Numerical and Experimental Study of Reduction of NOx on Diesel Combustion by Using Water Injection Systems

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Abstract

Marine diesel engine has been demanded dramatically to reduce harmful regulated pollutants, which are Particulate Matter (PM) and Nitrogen Oxide (NOx). In particular, NOx regulations for marine engines will require NOx reduction as much as 80% from the level in the first emission standard from IMO. Introduction of water into the combustion chamber has been recognized as an effective measure reducing NOx emissions from medium-speed marine diesels. There are two practical methods of water injection into the cylinder, FWE (Fuel Water Emulsion) and DWI (Direct Water Injection). The former method is to replace the diesel fuel with diesel/water emulsions as an alternative fuel. And the latter method is to inject the water directly into the combustion chamber separately from the fuel with two injectors or a single injector. However, optimization of these water injection systems has not been established yet. In this study, to observe spray propagation and combustion process of fuel-water emulsion and DWI system, experiments were carried out using a Rapid Compression and Expansion Machine (RCEM) with an electronic controlled double-needle type injector. This RCEM has a bore of 240 mm and a stroke of 260 mm. Combustion chamber is cubic shaped volume consisted of 200 x 66 x 80 mm and it has three quartz windows on the walls for objective of visualization. The pressure and the temperature of this combustion chamber at the injection were set to 10 MPa and 750 K, respectively. The combustion processes were taken by photographs directly using high speed camera (Photoron: Fastcam SA-4). Spatial resolution of photographs is 832 x 224 pixels and frame rate is 20,000 fps and exposure time is 5.8μs. In addition, temperature distribution of diesel flame was obtained from photographs analysed by Two Colour Method (TCM). After combustion, CO, CO2, O2, THC and NOx in the burned gas were measured by using exhaust gas analyser (HORIBA: MEXA-7100). Simulation of spray propagation and combustion processes were also carried out using three-dimensional CFD code: KIVA3V in order to evaluate the effect of water vapour distribution on cylinder temperature and NOx formation. In the DWI system, numerous and immiscible droplet collisions should happen inside the merging sprays from closely-located injection holes for water and fuel. Authors had developed the new collision models for simulating the complicated colliding behaviour of these immiscible droplets and implemented into KIVA3V code. Concentric water-in-oil type droplet had to be newly introduced as an outcome of oil and water droplet coalescence. And different treatments in calculating its breakup and evaporation processes were considered. Concentric water-in-oil type droplets were injected as an emulsion fuel in case of emulsion system. It has been concluded that when the water was injected appropriately, the temperature of flame became lower than in conventional diesel combustion. NOx emissions were reduced up to 40% with water addition of 25% of fuel mass in both the water injection technologies. The computational results were in agreement with experimental measurements and provided detailed information on the mixing process.

Key words: diesel sprays, modeling, emulsion, direct water injection, marine diesel engine

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