Ventilation as a means of controlling exposure of workers to environmental tobacco smoke (ETS)

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Summary

Environmental tobacco smoke (ETS), derived primarily from side-stream cigarette smoke between puffs, is a major contributor to indoor air pollution wherever smoking occurs. In the frame of activities to evaluate human exposure to ETS components in indoor environments, a series of tests were undertaken to investigate the impact of various ventilation rates on the air concentration of ETS-components. The tests were carried out at the European Commission-Joint Research Centre's INDOORTRON facility, a 30 m3 walk-in type environmental chamber.
Preliminary evidence indicates that changes in ventilation rates simulating conditions expected in many residential and commercial environments during smoking do not have a significant influence on the air concentration levels of ETS constituents, e.g. CO, NOx, aromatic compounds, nicotine. This suggests that efforts to reduce ETS originated indoor air pollution through higher ventilation rates in buildings, including residential areas and hospitality venues, would not lead to a meaningful improvement of indoor air quality. Moreover, the results show that "wind tunnel"-like rates or other high rates of dilution ventilation would be expected to be required to achieve pollutant levels close to ambient air limit values.

Introduction

Environmental tobacco smoke (ETS) is a complex mixture of thousands of compounds in particulate and vapour phases. The contribution of various environments to personal exposure to ETS components varies with the time-activity pattern of the exposed individuals, e.g. exposure of infants residing in the home of a smoker would be greater for those who do not attend day care. For adults residing with non-smokers, the workplace may be the principal location where exposure takes place. Although the exposures of nonsmokers are much lower than those of smokers, there is some evidence that secondhand (SH) exposure to tobacco smoke increases the risks of heart disease, lung cancer, asthma and other diseases. The evidence, however, is often conflicting. For example, some studies indicate an increased risk of lung cancer from ETS exposures while other do not. One important reason for the uncertainties in scientific studies is that estimates of the amount of ETS to which nonsmokers are exposed are not quantitative. This makes it more difficult to determine the relationships between ETS exposure and risk of disease.

After some preliminary test runs two series of experiments were designed and executed:

First series of experiments
Five cigarettes were smoked consecutively with a commercial smoking machine following the ISO smoking regime in the INDOORTRON facility.
For these experiments the chamber was operated at stagnant air conditions and at three different ventilation rates i.e. 0.2, 0.5 and 1 exchanges/hour while maintaining the relative humidity (RH) at 50 % and the temperature at 23 °C.

Second series of experiments
Four cigarettes were smoked simultaneously five times, making a total of twenty cigarettes smoked during each experiment.
The chamber was operated at five different ventilation rates i.e. 0.5, 1, 2, 3.5 and 5 air change rates/hour while maintaining the relative humidity (RH) at 50% and the temperature at 23°C (at 5 ach relative humidity dropped down to 23%).
During the experiments air samples were taken at distinct time intervals in order to follow changes in concentration of some of the characteristic compounds that are formed during cigarette burning.

The cigarettes used are commercially available with declared nicotine and tar amount of 0.6 and 7.0 mg/cigarette, respectively.

Smoking conditions:

	a) five cigarettes	**b) twenty cigarettes**
Puff volume	35 ml	4*35 ml = 140 ml [1]
Puff duration	2.0 sec	3.0 sec
Puff intermission	60.0 sec	60.0 sec
Butt length	35 mm	Approx 35 mm [2]

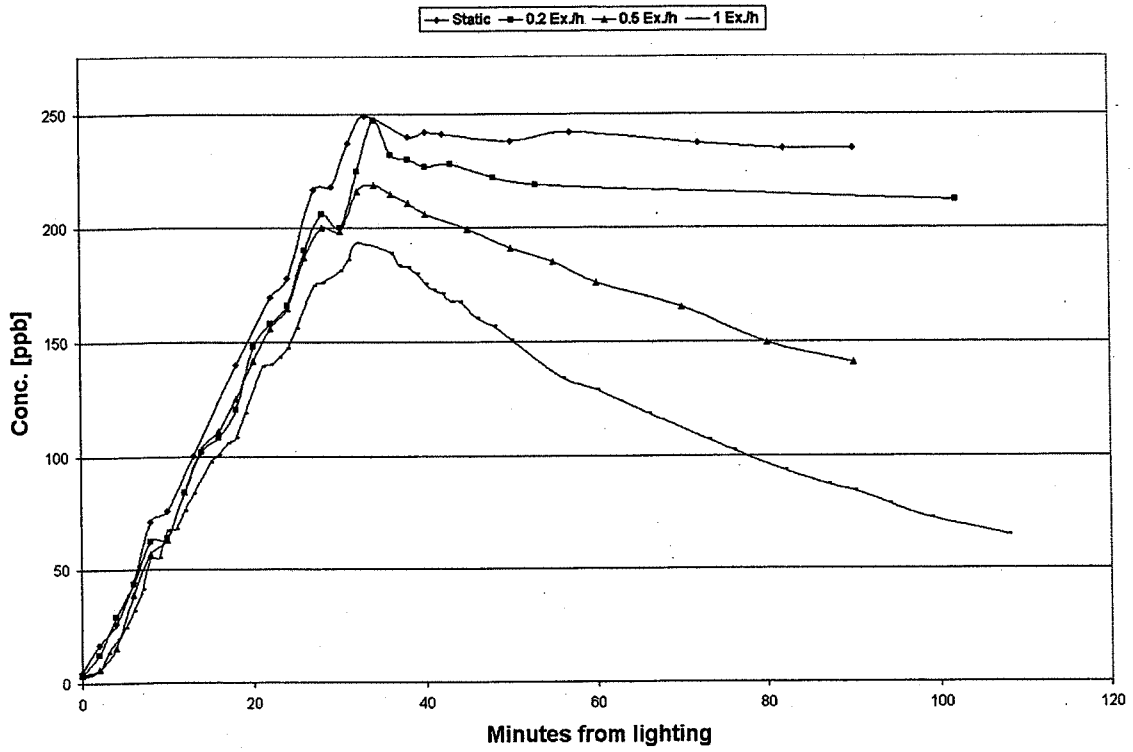
The following substances were analysed:

Volatile Organic Compounds (VOCs): benzene, toluene, pyridine, m+p-xylene, limonene and nicotine (first and second series of experiments at stagnant air conditions, 0.5,1 and 2 ach).
Carbonyl compounds: formaldehyde and acetaldehyde (second series of experiments at 0.5,1 and 2 ach).
Inorganic gases : NOx ($NO+NO_2$) and carbon monoxide (CO) [all experiments]

Results and discussion

[1] Puff volume set on the smoking machine 140 ml resulting from 35 ml for each cigarette in a four cigarette set.
[2] Approximate value because not under control of the IR detector of the smoking machine.

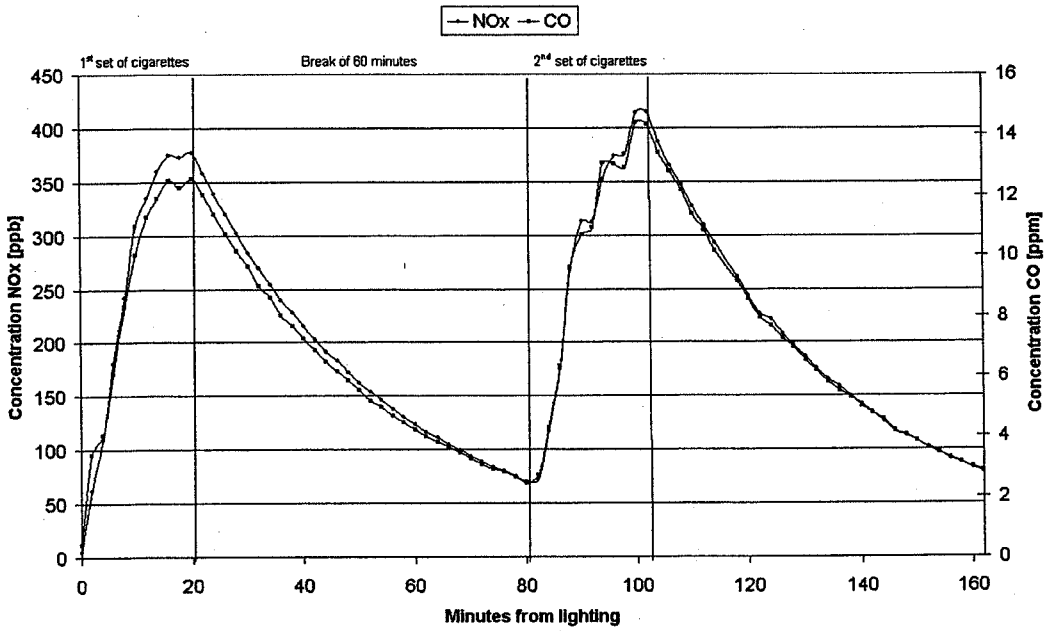
Figure 2: *Concentration of NOx at different air exchange rates (first series of experiments)*



The formation of carbon monoxide (CO) and of nitrogen oxides (NOx) (fig. 3 and 4) during the second series of experiments with twenty smoked cigarettes (and with clearly higher smoke volume produced) follows the same trend, already observed during the first series of experiments (five cigarettes smoked). During the smoking period (ca. 37 min.), peak concentrations up to 30 ppm (CO) and 800 ppb (NOx) were measured (at 0.5 ach). This corresponds, as expected, to concentrations up to four times higher compared to the concentrations measured during the first series of experiments. Variations of peak concentrations of CO and NOx during the initial phase of the experiment (smoking period) and at different ventilation rates (0.5, 1, 2 and 3.5 ach) do not exceed 47% despite the large change in air exchange rate. Twenty minutes after the end of the smoking period CO and NOx concentrations dropped down up to 80% at ventilation rates of up to three and a half exchanges per hour. An increase of the ventilation rate up to five exchanges per hour leads to a further reduction (up to 25%) of CO and NOx concentrations compared to those at 3.5 ach.

One experiment was carried out (at 2 ach) with smoking of ten cigarettes during a period of ca. 20 min, followed by a non-smoking period of 60 min and subsequent smoking of another set of ten cigarettes. Production and elimination of CO and NOx is shown in fig.5. Maximum concentrations of ca.370 ppb for NOx and of ca.12 ppm for CO were measured. During the non-smoking period of one hour the concentrations for both NOx and CO dropped down to 70 ppb and 3 ppm, respectively. Starting smoking again, NOx and CO levels reached values slightly higher than those measured during the first smoking period.

Figure 5: *Concentration of NOx and CO smoking ten cigarettes, stopping for one hour and smoking again 10 cigarettes at an air exchange rate of 2 (60 m^3/h)*



Volatile Organic Compounds

Apart from CO and NOx some organic compounds produced during cigarette burning were regularly monitored, in particular, during the initial phase of the experiments (smoking period). The results show that peak concentrations of benzene, toluene, m+p-xylene, limonene and pyridine do not change significantly when studied at different ventilation rates (table 1). For nicotine, the measured concentration at one air exchange rate amounts to ca. 85% of the concentration measured at stagnant air conditions.

Modelling

In addition to the experimental activity, modelling work was carried out with the aim to simulate CO and NOx buildup and decay during the entire period of the experiments (up to 120 min) at different air exchange rates. Moreover, an attempt was made to calculate at which air exchange rates CO and NOx concentrations reach levels comparable to those in ambient air (100-150 ppb for NOx, 3-5 ppm for CO) to which people is frequently exposed in urban areas.
As spatial homogeneity was guaranteed in most of the experiments, a first order, linear ODE (ordinary differential equation) was used to simulate mathematically the experimental setup. The concentration change of NOx or CO was attributed to

- emissions from the smoking device,
- removal due to air exchange and,
- introduction of outdoor polluted air into the chamber (for the experiments in "rinsing mode").

Besides assuming a well-mixed chamber, we considered no other source or sink terms for the two pollutants under consideration as little deposition on the steel walls of the chamber or chemical activity for the specific gases is expected to occur in such a short time (~2 h).
Expressing mathematically the aforementioned assumptions leads to the following equations, comprising the model:

$dC/dt = R/V - AER \times C$ during smoking (1)
$dC/dt = -AER \times C$ after smoking (2)

where
C.....[ppb] is the chamber concentration,
R.....[ppb×m^3/min] is the emission rate,
V.....[m^3] is the chamber volume,
AER.[1/min] is the air exchange and
t.....[min] is the time

Solving analytically the ODEs gives:

(1)=> $C(t) = R/(V \times AER) * [1-exp(-AER \times t)]$ for t<smoking duration
(2)=> $C(t) = Co \times exp(-AER * t)$ for t>smoking duration

where
Co....[ppb] is the concentration at the end of the smoking event

The static experiment data were used to estimate the emission rate of both NOx and CO applying a linear regression analysis as emission rate was expected to be constant during the burning of a cigarette. The same emission rate was used to simulate both the first and second series of experiments, multiplied by 4 in the latter case.
Model and experimental data agree fairly well confirming all the assumptions made in the model but verifying the quality of the experimental procedure as well. The correlation coefficient between measured and calculated time series stays above 99% in all cases while the normalized bias is kept below 5% in all but one dataset. Consequently, the model successfully reproduces the experimental results and thus can be readily and securely applied to give answers for hypothetical cases.

Concluding remarks

Results obtained from our studies clearly indicate, that cigarette smoking represents a strong source of a large number of chemicals such as: volatile hydrocarbons, carbonyls, polycyclic aromatic hydrocarbons, inorganic gases and particles etc. They are produced at high concentrations during the burning process and are not rapidly and substantially eliminated from the indoor air atmosphere, even when high air exchange rates were applied. Diffusion of the emitted compounds (side-stream compounds and burning products) is relatively slow, so dilution via mixing with new incoming fresh air is not very effective as a control measure.
Moreover, these preliminary results show that "wind tunnel"-like rates or other high rates of dilution ventilation would be expected to be required to achieve pollutant levels close to those frequently occurring in ambient air . Our findings are comparable with the results obtained in studies in the US, carried out at different hospitality venues (restaurants, bars).
Research activities on ETS using the INDOORTRON facility will be continued and extended to studies for further validation of the results in real indoor environments.

References

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