Chemical characterization of airplane soot: complete engine versus combustion chamber

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Emission of soot particles by airplanes are nowadays a big concern due to their effect on air quality and climate, either directly (interaction with incoming solar radiation) or indirectly (generation of nuclei for cirrus clouds formation). For example, up to 10% increase of cirrus clouds has been observed in flight corridors (Boucher, 1999). Soot chemical composition, especially surface chemical composition, plays a key role in its reactivity in the atmosphere. The hydrophilic or hydrophobic character of the compounds adsorbed on the soot surface will determine its ice nucleation potential.

The present work has been developed in the frame of the French national project MERMOSE (http:// mermose.onera.fr/), which aims to characterize the soot emissions from aircraft engines and to determine their role in the contrail formation. Our specific goals have been to provide a systematic characterization of soot particles that can be used to interpret ice nucleation studies under development in the frame of the project. We focused this study on two experimental tests performed during MERMOSE project. In the first campaign soot samples were collected from a complete airplane engine (SNECMA/Saturn PowerJet SaM-146 turbofan) operating in various engine regimes corresponding to the LTO cycle certification regimes. In addition, a regime representative of cruise condition was tested. Nevertheless, it has to be noted that the essay was performed at ground level, thus not all parameters were representative of the real high-altitude cruise regime. In the second test campaign, a combustion chamber representative of SAM-146 engine was tested in the M1 test bench at ONERA facilities. This bench allows reproducing the operating conditions of an engine throughout its flight cycle. Therefore in this test it was possible to optimize all the parameters to reproduce high-altitude cruise conditions.

We have used two mass spectrometry techniques to determine the surface chemical composition of the samples: Two-Step (Desorption/ Ionization) Laser Mass Spectrometry (L2MS) and Time of Fight Secondary Ion Mass Spectrometry (ToF-SIMS). In L2MS, the adsorbed phase is probed by nanosecond laser desorption, then, the ejected molecules are ionized with a second laser and further mass-separated by ToF-MS. In ToF-SIMS the sample is bombarded with a Bi_3^+ ion beam and the secondary ions generated are detected by ToF-MS. L2MS is especially well suited for the study of PAHs present on the soot surface, thanks to the resonant enhanced multi-photon ionization (REMPI) of these compounds at 266 nm. ToF-SIMS is complementary to L2MS since it gives a more uniform response to various families of molecules, also the higher resolution achieved with this instrument allows a more precise identification of certain compounds. On the other hand, the fragmentation produced in this technique is higher than in L2MS.

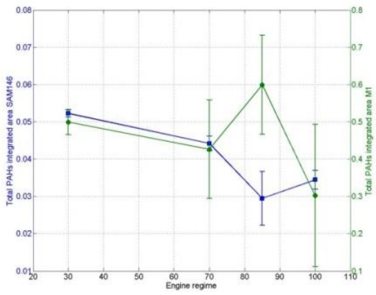

Figure 1. Total PAH content measured by L2MS technique for both campaigns

The mass spectrometry studies allowed a complete chemical characterization of the samples. In general the contents in PAH were higher for the soot collected from the combustion chamber. In both tests the PAH content presents a similar dependence with the engine regime (Fig 1.) with the only exception of the 85% regime.

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