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An overview of the soot suppressing ability of oxygenated compounds considered as sustainable alternative transportation fuels

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ABSTRACT

Currently, practically all land, marine and air transport is powered entirely by internal combustion (IC) and jet engines, with 95% of transportation energy coming from liquid fuels made from petroleum. Although the past few years have witnessed a surge in interest in the electrification of transportation, current alternatives to IC engines face significant barriers to unlimited expansion, which explains why 85–90% of transport energy is projected to continue to be derived from conventional liquid fuels powering combustion engines even well into the 2040s. Although engine researchers and manufacturers have targeted fuel consumption and pollutant emissions reduction for years, IC engines are still associated with massive emissions of greenhouse gas (GHG) (with the transportation of goods and people accounting for around 25% of global CO2 emissions from fossil fuel combustion) and pollutants, including unburnt hydrocarbons and particulate matter (PM). Soot, which refers to the carbonaceous particles issued from the high-temperature fuel-rich incomplete combustion of hydrocarbons, is subject to increasingly stringent regulations due to its harmful impacts on climate and human health. Indicated as a major factor in global warming, soot also drastically impacts air quality, and, as such, causes serious public health and safety issues. However, meeting current and incoming regulations aimed at restricting PM emissions issued from practical combustors requires identifying technological avenues in the fields of combustion chamber design and fuel formulation, hence prompting the need for a clarification of the impact of the composition and structure of hydrocarbon fuels on soot formation mechanisms, among others. Although the last half-century has seen major progress in the field, additional work is more than ever required, especially when it comes to using alternative fuels such as biomass-derived oxygenated substitutes, which have proved to constitute a positive soot suppression force.

In view of the forgoing, the aim of this presentation is to briefly review the current state of knowledge on the sooting propensity of a variety of oxygenated additives considered as sustainable alternative transportation fuels for use in spark ignition, diesel and gas turbine engines. After presenting a brief summary of the different steps involved in the formation of combustion-generated particles, the main indexes proposed in the literature to assess the propensity to soot of conventional fuels and biofuels (the threshold soot index (TSI), the oxygen extended sooting index (OESI), the yield sooting index (YSI) and the fuel equivalent sooting index (FESI)) will be introduced. The main trends issued from the use of the latter to characterize the soot suppressing effect of various oxygenated additives will then be summarized, along with the conclusions drawn in a series of insightful experimental works conducted in laminar and turbulent combustion media. Note that the emphasis herein will be placed primarily on alcohols and esters, which are commonly considered for blending with gasoline and diesel fuel, as well as on molecules such as aldehydes and ketones, which exhibit a strong ability to reduce soot formation. Note also that due to the growing interest in alternative biomass-derived molecules, such as furans and terpenes, for their potential use as jet fuel substitutes, the recent works conducted to assess the sooting tendency of these compounds will also be surveyed. To conclude, an overview perspective will be proposed on the key areas, including the development of predictive sooting tendency models, where further studies are needed to ultimately enable the identification and/or formulation of fuel blends from different chemical functionalities, providing a strong lever for reducing soot emissions at the exhaust of combustion-based transportation systems.