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学 位 論 文 内 容 の 要 旨

博士の専攻分野の名称　博士（工学）　氏名　Leang So Khuong

学 位 論 文 題 名

INVESTIGATION OF DROPLET EVAPORATION CHARACTERISTICS OF CONVENTIONAL AND CARBON-NEUTRAL TRANSPORTATION FUELS UNDER VARIOUS TEMPERATURE AND PRESSURE CONDITIONS

(様々な温度・圧力条件下での従来型およびカーボンニュートラル輸送燃料の液滴蒸発特性に関する研究)

Rising global awareness of climate change and CO_2 emissions drives the shift to alternative energy sources to meet the net-zero target by 2050. Carbon-neutral fuels like hydrotreated vegetable oil (HVO) and ammonia are promising options for reducing CO_2 emissions in transportation. Understanding fuel droplet evaporation is essential for optimizing combustion in engines and reducing greenhouse gas emissions. Incomplete evaporation can lead to issues like incomplete combustion, knocking, and high emissions. This study investigates the evaporation characteristics of single HVO and ammonia droplets under various conditions.

Several experiments were conducted to achieve the objectives of this study. First, surrogate HVO fuels were formulated and surrogate HVO droplet evaporation experiments were performed under high temperatures (573 K-873 K) and pressures (0.1-2.0 MPa) using conventional experimental setup. Next, a new experimental setup was designed and developed specifically for single ammonia droplet evaporation experiments. Then, ammonia evaporation characteristics were observed both experimentally and numerically at ambient temperatures (298 K to 673 K) and a fixed pressure of 0.95 MPa. Key parameters such as properties, droplet lifetime, and instantaneous evaporation coefficient (K_{inst}) of both surrogate HVO and ammonia fuels were analyzed. The effect of the initial droplet temperature and the droplet temperature during evaporation are also discussed.

The result reveals that HVO surrogate fuels exhibit shorter droplet lifetimes and higher evaporation rates than diesel under all ambient conditions due to its lower density, surface tension, and boiling point. Among HVO surrogate fuels, HVO:C_{15}-C_{18}/isododecane has the shortest droplet lifetimes because adding iso-dodecane reduces the initial heating period due to a lower boiling point. It was found that the evaporation characteristics are affected by not only the boiling point but also fuel compositions and thermodynamic properties such as thermal conductivity, latent heat of vaporization, and specific heat of gas. Increasing temperature decreases droplet lifetime and increases the evaporation rate due to high heat transfer from the ambient gas. However, the effect of pressure on droplet lifetime relies on ambient temperature (T_{amb}). As pressure increases, droplet lifetime increases at $T_{amb} < T_c$ (critical temperature) and decreases at $T_{amb} > T_c$. Increasing pressure at $T_{amb} \sim T_c$ has no significant effect on droplet lifetime.

Ammonia's low density, surface tension, and boiling point favor evaporation while high vapor pressure and latent heat of vaporization can significantly influence evaporation behavior. The normalized

diameter squared (D^2/D_0^2) decreases linearly, following the D^2 law, with deviations at later stages of evaporation while the K_{inst} decreases over time. This is due to the effect of impurities and changes in heat and mass transfer around the droplet. Due to its polarity, ammonia can attract and absorb moisture, which can impact the rate of evaporation. Increasing ambient temperature reduces droplet lifetime and enhances the evaporation rate due to the enhanced heat transfer from the ambient gas while initial droplet temperature has a minor effect on evaporation and is not the primary factor. Instead, other factors like ambient temperature and pressure play a more significant role in controlling the overall evaporation rate. Droplet temperature measurements show an initial rapid temperature drop due to the evaporative cooling effect from the latent heat of vaporization. Throughout evaporation, droplet temperature remains relatively stable under tested conditions, indicating a thermal balance between heat transfer from the ambient gas and heat used for vaporization. The theoretical model incorporating natural convection aligns closely with experimental results, highlighting the critical role of buoyancy-induced flows in enhancing ammonia droplet evaporation.

These findings hold significance for optimizing fuel injection strategies, enhancing combustion efficiency, and developing comprehensive evaporation models.