Approaches for improving the combustion, performance, and emissions of marine propulsion engines

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論文名　：

Title:　Approaches for Improving the Combustion, Performance, and Emissions of Marine Propulsion Engines (舶用推進エンジンの燃焼，性能および排出特性の改善策に関する研究)

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論　文　内　容　の　要　旨

Thesis Summary

The volume of marine transport is constantly increasing with the development of the world economy. In the short term, the introduction of more-efficient and less-emission diesel engines and natural gas fuels with low carbon content should be promoted, and in the long term, a fuel shift to carbon-free (CF) fuels such as hydrogen and ammonia is needed. The reasons for this are that there is a conflict between higher efficiency and lower emissions in diesel engines, the measures for higher efficiency and lower emissions when gas fuels are injected directly into diesel engines are still unknown, and the air introduction process and combustion characteristics of high-pressure gas jets of CF fuel, hydrogen, mixed with natural gas-based fuel, are not known. The air introduction process and combustion characteristics of a high-pressure gas jet of hydrogen mixed with natural gas (NG) fuel, which is CF fuel, are unknown.

This paper aims to investigate in detail, based on experiments and numerical predictions, methods to significantly reduce NOx emissions, which is a problem in existing diesel engines, to promote combustion to compensate for the lower combustion speed of NG-based fuels, and to clarify the process of air introduction and combustion characteristics when hydrogen is mixed with NG-based fuels, and ultimately the process to achieve CN in marine engines.

Chapter 1 begins with a review of technological developments and recent trends in emissions regulations in marine diesel engines, and clarifies the position and purpose of this research and its social and academic significance through the following discussion. First, the paper points out that existing NOx emission reduction measures such as exhaust gas recirculation (EGR) and water-emulsion fuel are problematic in that the former reduces the combustion rate due to lower oxygen concentration, while the latter saturates the effect of reduced NOx emissions in response to increased water blending. Next, he points out that while high thermal efficiency and NOx emissions below the regulation values can be achieved with lean premixed combustion of gas fuels, the problem is that unburned methane emissions reduce the effectiveness of global warming mitigation. emissions. Finally, as for the application of hydrogen as a CF fuel to marine engines, there are few examples of verification in actual engines, and since knocking is extremely difficult to suppress in premixed combustion, it is desirable to apply hydrogen to direct gas injection engines, and it is essential to

clarify the air introduction process of the gas jet and combustion characteristics.

Chapter 2 introduces the configuration and features of the Rapid Compression and Expansion Machine (RCEM), which can reproduce the in-cylinder conditions of a direct gas injection engine and covers the entire combustion chamber as a view area. The control system of the engine and the measuring devices is also described. The two-color method is applied to obtain the temperature distribution in the spray from the direct light image of the diesel spray flame.

Chapter 3 describes a method for estimating the amount of air introduced into the jet by combining the contour shape of the gas jet and the arrival distance at the tip of the jet acquired by the shadowgraph imaging system with information on the flow field near the boundary of the gas jet or diesel spray obtained by the time-series PIV system. Furthermore, a new method is proposed to estimate the distribution of air introduction into a gas jet based on the initial jet image's brightness values and the jet's surrounding area, which do not include tracers in the PIV analysis image.

Chapter 4 discusses EGR and water-emulsion fuel, the most common NOx reduction measures for marine diesel engines, and applies them to RCEM to visualize and measure the combustion process, obtain the combustion temperature distribution in the atomizing flame by two-color method, and quantitatively evaluate the reduction range of combustion temperature. Theoretically, the authors consider the gains and losses of the two by numerical prediction using the 3D-CFD KIVA-3V and 1D performance simulator GT-Power and also devise an original simple model for EGR assuming two conditions: constant air supply and constant oxygen supply. In addition, the feasibility of both conditions, such as the adiabatic efficiency of the supercharged turbine, is objectively examined by investigating the energy balance between the intake and exhaust gases using GT-Power. In the numerical prediction of water-emulsion fuels, we have developed our own model for the splitting and evaporation of the spray droplets, and have verified the validity of the numerical prediction of spray combustion of water-emulsion fuels by comparing it with the measured data.

Chapter 5 highlights a new gas emulsion method in which inert gases such as nitrogen and CO2 are mixed with gaseous fuels to deal with the problems of jet diffusion combustion when natural gas-based fuels are injected directly into the cylinder, such as reduced thermal efficiency due to longer combustion periods and NOx emissions that currently require after-treatment systems. The effect of gas emulsions was verified through high-speed visualization of the combustion process, thermogenesis analysis, and measurement of NOx, CO, and HC in the exhaust gas by attaching an originally designed high-pressure gas direct injection valve to the RCEM. emission reduction is smaller than that of water emulsification in liquid fuels, and the reasons for this are essentially discussed.

Chapter 6 proposes a method of mixing hydrogen into direct-injection natural gas-based fuel using the RCEM, as a promising measure to promote the introduction of hydrogen as a future CF fuel into marine propulsion engines. The development behavior of high-pressure gas jets during hydrogen addition is observed, and the CO2 reduction (hydrogen addition amount), heat generation process, NOx, CO, and HC emissions.

Chapter 7 summarizes the results of this thesis's wide range of measurements and analyses and mentions their academic and engineering contributions.