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DOCTORAL THESIS

Experimental and numerical study on ammonia fueled compression ignition engine

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Abstract

Ammonia is currently receiving more interest as a carbon-free alternative fuel for internal combustion engines. A promising energy carrier, easy to store and transport, being liquid, and has zero carbon-based emissions which makes ammonia a green fuel to decarbonize internal combustion engines and reduce greenhouse gas emissions. This thesis explores the development and use of ammonia with pilot diesel in dual fuel compression ignition engine, by retrofitting a single-cylinder diesel engine for experimental and numerical analyses. Hence, the first part of the thesis involves experimental development and the procedure of utilizing ammonia as a primary fuel with biodiesel in a dual-fuel mode. Thus, a single-cylinder diesel engine was retrofitted to introduce gaseous ammonia into the intake manifold, and then a pilot dose of biodiesel was injected into the cylinder to initiate combustion of the premixed ammonia-air mixture. The effects of various ammonia mass flow rates with a constant biodiesel dose on engine performance and emissions were investigated. In a subsequent study, the impacts of substituting diesel fuel with gaseous ammonia in a dual fuel engine were examined. The effects of various ammonia diesel ratios on combustion, emissions, and engine performance were tested. Additionally, a developed 1D model was utilized to analyze the performance of the dual fuel engine. The second part of the thesis discusses the development of two injection systems for the direct injection of liquid ammonia and biodiesel in a dual direct injection engine. The effects of liquid ammonia and ammonia energy share were investigated. In addition, various ammonia injection timings were studied to improve ammonia/biodiesel combustion and reduce emissions. Furthermore, a CFD model was developed and validated with experimental data to study ammonia sprays, combustion characteristics, and emissions formation. Finally, the impacts of the biodiesel injector configuration and its number of nozzles were explored. Hence, the number of nozzles in the biodiesel injector was blocked by welding in various configurations to improve injection and engine performance. Moreover, different injection timings of biodiesel were tested to determine the optimal injection timing for biodiesel in the dual direct injection engine. The main findings showed that a maximum of 84.2% of input energy can be provided by gaseous ammonia in port injection. Increasing the ammonia energy share changed the combustion mode from diffusion to premixed combustion resulting in a short combustion duration. Although ammonia significantly reduced CO_2, CO, and particulate matter emissions, it also increased NOx emissions and unburned ammonia (14800 ppm) in the port injection strategy. The results of dual direct injection strategy showed that higher ammonia energy share significantly reduced the local cylinder temperature due to the strong cooling effects of ammonia, therefore, a maximum ammonia energy share of 50 % was achieved. Direct injection of liquid ammonia reduced unburned ammonia by 10813 ppm compared to port injection. Moreover, the optimal injection timing for ammonia and biodiesel was determined at -10 and -16 CAD, respectively. Finally, since biodiesel was used as pilot fuel with lower injected mass, blocking three nozzles of the original six-nozzle injector increased indicated efficiency and reduced CO and NH_3 emissions.