Field Emissions of the TurboPatsari Insert: Can the Popular Be Made Clean

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Masters of Science Thesis

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Executive Summary

This research project sought to determine the particulate matter ($PM_{2.5}$) emissions reductions and combustion efficiency improvements, if any, of installing a fan insert into the combustion chamber of biomass-burning chimney cookstoves in the field. The 2.5 month-long study, funded by the U.S. Department of Energy, took place in Pátzcuaro, Mexico in the summer of 2015, and used the widespread Patsari chimney cookstove as a vehicle. In the past, stove interventions featuring cleaner-burning but non-traditional stove designs frequently have run into compliance problems among participants. These efforts operate on the principle of designing a clean stove then attempting to market the device, making the "clean, popular." The idea behind this project is a contrarian approach, attempting to make the "popular, clean," by choosing an already popular stove and integrating a device designed to improve combustion and reduce pollution.

Complete combustion, simply put, occurs when organic material such as firewood (containing carbon, hydrogen, and oxygen) combines with ambient oxygen in an exothermic reaction, producing carbon dioxide (CO_2), water (H_2O), and heat. When the supply of air/O_2 is too low, carbon monoxide (CO) and carbon are produced instead of CO_2. This is known as incomplete combustion, and results in the production of particulate matter deleterious to human health. By forcing air/O_2 into the combustion chamber, oxygen supply can be increased, reducing incomplete combustion and levels of CO and $PM_{2.5}$

The forced draft modification, dubbed the TurboPatsari in this study, is essentially an electric fan. It injects ambient air/O_2 into the combustion chamber of the cookstove, thereby potentially improving combustion efficiency. Improved combustion can reduce emissions of air pollutants, and improve human health outcomes.

This pilot study consisted of 10 participant households from the community of Napizaro, near the town of Pátzcuaro. Utilizing a small, unobtrusive sampling port in the stove chimney, samples of flue gas both before and after the TurboPatsari installation were collected during cooking and analyzed. Primary data included $PM_{2.5}$ flue gas concentrations, as well as modified combustion efficiency measured as $[CO_2/(CO_2 + CO)]$.

Particulate matter was analyzed gravimetrically using 37mm PTFE (Teflon) filters. Filters were weighed before and after sampling, with the difference corresponding to the mass of particulate matter captured during the sampling period. As the sampling flow rate (volume of air over time) was known, flue gas concentrations in mg/m^3 could then be calculated. CO and CO_2 values were captured using a TSI IAQ Calc. that recorded samples at 10s intervals. These were later used to calculate combustion efficiency (%) using the above equation.

To ensure reproducibility, participants served as their own baseline. In this way, differences between kitchen types, cooking styles, and other variables in the treatment and control ("baseline") groups were minimized. Participants were also asked to cook the same or very similar meals during the baseline and treatment sampling periods to reduce unwanted variability.

The analysis showed the TurboPatsari treatment was associated with a reduction of ~17.0 milligrams per cubic meter (mg/m^3) in $PM_{2.5}$ flue gas concentrations (p-value 0.05) over the cooking period. This corresponded to a 30.2% reduction in $PM_{2.5}$ flue gas concentrations among the treated group as compared to the baseline group. There was no detectable change in nominal combustion efficiency nor in fuel use.

Calculated $PM_{2.5}$ emissions per fuel weight emissions also showed a decrease when the treatment was applied (2.09 g/kg and 1.80 g/kg for baseline and treatment measurement periods respectively). Making several assumptions, including a 10% fugitive emissions rate from the Patsari chimney into the cooking area, these emissions approximately correspond to $PM_{2.5}$/min values of 11.9 mg/min (baseline) and 10.0 mg/min (treatment). Recognizing that there are as yet no standard testing procedures for chimney cookstoves to support the new WHO IAQ Guidelines (IAQGs) for vented cookstoves, the emissions found here seem to be above the intermediate level of 7.15 mg/min (total of fugitive and chimney emissions) in the IAQGs.