Emission of Ultra-Fine Particles from Domestic Burners

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1. Introduction

During the last few years it has been shows that primary particles with typical sizes smaller than three nanometers are easily produced close to the flame front of rich premixed flames and in non-premixed combustion systems [1-5]. These particles, which are probably composed by polymers of polycyclic aromatic hydrocarbons, may growth for effect of particle-particle coagulation process and for the addition of molecules from the gas-phase and lead to the formation of graphitic-like structures with typical size larger than ten nanometers, defined as soot or elemental carbon [6,7]. Therefore, the complete understanding of the mechanisms of the formation of the particles emitted from combustion requires the development of experimental techniques able to detect particles in the size range between 2-50 nm, accounting also for their different chemical composition. In recent years techniques such as Differential Mobility Analysis (DMA) [8,9] and Atomic Force Microscopy (AFM) [10] are becoming new tools for the determination of size distributions of particulates formed in combustion systems.

Aim of the present work is to investigate particles size distributions function, by DMA technique, at the exhaust of real burners used for home appliances: home heating boilers and cook top. The burners were fuelled by Natural Gas that is mainly composed from methane. Methane is the cleanest fuel with very low particulate emission and, as reported in a previous paper [11], it needs very rich flame condition to produce significant particulate mass emission. However, even if burned in lean or premixed condition, methane can produce a not negligible number of particles in the size range 1-10 nm [11].

2. Experimental procedure

The size distribution functions of the particles are determined by measuring the differential mobility of charged particles with a Scanning Mobility Particle Sizer: TSI Model 3936 SMPS. This apparatus is specifically designed to measure particles in the 3–50 nm range. The SMPS system consists of a diffusion charger (Kr-85 Bipolar), a nano-differential mobility analyzer (NDMA, type TSI 3085) and an ultrafine condensation particle counter (UCPC, type TSI 3025A). The SMPS was operated in high-flow mode (aerosol flow set at 1.5 L/min and sheath flow at 15.0 L/min).

Four combustion systems used for home appliances burning natural gas have been studied: three configurations of home heating and one for cook-top burners. The natural gas employed was constituted by about 84% of methane, 8% of ethane, 2% of propane, 5% nitrogen with others larger hydrocarbon in low concentration. The home heating burners consist in two premixed, differentiated by a knitted metal fibre and a drilled cylindrical heads, with identical dimension, configuration, power generation and operating excesses air. The metal fibre head is manufactured into a unique patented “sock”, that allows its application around the support without any welded seams [12]. Thus critical situation to components caused from thermal stress, are eliminated. The drilled cylindrical head presents approximately 60 holes/cm², the holes have 1 mm diameters. In both configuration, air-gas mixing take place within the
aspiration circuit from the air intake. From the gas train, the fuel flows inside the aspiration air vein and through a special mixer which is able to manage the different fluid-dynamics of the two elements. Here the mixing begins and finally ends within the burner spiral. The third burner is diffusive, it is constituted by a five-tube injector of gaseous hydrocarbons [12]. The experimental lay-out is reported in Fig. 1. The exhausts are collected by a chimney and sent to the inlet of the SMPS. The exhaust collection has been optimized for obtaining similar dilution of the exhausts for all the examined burners.

Fig. 1  Experimental configuration: Home heating burner configuration (a), cook-top burner configuration (b).

3. Results and discussion
The size distribution function of the particles have been measured in the exhaust of the experimental configuration reported in Fig. 1, by SMPS analysis. Figure 2 reports the size distribution functions measured at 16 kW and 19% excess air with the three configuration of home heating burners. Particle diameters range from 3 nm, the limit of the detection system,
up to 100 nm. In the same figure the size distribution function of the particles collected in the ambient air is also reported.

In the 10 nm–100 nm range, typical of primary soot particles, the number concentration of the particles measured at the exhaust of the combustion system is of the same order of magnitude of the number concentration of the particles present in ambient air, reported in Fig. 2 with a continuous line. Combustion of natural gas in the conditions of the three examined burners doesn’t produce particles larger than 10 nm. Below 10 nm the particle concentration in ambient air is below the instrumental detection limit while a large number concentration of very small organic carbon particles are measured at the flames exhausts. This is in agreement with previous investigation of methane combustion by in-situ optical measurements which showed that organic carbon nanoparticles are formed during methane combustion even though in non-sooting and premixed conditions [11]. The number concentration of particles produced by premixed burners is sensibly lower than that one produced by the diffusive one.

![Graph showing size distribution function of particles](image)

Fig. 2  Size distribution function of the particles in the exhaust pipe as measured by SMPS analysis (16kW and 19% excess air ∆ metal premix; □ drilled premix; ○ diffusive, continuous line ambient air).

The size distribution function of the particulate emitted by cook-top burner has been also measured by SMPS. In Figure 3 is reported a size distribution function measured at the exhaust of this burner configuration. Also in this case, only very small particles can be measured above the atmospheric air background. The mean size of the particles is of about 3 nm. It is worth noting that this burner configuration emits a larger particle concentration than the home heating burners.

4. Conclusion

An experimental study of the combustion characteristics of new burners burning natural gas used for home appliances has been presented with the aim of evaluating the emissions of particulate: soot and organic carbon nanoparticles. Pollutant emissions from these burners are compared to that one from a typical cook-top burner.
Particles size distribution function have been measured by using a Scanning Mobility Particle Sizer sensitive to particles in the range 3-60 nm. Three configurations have been studied for the home heating appliance. Two premixed and one diffusive burning natural gas as fuel. The premixed burners are differentiated by the combustion head: a metal fibre and a drilled cylindrical head have been used. The diffusion burner is a five-tube injector of gaseous hydrocarbons.

![Graph](image-url)

**Fig. 3** Size distribution function of the particles in the exhaust of the domestic cook-top burner measured by SMPS analysis (continuous line is the ambient air).

Primary soot particles in the 10 nm–100 nm range are not formed in all the conditions examined. In this size range the number concentration of the particle measured at the exhaust of the combustion system is of the same order of magnitude of the number concentration of the particles present in the ambient air. Measurements have shown that particulate matter with size in the 1 nm – 10 nm size range is formed in all the examined conditions. Even though total particulate emission are quite low, the amount of particulate smaller than 10 nm is sensibly larger than the atmospheric background. The emission from home heating appliance are less than that one measured in the cook-top burner configuration analysed in this work. This result evidence the importance to study particulate emission from natural gas combustion systems employed for home appliance in relation to the indoor air quality.

### 5. References