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Performance Evaluation of a Modern Wood Stove Using Charcoal

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Abstract

Modern wood stoves can achieve high efficiency and relatively low levels of harmful emissions. However, controlling wood logs' combustion remains challenging, and the emission levels of unburnt compounds are generally higher than for e.g. wood pellet stoves. One solution is to upgrade the fuel quality, enabling a more stable combustion process. Thermal upgrading of wood through carbonization yields the highest achievable quality of solid fuel from wood. In this work, two types of charcoal were tested in a commercially available wood stove at various loads, with and without a retrofitted custom-design catalytic converter. The test procedure was adapted from the Norwegian test standard NS 3058 for higher repeatability and comparison with existing data. Emission levels were continuously measured using both a conventional- and a FTIR gas analyser. Particle emissions were measured both using a dilution tunnel with a total filter and an Electric Low Pressure Impactor (ELPI).
The test results show that for the selected stove, without any modifications, the emission performance for most of the measured compounds was in a similar range to wood logs. CO emissions were significantly higher, though with the addition of a catalytic converter, measured CO emissions could be cut by 74-83% on average. The test campaign demonstrates that combustion stability improvement and reduced heat output throughout a longer combustion time can be achieved by using charcoal in a wood stove, but highlights the need for both design and operational changes to reach commercial solutions.

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Keywords: Charcoal, Carbonization, Emissions, Wood stove, Catalytic converter, Operational stability

1. Introduction

Emissions of particulate matter (PM) and harmful gases from combustion are a great concern due to their negative effects on health and environment [1-4]. Emissions from residential wood combustion are known to present a large

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range in available emission factors due to the variety of combustion technologies, fuel quality, operating conditions and emissions analysis methods.

Modern wood stoves can achieve high efficiency and relatively low levels of harmful emissions. However, controlling wood logs' combustion remains challenging, and the emission levels of unburnt compounds are generally higher than for e.g. wood pellet stoves. Applying advanced control systems, automatically regulating the air amount and distribution is one method to decrease the emissions of unburnt compounds further. Another solution is to upgrade the fuel quality, enabling a more stable combustion process. Thermal upgrading of wood (e.g., torrefaction, carbonization) yields improved fuel qualities [5, 6].

In addition, one can also consider the implementation of a catalytic converter at the stove outlet, which has the potential to further reduce emissions of unburnt compounds (e.g., CO, organic compounds, PM) [7, 8]. The reduction is based on the oxidation of gaseous and PM pollutants promoted by catalytic transition metal surfaces.

The general approach of the present work was to use charcoal in an unmodified modern wood stove and to evaluate its performance in terms of emissions. Two types of charcoal were tested in a commercially available wood stove at various loads, with and without a retrofitted custom-design catalytic converter. The test procedure was adapted from the Norwegian test standard NS 3058 [9] for higher repeatability and comparison with existing data. Emission levels were continuously measured using both a conventional- and a Fourier transform infrared spectroscopy (FTIR) gas analyser. Particle emissions were measured both using a dilution tunnel with a total filter and an Electric Low Pressure Impactor (ELPI) yielding particle size distribution and number quantification.

2. Experiments

2.1. Fuel characteristics

Two types of charcoal are used in the experiments, with charcoal pieces of similar size: (1) a commercially available charcoal sold in 10 kg paper-bags as a barbecue charcoal, hereafter called CharA; (2) a charcoal provided by Elkem mainly used as a reductant in metallurgical industry, hereafter called CharB. The results of the proximate and ultimate analyses are given in Table 1.

2.2. Combustion technology

A conventional modern wood stove with a nominal effect of 4.75 kW is used for the experiments. According to manufacturer's specifications, its heat effect can be varied from 2 to 7 kW using wood logs and it can achieve up to ca. 80 % efficiency. Particulate emission of 4.76 $g.kg^{-1}$ dry wood was measured when testing it in accordance with Norwegian Test Standard NS3058-NS3059. Converted to 13 % O_2, emissions in the nominal operating range have been measured to 0.09 vol% CO, 111 $mg.Nm^{-3}$ NO_x and 238 $mg.Nm^{-3}$ C_nH_m. Flue gas temperatures at the appliance exit are within 200-250 ºC in the nominal operating range. It has one main air supply inlet underneath the stove, a top flue gas exit and a single air slide-regulator. The air slide-regulator has three main positions. (1) Fully open (high burn rate): primary air open (when lighting the stove), secondary air open (afterburning) and glass rinse open. (2) Half-way (medium burn rate): secondary air open (afterburning) and glass rinse open. (3) Closed (low burn rate): minimum secondary air inlet open (afterburning).

A custom-made platinum/palladium catalytic converter was used to actively reduce the CO emissions and test its influence on other emissions. It consisted of a honeycomb structure located in the stovepipe just above the wood stove. It was activated by electric DC current of 4 A and 75 V, yielding a total effect of 300 W. This enabled the catalytic converter to maintain a temperature above 200 ºC. It was only present when activated, and thus its presence may have had an effect on the draught and thus generated slight differences in the combustion conditions.

2.3. Emissions measurement instrumentation

A Servomex online gas analyser monitored the O_2 and CO_2 concentrations sampled from the stovepipe ca. 50 cm above the wood stove. A Gasmet FTIR was used for quantification of H_2O, CO_2, CO, NO, N_2O, NO_2, SO_2, NH_3, HCl, HF, CH_4, C_2H_6, C_2H_4, C_3H_8, C_6H_{14}, CHOH and HCN. The heated sampling system was connected to the stovepipe ca. 50 cm above the wood stove.