

Abstract

In order to cope with the emission regulations and meet with the zero carbon policy requirements, ammonia (NH_3), as a carbon-free fuel, has a widely potential application for internal combustion engines. Due to the physical and chemical properties of ammonia, which lead to the issues of combustion instability and high emissions, the lower combustion efficiency and higher emission are the main challenges for ammonia as a fuel in application. The fundamental combustion experiment is an indispensable method to investigate combustion characteristics of ammonia. In this work, based on the Controllable Active Thermo-Atmosphere experimental platform, the experimental researches of ammonia and ammonia blending fuels have been explored in different addition ratios, co-flow temperatures, co-flow velocities, equivalence ratios and injection pressures. Furthermore, a pollutant generation simulation prediction has been used to reveal the emissions production mechanism at a high-temperature and high-background pressure condition, using the detailed chemical reaction kinetic mechanism.

Firstly, auto-ignition characteristics of turbulence jet flame of pure ammonia at a high temperature, based on Controllable Active Thermo-Atmosphere burner, have been investigated. The overall color of ammonia jet diffusion flames is orange. With jet pressure increases from 1.3 bar to 2.5 bar, lowest auto-ignition temperature increases from 1128 K to 1218 K. The ammonia jet flow cannot reach min auto-ignition temperature because a higher jet velocity reduces the mixing time between the jet flow and the co-flow. Flame morphology parameters including length, area and perimeter increase with co-flow temperature increases, while first increase then decrease when the injection pressure increases. If injection pressure beyond 2.2 bar, ammonia combustion is incomplete, which lead to a decline of flame morphology parameters. Once the co-flow temperature beyond the critical temperature (1198 K), slope of ignition delay and lifted height

decrease because the effect of co-flow temperature on ignition delay and lifted height dramatically reduces. Lifted height data are satisfactorily fitted by a modified mixing-strain model, showing that ammonia auto-ignition is controlled by the large-scale mixing. With increasing in co-flow temperature from 1148 K to 1223 K, standard deviation of lifted height shows a 90% decline which means combustion stability of ammonia increases significantly. A standard deviation of lifted height below 2 indicates a stable flame.

Second, three different flame enhancement methods (ammonia-hydrogen, ammonia-methane and ammonia-oxygen) have been investigated. Compared to pure ammonia, both ammonia-hydrogen and ammonia-methane flames have a higher flame brightness and a large flame area. Flame morphology parameters of ammonia-hydrogen increase tendency become slowly when hydrogen ratio beyond 10%. The 20% hydrogen is an optimal ratio for combustion stability of ammonia-hydrogen blending fuels because standard deviation declines tendency decreases. With co-flow temperature increases, ignition delay and lifted height of two blending fuels show a downward trend, and both are lower than that of pure ammonia combustion. Hydrogen has a stronger flame enhancement ability than methane which shows a max 46% decreases to ignition delay. Adding 20% hydrogen or 8% methane into ammonia can decrease 175 K or 50 K of minimum auto-ignition temperature compared to pure ammonia respectively. The brightness of ammonia-oxygen flame is brighter than that of pure ammonia, which represents that chemical reaction of combustion is more violent. With excess oxygen coefficient (R_o) increases, the ignition delay first decreases then increases. The ignition delay of ammonia-oxygen has a 30% to 39% decline than the pure ammonia at same co-flow temperatures.

Finally, the auto-ignition and emission characteristics of ammonia, ammonia-hydrogen, ammonia-methane and ammonia-oxygen blending fuels at different temperatures have been investigated by CHEMKIN simulation. As the temperature increases, the NO, NO₂ and N₂O, all increase. NO is the main combustion pollutant under high temperature conditions. For ammonia-hydrogen blending fuels, with the increase of temperature and hydrogen ratio, NO_x increases. The N₂O has an obvious increment at the auto-ignition boundary. Compared to the pure ammonia, ammonia disassociation blending fuel has a lower N₂O emission at auto-ignition boundary. The NO_x of ammonia/10% methane blending fuel is higher than that of pure ammonia. The NO and CO₂ show a competition under higher temperatures. When temperature beyond 1400 K, the NO will be main pollutant.

Key words: Ammonia, Auto-ignition, Turbulent flame, NO_x pollutant.