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Characterization of airborne particles emitted by an electrically heated tobacco smoking system

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ABSTRACT

Smoking activities were recognized as a main risk factor for population. Indeed, mainstream smoke aerosol is directly inhaled by smokers then delivering harmful compounds in the deepest regions of the lung. In order to reduce the potential risk of smoking, different nicotine delivery products have been recently developed. The latest device released is an electrically heated tobacco system (iQOS®, Philip Morris) which is able to warm the tobacco with no combustion. In the present paper a dimensional and volatility characterization of iQOS-generated particles was performed through particle number concentration and distribution measurements in the mainstream aerosol. The experimental analysis was carried out through a condensation particle counter, a fast mobility particle sizer and a thermo-dilution sampling system allowing aerosol samplings at different temperatures. Estimates of the particle surface area dose received by smokers were also carried out on the basis of measured data and typical smoking patterns.

The particle number concentrations in the mainstream aerosols resulted lower than 1×10^8 part. cm^{-3} with particle number distribution modes of about 100 nm. Nonetheless, the volatility analysis showed the high amount of volatile fraction of iQOS-generated particles, indeed, samplings performed at 300 °C confirmed a significant particle shrinking phenomena (modes of about 20 nm). Anyway, the particle number concentration does not statistically decrease at higher sampling temperatures, then showing that a non-volatile fraction is always presents in the emitted particles. The dose received by smokers in terms of non-volatile amount of particle surface area was equal to 1–2 mm^2 per puff, i.e. up to 4-fold larger than that received by electronic cigarette vapers.

1. Introduction

Smoking activity is the main preventable cause of morbidity and mortality in the world (Feigin et al., 2013; World Health Organization, 2008) being responsible of many deadly diseases such as cardiovascular diseases, chronic obstructive pulmonary diseases and different types of cancer, especially lung cancer. There is a strong evidence between physical-chemical characteristics of the mainstream aerosol of traditional cigarettes (tobacco cigarettes) and lung cancer risk (Stabile et al., 2017). Indeed, particles generated during tobacco cigarette combustion processes contain more than 4000 semi-volatile and non-volatile compounds, some of which are classified as carcinogenic IARC-Group 1 (International Agency for Research on Cancer, 2004). The composition of the mainstream smoke of traditional cigarettes (a complex mixture of particles through which toxic compounds can condense and penetrate in the human body) is strongly influenced by the tobacco blend, filter type and flavor materials (Borgerding and Klus, 2005). To this end, in a recent study Stabile et al. (2017) characterized the sub-micron and super-micron particles emitted by different brands of tobacco cigarettes. Moreover, on the basis of the mainstream aerosol chemical analysis reported in the scientific literature, an excess lifetime cancer risk model was applied (Sze-To et al. (2012)), then obtaining the risk of the different tobacco cigarette brands (Stabile et al., 2017). The authors also recognized that the effect of

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such particle-bounded pollutants is strictly linked to the number of particles emitted offering high surface area where such carcinogenic compounds may condense.

Recently, new nicotine delivery products were developed as alternative ways of smoking in order to avoid the intake of compounds produced during combustion processes. In particular, electronic nicotine delivery systems (known as electronic cigarettes), i.e. cigarettes based on the vaporization of a liquid including nicotine, solvents and some bioactive flavor compounds, were recently commercialized and rapidly gained popularity amongst smokers (Goniewicz et al., 2013) due to the supposed lower emission of harmful compounds. Nonetheless, recent studies shown that carcinogenic compounds and toxins are also present in the mainstream aerosol of electronic cigarettes (As, Cr, Ni, tobacco-specific nitrosamines) even if their concentrations are lower than those typical of tobacco cigarette (Farsalinos et al., 2015; Goniewicz et al., 2013; Shahab et al., 2017). As regard the emission of sub-micron particles, concentrations similar to or even larger than the tobacco cigarette ones were measured in the mainstream aerosol of different types of electronic cigarettes considering different liquids (in the 10^8-10^9 part. cm^{-3} concentration range (Belka et al., 2017; Fuoco et al., 2014; Manigrasso et al., 2015; Schripp et al., 2013; Scungio et al., 2018; Stabile et al., 2017);). However, Scungio et al. (2018) recognized that a large fraction of electronic cigarette-emitted particles is made up of volatile compounds; this lead to a lower dose received by vapers and a related lower excess lifetime cancer risk compared to tobacco cigarettes (but still higher than the World Health Organization tolerable value, 1×10^{-5}).

Lately, Philips Morris International also entered the alternative smoking market developing a "heat-not-burn" tobacco product with a new device named iQOS (acronym of "I quit ordinary smoking") which is an electrically heated tobacco system where tobacco sticks are warmed to a temperature high enough to release an aerosol but not able to cause combustion (Caputi, 2016). iQOS cigarettes are made up of three elements: a charger, a heat-stick and a heater. The heater presents a resistance able to warm the stick at a temperature lower than 350 °C then avoiding tobacco combustion. The absence of the combustion process, and of the related combustion-related chemicals, pretends that these devices can be considered safer than the tobacco cigarettes. Different heat-sticks in terms of flavors and nicotine levels were released on the market. According to the manufacturer, the heat-stick duration is roughly similar to the conventional cigarette one.

Due to their recent release, very few studies aiming to characterize the emission of iQOS cigarettes were carried out. In a recent study Mitova et al. (2016) compared the effect of iQOS and traditional cigarettes on indoor air quality showing that the indoor concentration of $PM_{2.5}$, tobacco smoke-related markers of combustion, and volatile organic compounds during iQOS use is comparable to the indoor background concentrations and much lower than the traditional cigarette one. Similarly, Ruprecht et al. (2017) highlighted that iQOS emissions resulted negligible in terms of heavy metals compared to both traditional cigarettes and electronic cigarettes, whereas Davis et al. (2018), Bekki et al. (2017) and Li et al. (2018) recognized the iQOS emission of formaldehyde cyanohydrin even at low temperatures, a nicotine content similar to the conventional cigarette one, and a reduced (but not negligible) emission of tobacco-specific nitrosamines. Protano et al. (2017) and Protano et al. (2016) measured the number concentrations of sub-micron particles in a test-chamber where different kind of smoking devices were tested: they found that indoor particle concentrations due to iQOS use is one order of magnitude lower than that due to the tobacco cigarette use then also leading to a lower particle dose. Nonetheless, despite the abovementioned studies focused on the iQOS second-hand-smoke, there is still a lack of knowledge concerning iQOS emission since no data on mainstream aerosol characterization are present. Therefore, in the present paper the authors aimed to (i) characterize the emission of iQOS in terms of different aerosol metrics of sub-micron particles in mainstream smoke, (ii) evaluate the effect of the heat-stick flavor on concentrations and size distributions of iQOS-generated particles, (iii) characterize the volatility of iQOS-emitted particles using a thermo-conditioning system, (iv) estimate the particle surface area doses in the human respiratory apparatus by means of deposition model successfully applied in our previous studies (Buonanno et al., 2012; Pacitto et al., 2018).

2. Materials and methods

2.1. Experimental apparatus

In order to carry out an exhaustive dimensional characterization of the mainstream aerosol emitted by iQOS cigarettes, particle number concentrations and size distributions were measured in the mainstream smoke sampled during iQOS use. Measurements were performed at the European Accredited (EA) Laboratory of Industrial Measurements (LAMI) of the University of Cassino and Southern Lazio (Cassino, Italy) in the period December 2016–February 2017. Tests were carried out in a 150-m^3 room having an ordinary mechanical ventilation system (air exchange rate equal to 0.3 h^{-1}) able to guarantee constant thermo-hygrometric conditions: temperature and humidity were kept constant at 20 ± 2 °C and 50 ± 5% RH, respectively. The following instruments were used in the experimental analysis: (i) a TSI model 3775 Condensation Particle Counter (CPC) able to measure total particle number concentrations down to 4 nm in diameter with a 1-s time resolution; (ii) a TSI model 3091 Fast Mobility Particle Sizer (FMPS) spectrometer able to measure particle size distributions and total concentrations in the range 5.6–560 nm through an electrical mobility technique with a 1-s time resolution; (iii) a Thermo-dilution system (two-step dilution) made up of a Rotating Disk Thermodiluter (RDTD, model 379020; Matter Engineering AG) (Hueglin et al., 1997) and a Thermal Conditioner Air Supply (model 379030; Matter Engineering AG) (Burtscher, 2005) allowing to ensure a proper sample conditioning during cigarette-generated particle number distribution and total concentration measurements. Temperature control is also allowed in the thermo-dilution section by a built-in heater with selectable temperatures.

To measure the mainstream aerosol characteristics, iQOS was connected to the aerosol sampling line as shown in Fig. 1. In particular, before entering the instruments (CPC or FMPS), the aerosol was flown to the thermo-dilution system to prevent measurement artefacts which likely happens in the sampling process (Burtscher, 2005; Hueglin et al., 1997). The iQOS-emitted mainstream aerosol was sampled by the thermo-dilution system at a fixed flow rate of 1 L min^{-1}. Flow rates were checked through the Flow meter TSI 4410. After the thermo-dilution process, the aerosol was flown to the CPC (aerosol flow rate of 1.5 L min^{-1}) or to the FMPS (aerosol flow rate of 10 L min^{-1}), depending on whether particle number concentrations or size distributions will be measured. A dilution ratio of 1:600 was adopted in the experimental analysis.

2.2. Measurement of particle distributions and concentrations

iQOS characterization was performed considering four different heat-stick flavors (commercialized with the names "white", "orange", "blue" and "silver"). Aerosol sampling was performed considering a thermo-dilution temperature of 37 °C in order to simulate the human body temperature. Each test was performed