A Computational Study of Hydrogen Engines: Spark Ignition vs. Pre-chamber

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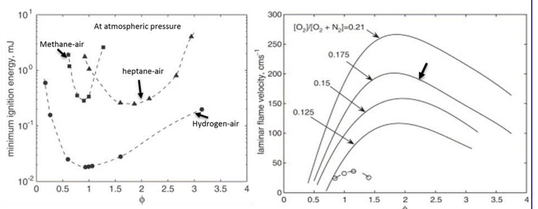
Introduction

Hydrogen is a promising future fuel to enable the transition of transportation sector toward carbon neutrality. The direct utilization of H_2 in internal combustion engines faces two major challenges: high NO_x emissions and severe pressure rise rates and pre-ignition at mid to high loads. The current investigation starts with assessing the feasibility of converting an existing compression ignition diesel engine into operation with hydrogen in spark ignition (SI) or pre-chamber (PC) modes. The practical goal is to implement a retrofit solution with minimal changes to an existing commercial engine architecture.

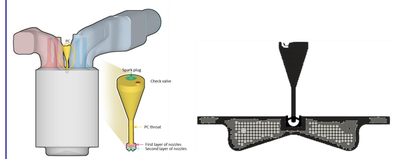
Why ultra lean conditions?



In this study, the potential of H_2 combustion in a truck-size engine operated in SI and PC mode was investigated. To mitigate the high pressure rise rate with the SI configuration, the effects of three primary parameters on the engine combustion performance and NO_x emissions were evaluated, including the compression ratio, the air-fuel ratio, and the spark timing.

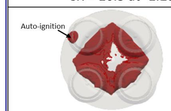
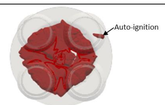
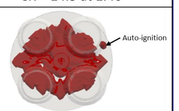
Methodology

CONVERGE™ 3.0 was used to conduct 3-D CFD simulations.

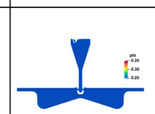
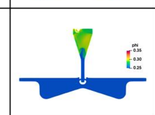
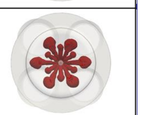
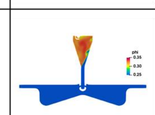
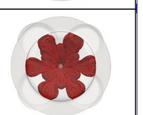
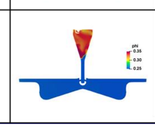
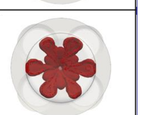


Engine type	4-stroke
Bore/stroke (mm)	131/158
Connecting rod length (mm)	255
Displacement volume (L)	2.13
Geometric compression ratio	17:1
Intake valve open (°aTDC)	347
Intake valve close (°aTDC)	-167
Exhaust valve open (°aTDC)	-140
Exhaust valve close (°aTDC)	352
H_2 injected mass (mg/cycle)	38.2

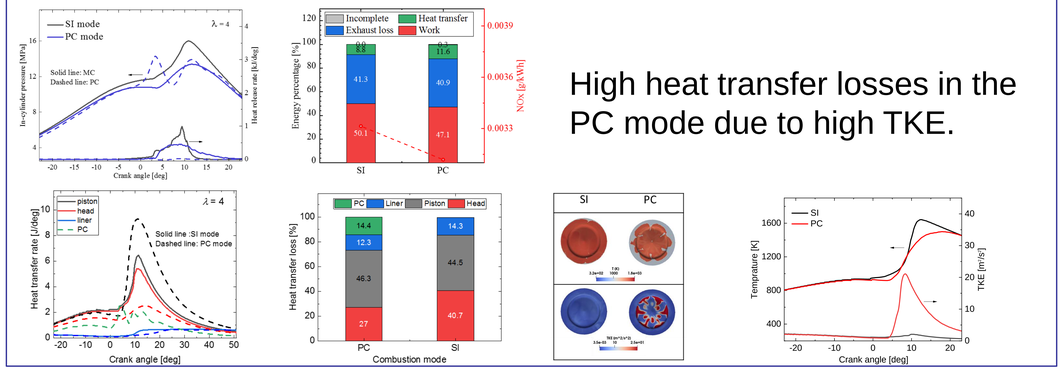
Detecting knock for different of CR using SI mode

CR = 16.5 at -1.28°	CR = 15.5 at 0.116°	CR = 14.5 at 1.40°
		

Effect of using different PCFR% in PC mode

	-2 CAD	2 CAD	4 CAD	5 CAD
PCFR 0%				
PCFR 0.5%				
PCFR 1%				
PCFR 1.5%				

Results



High heat transfer losses in the PC mode due to high TKE.

Summary

As an overall comparison between SI and PC mode for the conditions under study, the PC mode generated a higher heat transfer loss owing to the significantly stronger jet flame-piston wall interaction and additional heat transfer through the PC assembly. Due to the high flame speed of H_2, even under ultra-lean conditions, a high ITE was achieved even at the SI mode by optimizing the ST and air-fuel mixture preparation. Moreover, combining moderate CRs with air dilution could be a potential solution to allow a larger range for engine controllability where PC can be more suitable compared to the normal SI mode.

Ongoing Work

- Validating the simulation results against the experiment.
- Optimization of the PC geometry through machine learning.
- Direct injection mode for H_2 combustion.