Health effects of particulate emissions from small scale biomass combustion - BIOHEALTH

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Public Abstract

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PREFACE

This work is the short abstract of the research project "Health effects of particulate emissions from small scale biomass combustion (BIOHEALTH)" which is a part of the ERA-NET Programme, Joint Call Clean Biomass Combustion. The project was based on work in a multidisciplinary consortium (engineering, physics, chemistry and toxicology) of 13 internationally well-established research partners from 4 countries.

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INTRODUCTION

Fine particles constitute the most important air pollutant in ambient air in regards to health effects. It is estimated in the European community that about one third of people living in cities are exposed to excessive levels of suspended particles. The impact of airborne particles on health includes impaired lung growth in children, worsening of asthma, COPD and cardiovascular diseases.

The use of biomass combustion is strongly increasing because it is considered neutral in relation to greenhouse gas emissions. However, the adverse effects of fine particles from combustion on health and climate need to be further investigated and reduced. Progress in combustion techniques has been going on for several years (e.g. in relation with the creation of several voluntary labelling throughout Europe like the "Green Flame" label in France, the "Blaue Engel" in Germany and the "UZ37" in Austria) and has already resulted in clear improvements. However, still further improvements are required.

Domestic biomass combustion has a substantial contribution to the total fine particulate emissions in most European countries. This is mainly due to a widespread use of old, un-optimized small-scale wood log appliances in residential heating. Other contributors to particulate air pollution from biomass include green waste open burning by individuals, as well as open fireplaces and fires.

In epidemiological studies, small-scale wood combustion has been associated with increased cardiac and respiratory hospital admissions. These epidemiological data are supported by chamber studies where exposure to wood combustion emissions has increased inflammation, blood coagulation and oxidative stress in humans. It has also been observed that wood smoke aerosol may impair immunological and host defense functions, e.g.

clearance of bacteria from the lungs. Recent studies have demonstrated immunosuppressive properties of urban air fine particulate samples related to poor biomass combustion. Moreover, aromatic organic compounds from incomplete biomass combustion may lead to cancer development in long time exposures.

However, there is only very limited scientific evidence on the source-specific harmful characteristics of particulate matter including small-scale biomass combustion. Since the small-scale and residential biomass combustion sector comprises a broad range of technologies, operation procedures and fuels, it is difficult to extract accurate and generally applicable information of the impact of the fine particle emissions on environment and human health.

In this project, original scientific data on fine particle emissions from various combustion appliances and fuels and their relationship to activated toxicological responses was provided. The measurements of different particle properties (mass and number size distributions, density, morphology, chemical composition) simultaneously with the parallel techniques gave a very versatile picture of fine particles from biomass combustion. The resulting information was used in the evaluation of the particle deposition to the human lungs and the consequent health effects. A study with synthetic particles and doped fuels, containing the same compounds as biomass combustion emissions were performed in order to identify the effects of the most relevant species in real emission particles. Health related toxicological effects were studied with the wide pattern of different in vitro methods. With exposure chamber studies, also information about the links between in vitro toxicological effects and human health effects were obtained. On the whole, the highly innovative approach of this project was to connect human exposure studies, cellular toxicology and detailed characterization of particle properties of the fresh and aged biomass combustion derived particles and production of synthetic biomass combustion particles.

PROJECT CONTENT

Practically, the project was divided to four technical Work Packages (WP1-4) and Work Package for Project Management (WP0) including 14 different Tasks. In addition to composing of previous literature data, the focus of WP1 was to compile and provide original scientific data on fine particle emissions from various combustion appliances and fuels and their relationship to activated toxicological responses in real combustion conditions. Complementary test runs were performed using new biomass fuels; straw, mischantus and poplar in efficient boilers; French practices were studied from the new generation woodlog stove, the pellet stove and the old generation woodlog insert. Furthermore in WP1, the influence of atmospheric ageing on the physicochemical and toxicological properties of typical particulate emissions was studied in a stainless steel chamber. Emissions used were produced from a modified wood stove that was operated at two modes, “normal” firing procedure at nominal load and adjusted “sooty” firing procedure.

In WP2, further understanding was produced of physico-chemical (e.g. size, detailed chemistry) properties of combustion generated PM and their associations to health related toxicological responses. Detailed physical, chemical and toxicological characterization of fine particles were performed in different combustion conditions produced by a adjustable combustion reactor. Pure synthetic particles were produced with a flame soot generator (soot) and by a flame spray pyrolysis (alkali salts and zinc). In addition, the role of single potential causative component in the highly complex mixture of compounds in combustion PM was studied with pellet fuels doped with different content of zinc and cadmium.

In order to determine consistency between in-vitro (WP2) and real life health effects, dedicated human exposures to selected biomass combustion situations were conducted in WP3 in controlled human exposure chamber studies. Measurements in this task included also measurement of respiratory tract deposition and ambient air experiments. The ambient air samples were collected in the Grenoble area, France, for which a previous study has shown it exhibits a high contribution of wood combustion emissions to the levels of PM_{10} and PAHS. From these samples, also the ability of the human lung fluid to solubilise metals contained inhaled particles (bioaccessibility tests) was studied. This bioaccessibility test was also applied to french combustion samples from WP1. In WP4, all the information produced in WP1-3 was compiled.

CONCLUSIONS AND RECOMMENDATIONS

Biomass combustion emission chemistry is very complex due to large variety of combustion appliances, users and fuels leading to different combustion conditions and emissions. During incomplete or smouldering combustion organics and soot dominate the particulate matter in contrast to efficient combustion where inorganics dominate the particulate matter chemical composition. In all cases the particle size mode is in the fine (<1 µm) particle range, but the combustion conditions affect the chemistry, particle size and morphology significantly.

The following general conclusions and recommendations were summarized in this project:

[1] **Efficient biomass combustion is recommended in order to minimize the harmful effects of fine particles on health and climate.**

In this project several combustion appliances (e.g. stoves and pellet boilers), fuels (e.g. wood chips and pellets from different biomass feedstocks) and combustion conditions (from efficient to smouldering combustion) were studied. All the studied appliances and fuels emitted particles which caused toxicological responses in the cell studies. However, particles from efficient combustion induced mild and clearly lower responses compared to the incomplete combustion. In addition, the same amount of energy produced during efficient combustion resulted in lower emissions compared to incomplete combustion. Thus efficient biomass combustion is recommended in order to minimize the harmful effects of fine particles on health and climate.

[2] **It is recommended to use biomass fuels with low Zn content, such as pure stem wood based fuels, instead of e.g. waste wood or bark with high Zn-contents.**

Efficient combustion also releases particles containing zinc (typically as ZnO). Highly toxic responses were found for the combustion of fuels with relatively high Zn concentration. Thus in small scale combustion applications, it is recommended to use only biomass fuels with low Zn content, such as pure stem wood based fuels, instead of e.g. waste wood or bark with high Zn-contents.

[3] **PAHs and soot are the most harmful species in incomplete combustion conditions.**

During incomplete biomass combustion organic compounds and soot dominate the particulate matter leading to clear toxicological effects on cells. Especially the PAH content showed a clear connection with the toxic responses of the fine particles. The PAH emissions seemed to be the most sensitive marker of combustion efficiency in relation to toxicity. Also soot is the major climate forcer in wood smoke emissions. Thus, the promotion of combustion technologies that ensure efficient and complete combustion and avoid elevated soot and PAH emissions is motivated due to both public health and climate impact reasons.

[4] **Ageing of the emissions affects particle toxicity.**

Emissions undergo transformation processes (i.e. ageing) after release from the chimney to the atmosphere, including sun-light driven processes and chemical reactions, e.g. with ozone. In this study, ageing with ozone showed significant effects on the toxicological responses of wood smoke particle emissions. Aged samples, especially from soot and PAH rich combustion, had higher toxicological responses than samples without ageing.

Particles in ambient air samples collected from an urban area known to be impacted by wood combustion emissions induced nearly similar toxicological responses as wood combustion emission samples collected in the laboratory. The differences observed were expected to be due to the fact that outdoor air samples included emissions from several non-wood combustion sources. The samples containing the highest amounts of PAHs and wood smoke tracers (e.g. levoglucosan) generated stronger toxicological responses than samples with lower contents of these pollutants. However this high amount of PAHs could not specifically be linked to a main contribution of wood smoke combustion, since the samples were also associated to periods with high levels of NOx which could indicate a combined effect of wood combustion and traffic emissions to the particulate matter (PM).

[5] The respiratory tract deposition varied between particles from different emission sources.

The total respiratory tract deposition of biomass combustion particles was lower than that for traffic pollution. Particles in sooty wood smoke were more likely to deposit in the lungs than the alkali salt particles from efficient pellet combustion. Persons with chronic obstructive pulmonary disease (COPD) had higher particle deposition than healthy subjects, which could cause further deterioration of their health.

[6] Results from human chamber exposures were consistent with the cell studies.

Experimental exposure of healthy persons to a soot rich wood smoke caused cellular effects in the lungs. Novel findings were also that this type of wood smoke causes adverse acute effects in blood vessel function in humans. The present results from the human exposures, in combination with previous epidemiological and toxicological studies, give strong evidence of the harmful effects of emissions from incomplete biomass combustion. Also exposure to alkali salt dominated particle emissions from efficient combustion of softwood pellets caused mild inflammatory effects in the lungs of human subjects.

As a summary, toxicological responses induced by fine particles in biomass combustion emissions are strongly dependent on their chemical composition. This extensive international study indicates that the most harmful components of the particles are polycyclic aromatic hydrocarbons (PAHs), soot, and zinc oxide (ZnO). Only pure potassium salts (K2SO4 in this case) were non-toxic. PAHs and soot are produced during incomplete combustion conditions. Metals, such as ZnO and potassium salts are produced during both efficient and incomplete combustion conditions. With modern low emission residential biomass heating systems and correct operational practices it is possible to substantially reduce the total emissions and the harmful effects of fine particles.

The chemical properties of these fine particles can vary considerably, but this project has identified that the PAH emissions are the most sensitive marker for combustion efficiency in relation to toxicity. At the same time soot is the major climate forcer in wood smoke emissions. Thus the promotion and support for new technologies, that ensure efficient and complete combustion and prevent high soot and PAH emissions, is motivated by both public health and climate impact reasons.

Future perspectives

In future scenarios with increased small and medium scale biomass heating, also new biomass fuels (e.g. straw, miscanthus and poplar pellets) are likely to be used. Thus, technologies producing limited emissions, exhibiting low toxicity, for different sectors and fuels should be promoted. Moreover, in order to gain a comprehensive effect on air quality the substitution of old appliances by these new low emission technologies must be supported. For that purpose research and test methods should be further developed, e.g. to better elucidate toxicological links to chemical and physical properties of fine particles, to simulate atmospheric ageing, and to assess public health effects and give recommendations in future scenarios with increased biomass combustion. Moreover, such an approach should not only be focused on the emissions from residential wood combustion. Instead, same methodology should be applied to different types of sources in order to position emission levels and toxicity of wood combustion particles against other combustion processes including the automotive and industrial sources.