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Towards Elimination of Aircraft Soot Emissions

Georgios A. Kelesidis*[a,b], Amogh Nagarkar[a], Una Trivanovic[a], and Sotiris E. Pratsinis*[a]

*Correspondence: Dr. G. A. Kelesidis, E-mail: georgios.kelesidis@rutgers.edu
[a]Particle Technology Laboratory, Institute of Energy and Process Engineering, Department of Mechanical and Process Engineering, ETH Zürich, Sonneggstrasse 3, CH-8092 Zürich; [b]Nanoscience and Advanced Material Center, Environmental and Occupational Health Science Institute, School of Public Health, Rutgers University, Frelinghuysen 170, 08854 Piscataway, NJ, USA

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About a million tons of carbonaceous (soot) nanoparticles are released every year by aviation through incomplete combustion of jet fuel. Such nanoparticles are rather toxic affecting the health of airport employees and nearby communities. Furthermore, aircraft soot emissions contribute to global warming mainly through the formation of contrail cirrus clouds that make up more than half of the total climate impact from aviation. Climate models have revealed that a 90 % reduction of soot emissions can halve the climate effect as a result of contrail cirrus clouds.

Such a reduction can be attained through judicious injection of air downstream of aircraft combustors. In fact, the design of quite a few of these combustors are based on the rich-quench-lean (RQL) concept where swirling and cross-flow jets of air are used in the primary (rich) zone of the combustor to burn the fuel and generate the required energy for aviation resulting in high concentrations of soot (Fig. 1). This is followed by a lean zone where additional air is injected to oxidize that soot. However, only a fraction of it is removed in current RQL combustors. This is attributed to the inhomogeneity of oxygen concentration and high temperature particle residence time (HTPRT) there. As a result, some soot survives oxidation and escapes into the atmosphere.

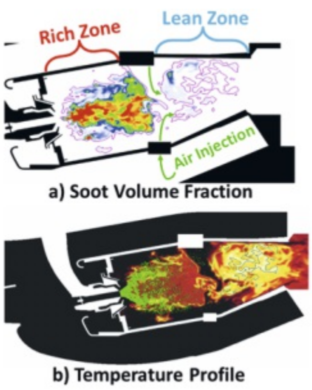

Fig. 1. Cross-sections of an RQL aircraft combustor along with the soot volume fraction (a) and temperature (b) profiles obtained during jet fuel combustion (adapted from Mueller & Pitsch, ref. [1]).

Here, an enclosed unit for spray combustion of jet fuel following the RQL concept is used that emulates soot emissions from aviation. The elimination of such emissions is explored by systematic swirl-injection of O_2-containing N_2 through 12 jets using a torus ring. This unit has been designed by computational fluid dynamics (CFD) to optimize the mixing between particles and gases and closely control the HTPRT. It has been shown that increasing the O_2 concentration to 20 vol % in its dilution zone of this unit enhances soot oxidation, cutting the emitted concentration of soot by about 90% and its mass by 98% (Fig. 2).

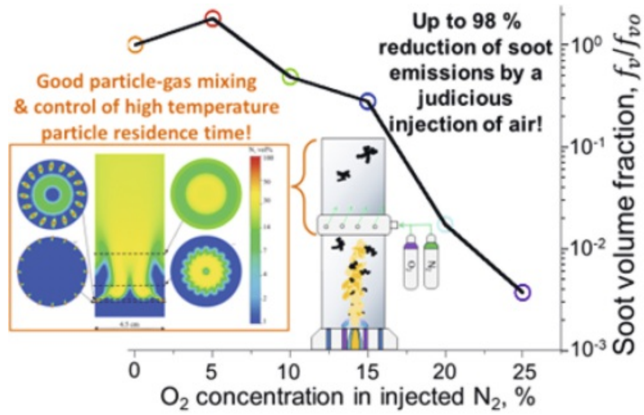

Fig. 2. Reducing soot emissions by swirl-injection of O_2-containing N_2 downstream of an enclosed unit for spray combustion of jet fuel (inset) that has been designed for optimal mixing between particles and gases, as well as the HTPRT (orange-framed inset; adapted from Teleki *et al.*, [2]). The emitted soot volume fraction, f_v, is measured at the exhaust of the unit as a function of O_2 concentration in the injected gas and normalized with the f_{vo} obtained at 0 vol % O_2 (solid line & symbols; adapted from Kelesidis *et al.*, [3]).

Thus, a clever control of the HTPRT and particle-gas mixing is essential for judicious injection of air in the dilution zone of RQL aircraft combustors to reduce drastically their soot emissions and minimize their impact on health and climate.

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Tel.: +41 71 222 16 81, E-mail: analytical_highlights@chimia.ch