主　論　文　の　要　約

論文題目　**Study on combustion and NO_x emission characteristic of NH_3 flame**
(アンモニア火炎の燃焼特性と窒素酸化物排出特性に関する研究)

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論　文　内　容　の　要　約

This thesis includes six chapters. The literature review and background information on the use of NH_3 as an alternative fuel are summarized in Chapter 1. The world energy and environmental issues has been firstly introduced, following with the introduction of alternative fuels and NO formation during premixed combustion. Furthermore, the motivations of using NH_3 as an alternative fuel have been summarized. Finally, the objectives and outline of the thesis have been presented in Chapter 1.

Chapter 2 reports the experimental investigation of the combustion characteristics and NO_x formation in NH_3-H_2-air flames. The potential of H_2 and NH_3 as carbon-free fuels was evaluated. The combustion characteristics and NO_x formation in the combustion of H_2 and NH_3 at different air-fuel equivalence ratios and initial H_2 concentrations in the fuel gas were experimentally studied. The burning velocity of NH_3-H_2-air flame was measured by the Bunsen burner method. The emissions, including unburnt NH_3, H_2, O_2, N_2, and NO in the exhaust gas, were experimentally analyzed. The results show that NH_3 burning velocity improved because of increased amounts of H_2 atom in flame with the addition of H_2. NH_3 burning velocity could be moderately improved and could be applied to the commercial gas engine together with H_2 as fuels. H_2 has an accelerant role in H_2-NH_3-air combustion, whereas NH_3 has a major effect on the maximum burning velocity of H_2-NH_3-air. In addition, fuel-NO_x has a dominant role and thermal-NO_x has a negligible role in H_2-NH_3-air combustion. Thermal-NO_x decreases in H_2-NH_3-air combustion compared with the case for pure H_2-air combustion. NO_x concentration reaches its maximum at stoichiometric combustion. Furthermore, H_2 is detected at an air-fuel equivalence ratio of 1.00 for the decomposition of NH_3 in flame. Hence, the stoichiometric combustion of H_2 and NH_3 should be carefully considered in the practical utilization of H_2 and NH_3 as fuels. H_2 as fuel for improving burning performance with moderate burning velocity and NO_x emission enables the utilization of H_2 and NH_3 as promising fuels.

In Chapter 3, a freely propagating adiabatic, premixed, laminar flame speed calculation model in CHEMKIN 4.0 is demonstrated. The combustion and emissions characteristics of premixed NH_3–air flame under preheating conditions (ranging from 298 K to 573 K) were numerically investigated. The burning velocity and molar fractions of all species were determined using the Miller and Bowman and the Reductive Konnov mechanisms. The results show that both the equivalence ratio and preheating temperature have important effects on the laminar burning velocity and adiabatic flame temperature of NH_3. The reaction rate of production and molar fraction of H, O, and OH radicals, together with nitrogen radicals such as NH_2, NH, and N in the reaction zone increases as the preheating temperature is increased from 298 K to 573 K. Although NO concentrations in the exhaust gas increased with increasing preheating temperature under fuel-lean conditions, they could be maintained at a reasonably low level at all preheating temperatures, mainly due to the increased reduction reaction of NO with NH_2, NH, N radicals. The main N radical formation in the NH_3–air combustion is originated from NH_3 while not N_2, which indicates that the N_2 dilution effect of NH_3–air flame is negligible for NO formation. Furthermore, the equivalence ratio has a dominant effect on NO yields, because of the higher reduction reaction and lower flame temperature at higher equivalence ratio conditions, leading a lower formation of HNO, which indicates a potential in reducing NO emissions in NH_3 combustion. Therefore, the preheating temperature and equivalence ratio should be well considered in practical operations to minimize NO formation in combustion of NH_3 as a clean fuel.

In Chapter 4, the combustion of NH_3 under oxygen-enriched condition has been proposed as a novel method for improving NH_3 combustion. As a key parameter for a fuel in real combustion development, the burning velocity of NH_3, which is usually low, limits its application in the energy device. The oxygen concentration in the combustion air was varied from 21% to 30%. The results show that O_2–enriched combustion has positive effects on both laminar burning velocity and adiabatic flame temperature of NH_3. The maximum burning velocity of NH_3 is 38.6 cm/s at O_2 content of 30 %, which is approximately 2.6 times the value obtained at an O_2 content of 21 %, mainly due to the increased reaction rates of OH, H, O, and NH_2 radicals in the reaction zone at higher O_2 contents. NO emissions increase with an increase in the O_2 content of the combustion air. Whereas, the reactions between NO and surplus NH_2, NH and N radicals cause more NO consumption especially at fuel-rich conditions, showing the potential in reducing NO emission in NH_3–air combustion. Therefore, O_2–enriched combustion is a suitable method for improving NH_3 combustion when NH_3 is utilized as fuel.

Chapter 5 presents the investigations of the performance and efficiency of a natural gas spark-ignition engine fueled with ammonia/hydrogen (NH_3/H_2) in order to evaluate the NH_3 combustion performance during engine combustion. NH_3, and H_2 from NH_3 decomposition, have been proposed as fuels for a gas engine system in this research. The effects of the direct injection of gaseous NH_3, together with H_2 from NH_3 decomposition, on the engine performance and efficiency have been experimentally investigated. The results show that a maximum of 60 % NH_3 addition (LHV basis) can be reached when the gas engine fueled by NH_3 and CH_4 with a fixed rotation speed of 1950 rpm. The gas engine operates stably at a maximum high addition ratio of 92.5% NH_3+H_2 (LHV basis) addition to total fuel under fixed rotation speed with tiny vibration of 1.0%, showing a feasible replacement of NH_3+H_2 as major fuel of the gas engine fueled by CH_4. The cylinder pressure of gas engine decreases with the addition of NH_3, while increases with the addition of H_2. A lower energy density of NH_3 and H_2 leads a lower power generation efficiency of the gas engine when fueled by $NH_3/H_2/CH_4$ compared with CH_4.

Chapter 6 summaries the conclusions of this study and suggestions in the future work about the combustion and emissions characteristics of NH_3 flame when use NH_3 as a carbon-free alternative fuel.