Proceedings of the 10th World Congress on Momentum, Heat and Mass Transfer (MHMT 2025)
Barcelona, Spain – April, 2025
Paper No. CSP 123
DOI: 10.11159/csp25.123

Simultaneous Research and Development of Carbon-neutral Heavy-duty Vehicles and Construction Machinery powered by Hydrogen ICEs

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Extended Abstract

The industrial sector accounts for 34% of Japan's carbon dioxide emissions and the transportation sector for 18.5%; total annual emissions of carbon dioxide are approximately 550 million tons. [1] Carbon dioxide is one of the primary contributors to global warming, and both sectors face strong demands for significant reductions in their carbon dioxide emissions. Reductions of carbon dioxide emissions from construction machinery and heavy-duty vehicles are required in both sectors. Various research and development efforts are being actively promoted to achieve carbon-neutral powertrains. Among the approaches based on the choice of fuel, electricity and hydrogen have emerged as promising candidates. Notably, electric vehicles have garnered significant attention due to technological advances and market potential. In the case of electric heavy-duty construction machinery and electric heavy-duty vehicles, challenges remain regarding operating time and driving range due to energy density constraints. Consequently, attention has been directed toward hydrogen-only internal combustion engines, which offer larger cost advantages and better retrofit feasibility compared with electric powertrains. In this study, two types of diesel engines were modified and converted to hydrogen engines designed for construction machinery and heavy-duty vehicles. Engine bench tests were conducted to evaluate the performance and characteristics of these hydrogen engines.

The construction machinery hydrogen engine was based on a 5.2L inline four-cylinder direct-injection diesel engine, while the heavy-duty vehicle hydrogen engine was based on a 5.1L inline four-cylinder direct-injection diesel engine. Both engines were modified by replacing the pistons to accommodate hydrogen and adding an ignition system and a hydrogen fuel supply system, and were equipped with dedicated electronic control units. In the engine bench tests, the C1 mode (discrete) was adopted for the construction machinery hydrogen engine, whereas the World Harmonized Stationary Cycle (WHSC) was employed for the heavy-duty vehicle hydrogen engine under steady-state operation. [2] [3]

The bench test results for the construction machinery hydrogen engine and the heavy-duty vehicle hydrogen engine revealed the following output characteristics: the former hydrogen engine achieved a maximum output of 108 kW and a peak torque of 500 Nm, while the latter hydrogen engine achieved a maximum output of 157 kW and a peak torque of 665 Nm. Notably, these output characteristics reached 90% of the output characteristics of the base diesel engines. The combination of thermal efficiency and NOx emissions was calculated for the maximum thermal efficiency control setting and the minimum NOx emissions control setting in each operating mode. Since operating modes and emission regulation values for hydrogen engines have not yet been defined in Japan, this study referenced the operating modes and emission standards of diesel engines as guidelines. For the construction machinery hydrogen engine, the control parameters that maximized thermal efficiency yielded a net thermal efficiency of 39.7% and NOx emissions of 1.40 g/kWh, while the control parameters that minimized NOx emissions resulted in a net thermal efficiency of 38.7% and NOx emissions of 0.40 g/kWh. For the heavy-duty vehicle hydrogen engine, the control parameters that maximized thermal efficiency resulted in a net thermal efficiency of 32.3% and NOx emissions of 1.36 g/kWh, while the control parameters that minimized NOx emissions resulted in a net

thermal efficiency of 31.5% and NOx emissions of 0.6 g/kWh. These results indicate that the construction machinery hydrogen engine has the potential to achieve thermal efficiency exceeding 38% while meeting NOx emission regulation standards without the application of an after-treatment device in the C1 mode comprehensive evaluation. For the heavy-duty vehicle hydrogen engine, a low NOx emission value of 0.60 g/kWh was achieved in the comprehensive evaluation simulating the WHSC mode without the use of an EGR after-treatment device.

References

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