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# Fuel switching in a portable cookstove: impact of the use of agricultural residue pellets on particulate matter emissions

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3.1 Biomass integration into energy systems

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## **APPLICABLE TOPIC AND SUB-TOPIC NUMBER**

Topic 3 (*Biomass, bio-based products and bioenergy integration*) and Subtopic 3.1 (*Biomass integration into energy systems*) were chosen as they align directly with our study on fuel switching in portable cookstoves, where the impact of woody and agricultural biomass pellets on particulate matter emissions is examined. Innovative insights are offered into cleaner bioenergy applications for small communities, addressing both sustainability and health.

## **ABSTRACT SUMMARY**

Around 2.7 billion people worldwide do not have access to clean cooking equipment, which leads to health problems due to high emissions. The SHE project (Smart Home Energy, LEAP-RE) aims at developing an optimized portable micro-gasifier (or cookstove) to be used with agricultural residue pellets and thus contribute to reduce health risks, deforestation and bioresources valorization in South Africa and Uganda. In this context, particle matter emissions need to be assessed to guarantee a safe use of the cookstove with biosourced fuels. This study aims to propose the best fuel, in terms of emissions and efficiency, to substitute coal and standard wood pellets by considering agricultural residues and energy crops widely available in rural areas.

To this purpose, four reference biomass species (softwood, miscanthus, fern and rice husk) were selected. Pellets from these resources were characterized in terms of proximate and ultimate analysis [1] and thermal behavior (TGA, HHV). Secondly, these reference biomass species were tested in the cookstove. Permanent gas (CO, CO<sub>2</sub>, H<sub>2</sub>, CH<sub>4</sub>) and PM (particle matter) emissions were characterized in detail according to ISO 19867-1 standards [2]. PM were quantified by using a Testo 380 and a gravimetric method. PM were collected and characterized in terms of organic and inorganic composition. In parallel, 50 African biomass species were characterized at lab-scale (ash content, moisture content, HHV, elemental composition). Principal Component Analysis (PCA) was used for data treatment so as to identify the corresponding reference biomass for each of the new samples, in terms of similar composition, and thus being able to predict its behavior as a fuel in the cookstove.

Characterization results for reference biomass species show that wood and miscanthus pellets comply with ISO 17225-6 specifications [3]. However, some parameters of agricultural biomass may be problematic, such as ash and silicon content in rice husk or nitrogen content in fern. ICP results show the presence of alkaline and alkaline earth metals (AAEMs), which can positively influence gasification in the cookstove [4] and thus explain the thermal behavior discrepancies observed between the reference biomass samples. The preliminary results on gas emissions show that some biomass species comply with ISO 19867-1 recommendations [2], while other species, mainly agricultural biomass, require less stringent criteria, yet still meet WHO (World Health Organization) cooking standards related to emissions and efficiency to be used in the cookstove. PM emissions measured for the reference biomass species according to ISO 19867-1 standards were relatively low, but their composition and potential toxicity still needs to be assessed.

To conclude, this study proposes locally available agricultural residues and energy crops to be used as alternative fuels in a cookstove instead of coal and wood pellets by examining their permanent gases and PM emissions. Preliminary findings indicate that the variability in emissions among different biomass types would be related to the heterogeneity in agro-resources physicochemical properties. PCA analysis will help in developing criteria for selecting suitable fuels for cookstove use, in comparison to reference biomass species, ultimately enhancing the efficiency of the portable micro-gasifier and reducing health risks as well as deforestation.

## EXPLANATORY PAGES

### INTRODUCTION

More than 45% of Africa's population lives in isolated rural communities. Rural energy needs have been met by biomass for many centuries, albeit in a traditional way, which is associated with high per capita fuel use/low thermal efficiency and health risks (smoke inhalation and fire risks). In addition, over 70% of rural areas in Africa do not have adequate access to electricity. In this context, the objective of the LEAP-RE Smart Home Africa (SHE) project is to propose and optimize an affordable smart energy device, flexible in terms of feedstock, that can provide electricity and cook/heat to support grid independence and self-sufficiency. The proposed device is based on an existing portable micro-gasifier cookstove using wood pellets [5]. The use of wood as fuel is problematic because of the natural deforestation due to the use of harvested wood as the primary fuel. Many devices do not respond well to changes in fuel [6], thus, one of the major issues in democratizing the use of cookstoves is their ability to be used with different fuels, i.e., fuel switching.

### AIM AND APPROACH

The aim of this study is to:

- Substitute coal and wood pellets with available agricultural residues and perennial energy crops as affordable and readily available fuels.
- Check the conformity of using the selected biofuels in the cookstove in terms of WHO cooking standards related to emissions (gas, particle matter) and efficiency.

Four biomass species (softwood, miscanthus, fern and rice husk) under the shape of pellets were characterized into detail and considered as reference species due to their availability and representativeness of biofuel diversity, namely woods, crop residues and energy crops. Proximate and ultimate analysis were carried out for these reference species according to standards methods [1]. Their thermal behavior was also assessed by thermogravimetric analysis (TGA). At pilot scale, the reference biomass species were tested in the cookstove, and their permanent gas (CO, CO<sub>2</sub>, H<sub>2</sub>, CH<sub>4</sub>). At the same time, PM emissions were quantified into detail according to ISO 19867-1 standards [2]. The composition of PM emissions (organic or inorganic) will also be determined.

In parallel, 50 agricultural residues from the Western Nile Region were characterized. The objective was to determine if they meet ISO recommendations, as well as to predict their thermal behavior and associated emissions when used as fuels in the cookstove, by comparison of their characteristics to those of the reference biomass species.

### SCIENTIFIC INNOVATION AND RELEVANCE

- **Innovation:** An optimized portable micro-gasifier was developed to use agricultural residue pellets as fuel, offering a cleaner, more efficient alternative to traditional biomass stoves. This novel approach reduces health risks and deforestation while maximizing the use of available resources.
- **Relevance:** This research addresses critical challenges faced by isolated rural populations in Africa, where a lack of electricity access often forces reliance on harmful open fires and where agricultural residues are currently available.
- **Impact:** This work holds promise for broad applications in environmental and social contexts, reducing deforestation and health disparities.

## MATERIAL AND METHODS

The proposed device consists of a top-lit updraft gasifier (TLUD) cookstove operated with a fan for forced draft air supply and designed for pellets (Figure 1). Developed in a previous study, it is the currently available best performing cookstove regarding CO emissions [5]. CO emissions measured using wood in the cookstove were below 200 mg.MJdel<sup>-1</sup>, which were already below WHO standards (<300 mg.MJdel<sup>-1</sup>) and were 15 to 20 times below the basic forced draft stove concept [5].

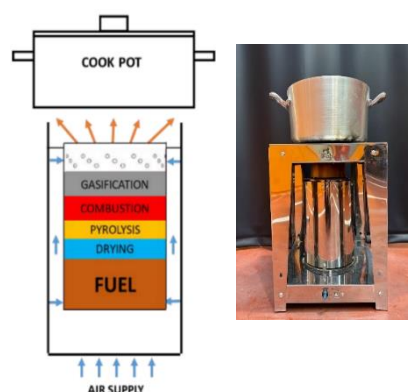


Figure 1: Cookstove operating principle

Reference biomass pellets were milled and sieved to a size range of 500 µm before analysis. Proximate and ultimate analysis was carried out according to standard methods [1]. Elemental composition (C, H, N, S, and O) was determined using a Thermoquest NA 2000 elemental analyzer. Inorganic speciation was determined using HORIBA Jobin Yvon Ultima 2 inductively coupled plasma optical emission spectrometer (ICP-OES). The thermal behavior of fuels in chemical regime for extreme conditions, i.e. pure pyrolysis and pure combustion, was performed using ATG-DSC LABSYS (Evo Setaram).

Reference biomass pellets emissions were evaluated in the optimized cookstove in terms of permanent gases and PM according to ISO 19867-1 standards [2]. To this purpose, an experimental setup was built (Figure 2). The particles were quantified using a Testo 380 and a gravimetric method. They will be characterized in terms of their organic and inorganic composition.

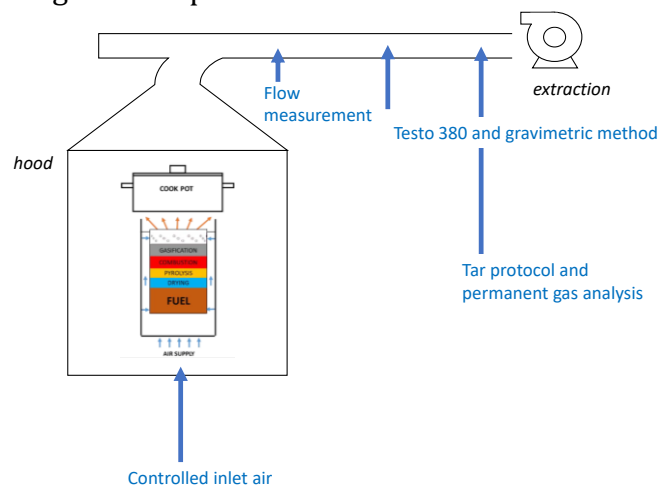


Figure 2: Principle of the experimental rig for PM and permanent gas emissions measurement

## RESULTS

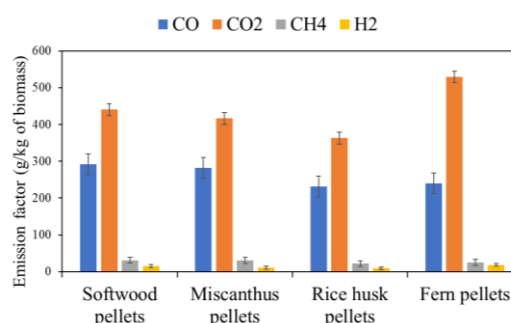
Characterization results showed that wood and miscanthus pellets comply with ISO 17225-6 specifications [3] (Table 1). However, when dealing with agricultural biomass, some parameters may pose challenges, such as the ash content in rice husk pellets. ICP (not shown) and elemental analysis results reveal that some biomass may also contain high levels of nitrogen (fern pellets) or silicon (rice husk pellets), compounds that may be problematic in thermochemical conversion processes. In fact, the nitrogen content can lead to NO<sub>x</sub> emissions and silicon is known as an inhibitor of the gasification

reaction. ICP results show the presence of AAEMs, which can positively influence the gasification behavior in the stove [4]. AAEMs may also explain the thermal behavior discrepancies observed between the studied biomass.

*Table 1: Average fuel properties and specifications of the ISO 17225-6 standard*

Biomass	Moisture Content (MC)	Ash Content (815°C)	C	H	N	S	O*	HHV
	w%, wb		w%, daf					MJ/kg, db
Softwood pellets	6.5	0.9	49.9	6.3	0.0	0.0	43.8	20.8
Miscanthus pellets	6.0	1.9	48.6	5.6	0.1	0.0	45.7	18.5
Fern pellets	6.4	6.2	51.8	12.1	2.4	0.0	33.7	18.9
Rice husk pellets	6.3	15.5	48.1	6.0	0.8	0.0	45.2	15.8
ISO 17225-6 [3]	≤ 15	≤ 10	-	-	≤ 2.0	≤ 0.30	-	-

Preliminary emissions results (Figure 3) show discrepancies between the four references biomass samples. In fact, rice husk and fern pellets present the lowest CO emissions. These differences are linked to the high ash content (rice husk) and the presence of potassium (rice husk) and calcium (fern pellets), both metals already pointed out for their catalytic effect on gasification.



*Figure 3: Cookstove permanent gas emissions*

Experiments to characterize the thermal behavior of reference biomass species, including detailed PM emissions, are currently ongoing, as well as PCA for associating the 50 African biomass to the four reference species and thus be able to predict their thermal behavior and emissions in the cookstove.

## CONCLUSION

In conclusion, this study aims to identify the best alternative agricultural residues and energy crops widely available to be used as fuels for a cookstove, focusing mainly PM emissions due to their potential toxicity. Preliminary results show differences among the biomass species studied, in agreement with their different physicochemical properties, which confirms their choice as reference biomass species. PCA results will help in determining if these reference biomass species are representative of the African diversity, and thus establishing criteria for selecting fuels for use in the cookstove.

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