THE ENVIRONMENTAL ASSESSMENT OF THE WOOD COMBUSTION

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In this paper, the authors analysed the emissions from residential boilers fired with wood logs, bark pellets, wood briquettes and wood pellets. Three boilers, selected with respect to age, design, connection to heat storage tank, and type of biofuel, were included in the study. The emissions collected comprised carbon monoxide (CO), carbon dioxide (CO_2), oxygen (O_2), total organic carbons (TOC), nitrogen oxides (NO_x), polycyclic aromatic hydrocarbons (PAC) and 33 volatile organic compounds (VOC).

We have used the Life Cycle Inventory method in order to identify the main stressors generated by the wood combustion stage. In this purpose, we have analysed one type of old boiler, one type of modern boiler and a multi-fuel boiler, which can burn wood logs, bark pellets, wood briquettes and wood pellets. In this article, we selected only the wood combustion stage because it's the most important according to the emissions produced.

Keywords: briquettes, pellets, combustion, LCA.

1. Introduction

Wood is a renewable resource and "environmentally friendly" compared with other materials [1]. The renewable resource aspect can be substantiated when forestry operations are accompanied by third party certification for sustainable management practices. Unfortunately there is a large source of non-technical information available to the public that discourages harvesting and the use of wood products. In a publication by Watershed Media [2], reference is made several times to the destruction of forest or harvesting old-growth wood in order to build a wood-framed house. To address claims like these, the scientific community world wide has been developing methodology that accurately assesses the environmental impact a product or process my cause over its life cycle.

Life-cycle assessment (LCA) is one approach to accurately assess the environmental burdens associated with the manufacturing of a product from resource extraction to end-of-life. The development of the LCA methodology has helped to quantify and provide information about a product where environmental qualities were lacking [3]. A LCA is comprised of three interrelated components:

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1.) an inventory phase, 2.) an impact assessment phase, and 3.) an improvement phase. By definition, it is an objective process to evaluate the environmental burdens associated with a product, process or activity. The life-cycle inventory (LCI) conducted in this study presents the quantitative results for three boilers proposed. The LCI presented is focused on two main environmental assessments: 1.) energy requirements and 2.) emissions to the environment for the wood combustion (by using different products of wood) . The LCI's developed are in accordance with the CORRIM Research Guidelines [4] and the International Organization for Standardization (ISO) protocol for performing life-cycle assessments [5]. In this paper we have presented the life cycle inventory in order to identify the main emissions generated in the wood combustion stage.

The common types of residential combustion devices have been described by, for instance [6]. Modern wood boilers are usually designed for downdraught combustion and with a ceramic-lined burn-out zone (Fig. 1A), and are normally connected to storage tanks. In old-type wood boilers up-draught combustion is most common, and the boilers are water cooled. An example is shown in Fig. 1B. Up-draught combustion is also typically used in wood stoves. In general, development of wood boilers has led to combustion devices with increased efficiency and decreased emissions.

Except for some work on particle emissions [7], information on emission characteristics related to residential biofuel boilers is scarce. There is a need to compare emissions from different techniques of biofuel boilers to ensure an ecologically sustainable use of biofuels. Consequently, the present work focuses on comparing gaseous and particulate emissions from old type and modern boilers by means of systematic variation of combustion device, fuel quality, firing behavior, and the influence of heat storage tank. Unsystematic irregularities caused by user habits are avoided by performing tests in the laboratory. Instead, user habits are simulated in a schematic way. The purpose of the comparison is to determine the emission differences between old-type and modern residential biofuel boilers and to quantify emission characteristics of different kind of biofuel combustion.

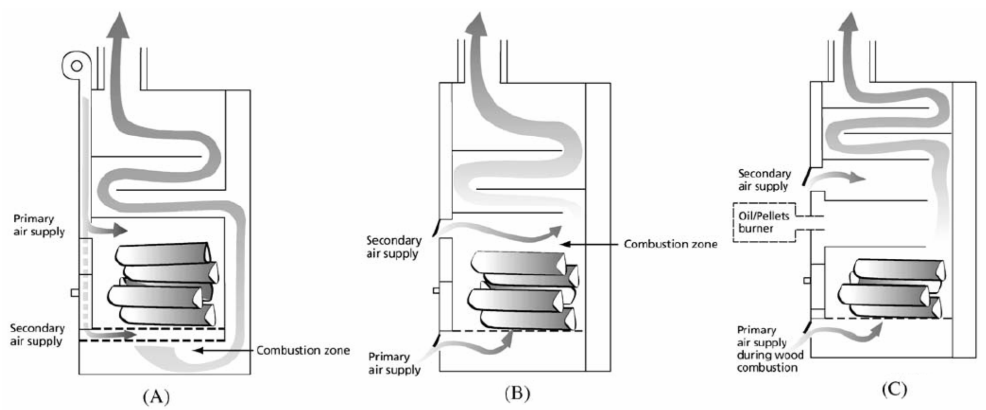

Fig. 1 A wood boiler designed for down-draught combustion (A), a wood boiler designed for up-draught combustion (B), and a multi-fuel boiler (C), which can burn wood logs, bark pellets, wood briquettes and wood pellets.

2. Life cycle inventory of the wood combustion

The chemical composition of the wooden fuels, pellets, briquettes and wood logs, is similar (Table 1), except that the moisture content was approximately 8 % in the pellets and briquettes, and 15 %, 26 %, or 38 % in the wood logs. Wood logs, of birch, with moisture content of 15% are considered dry, while higher moisture contents represent wet fuel. The ash content in the woody fuels is low compared to bark pellets, which also has a higher fraction of nitrogen. The length of the wood logs was about 500 mm. The cylindrical log was split once or twice with a resulting transversal size of 100 mm. Wood and bark pellets had a diameter of 8 mm and a length of 15–20 mm.

Table 1

Elemental analyses and heating values of the fuels [8]

	Wood pellets	Bark pellets	Wood briquettes	Wood logs
Ash	0,5	3,7	0,3	0,3
Moisture	7,6	7,8	7,5	15/26/38
Lower heating value (MJ/kg)	19	20,1	18,9	19
Content				
Carbon	50,2	52,1	50,6	50,6
Oxygen	43,2	37,8	42,7	42,7
Hydrogen	5,9	5,9	6,4	6,4
Nitrogen	0,08	0,48	0,05	0,05
Sulphur	<0,01	0,03	<0,01	<0,01

Moisture – wt % wet fuel, other data wt % dry fuel

The emissions of CO, TOC, methane, non-methane VOC (NMVOC), PAH, mass and number concentrations of particles, and NO_x are presented in

Table 2. To simplify the results, the emissions from all the operational cases of Table 1 are sorted into groups and plotted against some related parameter, prior to presenting the influence from combustion device, firing behavior, fuel quality, and connection of heat storage tanks. Three groups of emissions were identified: unburned emissions compounds, particles, and nitrogen oxides. Unburned emissions compounds, i.e. CO and hydrocarbons, are a consequence of imperfect combustion conditions, which can be explained by the well-known criteria for favorable combustion: long enough residence time at sufficiently high temperature with adequate mixing of air and combustible gases. We know that the CO concentration increases with increased excess air. Consequently, oxygen was not the limiting parameter for CO oxidation during poor combustion conditions. Instead, high excess air can be suspected to cool the combustion chamber, resulting in high CO emissions. Analyzing the data collected in the Table 2, we could say that there are linear correlations between CO and TOC for wood boilers, pellet burners, and oil burners, and obviously TOC is also influenced by the air supply, just as CO, VOC (methane+NMVOC) and PAH.

Table 3

CO_2, CO, TOC, particles and NO_x emissions [8]

	CO_2 (%)	CO	TOC	CH_4	NMVOC	PAH	Particles	NO_x
Old type wood boilers	8,4	4 100	660	-	-	-	87	65
Modern wood boilers	12,2	707	14	1	1,9	0,21	27	125
Pellet burners and boilers	9,5	36	4	0,76	1,2	0,32	22	68

Emissions are in mg/MJ, where not other units are indicated

The particles emitted contain both organic material, i.e. unburnt solid material, and inorganic material, i.e. ash particles. Regardless of combustion conditions, ash particles always remain as a by-product. It can be seen (Table 3) that the mass concentration of emitted particles was rather constant up to a concentration of about 100 mg/MJ TOC. At higher concentration the particle emission increased. The increase in mass concentration of particles during poorer combustion conditions agrees with earlier work, for example by Muhlbaler Dasch [9]. The enhancement of particle emission during poor combustion conditions is due to carbonaceous particles. The number concentration of emitted particles also increased for poor combustion conditions, as indicated by the dependence on TOC (Table 3). Nitrogen oxides are formed from combustion air or from fuel nitrogen. The importance of fuel nitrogen is implied by a correlation between the NO_x emissions and the fuel nitrogen content (Table 3). As seen in Table 3, no clear effect of excess air on the NO_x emissions could be observed, probably because of a balance between the tendencies of excess air to increase the formation of NO and of the falling temperature to reduce the formation (of fuel-NO).

The low emissions of particles and unburned emissions compounds from oil burners were expected, since small scale continuous combustion of a fluid fuel can be better controlled than batch-wise (wood boilers) combustion of solid fuel and semi-continuous combustion of pellets. However, it is possible to improve the control of batch wise solid fuel combustion, as is shown in this study by comparing old-type wood boilers with modern wood boilers. This can probably be even better developed in the future. Pellet burners are new designs and can most likely be further improved to emission levels comparable to those of oil burners. Domestic pellet burners were developed in the 1980s, but not until the late 1990s these devices contributed to significant shares of the market in countries like Sweden, Denmark, and Austria [6]. Regardless of somewhat higher emissions of particles and unburned emissions compounds from modern biofuel boilers compared with oil burners, modern domestic biofuel boilers are ecologically sustainable heating options as they do not contribute to the climate change.

Very large differences in emissions were observed between old-type and modern biofuel boilers. In particular, high emissions of the greenhouse gas methane were recorded for old-type wood boilers, which are the ones most frequently installed in houses today. The effect on climate change from an old-type wood boiler, because of high methane emissions, can be compared with residential oil burners emitting CO_2 by using the global warming potential (GWP). This parameter expresses the impact of a gas on the climate change in relation to CO_2. GWP for methane is 21 kg CO_2-equivalent/ kg methane [10]. The emission from the worst old-type wood the methane emission was 4800 mg/MJ, which gives around 100 000 mg CO_2-equivalents/MJ. Consequently, an old-type wood boiler may have more than twice as high an impact on climate change as an, for example, oil boiler, besides high emissions of particles and unburned emissions compounds.

3. Conclusions

There are high emissions of unburned emissions compounds and particles from old-type residential biofuel boilers. The measured VOC compound with highest concentration was methane in all cases, and as a consequence of methane emissions, the influence on climate change of an old-type wood boiler could be higher than that of an oil boiler, for example. As an example, substitution of an old-type wood boiler with a modern wood boiler attached to a storage tank or with a pellet boiler could reduce methane emissions 8 to 9000 times, at the same time as the efficiency would increase. Installation of a heat storage tank in connection to an old-type wood boiler could reduce the methane emission seven times and the particle emission 21 times, thus improving the environmental performance to some extent. A similar improvement was observed when changing firing behavior to charging smaller batches of wood logs. Modern wood boilers seem to maintain their low emission performance also in the case of degradation of the fuel quality in the form of increased moisture content. However, changing the fuel's composition from wood based fuel like wood logs, wood pellets, and wood briquettes, to a fuel manufactured from a lower quality material, such as bark, results in higher emissions of particles and NO_x, because of higher ash and nitrogen content in bark.

Increased emissions of CO were found at high excess air ratios. This agrees with earlier studies on wood stoves [11], and is probably a result of cooling of the combustion process. The enhanced emissions of CO were accompanied by emissions of other unoxidised components: TOC, CH_4, NMVOC, and PAH. The mass concentration of emitted particles was rather independent of emission of unburnt gaseous compounds up to a concentration of about 100 mg/MJ TOC, after which the particle emission increased, probably because of high concentrations of unburnt particulate matter. The mass concentration of particles was 180 times larger in the worst old-type compared to the best modern boiler. The number of particles emitted increased with increased emissions of unburned emissions compounds. From the number and mass size distributions it can be concluded that the emission of sub micron particles, especially ultrafine particles (size100 nm) is enhanced by poorer combustion conditions.

Most biofuel boilers installed today are of the old type, and cause high emissions of particles and unburned emissions compounds, as well as a climate change effect comparable with oil burners. It is urgent from both environmental and health point of view that they are replaced with modern residential wood boilers attached to storage tanks, or pellet boilers.

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