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Influence of pellet length on performance of pellet room heaters under real life operation conditions

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ABSTRACT

Wood pellet combustion for heating is increasing in importance in Europe. However, the most commonly used heating appliances such as wood pellet stoves are responsible for emissions which could negatively affect human health. The emissions quality of pellet stoves is influenced by pellet properties and combustion phase characteristics. The goal of this study is to investigate the influence of pellet length on the performance of pellets stoves under real life operation conditions. Three softwood pellet samples were produced, differing only in length. Combustion tests with two different types of pellet stoves were performed in steady and non-steady combustion phases. Gaseous and particulate emissions as well as fuel mass flow were measured. Results show a reduced fuel mass flow (up to 36%) into the combustion chamber for long pellets compared to short pellets. The results of the combustion tests show a considerable influence of pellet length on the performance of both pellet stoves. For example, carbon monoxide emissions and particulate emissions of one stove in nominal load operation increased for long pellets compared to short pellets from 185 mg/m^3 to 882 mg/m^3, and from 27 mg/m^3 to 37 mg/m^3 respectively. Results also show a considerable influence of the combustion phase on the emissions level.

1. Introduction

Wood combustion is the main renewable energy source for residential heating purposes in Europe [1]. Wood use is a sustainable source of heat and could reduce the production of greenhouse gasses into the atmosphere and reduce the dependence on fossil fuels. Wood pellets in particular have become an important wood fuel source in recent years. They are mainly used for domestic heat production in Europe. In total 8.2 million tons of wood pellets were used for residential heating in Europe in 2014 [1]. The predominant combustion appliances for residential heating are small-scale pellet stoves (i.e. those that are mainly used as room heaters) and boilers (i.e. those that are connected to water-based heating system). The proportion of installed pellet stoves varies widely across European countries. For instance, Italy has the highest proportion of installed pellet stoves in Europe [2], while in Germany pellet boilers are more common. Especially in winter time, wood combustion has been identified as an important source for gaseous and particulate emissions [3–7]. Various studies have shown a negative effect of such pollution on human health [8–12].

In general emissions from wood combustion vary widely due to the type of combustion technology (e.g. automatically and manually stoked combustion systems) and type of fuel (e.g. firewood, wood chips, wood pellets) [13–15].

Emission quality of pellet stoves is strongly affected by the type of stove, combustion phase and the properties of the wood pellets. Two studies stated that combustion tests with pellet stoves using identical fuel and test conditions can lead to significantly different emission levels for different stoves. These differences are most likely caused by the design of the stove (i.e. mainly the combustion chamber), combustion control system and the resulting combustion parameters such as air-fuel ratio and combustion temperature [16,17].

Pellet stoves can be operated in different combustion phases. The steady-state phases are directly influenced by the user when they adjust the heat output level at the stove (e.g. nominal load or partial load). On the other hand, non-steady-state phase occur as start-up phases (i.e. starting from cold or warm conditions), interphases between load level changes, and the stop phases. The stop phase is defined as the time when the stove is switched off until the end of the combustion. In addition, the majority of pellet

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stoves perform a cleaning interval after a fixed time of operation in order to reduce the embers on the grate in the combustion chamber. A common practice for this cleaning process is an interval with increased flue gas fan power and reduced fuel transport into the combustion chamber which takes a few minutes.

The performance regarding emissions and thermal efficiency of a pellet stove differs significantly during the described operation phases, and were only reported in few studies. Boman et al. reported an increase of carbon monoxide emissions of a pellet stove from 100 mg/MJ in high load to 470 mg/MJ in low load. Particulate matter (PM) also increased from 23 mg/MJ to 40 mg/MJ [16]. These results were further corroborated by other studies [2,3,13,18]. However, the majority of available studies evaluated combustion performance of the pellet stoves entirely in steady state conditions at one load level (i.e. mainly in full load operation) [13,17,19–21].

In real life operation pellet stoves are operated in steady and non-steady phases [2]. Reproducible and representative data from field measurements about the emissions during different combustion phases is missing. However, it may be assumed that pellet stoves which are mainly used as room heating appliances with limited fuel storage are operated similarly to firewood stoves [22] with regular on and off operation. This assumption is underlined by simulation results of Fiedler et al. [23]. They stated that a pellet stove without water jacket in normal use would experience an average of 136 starts in modulation mode and 304 starts in on/off mode per year [23]. In general, the user influence on the performance of pellet stoves is low compared to firewood stoves [22] and therefore it is possible to rebuilt real life operation in the laboratory [16].

The performance of wood pellet stoves is strongly correlated to the quality of the fuel used. One key parameter is the wood species used as pellet raw material. The different species strongly affects the emissions of pellet stoves [2,17,19,21]. This influence is also known from other biomass combustion units such as pellet boilers [24] and firewood stoves [25–27].

The influence of mechanical and physical pellet parameters such as pellet durability, the proportion of fines or pellet length on the performance of pellet stoves have not yet been a focus of scientific investigations. However, some studies and our own experiences show that the combustion of similar pellets (i.e. of the same quality) in the same pellet stove under comparable conditions may lead to significantly different emissions [19,20,28]. Hartmann et al. [28] for instance, used 12 quality pellet samples which were bought on the European market (certified according to ENplus, identical quality class) for combustion tests in an 8 kW pellet stove and measured very large emissions variations. PM emissions were between 45 mg/m^3 and 203 mg/m^3 in full load conditions and were not clearly correlated to ash content, potassium content or bulk density of the pellets [8,29,30].

In summary, it can be stated that pellet related influence factors on the performance of pellet stoves have been insufficiently investigated. High emission variation of certified pellets shows the need for further investigation in order to understand the influence of fuel related parameters.

The goal of this study is to investigate the influence of pellet length on the performance of pellet stoves under real life operation conditions which is a novel research approach. Pellet length was chosen due to its high impact on the fuel mass flow in pellet stoves [31–33] which is expected to have a strong influence on the combustion process. The pellet length is regulated in current pellet standards [34] and certification systems [35]. However, these regulations only limit the pellet length to a range between 3.15 mm and 40 mm (and max. of 1% in the range between 40 mm and 45 mm) and no pellet length distribution is required.

The sole consideration of pellet length is unique and requires steady conditions of all other parameters in terms of fuel and combustion conditions including physical properties of suitable pellets.

This paper contributes to the explanation of variations in pellet stove performance.

The results of this study can be used in future research, pellet stove manufacturing and wood pellet industry in general. The understanding of influence factors on the performance of pellet stoves is of high importance for stove manufactures to avoid high emissions in the real life operation or dissatisfaction of their customers due to a change in heat output of their stoves. In addition, results are important for the wood pellet industry which should consider the effect of pellet properties on the combustion in their production and for further pellet developments.

2. Material and methods

2.1. Pellet production

Saw dust and shavings of Spruce (*Picea Abies*) were collected from a commercial pellet plant (*FireStixx Holz-Energie GmbH*) in January 2016 and brought to the laboratory of the University of Applied Forest Sciences in Rottenburg. Spruce is the major feedstock for pellet production in Central Europe.

The feedstock was already dried and the particle size was reduced by a hammer mill to a suitable size distribution for densification (Fig. 1). Before pelletization 0.6% of wheat starch was added which is common in commercial pellet production to support the densification process [30]. The water content of feedstock was adjusted to 11% by adding water during the mixing process.

Pellets of 6 mm in diameter were produced using a semi industrial pellet mill (*Münch RMP 250*) equipped with a rotating ring die and fixed roller-cylinders. The ring die had channels with 6 mm diameter and 30 mm length. The pellet mill offered adjustable shear blades which allow the production of pellets of different lengths. After the start-up phase (i.e. to reach constant die temperature) pellets were produced with constant mass flow of 100 kg/h. In order to produce pellets in three different lengths, share blades positions were set to the corresponding distances to the die (i.e. short, middle and long pellets). After the densification process, pellets were screened using a vibrating screen and cooled to room temperature by using a counter stream cooler. The pelletization was done in one production run for all pellet samples to ensure consistent conditions.

2.2. Pellet characterization

Pellet samples were characterized according to European biofuel standards. Table 1 shows the measured parameters and the corresponding standards. Durability and bulk density were measured for each pellet batch (i.e. short, middle and long). Other parameters were measured using a mixed sample of all produced pellets.

To verify the length differences, the pellet samples were sent to the *Holz-Energie-Zentrum Olsberg GmbH* and analyzed by an optical single pellet analyzer. The system measured the length of each individual pellet in an 11 kg–13 kg sample [36].

All described production and characterization work of the pellets (except pellet length measurement) as well as combustion tests were done in the laboratories of the University of Applied Forest Sciences in Rottenburg, Germany.

2.3. Combustion tests

For combustion tests, two pellet stoves in accordance with EN