Abstract

Diesel engines are sophisticated devices with more than 130 years of research and development. They are known for their high thermal efficiency, durability, reliability, and robustness. They are a major source of prime movers and will remain the same for the next few decades. However, fossil fuels are an exhaustible resource, and combustion-originated emissions degrade our environment and public health. These problems compel us to diversify energy resources and look for new, cleaner alternative fuels. Soot and NOx are major Diesel engine emissions, and their simultaneous reduction is difficult, primarily due to the soot-NOx trade-off. The current soot and NOx limits of a heavy-duty Bharat Stage (BS) 6 vehicle are 10 mg/kWh and 400 mg/kWh, respectively, at steady-state test conditions. And for the passenger cars, soot and NOx limits are 4.5 mg/kWh and 80 mg/kWh, respectively. To meet such a stringent emissions norm without costly and bulky after-treatment devices, we must look for advanced combustion concepts and alternative fuels with lesser emission potential. This solution is appropriate for light-duty vehicles, especially on single-cylinder engines where cost and weight are impediments. Dimethyl ether (DME, CH_3OCH_3) is an oxygenated fuel that can be used in Diesel engines. The most distinctive characteristics of DME are the lack of a direct C-C bond and the availability of Oxygen atom. These two factors make the combustion of DME smoke-free.

In this work, reacting spray characteristics, engine performance, combustion, and emission formation characteristics of direct and port-injected DME-fueled engines were numerically studied. Combustion simulations require a chemical kinetic mechanism; therefore, a skeletal mechanism for DME-n-heptane combustion was developed from the detailed and well-validated mechanism available in the ANSYS Model Fuel Library. The developed skeletal mechanism has 105 species and 705 reactions, including the NOx formation mechanism. Spray combustion and emissions formation characteristics of n-heptane, DME, and their blends (10, 25, and 50% DME in n-heptane) were numerically studied in a constant volume chamber under Diesel engine combustion conditions. Results show that the n-heptane spray combustion has the highest heat release rate with an intense premix combustion phase, whereas DME spray combustion has the lowest heat release rate and shortest premix combustion phase. The magnitude of the premixed phase and heat release rate decreases with the increase in DME mass fraction in the blends. Soot, carbon monoxide (CO), unburned hydrocarbon (UHC), and nitric oxide (NO) emissions decreased with the increase in the DME mass fraction in the blends and were lowest for the DME.

A retrofitted DME-fueled DI engine generally uses a longer fuel injection duration to compensate for its lower calorific value, which hindered the utilization of the full potential of DME fueled engine. Thus, an appropriate way to increase the mass flow rate of a DME-fueled DI CI engine was found by varying the number of nozzle holes, nozzle hole diameter, and injection pressure. The results show that increasing the mass flow rate of the fuel injector increases peak combustion pressure and heat release rate but decreases combustion duration. Increasing the number of injector holes increases indicated specific fuel consumption (ISFC) and exhaust emissions due to mixing between unburned fuel spray and neighboring combustion products. Increasing the nozzle hole diameter or fuel injection pressure increases spray tip penetration and improves fuel-air mixing before combustion initiates. Increasing the nozzle hole diameter by merely 22μm than the baseline injector reduces ISFC and exhaust emissions at a slightly retarded start of injection (SOI). However, the lowest ISFC was found at the 30 MPa injection pressure at the most advanced SOI, at the expense of higher NOx.

The port injection of DME was studied by substituting 20%, 40%, and 60% of total energy with DME for two different compression ratios, viz. 18 and 14. The results show that a DME-Diesel dual-fueled engine with a compression ratio (CR) of 18 can have up to three stages of heat release. The first and second stages of heat release are due to DME's low and high-temperature reactions. And the third stage of heat release originated due to Diesel combustion. The port injection of DME resulted in a slight decrease in gross indicated power due to DME's heat release well before the top dead center (TDC), which increased negative work and cooling loss and a reduction in combustion efficiency. Soot emissions decrease, while NOx, CO, and HC emissions increase as DME quantity increases. Lowering the compression ratio retards the start of combustion and combustion phasing, which reduces negative work and cooling loss, resulting in an improved gross indicated power output. Reducing the CR further reduces soot and NOx emissions while the CO and HC emissions increases. The effect of intake boost pressure and EGR was also numerically investigated.

Keywords: Dimethyl ether, Spray characteristics, Nozzle hole diameter, Dual fueled engine, Diesel engine emissions.