and 2.74 ppm in ignition, flaming, and smoldering phases respectively.

On the other hand, the average NO concentrations are 477 ppb, 2100 ppb, and 83 ppb. Generally, the concentrations in smoldering phase is smaller than those in ignition phases. This is due to a decrease in fire feeding, which significantly decrease the amount of smoke in smoldering phases. Thus, causing a decrease in concentrations of emissions.

It is also important to note that the gyapa stove reduced the CO concentrations by 46% from the ignition phase to the smoldering phase. Our calculations show that the 3-stone stove reduced the CO concentrations by 87.5 % from ignition to smoldering phase. However, the big reduction might have been caused by the weather conditions of wind turbulence, which would have reduced the amount of smoke captured by our device.

Conclusion and Future work

The general trend shows that the pollutant concentrations are higher in the flaming phase than in other phases of solid fuel combustion. Also, the emissions in the ignition phase are higher than the emissions in the smoldering phase.

In order to confirm this trend of emissions, we still need to take more data to have more accurate information on emissions. The wind conditions at anytime may reduce the amount of smoke captured through the canopy, which would affect the concentrations values.

For the next analysis, we will incorporate the flow rate and integrating to get mass of pollutant per mass of fuel burned for each stove (emission factors) in order to compare multiple cooking events with different parameters such as wood types, pot sizes, and meal types.

References

1. Kariher, Peter, and James J. Jetter. 2009. "Solid-fuel household cook stoves: Characterization of performance and emissions". *Biomass and Bioenergy*.
2. Smith, K, and J McCracken. 1998. "Emissions and efficiency of improved woodburning cookstoves in Highland Gatemala". *Environment International*.
3. Burwen, Jason, and David I. Levine. 2012. "A rapid assessment randomized-controlled trial of improved cookstoves in rural Ghana". *Energy for Sustainable Development*.
4. Ezzati, Majid, Bernard M. Mbinda, and Daniel M. Kammen. 2000. "Comparison of Emissions and Residential Exposure from Traditional and Improved Cookstoves in Kenya". *Environ. Sci. Technol.* 34, no. 4: 578-583.

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