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Effect of draught conditions and ignition technique on combustion performance of firewood roomheaters

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ABSTRACT

Firewood roomheaters are popular, widespread and important for reaching European CO_2 emission targets. Since they contribute significantly to local air pollution, they have to be optimized towards minimal emission release, especially in real-life operation. Draught conditions and user behavior, particularly the ignition technique, significantly affect the emission and efficiency performance of firewood roomheaters. This study assessed the effects of the respective parameters experimentally. The results revealed a clear correlation between draught conditions and thermal efficiency. Increased draught conditions up to 48 Pa significantly decreased thermal efficiency by 6%–11% absolutely. However, for gaseous emissions no clear trend was observed. Accordingly, CO and OGC emissions increased at higher draught conditions for one tested roomheater by 30% and 60%, but decreased for two other tested roomheaters by 13%–45%. For PM emissions no effect of increased draught conditions was evident. Top-down ignition technique did not lead to a significant decrease of PM emissions compared to bottom-up ignition. In contrast, bottom-up ignition led to best thermal efficiencies. The use of either spruce or beech as kindling material revealed no significant relevance for the ignition performance.

1. Introduction

The oldest and even the most common way of woody biomass utilization is the provision of thermal heat for room heating or cooking purposes by using small-scale and batch-wise operated firewood stoves [1,2]. In Europe, the stock of firewood stoves with more than 65 million as well as their annual sales volume of more than 3.5 million appliances reveal a widespread market distribution and a great popularity [3]. Beside economic and ecological reasons firewood stoves are fairly relevant for reaching the European CO_2 emission targets [4–6]. However, since they contribute significantly to harmful gaseous as well as particulate emissions [7–11], they have to be optimized towards minimal emission release, especially in real-life operation.

Technological optimization by implemented primary measures promotes optimal combustion conditions and therefore can significantly prevent emission formation due to incomplete combustion processes [12,13]. In the last years several primary measures were further developed and were implemented in firewood roomheaters [14,15]. However, it has to be considered that the market stock is represented by older combustion appliances. Different studies showed a worse performance of those appliances compared to modern primary optimized ones [16,17]. The utilization of secondary abatement technologies, i.e. fabric filters, electrostatic precipitators (ESP) and catalysts, could be a possible measure for emission reduction for such types of appliances. But most of secondary abatement technologies are still under development and they are not ready for a widespread market introduction yet [18,19].

Beside appliance specific technological aspects also operational aspects related to the installation conditions and to the user behavior are essential for emissions and efficiency of firewood room heating appliances under real-life conditions. The properties of the chimney system, like material and dimensions (diameter and height), weather conditions, and flue gas temperature are the most relevant characteristics for induced draught conditions during

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heating operation [20,21]. Generally, a sufficient draught level in the chimney is important to enable stable and safe operation. Under type testing conditions for firewood roomheaters a constant draught of 12 ± 2 Pa is required [22]. If the flue gas draught exceeds 12 Pa the volume flow of combustion air supply increases. Consequently, combustion conditions are affected and hence emission formation and thermal efficiency are influenced with lower thermal efficiency at higher draught conditions [20,23,24]. However, no clear correlation between draught and gaseous as well as particulate emissions was observed.

The findings of a European survey about user behavior and operating conditions of firewood and pellet room heating appliances showed that 66% of the related chimneys are between 5 m and 10 m high [25]. Measurements under lab conditions and during long term field tests performed with respective chimney heights revealed that these chimney heights typically correspond with a flue gas draught between 20 Pa and 30 Pa [20,26]. This shows that the draught level of 12 Pa applied during standard type testing procedure [22] is exceeded significantly under real-life conditions. Only in case of a masoned chimney system with an effective height of 3.4 m (which is far below the identified EU average) a flue gas draught of 13 Pa was measured in the field [20].

In contrast to flue gas draught conditions, which are not directly affected by the user during heating operation, the term "user behavior" defines all operational aspects that are directly influenced by the user, i.e. kind, quality and mass of used fuels, air valve settings for combustion air supply and mode of ignition of the first fuel batch [27–30].

The ignition technique, as an important aspect of user behavior, was found to have a high effect on emission release of gaseous and particulate emissions. PM emissions of the ignition phase were reduced about 50%–80% and CO emissions about 60% by applying the top-down ignition technique instead of the traditional bottom-up ignition technique [21,31,32]. Top-down ignition means that firewood pieces are directly placed on the grate. The kindling material is placed above the firewood pieces and on the top of the kindling material the specific starting aids are located. Then, the starting aids are lighted and the combustion process is induced by a subsequent downward ignition of kindling material and the firewood pieces on the grate. In contrast, bottom-up ignition means the placement of kindling material and starting aids directly on the grate below a few pieces of firewood. Then, the starting aids on the grate are lighted and the combustion process is induced upward the fuel batch. The above mentioned studies [21,32] hypothesize that the moderate progress of combustion processes of top-down ignition technique would be advantageous since it would lead to slower pyrolysis and gasification processes and hence reduce the risk of incomplete burn out of gaseous intermediates due to low combustion temperatures above the fuel bed.

In Austria, only around 10% of the users of firewood roomheaters commonly apply the top-down ignition technique [33,34]. Also the European survey showed that the bottom-up ignition technique is the predominant ignition procedure [25].

The assumption that the ignition technique may be a significant contribution to reduce real-life emissions of firewood stoves is not yet underpinned by a satisfying number of systematic studies, even more as recent works showed that top-down ignition technique can even result in higher gaseous CO and OGC emissions (OGC: organic gaseous compounds) compared to bottom-up ignition technique [35].

Therefore, this study investigates and evaluates the effect of different ignition techniques and of flue gas draught conditions on gaseous and particulate emissions as well as on thermal efficiency of firewood roomheaters. In more detail, the objectives of this study are:

- Investigation and evaluation of the effect of different ignition techniques on emissions and thermal efficiency. Thereby, a comparative assessment of top-down and bottom-up ignition procedure and an investigation of the difference of spruce and beech used as kindling material is done.
- Investigation and assessment of the effect of draught conditions on emissions and thermal efficiency.

The findings shall reveal measures to improve the real-life behavior of firewood roomheaters and support the respective technological development. Moreover, the results may be useful contributions to legislative and normative processes and procedures.

2. Material and methods

2.1. Performed test series and general testing procedure

In order to investigate the objectives of this study two different test series were conducted:

I. Ignition technique test series – Performance of comparative ignition combustion tests regarding differences of gaseous (CO, OGC) and particulate (PM) emissions and thermal efficiency (η): The test runs were conducted under controlled constant draught conditions of 12 ± 2 Pa at two different firewood roomheaters applying the top-down and bottom-up ignition technique. Softwood (spruce – "*picea abies*") and hardwood (beech – "*fagus sylvatica*") were used as kindling material for each ignition technique. For each variation three ignition combustion tests were performed.

II. Draught conditions test series – Investigation and assessment of the effect of draught conditions on CO, OGC and PM emissions as well as on thermal efficiency (η): Combustion test cycles were conducted at 12 ± 2 Pa, 24 ± 2 Pa and 48 ± 2 Pa. For each draught setting combustion test cycles were performed with three different firewood roomheaters.

All combustion tests were conducted under constant draught conditions. For test series I only the ignition batch was performed. For test series II several combustion test cycles consisting of five consecutive batches were carried out starting from cold conditions (Fig. 1).

The ignition procedure was done consistently over all tests of a test series either top-down or bottom-up. As kindling material spruce or beech kindling together with specific starting aids were used. The second fuel batch was recharged when flames of batch 1 were extinguished. The subsequent fuel batches (batch 3–5) were placed directly on the firebed when the CO_2 concentration (v/v) of the flue gas declined to 25% of the maximum peak of CO_2 during the respective batch. This corresponded well with the recharging criteria of a maximum variation of firebed mass ±0.05 kg according to EN 13240 standard [22]. The adjustment of air valve settings for combustion air supply was done manually. During the ignition (Test series I) and preheating batch (Test series II) the air valve settings for primary and secondary air were fully open for all test runs. After the preheating batch the air valve settings were adapted according to the specifications of the user manual on constant settings (Test series II).

Flue gas temperature, flue gas draught and gaseous emissions were measured continuously over the whole test duration. The flue gas temperature for determination of thermal heat losses for indirect efficiency calculation was measured with a thermocouple centrally placed in the flue gas pipe. The gravimetric PM measurement was done discontinuously over the complete batch