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The role of bioethanol flueless fireplaces on indoor air quality: Focus on odour emissions

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ABSTRACT

This study concerns flueless fireplaces powered by liquid or gel bioethanol based fuels. These devices have a pleasant aesthetic design and can be used in indoor environments; in particular, they do not need any connection to a stack to evacuate the flue gases.

This work evaluates the polluting impact of the mentioned fireplaces, with a special focus on their odour emissions, in order to assess the environmental impact of these items and to provide the European Commission information useful to define the guidelines for a dedicated legislation. For these reasons, a series of experimental tests, structured with well-defined steps, alternating operation (combustion) and shutdown phases, was performed for several fireplaces.

The concentration trends of both the main combustion products and by-products as well as the odour were monitored; furthermore, specific odour emission factors (OEFs) were calculated. The combustion pollutants were mainly released during the operation phase, while the most significant odour emissions occurred during shutdown. The average OEFs reached values between 40 and 110 [*100 ouE kJ^{-1}] during the shutdown, but they were below 10 [*100 ouE kJ^{-1}] during the operation periods. It was found that the extent of odour emissions depends crucially on the burner design and geometry of each fireplace; in particular, the air-fuel contact surface is the most relevant parameter.

Moreover, this study proved that the electronic nose can be a valid additional instrument in activities aimed at evaluating the indoor air quality, and considering its peculiarities, the idea of using it not only as an odour detector, but also as an integrated device in air ventilation systems for indoor environments, is both interesting and achievable.

1. Introduction

Environmental pollution is an important field of research and recently a strong interest in indoor environments pollution has grown [1,2]. The reasons for this new focus concern the high amount of time spent by many people in indoor environments [3–5] and the high concentration levels of some pollutants that can be reached in such spaces. The outside air, which may already contain a significant level of pollution, gets in closed environments, where it can stay for a long time. During this period, the air is enriched of pollutants coming from the building or the furnishing materials [6] rather than by the activities carried out in indoor environments, such as cooking, kerosene heating, wood burning, candles lighting and incenses burning [7–11]. Problems like the building related illnesses (BRI) and the sick building syndrome (SBS) exist and they are linked with the bad quality of indoor air [12–14]. Furthermore, because of the growing interest concerning energy saving problems, the aeration standard is usually low and, obviously, this penalizes the air quality [15,16].

As well as the other pollutants, odour is one of the main causes of bad indoor air quality [2–6]. Nowadays the public opinion pays a lot of attention to odour, in fact, often people associate it with the presence of possible health hazards [17]. In general, this relationship is not verified, due to the fact that the odour threshold concentration of many chemical species is lower than the corresponding threshold limit value (TLV) which could eventually have direct health effects.

This study concerns flue-less fireplaces powered by liquid or gel bioethanol based fuels. These devices have a pleasant aesthetic

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design and can be used in indoor environments; in particular, they do not need any connection to a stack to evacuate the flue gases. This is allowed since the manufacturers claim that these fireplaces are decorative items and therefore heating is not the primary objective. For marketing purposes, the producers focus on the biological origin of the fuels, relying on the fact that people commonly associate the use of “natural” products with zero emissions. However, it must be stressed out that the prefix “bio” refers just to the ethanol production process, which is based on the fermentation of biomasses, but ethanol is not the only constituent of the fuel [18].

For the aforementioned reasons, these fireplaces were very successful and a large amount of them has been sold all over Europe.

Flueless bioethanol fireplaces represent a source of indoor air pollution in those domestic or non-domestic places, where they are installed and used, because combustion products are entirely released in the ambient where people live or spend a great deal of their time. Since in these devices a combustion reaction occurs, in order to ensure no health hazards, this kind of fireplaces should comply with specific regulations. However, as decorative devices, they are not subjected to those compulsory regulations and standards applicable to heating appliances [19]. Nevertheless, up to now, there is no dedicated legislation in Europe [20], but only a few national regulations exist; they indicate some building characteristics and describe the conditions to ensure safety and to conduct performance tests.

Only two studies were published about this topic: one in France [18] and the other in Germany [21]. They both revealed problems regarding safety as well as air quality; they highlight some problems concerning especially the release of CO, NOx and Volatile Organic Compounds (VOCs) into the indoor environment. Hence, the European Union decided to investigate whether it is worthwhile to devise a specific legislation for bioethanol fueled fireplaces [20], by activating also a study on alcohol-powered flueless fireplace combustion and its effects on indoor air quality [22].

The aim of this work is to evaluate the polluting impact of the mentioned fireplaces, with a special focus on their odour emissions. For this reason, the odor concentration trends were investigated and the corresponding odour emission factors (OEFs) were calculated. Each OEF consists of the instantaneous odour production term within the balance imposed on the considered system, weighted with respect to the thermal power of the examined fireplace. In order to carry out these analyses, the use of conventional analytical instruments for airborne pollutants detection and measurement was combined with an electronic nose monitoring.

An interesting feedback of this study is to evaluate the electronic nose performances within indoor environments, in order to investigate the possibility of using it as an additional tool to improve the results of experimental activities aimed at evaluating the air quality. A further aspect is the evaluation of the opportunity to employ an electronic nose as an integrated device in air ventilation systems for indoor environments.

2. Materials and methods

The experimental activity was carried out inside a ventilated test chamber (3.4 × 2.9 × 3 m3), whose ventilation conditions were appropriately controlled to realize a well-mixed environment. Five different fireplaces, three powered by liquid fuels and two by gel fuels, respectively, were tested. The main technical data of the investigated fireplaces are summarized in Table 1. As some of the investigated fireplaces have a characteristic dimension of about 1 m, to ensure that the presence of such an obstacle does not affect the air mixing within the test chamber, a ventilator was also installed into the experimental setup. It was located quite far from the investigated appliances, so as to minimize possible perturbations of the combustion process.

The study also involved the use of different bioethanol based fuels, three gel and three liquids (Table 2). They contain denatured bioethanol and other substances, such as perfumes and dyes [18], whose quality and quantity are often not specified (Table 3).

During the experiments, all the parameters were monitored using a combined set of different experimental techniques, in particular macro species, such as CO_2, CO, NOx, were measured using a continuous gas analyser (HORIBA PG-250, with NDIR and chemiluminescence detectors).

A specific sampling technique (with Tenax™ and Carbosorb™ sorbent cartridges) was also adopted to collect some micro pollutants such as Volatile Organic Compounds (VOCs); in particular, active sampling on sorbent cartridges, by means of a sampling pump, was carried out for generic VOCs. Samplings were performed, during each test, when the CO_2 concentration inside the test chamber was in the range between 0.4 and 0.5% by vol.; these conditions can be assumed as the acceptable limit for people to stay in the room, higher concentrations are not considered representative of a real life situation then, the VOCs identification and quantification was carried out by means of GC–MS analysis. The concentration determined with this approach can be also representative of the average conditions found during different phases of the experiments. The hygrometer data-logger PCE HT 110 measured the temperature and the relative humidity inside the ventilated test chamber. This device allowed the continuous monitoring of these parameters by means of two specific detection channels.

An electronic nose, EOS 507C [23] developed in collaboration with Sacmi (Imola, Italy), was employed in order to detect the odour trends. This device is shown in Fig. 1.

This electronic nose is equipped with six metal oxide semiconductor (MOS) sensors, different in type and exercise temperature (Table 4), whose resistance values change as a function of the interacting compounds.

This electronic nose is equipped with an autonomous system for the reference standard daily preparation (n-butanol), continuous auto-calibration and it is also able to adjust the humidity of the reference air, depending on the sample humidity, in order to improve the measures reproducibility. For this purpose, the EOS 507C automatically runs a calibration procedure every day and every time it is necessary. This means that when the electronic nose perceives a significant variation in terms of sample humidity, it stops operating and it defines a new humidity operational value, depending on the humidity content measured, and re-calibrates according to such value.

The instantaneous output signal considered for each sensor (1) is expressed in Eos Units (EUs), which are calculated according to the following expression:

$$EU_i = a_i * \left(\frac{R_i}{R_{std,i}} \right)^{b_i} \tag{1}$$

where R_i is the resistance value, $R_{std,i}$ is the standard resistance value, a_i and b_i are characteristic coefficients depending on the sensor type.

The so defined Eos Units can be correlated with odour concentration (in odour unit for cubic meters – ou_E/m^3).

The EOS 507C has also to be able to recognize the different operation phases of the test cycle. For this purpose, a specific instrument training is necessary. When the EOS 507C works in training mode, it mixes a defined sample percentage with neutral air, then it dilutes this mixture with neutral air in several steps, in