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Solid-fuel household cook stoves: Characterization of performance and emissions

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ABSTRACT

In this study, 14 solid-fuel household cook stove and fuel combinations, including 10 stoves and four fuels, were tested for performance and pollutant emissions using a WBT (Water Boiling Test) protocol. Results from the testing showed that some stoves currently used in the field have improved fuel efficiency and lower pollutant emissions compared with traditional cooking methods. Stoves with smaller-mass components exposed to the heat of fuel combustion tended to take lesser time to boil, have better fuel efficiency, and lower pollutant emissions. The challenge is to design stoves with smaller-mass components that also have acceptable durability, affordable cost, and meet user needs. Results from this study provide stove performance and emissions information to practitioners disseminating stove technology in the field. This information may be useful for improving the design of existing stoves and for developing new stove designs. Comparison of results between laboratories shows that results can be replicated between labs when the same stove and fuel are tested using the WBT protocol. Recommendations were provided to improve the ability to replicate results between labs. Implications of better solid-fuel cook stoves are improved human health, reduced fuel use, reduced deforestation, and reduced global climate change.

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1. Introduction

Approximately half of the world's human population depends on burning solid fuels for cooking, boiling water, and heating. Solid fuels include wood, charcoal, coal, crop residues, other biomass, animal dung, and various wastes. The WHO (World Health Organization) estimates that more than 1.5 million people prematurely die each year due to exposure to the smoke and other air pollutants from burning solid fuels [1]. Millions more people suffer with difficulty in breathing, stinging eyes, and chronic respiratory disease. Women and children are disproportionately affected, because they tend to spend more time close to cook stoves. WHO identifies indoor smoke from solid fuels among the top 10 health risks, and indoor air pollution is responsible for an estimated 2.7 percent of the global burden of disease [2].

The PCIA (Partnership for Clean Indoor Air) was launched at the World Summit on Sustainable Development in Johannesburg in September 2002 to address the enormous environmental health risks faced by people who burn solid fuels for their household energy needs. This voluntary partnership is bringing together more than 160 governments, public and

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private organizations, multilateral institutions, industries, and others to increase the use of affordable, reliable, clean, efficient, and safe home cooking and heating practices. PCIA information is available via the Internet at http://pciaonline.org. The work described in this publication was designed to support PCIA activities.

A literature survey was conducted, and we found that many solid-fuel stoves have been tested for performance and emissions [3–19]. Smith et al. [10] found "that solid biomass fuels are typically burned with substantial production of PIC (products of incomplete combustion)." PICs include non-CO_2 (carbon dioxide) greenhouse gases and particles that affect global climate change as well as toxic air pollutants that adversely affect human health. Smith et al. also found that so-called "improved" stoves that were tested had improved fuel efficiency but actually had worse PICs' emissions than traditional stoves. Stoves with improved fuel efficiency reduce fuel use and deforestation, but higher emissions are of concern for health and for climate change. Better stoves have been developed to reduce emissions and improve fuel efficiency, but test results have not previously been reported in the peer-reviewed scientific literature.

Objectives of this study were to:

1. determine if some cook stoves have improved fuel efficiency and lower pollutant emissions compared with the traditional 3-stone fire;
2. provide useful cook stove performance and emissions information to PCIA partners and others disseminating stove technology in the field; and
3. compare test results using the Water Boiling Test (WBT) protocol with a PCIA partner, Aprovecho Research Center (ARC), Cottage Grove, Oregon.

2. Experimental

2.1. Stoves tested

Stoves that were tested in this study are shown in Fig. 1. Four of the 10 stoves were variations of the "rocket" stove design. Many variations of the rocket stove have been developed by ARC and other PCIA partners, such as stoves A, D, G, and J that are described below. A rocket stove has an opening on one side near the bottom of the stove for fuel to be inserted and for air to enter the combustion chamber. Draft is created by the large temperature difference between the air entering the bottom of the stove and the hot combustion gases exiting from the top of the vertical combustion chamber. Some rocket stoves have a metal skirt around the sides of the pot for improved heat transfer from the hot combustion gases to the pot.

Following are descriptions of the stoves shown in Fig. 1:

(A) Ecostove. The Ecostove is the only stove tested that has a chimney and a flat steel plate top for grilling foods or making tortillas. The vented Ecostove has been shown to reduce indoor air pollution compared to unvented traditional wood fires [20]. The Ecostove's rocket combustion chamber is constructed from "baldosa" ceramic tiles that are locally available in Central America, and the combustion chamber is surrounded by insulation such as wood ash, pumice, or vermiculite. The stove that was tested had vermiculite insulation.

(B) VITA stove. The VITA (Volunteers in Technical Assistance) stove [21] provides a shield around the fire that may be beneficial during windy conditions, and a skirt around the sides of the pot improves heat transfer from the hot combustion gases to the pot. Fuel wood is burned on a grate on the bottom of the stove. The same stove was tested by ARC, so results could be compared. VITA stoves have been widely used in the field.

(C) UCODEA charcoal stove. The Urban Community Development Association (UCODEA), Kampala, Uganda, charcoal stove has a metal body with a ceramic liner and grate to hold the hot charcoal. Two doors on the side near the bottom of the stove can be used to control the amount of air that flows up through the grate to the burning charcoal.

(D) WFP rocket stove. This rocket stove was developed by ARC for the United Nations World Food Programme (WFP). Metal food containers are used as materials of construction. The combustion chamber is constructed from sheet metal and is surrounded by insulation such as wood ash, pumice, or vermiculite. The stove that was tested had vermiculite insulation and had a pot skirt. The relatively low mass of the stove minimizes heat loss and results in higher temperature combustion to reduce pollutant emissions. However, the sheet metal combustion chamber becomes red-hot during operation, so the stove deteriorates rapidly compared to other stoves that were tested. The WFP rocket stove typically must be repaired or replaced after about 3 months of daily use. A similar stove was tested by ARC, so results could be compared. WFP rocket stoves have been widely used in the field, particularly in refugee camps.

(E) 3-Stone fire. The most commonly used traditional method of cooking is the 3-stone fire. A cooking pot is placed on three stones, and a fire is made in the center of the stones under the pot. Fuel wood sticks are pushed into the center of the fire, so the ends of the sticks burn. A 3-stone fire was tested as a baseline for performance and emissions. The dimensions of the three bricks used as stones and the standard cooking pot were identical to those used by ARC, so results could be compared.

(F) Philips stove. Royal Philips Electronics of the Netherlands is currently testing this stove in India. The Philips Model HD4010 stove has a cylindrical, stainless-steel combustion chamber, a small electric fan, a rechargeable battery, and a thermoelectric generator. The battery provides electrical power to the fan during start-up when the stove is cold, and the thermoelectric generator recharges the battery and powers the fan when the stove is hot. A relatively small amount of primary air is injected into the fuel in the bottom of the combustion chamber and a relatively large amount of secondary air is injected into the burning gases in the top of the combustion chamber. Air flow provided by the fan keeps the combustion chamber from overheating while the air is preheated before it is injected into the combustion chamber. During operation of the stove, small pieces of solid fuel are inserted between the top of the