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## Comparison of combustion process of ammonia internal combustion engine:

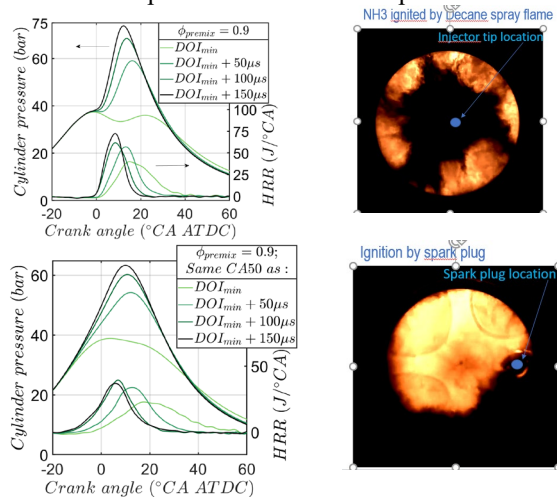
### Premixed and RCCI combustion

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#### Abstract

The increased interest in ammonia as a hydrogen carrier and a carbon-free fuel for combustion applications continues to present several challenges to address. Ammonia combustion properties, such as the low Laminar Flame Speed, i.e., 7 cm/s in comparison to 40 cm/s for current gasoline or 210 cm/s for pure hydrogen, and the high minimum ignition energy, 8 mJ in comparison to gasoline and hydrogen (both under 0.2 mJ), can result in instabilities and cold starts difficulties for operating as a fuel for Internal Combustion Engines (ICE) [1-3]. Moreover, the high auto-ignition temperature (925 K) limits the use of ammonia in compression ignition engine at very high compression ratio (more than 25). Therefore, the retrofit of diesel marine engine is feasible if an ignition system, like a spark plug or an ignition promoter, like a reactive fuel are added. Therefore, the objective of this study is the comparison of the ammonia combustion process in Spark-Ignition (SI) and Reactivity Controlled Compression Ignition (RCCI) combustion modes, in a diesel single cylinder engine (with or without optical accesses) with the objective of comparing both ignition processes and the resulting emissions. The combustion development of ammonia ignited by the injection of diesel (or a surrogate, the decane, in the case of optical engine), as a pilot-fuel shows that the heat release rate could be in two stages as a function of the injection phasing and the diesel energy fraction, one stage related to the pilot-fuel combustion followed by the ignition of the premixed ammonia/air mixture, due to the local increase of temperature and radical specie. From the first visualization of radicals in the optical engine, it is observed that an increased delay of the Start of Ignition related to the radical's production and consumption.



For the same engine operating with Spark-Ignition, the flame propagation is very similar to a classical premixed combustion in gasoline engine [4], but the combustion duration (CA90-CA10) is much longer when operating in Reactivity Controlled Compression Ignition (RCCI) mode. In regards of engine emissions, the unburned  $\text{NH}_3$  emissions seems to bottom out at 1% (for both combustion modes) related to combustion chambers crevices due to the diesel engine design, that trap the ammonia. Moreover, the flame quenching distance for ammonia flame is estimated to be 2 times that of gasoline.  $\text{NO}_x$  emissions are higher with SI than RCCI and in this case, they are reduced considerably when increasing the diesel energy fraction.

The global warming impact is much reduced than traditional fossil-fuels based engines, but carbon dioxide is present for RCCI due the pilot-fuel and the  $\text{N}_2\text{O}$  emissions (265 times greater than  $\text{CO}_2$ ) is mostly constant at 50 ppm for both combustion modes for vary premixed equivalence ratios. Further studies are needed to get a better understanding of ammonia/diesel fundamental combustion properties (auto-ignition delay, kinetic mechanisms, local air/fuel distribution, turbulent enhancement of the combustion...) and experiments of the interaction between premixed ammonia/air and the pilot-fuel spray.

**Keywords:** diesel design engine, Ammonia, combustion process, premixed combustion, RCCI combustion, emissions

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