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AE International – Europe

Atmospheric Environment 38 (2004) 2017–2027

ATMOSPHERIC ENVIRONMENT

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Particle pollution in the French high-speed train (TGV) smoker cars: measurement and prediction of passengers exposure

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Received 29 October 2003; received in revised form 26 January 2004; accepted 4 February 2004

Abstract

The present study deals with particle pollution in a particular micro-environment: a French high-speed train smoker car. In the first part, measurements carried out in a real train are described. Both smoker and non-smoker cars' particle concentrations have been measured during a round trip. Additional experiments have been done in a stationary car with controlled particle pollution to evaluate parameters such as ventilation rates, deposition velocities and filter efficiencies involved in the particle mass balance of the studied zone. In the second part, a one-zone model has been developed to predict the particle concentration in the train car. Particle transport, deposition and filtration phenomena have been estimated from the stationary car experiments considering the well-mixed zone assumption. The model has then been applied to the round trip train to determine the particle concentration during the journey. Results show that the smoker car indoor air quality can be easily improved by changing the usual utilized filter by a high-efficiency H10-type filter, leading to a 34% reduction of the passengers inhaled dose.

Keywords: Particle; Pollution; Indoor air; Train car; ETS

1. Introduction

Recent statistics on the American people's way of living (Klepeis et al., 2001) show that they spend 87% of their time indoors, 8% outdoors and 5% in transportation (by car, bus, train or plane). In Europe, similar tendencies are observed: 90% indoors, 6% outdoors and 4% in transportation (Aliaga and Winqvist, 2003) for French people. As a consequence, indoor air quality has a preponderant role in the evaluation of people exposure to air pollutants.

In the space of 10 years, indoor particle pollution becomes an important topic of the indoor air quality research area. Most of the previous studies have been focused on evaluating particle concentration in common building spaces such as offices, schools, restaurants and homes but some studies dealt with particular micro-environments such as aircrafts (Lindgren and Norback, 2002), cars (Adams et al., 2001; Riediker et al., 2003) and train cars (Leutwyler et al., 2002). The present study deals with one of these micro-environments which gather high particle pollution level and long duration together: a French high-speed train smoker car.

The first phase of the present study was to realize particle concentration measurements in both a train smoker and non-smoker car. First, the particle concentration evolution of cigarette smoke has been measured in a train car during its round trip. Then, additional measurements have been carried out in a similar car in stationary condition, without passengers and under controlled particle source in order to evaluate parameters such as ventilation rates, deposition velocities and filter efficiencies involved in the particle mass balance of the studied zone.

In a second phase, a one-zone model was developed to predict the particle concentration in the train car. This

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1352-2310/$ - see front matter © 2004 Elsevier Ltd. All rights reserved.
doi:10.1016/j.atmosenv.2004.02.013

simple model allows to take into account the particle transport, deposition and filtration. The round trip conditions have then been modeled to study the influence of the filter efficiencies on the train smoker car indoor air in order to improve its quality.

2. Experimental study

After a short description of the studied train car, an analysis of the particle source is carried out to determine the particle counter model to be used. Two sets of experiments are then described. The first one, performed in a train in service, allowed the evaluation of the particle concentration evolution in both a smoker and non-smoker car. Note that the particle concentration measurements have been made for particles larger than 0.3 μm, which represent only a fraction of the total cigarette smoke particle distribution. The second set consisted in determining the influence of several particle filters on the particle concentration levels in order to improve the indoor air quality of this micro-environment.

2.1. Train car ventilation system

This experimental study was performed in the upper floor car of the latest French high-speed train. The dimensions of the car are: 10 m long × 4 m wide × 2 m high. It is equipped with a ventilation system that allows a total air (outside and recirculated air) change rate of about 30 ACH in service. The air enters the zone through lateral inlets located along the windows (Fig. 1). This air is composed of one-third of fresh outdoor air and two-thirds of recycled air from the zone itself. The air leaves the zone by an unique outlet located close to the door at the end of the car.

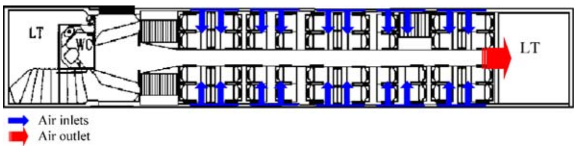

Fig. 1. High-speed train car pictures and ventilation principle.

2.2. Characterization of the cigarette smoke

The characterization of a pollutant source such as cigarette smoke is not easy to achieve. Hinds (1982) determined that the median diameter of cigarette smoke particles deduced from the distribution in number, goes from 0.1 to 0.5 μm. However, measurement made by Offermann et al. (1985) and Sexton et al. (1986) showed that the median diameter equals 0.15 μm with a standard deviation of 2. Klepeis et al. (2003) found a median diameter of 0.20 μm with a standard deviation of 2.3 for both cigarettes and cigars smoke.

More recently, several studies dedicated to the characterization of the cigarette smoke distinguished the smoke that is inhaled and exhaled (mainstream smoke) and the one that directly contaminates the air from the cigarette itself (sidestream smoke). Morawska et al. (1997) and Miller and Nazaroff (2001) showed that the median diameter is 0.136 μm with a standard deviation of 1.77 for the sidestream smoke and is 0.238 μm with a standard deviation of 1.65 for the mainstream smoke, the ratio mainstream smoke/sidestream smoke varies between 0.14 and 0.25. However, Robinson and Yu (1999) evaluated the influence of the particle coagulation inside the smoker and showed that the median diameter for the mainstream smoke goes from 0.2 to 0.35 μm after 2 s in the smoker mouth.

The present study is focused on people's exposure but inhaled dose is directly linked with the inhaled mass; that means the particles number and size and not the number of inhaled particles alone. Sextro et al. (1991) determined the rate of the cigarette smoke particles according to the size distribution, considering a particle density of 1.4 g cm^{-3}. They showed that the total cigarette smoke, i.e. taking into account both mainstream and sidestream smoke, is centered on 0.50 μm.

2.3. Measurement in the train car during the round trip

2.3.1. Experimental protocol

Two sets of particle concentration measurement were carried out in the train car during the round trip: the first one was performed in the smoker car during the first trip to measure the exposure of smoking people, the second one was done in a non-smoker car during the return to evaluate the usual particle concentration. Two calibrated optical particle counters were used to measure the concentration of particles in the range [0.3–10] μm. GRIMM G1.108 model counters were chosen according to the size distribution of the cigarette smoke. As an illustration, Fig. 2 presents the size distribution of the cigarette smoke obtained from the smoker car measurement. Particles within the range [0.30–0.40] μm are the most numerous. Particles larger than 0.65 μm in diameter are in negligible quantity.

The two counters were located in the middle of the car, the first one was close to the ceiling and the other one was placed at the passengers head plan. During the measurement, each fact that is supposed to influence the particle concentration such as people movement or lighted cigarettes number is noted.