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Chimney emissions from small-scale burning of pellets and fuelwood - examples referring to different combustion appliances

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Abstract:

Most wood boilers used for residential heating today are old-fashioned and emit large quantities of organic compounds. The installation of a pellet burner and a change to wood pellets as fuel normally decreases the emissions remarkably. In this study, the emissions from different equipment for burning of wood and pellets are compared.

The organic fraction of smoke from traditional wood burning is to a great extent composed of methoxyphenols, with antioxidant effects. Methoxyphenols were also identified in smoke from pellet stoves. A fuelwood boiler or a furnace with an inserted pellet burner is heated to a higher combustion temperature, decreasing the total amount of organic compounds in the smoke. Above 800°C, methoxyphenols are thermally decomposed and carcinogenic polycyclic aromatic compounds (PACs) are formed. The combustion-formed aromatic hydrocarbon benzene is present in smoke from all kinds of burning, but the proportion relative to primary organic compounds increases with increasing combustion temperature.

In smoke from an environmentally labelled wood boiler and from some pellet burning devices, the levels of PAC and benzene were found to be low. Evidently, the combustion was nearly complete. Although the change from wood to pellets significantly decreases the emissions, considerable differences exist between various combinations of pellet burners and boiler furnaces.

Keywords: Wood; Pellets; Combustion; Methoxyphenols; Benzene; PAH

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1. Introduction

In Sweden wood burning was the predominant house heating method, until less than a hundred years ago. In the 1950s, oil burning became very popular, and replaced wood burning to a large extent. The oil burning enthusiasm decreased during the 1970s oil crises. Since then the interest in oil burning has continued to fall with increasing oil prices and environmental awareness, and biofuels like wood have become more popular again. Today fossil fuels are replaced by biomass to decrease the emissions of carbon dioxide causing global warming.

New technologies for wood burning have entered the market during the last ten years. Modern wood boilers are energy efficient and their emissions are very small. Wood pellets are a processed biofuel that may replace oil as well as wood logs for residential burning. The use of wood pellets has grown very rapidly in recent years.

At present, small-scale combustion of biomass accounts for 12 TWh of Sweden's energy supply [1]. The use of biofuels is expected to increase, in accordance with the effort to achieve a sustainable energy supply. Emission data are essential for estimating environmental and health effects of the present, and the future increased, small-scale biomass burning. Knowledge about the smoke constituents is also necessary when setting regulations and developing better technologies for wood combustion. It is therefore of great importance to investigate the emissions from biomass burning.

2. Experimental

Semi-volatile compounds in smoke from residential burning were collected on Tenax adsorbent cartridges in the chimney outlets [2]. The samples were analysed using gas chromatography and mass spectrometry. The emissions were quantified using two different methylbenzene reference gases [3].

Smoke samples for assessment of carbon dioxide, carbon monoxide and methane were collected in Tedlar bags and analysed with gas chromatography with thermal conductivity and flame ionisation detection. Parallel measurement with an electrochemical cell instrument confirmed the results [2].

3. Results and discussion

3.1 Smoke constituents

In Table 1, the different appliances are listed in order of increasing combustion efficiency. The old wood stove was the least efficient and emitted methane and methoxyphenols in high concentrations. Methoxyphenols also occurred in the smoke from the pellet stove. When the pellet burner worked on full effect, it achieved equivalent high performance as the eco-labelled wood boiler. The emissions increased considerably when run on low effect. Hence, the automatic altering in effects of this burner, impair its total environmental performance.

Table 1: Concentrations of selected air pollutants in mg/m^3 in the chimney outlet of small-scale burning devices. The results should be seen as examples rather than representative for specific devices. Combustion efficiency = $[CO_2]/([CO_2]+[CO])$.

Fuel	Wood	Pellet	Pellet	Pellet	Wood
Device	stove [a]	stove [b]	burner [c]	burner [c]	boiler [d]
Effect	20 kW	7 kW	low	20 kW	30 kW
CO_2	120 000	46 000	50 000	130 000	120 000
CO	4 100	610	470	13	190
CH_4	120	5	3	0.3	3
Benzene	13	0.6	0.5	0.01	0.4
Methoxyphenols	44	2	0.0	0.0	0.0
Pyrene	0.4	0.0	0.0	0.0	0.14
Combustion efficiency	0.97	0.99	0.99	1.00	1.00

[a] residential fire place like boiler from 1981 coupled to a water tank; [b] top fed; [c] top fed, installed in an old boiler (for wood, oil and electricity) coupled to a water tank; [d] environmentally labelled modern wood boiler from 2001, coupled to a water tank

The chemical composition of the smoke is dependent on the fuel and the combustion conditions and is of great importance with respect to environmental effects and human health. Incomplete combustion in traditional devices, like wood stoves and open fireplaces, emits large quantities of organic compounds that to a great extent are primary thermal decomposition products of lignin and cellulose [4].

Lignin-derived methoxyphenols, assessed in the smoke from the wood and pellet stoves, are antioxidants that may counteract the negative health effects from more hazardous smoke components. Softwood lignin is built up of guaiacyl propane units. On burning, 2-methoxyphenols (guaiacyl compounds) are released as primary thermal decomposition products [5]. Hardwood lignin also contains syringyl propane units. Hence, smoke from hardwood burning contains 2,6-dimethoxyphenols (syringyl compounds) together with 2-methoxyphenols.

The antioxidant effect depends on the chemical structure of the methoxyphenols [6]. The 2,6-dimethoxyphenols are more effective antioxidants than the 2-methoxyphenols. The structure of the side-chain which may contain up to three carbon atoms, is also relevant to the antioxidant effect.

Methoxyphenol antioxidants are mainly formed on incomplete burning at low combustion temperatures [4] and their total proportion decreases between 600-800ºC. Guaiacol and syringol, and their analogues with a methyl side-chain, are more stable than methoxyphenols with unsaturated alkenyl groups, and are prominent in smoke from slightly more efficient burning [3,5].

Anhydride sugars are primarily formed on thermal decomposition of cellulose and hemicellulose. 1,6-Anhydroglucose (levoglucosan) is the dominant cellulose decomposition product [5].

The proportion of health hazardous secondarily formed combustion products, such as polycyclic aromatic compounds (PACs) and benzene, increases with improved combustion efficiency. In Table 1, the PACs are represented by pyrene. Among the examples in the table, the old wood stove had the largest emissions of pyrene. Previous studies of a conventional wood boiler, coupled to large water tanks, showed alarmingly high emissions of PACs [7]. That boiler was not environmentally approved for urban areas.

Polycyclic aromatic compounds are mainly formed at combustion temperatures of 700-900ºC. The examples in Table 1 indicate that in modern, efficient wood combustion devices, the burn out of methoxyphenols as well as polycyclic aromatic compounds is almost complete.

The concentrations of benzene, the remaining aromatic compound, were also low in smoke from the modern burning devices. This often discussed carcinogenic compound, is the predominant aromatic hydrocarbon in smoke from wood burning at low as well as high combustion temperatures, but compared to other organic compounds its proportion increases steadily with the combustion efficiency. The percentage proportions between antioxidative methoxyphenols and benzene in smoke from different methods of biomass burning, arranged after increasing combustion efficiency, are illustrated in Figure 1.

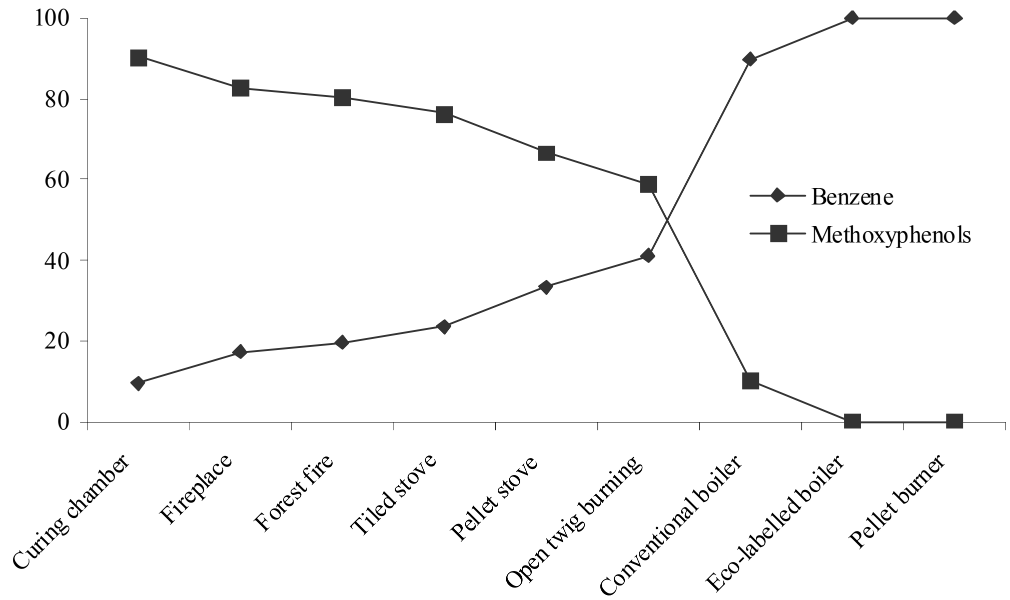

Figure 1: Proportion of antioxidant methoxyphenols and carcinogenic benzene for applied biomass combustion at increasing combustion efficiency [4]

3.2 Emissions from varying methods of combustion

The total amounts of organic compounds in smoke from biomass combustion decrease with more efficient burning. In Table 2 varying types of combustion have been divided into three classes: incomplete, mid-efficient and efficient burning [4]. Most wood boilers used for residential heating today are old-fashioned and emit large quantities of organic compounds. When combustion is almost complete, the emissions of organic compounds are minimal.

Table 2: Characteristic smoke components emitted from biomass burning with different combustion efficiencies [4].

Combustion	Temp (ºC)	Burning example	Characteristic components
Incomplete	< 700	Meat curing chamber Smouldering forest fire Fire-place, tiled stove	Methoxyphenols and 1,6-anhydroglucose
Mid-efficient	700-900	Conventional boiler	Benzene and polycyclic aromatic compounds
Efficient	> 900	Wood pellet burner Eco-labelled boiler	

The introduction of wood pellets on the Swedish market has led to much lower emissions, when they are burnt in correctly installed well-functioning pellet stoves, burners or boilers [2,3,8]. The installation of a pellet burner and a change to wood pellets as fuel normally decreases the emissions remarkably [3,8]. The production and use of wood pellets has increased steadily in Sweden during the last few years [9]. Although the change from wood to pellets significantly decreases the emissions, considerable differences exist between pellet burners, boilers and stoves as well as between various combinations of pellet burners and boiler furnaces [2].

The development of very effective wood boilers has also escalated during the past few years. Sweden's first eco-labelled wood boiler (Table 1) was recently approved. Such highly efficient residential boilers are constructed for reversed combustion and have ceramic fireplaces. On reversed combustion, the woodpile is burning from below and pieces of wood are continuously falling down into the combustion chamber, leading to uniform heat development throughout the burning cycle. The function of the ceramic combustion chamber is to maintain a high combustion temperature during the whole burning cycle, resulting in decreased emissions during the gas combustion phase and an increased energy yield during the coke combustion. Air intake in two steps guarantees adequate oxygen supply. The residence time is increased by long gas-paths. This is important for complete combustion of organic compounds, and for efficient heat transfer from the hot smoke gases. Heat storage in a large water tank makes it possible to run the boiler at a high effect without over-heating.

3.3 Environmental requirements of wood boiler emissions

Several countries have developed a positive environmental labelling with the intention of guiding consumers towards less environmentally harmful products. SIS Eco-labelling, responsible for the environmental label the Swan, has elaborated the Nordic criteria for wood boilers. Pellet stoves and boilers are well suited for environmental labelling as well. The performances of pellet burners are highly dependent on the devices that they are installed in. It may therefore be necessary to eco-label specific combinations of burners and boilers.

At present, new wood boilers installed in Swedish urban areas must comply with the emission limits set by the authorities. Today's Swedish emission limits for wood boilers, according to authority regulations and eco-labelling, are listed in Table 3. About 90 % of the boilers sold today are environmentally approved for urban areas.

Table 3: Present limits for emissions to air from wood boilers in mg/m^3 dry gas at 10 % O_2.

	Swedish authorities	The Swan[a]
Boiler effect	<50 kW	<100 kW
Organic carbon	150	70
Carbon monoxide	-	1000
Particles	-	70

[a] Nordic eco-label

With regard to human health, future emission requirements for eco-labelling should include benzene and a representative polycyclic aromatic compound, preferably pyrene. From a global environmental perspective, the greenhouse gas methane should be included as well. Since the concentration of methane in wood smoke decreases with improved combustion efficiency, high emissions of methane also indicate bad energy management. The emissions should be related to the concentration of carbon dioxide, to eliminate dependence on dilution.

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