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News & Views

Towards fossil-free fuels in sustainable powertrain; alcohol-fueled low-temperature combustion (LTC)

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Low-temperature combustion (LTC) engines are able to reduce nitrogen oxides (NO_x) and particulate matter (PM) emissions, simultaneously. LTC engines suffer from higher amounts of unburned hydrocarbon (uHC) and carbon monoxide (CO) emissions, particularly in low-load operating conditions of the engine. The existence of oxygen molecules in the alcohol fuels not only results in more combustion completeness but also leads to lower CO and uHC emissions.

LTC strategies in internal combustion engines provide lower emissions besides high engine performance according to chemically controlled combustion temperature. These strategies are divided into three engine types which are premixed charge compression ignition (PCCI), homogenous charge compression ignition (HCCI), and reactivity control compression ignition (RCCI) engines [1]. The main purpose of LTC is to provide a lean homogenous air-fuel mixture to obtain lower emissions along with appropriate engine power output. Various fuel supply strategies together with different fuel types are applied in LTC, including low reactivity fuels (LRF) (e.g., gasoline and alcohols) and high reactivity fuels (HRF) (e.g., diesel, dimethyl ether etc.) [2]. A combination of LRF and HRF has been used in LTC strategies. Alcohol fuels have been more of interest among other types of LRFs for LTC engine application in several studies. Ethanol, methanol, butanol, and n-butanol are four types of these fuels used as LRFs in LTC engines [3,4]. These fuels are usually employed with HRFs like diesel (n-heptane in numerical study) or due to cooling effects employed at high engine loads as single fuels. Owing to their diverse chemical and physical properties, the alcohol fuels can affect differently on the engine combustion and emission characteristics [5]. The relationship between different pollutants for different values of local equivalence ratio and temperature in the combustion strategies of conventional diesel combustion (CDC), HCCI, PCCI, and RCCI is shown in Figure 1. Although the boundaries shown in Figure 1 are slightly non-marginal, the form is useful for understanding the different combustion properties [1]. According to Figure 1, CDC comprises areas with high local equivalence ratios and high local temperatures, but LTC strategies tend to operate in poor equivalence ratios with lower maximum temperatures than the formation of nitrogen oxides (NO_x) and soot emissions prevented. However, LTC zones are those where the least oxidation of unburned hydrocarbons and carbon monoxide occurs. Although LTC strategies can reduce the emissions of NO_x and soot while maintaining diesel cycle performance with higher efficiencies, they regularly increase the emissions of uHCs, CO together with lower combustion controllability. These strategies also increase the maximum pressure rise rate (PPRR) of the combustion [2]. Methanol, ethanol, and butanol are the most utilized alcohol-based fuels in both spark ignition (SI) cycle and compression ignition (CI) cycle engine applications. The chemical structure of alcohol is represented as $C_nH_{2n+1}OH$. The higher-octane number of alcohols can reduce the knocking tendency in SI engines, whereas the presence of fuel oxygen content in alcohol diesel blends lowers the soot formation tendency in compression ignition engines. Concomitantly, blending alcohol results in lower emissions in both the SI and CI version of ICEs [6]. Since the LTC strategy improves fuel atomization and mixing, it not only lowers the local equivalence ratio but also reduces combustion temperature [7,8], which can abate the NO_x and particulate matter (PM) emissions simultaneously [9,10].

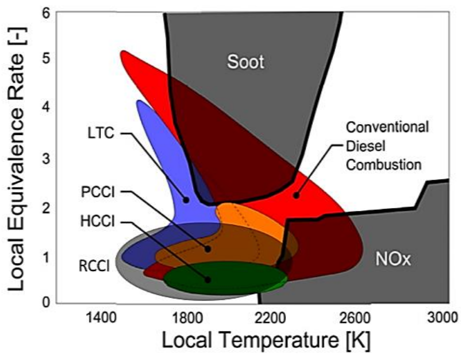

Figure 1. Temperature and equivalence ratio changes in operational regimes of CDC, HCCI, PCCI, and RCCI [1]

The alcohol fuels take advantage of the full merits of HCCI combustion due to their desirable properties such as higher-octane number, a wider range of equivalence ratios together with emissions reduction [7]. The alcohol fuel used in another mode of LTC, such as the RCCI engine, increases the thermal efficiency along with decreasing harmful exhaust pollutants [9]. CO and HC emissions are the main concerns in LTC strategies which are the result of incomplete combustion of fuel (misfire) in the engine [8]. CO emission is strongly dependent on the combustion temperature of the homogeneous lean mixtures, and as a result, in ultra-lean mixtures, the temperature becomes too cold for completion of the oxidation reactions and causes a high level of CO in HCCI combustion. The variation of CO emissions for natural gas, ethanol, and methanol fuels in HCCI combustion is illustrated in Figure 2. It can be perceived from Figure 2 that the CO emission level in the natural gas-fueled case is high above the two other fuels, and for all fuel equivalence ratios and intake temperatures, its value is higher than the limits of the Euro 6 pollution regulations, which is under 1.5 gr/kWh [10]. But as shown in Figure 2, for ethanol and methanol-fueled cases, it is possible to define the operating region based on Euro 6 pollution regulations for CO emission. As mentioned, the presence of fuel oxygen content in alcohol fuels resulted in complete combustion leading to lower CO and uHC emissions.

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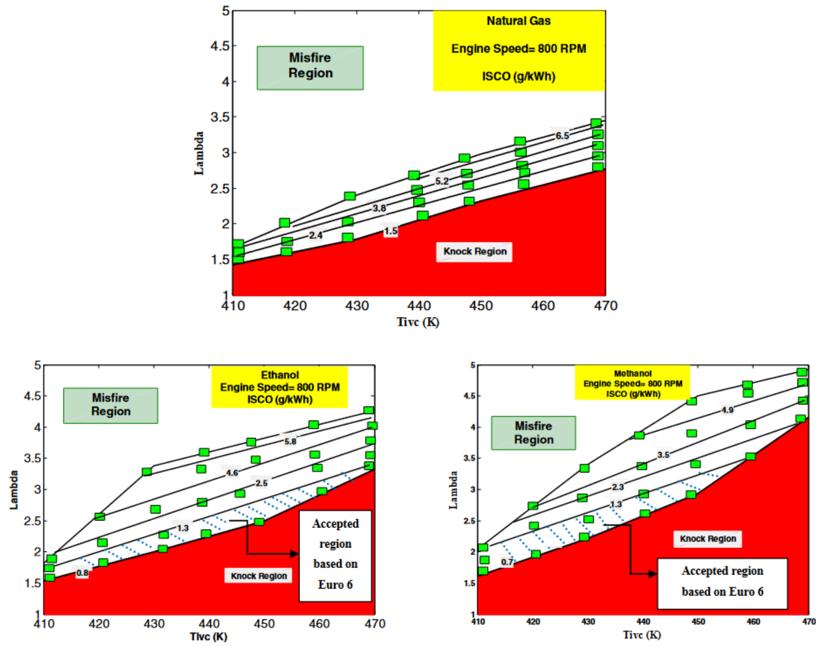

Figure 2. Operating range of HCCI engine based on CO emission for various fuel [7]

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