EMISSIONS REDUCTION IN A HOUSEHOLD BIOMASS COOK STOVE WITH A SIMPLE MODIFICATION

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ABSTRACT: Air pollution is the world's largest single environmental health risk. Globally, 3.8 million deaths were attributable to household air pollution in 2016, almost all in low- and middle-income countries. This is mainly due to cooking with solid biomass in substandard traditional stoves, as 2,700 million people (38 % of world population) rely on this method. These traditional processes produce very high emissions of unburnt products as CO, volatile organic compounds (VOC), polycyclic aromatic hydrocarbons (PAH), and soot, which lead to several health problems.
One possible solution to address this situation is to re-engineer the employed devices and methods, with concepts such as the top-lit updraft gasifier (TLUD). In this work, a TLUD-based cook stove employed in Uganda is further optimized in order to reduce its emissions. The conducted simple modification increases the residence time of the flue gas in sufficiently high temperatures for combustion (> 700 - 750 °C). In this way, the CO emissions are reduced from 8.5 to 2.2 gCO/MJ_{del}. The obtained 75 % reduction in CO emissions can be therefore achieved with simple measures. These concepts can then lead to significant health improvements for biomass cook stove users.
Keywords: emissions, stove, developing countries.

1 INTRODUCTION

Globally, 3.8 million deaths were attributable to household air pollution in 2016 (HAP), almost all in low- and middle-income countries [1] (see Table I). This is mainly due to cooking with solid biomass in substandard traditional stoves, as 2,700 million people rely on this method (see Table I for regional distribution) [2]. Traditional biomass utilization represents almost 6 % of the world primary gross energy consumption (776 Mtoe in 2014) [3]. The main employed fuel is wood, but crop residues, char, animal dung, and various wastes are as well used. However, traditional biomass cook stoves lead to health and environmental problems due to the high emissions of unburnt products, including carbon monoxide (CO), volatile organic compounds (VOC), polyaromatic hydrocarbons (PAH) and soot [4]. Furthermore, the typically low efficiencies in traditional biomass utilization enhance deforestation and additional anthropogenic greenhouses are emitted, besides CO_2 (CO, NO and VOC are ozone precursors, and soot – black carbon – is also a climate forcing agent).

Table I: Regional distribution of population relying on traditional use of biomass for cooking [2] and number of deaths per year due to household air pollution [1] (Note: Eastern Mediterranean region is not included in HAP regional distribution, as it includes both African and Asian countries).

	Population relying on traditional use of biomass for cooling [Millions]	Number of deaths per year due to household air pollution
Africa	754	739,000
Asia	1,895	2,678,000
America	65	84,000
Total	2,722	3,770,000

Efforts to replace traditional biomass use have largely failed. In the last 40 years, the total number of people still using solid fuels for cooking in traditional devices remained fairly constant at around 2.7 billion [5]. One possible solution to address the current situation is to re-engineer the employed devices and methods, with concepts such as the top-lit updraft gasifier (TLUD). In a TLUD (see Figure 1), a batch combustion takes place within a simple reactor configuration, usually with two concentric cylinders. In the lower cylinder solid biomass is gasified in an updraft configuration, introducing primary air from the bottom. In the upper cylinder (combustor) the volatiles are combusted after the introduction of secondary air. With this configuration, it is possible to reduce emissions in comparison to other conventional natural draft devices. The objective of this work is to further optimize a TLUD-based cook stove employed in Uganda (Awamu Gasifier Stove, see Figure 1) in order to reduce its emissions.

2 COOK STOVE MODIFICATION AND EXPERIMENTAL SETUP

The objective of this work is to reduce the emissions of a biomass cook stove with simple methods that do not significantly increase the production costs. For that purpose, an extra combustor with insulation was built and installed on top of the originaIncrel combustor (see Figure 2). This modification was conducted in order to increase the residence time, temperature and draft in the combustion zone. The height of the improved combustor is approximately 26 cm, which is 11 cm more than in the original cook stove. The total height of the modified cook stove, including a 5 litre cooking pot, is of approximately of 72 cm. The outer diameter of the extra combustion is selected so that it can be easily connected to the original combustor. Rock wool is employed for the insulation.

Figure 1: TLUD cook stove concept (left) and in operation (middle) [5]. Employed original Awamu cook stove in this work, based on the TLUD concept (right).

Experiments were conducted with the original and modified cook stove. In all tests the stove is operated in a full load position. The efficiency is measured according to the water boiling test (WBT) with a cold start [6]. The WBT was conducted in an open space and after an ignition time of 5 minutes. A 5 litres stainless steel pot was filled with 4 litres of water in each test. The water temperature was measured with a type K thermocouple. For the measurement of CO emissions, the stove with the pot are placed inside the combustion chamber of a boiler (see Figure 3) with an under-pressure of 10 Pa. In this way it is possible to measure to measure the mass flow of introduced air, and the flue gas is collected and its composition is measured with a Testo 350 XL exhaust gas analysis system (similar configuration than in [7]).

Experiments were conducted with an initial amount of 0.5 kg of spruce wood chips (11% mass w.b. moisture, 0.74 % d.b. mass ashes). The amount of fuel was selected so that the water starts to boil at the end of the experiment (roughly end of pyrolysis). It should be noted that during a normal operation of the cook stove in Uganda, eucalyptus wood logs are employed, leading to a higher initial mass in the batch. After the experiment, the remaining biochar in the reactor was collected and weighted.

3 RESULTS AND DISCUSSION

The WBT has been conducted three times for each case and the obtained results are listed in Table II, showing that there is a good reproducibility. The average time to boil the water was shorter with the improved cook stove because of the higher firepower. This is caused by the higher natural draft obtained with the increased total height of the combustor in the improved cook stove. The obtained averaged thermal efficiency (27 - 28 %) is similar for the original and improved cook stove. These values are lower than the ones reported for the Mwoto and Quad TLUD stoves (41% and 33%, respectively) and similar to the one of the Troika gasifier stove (30.9%) [8]. The main reason for the lower efficiency in comparison to similar cook stoves from the same company is most probably the smaller amount of fuel used (lower bed height and with a lower density than the typically employed eucalyptus logs) and the relatively long ignition time employed. The efficiency is however a typical one for this kind of traditional devices [7]. Besides the energy transferred to the pot, around 50 g of biochar are obtained at the end of each experiment.

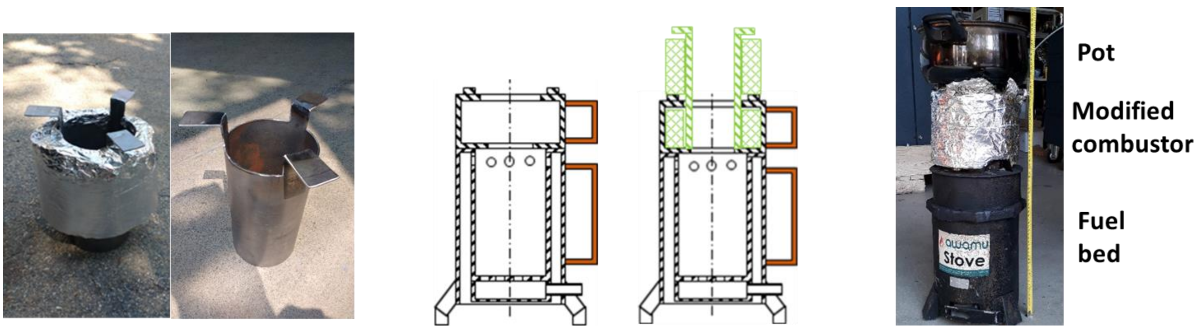

Figure 2: Picture of extra combustor with and without insulation (left), schematic representation of original and modified Awamu cook stove with novel combustor in green (middle) and picture of the modified cook stove with a 5 litre pot on the top.

Figure 3: Picture of the setup for the water boiling test (left) and measurement of CO emissions (right) with modified Awamu cook stove and 5 litre pot (Note: the boiler door is closed during the CO emissions test).

Table II: Results of water boiling test with cold start and CO emissions for original and modified cook stove.

	Original cook stove	Modified cook stove
Time to boil [min]	22.3 ± 2.1	19.7 ± 2.1
Firepower [kW]	3.94 ± 0.36	4.65 ± 0.51
Thermal efficiency [%]	28 ± 1	27 ± 2
CO emissions [gCO/Nm^3 @13%O_2]	5.28	1.31
CO emissions [gCO/MJ_{del}]	8.53	2.16

The results of the CO emissions tests are shown in Table II and Figure 4. The CO emissions of the improved cook stove are much lower due to the improved design of the combustor. It should be noted that the CO emissions are evaluated until the time when the WBT ends (see Table II), which is roughly at the end of pyrolysis and when the flame is gone. The CO tests were conducted longer, as the flame was not visible (test done inside a boiler), and the CO emissions increase in the final burnout phase. However, in normal operation, cooking should stop at the point where the WBT ends, and the solid biochar remaining in the reactor is as well a valuable by-product. The original Awamu Gasifier Stove had average CO emissions similar to the Troika results from CREEC (9.5 gCO/MJ_{del}) [8]. The improved cook stove showed an average CO emission reduction of approximately 75% in comparison to the original one (see Table II). The obtained value (2.2 gCO/MJ_{del}) is significantly lower than most of natural draft cook stoves [7].

Further work should be directed to implement this kind of design modifications for the production of low-cost household biomass cook stoves. Design constraints should be as well considered, e.g. cook stove users in Uganda want to directly see the top of the pot while cooking when sitting down, which limits possible increases in the total height of the device.

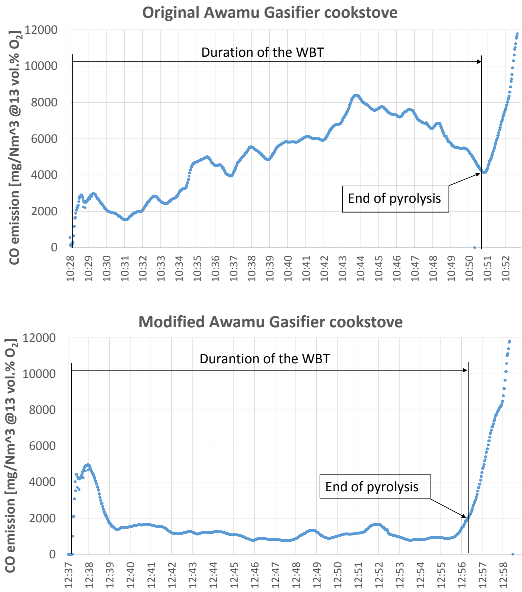

Figure 4: CO emissions in mg/Nm^3 (at 13% O_2) during a batch with original (top) and modified (bottom) cook stove.

4 CONCLUSIONS

This work shows how it is possible to reduce CO emissions in traditional biomass cook stoves with simple methods derived from basic principles of combustion engineering. A CO emissions reduction of 75 % has been achieved with the proposed modification in this work, obtaining the same thermal efficiency as with the original cook stove. These simple solutions can be implemented in commercial cook stoves, improving the design of the combustion chamber without a very significant increase of the production costs. Significant health benefits can be achieved with these solutions, as household air pollution is a major (and often overlooked) health risk. Further work should be directed to implement this kind of design modifications for the production of future low-cost household biomass cook stoves, increasing the (turbulent) mixing of flue gas and air as well as the residence time of the flue gas at sufficiently high burnout temperatures in the combustion chamber.

5 REFERENCES

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10 LOGO SPACE