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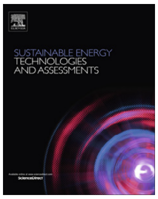

Multiple biomass fuels and improved cook stoves from Tanzania assessed with the Water Boiling Test

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ABSTRACT

Improved cook stoves can reduce fuel consumption and indoor air pollution, but are not always used as expected. A household survey in rural Tanzania showed that cooking fuels such as firewood and charcoal were supplemented with agricultural residues, and households combined improved and traditional stoves. The WBT was used to assess 7 biomass fuels in 6 stoves. Maize stalks and cobs, and stalks from sunflower showed similar burning parameters to firewood, cow dung significantly different. Ash made agricultural residues unsuitable in improved firewood stoves. The three stone fire was versatile, an advantage where fuels are limited. Okoa-II with firewood was significantly more efficient than the three stone fire, whereas Okoa-I showed no improvement. Improved charcoal stove Jiko Bora was not significantly better than its traditional counterpart. PM across fuels corresponded with «the energy ladder»; CO to lesser degree. A local sawdust stove was functional and is increasingly common in Tanzania. Where access to energy is limited by poverty and multiple fuels are utilised, dissemination of a range of stoves optimised for specific fuels or conversely a cook stove as versatile as the open fireplace, may improve cooking conditions.

Introduction

Energy poverty is the daily reality for almost half the world's population and can be described as 'the inability to cook with modern cooking fuels and the lack of a bare minimum of electric lighting to read, or for other household and productive activities after sunset' [1,2]. Development interventions aimed at household cooking date back to the 1970s and have been motivated by the theory that development of domestic energy use occurs as linear switching from agricultural residues and biomass fuels, to liquefied petroleum gas (LPG) and electricity – up the energy ladder – with socio-economic development [3–5]. Whereas appropriate policy and general development have resulted in urban energy transition, rural energy consumption patterns have been harder to modernise [4–6].

Rather than switching completely to increasingly modern fuels, multiple fuels have instead been found to be used simultaneously [6–9], such as in Mexico [10,11], Botswana [12], India [13] and Kenya [14]. Lower quality and inconvenient fuels are kept and used as a risk minimization strategy in the event of supply shortage and associated high prices of the preferred fuel, and multiple fuel use may be a risk minimization strategy where erratic commercial energy prices at times render the primary fuel temporarily unaffordable [3,6,9]. Such shortage might be due to seasonal conditions such as increased rainfall and hence lack of dry firewood, which in turn leads to increased fuel prices [15]. It has also been observed that particular fuels may be used for different purposes [8,16–18]. Some fuels may be more suitable [9,16] and/or efficient for specific cooking tasks [10], and may enhance overall energy efficiency in households [19]. The multiple fuel model, or "fuel stacking", has been proposed as an alternative to the energy ladder because it reflects how people maximize energy security and allocate fuels to activities where burning parameters make them most convenient. Rather than being a hindrance to dissemination of improved stoves, the model points to overall positive synergies such as saved energy and expenditures [11].

Firewood in the traditional 'three stone' fireplace (Fig. A.1) is typically used as a lower reference value in stove testing of improved stoves and modern energy [19–23], for instance in analysis of multiple fuel use in Mexico where firewood is combined with LPG [10,11]. However, agricultural residues are also used around the world [24]; commonly in combination with other fuels

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in rural areas [13,25,26]. Agricultural residues are considered dirty and inefficient used as fuels for cooking, and the segment of society using these fuels is constrained by lack of assets, institutional support and access, and are therefore those that are hardest to relieve from energy poverty while also being those who need it the most. For them energy poverty is first and foremost a consequence of general poverty which constrains affordability and accessibility even to firewood [2,27].

Versatility may be an important technical quality of a stove which is to meet heating tasks necessitating different burning parameters. For people relying on a variety of fuels, a stove's versatility to fuel could also be critical for its utility. Improved cook stoves are normally optimized on thermal efficiency for a single fuel, typically firewood or charcoal. The three stone fire is on the contrary generally considered inefficient, but would be flexible to biomass fuel size and type compared with improved stoves. The simplified categorisation of stoves as traditional and improved is based on thermal efficiency and smoke emissions [2,27,28], but stove-tests suggest that this distinction not always is fitting [20–22,29]. Moreover, the utility of thermal efficiency and smoke emissions may be of limited value if the stove cannot be used with those fuels that are accessible and affordable to people.

Past experience with energy transitions in developing countries suggests that a less rigid approach than instigating fuel switching along the energy ladder could be more effective [30,31]. While acknowledging that energy poverty primarily is a matter of general poverty we recognize the importance of understanding technical aspects of fuel use from a local perspective [32]. This opens for exploring burning characteristics of "inferior" biomass fuels in light of the multiple fuel model.

The Water Boiling Test (WBT) has been applied extensively in studies exploring burning characteristics of firewood and modern fuels in traditional and improved cook stoves [e.g. 33]; agricultural residues have to our knowledge not been analysed with WBT. The protocol was intended for use in the design phase of stoves for quick feedback on modifications, and calculated burning parameters are not necessarily predictive of stove performance in real kitchens. The test may however serve a purpose when comparing and ranking burning characteristics of fuels and stoves [19,22,29,33,34].

This paper uses the WBT to analyse biomass fuels and stoves, including a variety of agricultural residues. First objective is to explore how and what stoves and fuels are used for cooking in Siha district, Kilimanjaro region in Tanzania. Secondly, biomass stoves' performance with a variety of biomass fuels are measured following the WBT protocol while recording concentrations of carbon monoxide (CO) and particulate matter (PM).

Materials and methods

Household survey

A household survey was conducted in Siha district, Kilimanjaro region, Tanzania from October to December 2009 to identify stoves and fuels used for cooking, also including non-biomass cooking options. Eighty (80) households were selected based on purposive sampling aimed at collecting information from households with different socio-economic background and energy use pattern, and among those with and without traditional and modern stove and fuel use. The intention was to see a wide range of energy options in use. The area is rich with natural resources and relatively well developed infrastructure such as road and grid electricity with close access to markets in the urban centres. Areas such as around Sanya Juu town in Siha district were deemed to show prevalence of multiple fuel use since both local and commercial fuels and technologies are obtainable. The NGO Tanzania Traditional Energy and Development Organisation (TaTEDO) had also been disseminating renewable energy technology in the area since the 1990s, including the improved stoves analysed in this study. TaTEDO develops and disseminates renewable energy technologies across Tanzania. In Siha, data collection was done in collaboration with a local artisan who had been trained by TaTEDO.

Water Boiling Test

From the household survey only biomass fuels and stoves were analysed further. Burning characteristics of combinations of stoves and fuels were analysed with the WBT. In this stove test all factors except the stove itself are controlled, including ambient temperature, humidity of materials and local boiling point [33]. It is therefore useful for analysis of design and comparison of stoves [29]. Three or more repetitions were made for each combination of stove and fuel. Stove testing experiments were conducted at the Sustainable Energy Development Centre (SEDC: S 6° 43′ 48.06″, E 39° 11′ 20.91″) in Dar es Salaam, Tanzania, October 2009 and August 2010. SEDC made available TaTEDO's improved stoves for analysis. SEDC is an affiliate of TaTEDO.

The charcoal and firewood burning stoves identified in households in Siha district were available at SEDC. The sawdust stove was obtained in a marketplace in Kilimanjaro region, Tanzania. The sawdust stove's physical dimensions were typical for sawdust stoves used by households in the area and is described in Grimsby and Borgenvik [35].

Maize stalks, maize cobs, sunflower stalks and sawdust were obtained in Siha. Firewood, charcoal and cow dung was obtained in Dar es Salaam. The cow dung was from stall fed cows, and it could contain less combustible fibre than cow dung from grazed livestock. Size of the fuel influences combustion. Although this was considered when preparing the stove tests, it was not possible to make this parameter similar for all the fuels. Calorimetric measurements to determine Higher Heating Value 'as received' (HHV_{ar}) of fuels were made following ASTM D240-09 and were made on a Gallenkamp Bomb Calorimeter. Moisture content was determined by DIN 51718 standard at 106–108 °C for 2 h using Vecstar Furnace.

For all the solid biomass burning stoves except the sawdust stove, the trials were conducted by following the procedures given in the WBT. Procedure for testing the sawdust stove is found in Grimsby and Borgenvik [35].

Smoke emissions

Air pollutant concentrations were monitored in a test room. For analysis of PM (range of $PM_{0.1}$–PM_{10}) and CO in the smoke, two combustion analysers were used: Model 6203 Series CA-Calc™, TSI Inc; and, Microdust pro Aerosol Monitoring System, Casella Cel, calibrated following ISO 12103-1 A2. The facility used for this study was a roofed construction of approximately 3 × 3 m, with 2.5 m under the roof. A plastic canvas was wrapped around it allowing smoke to disappear under the edges of the ceiling to simulate indoor cooking in a traditional kitchen. The measurements were done by continuously moving the instruments in a 1 m radius around the stove, and 1 m above the floor. Note that this method should be replicated and results compared with some caution, since pollutant concentrations depend on the mixing conditions and air exchange rate in the room, which in turn depends on weather conditions. To minimize influence of wind and air