Investigation of a multiple spark ignition approach to burn ammonia in a spark ignition engine: An optical study

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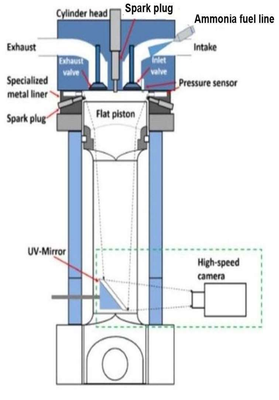
KAUST Research Conference:
Hydrogen-Based Mobility and Power

Introduction

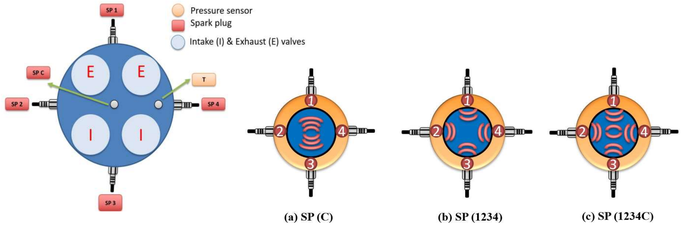
- The future of the internal combustion (IC) engine will rely on renewable carbon-free fuels to mitigate climate change.
- Ammonia (NH_3) is a promising carbon-free fuel which can be used as an energy carrier for hydrogen (H_2) and directly as a combustible fuel inside the engines.
- The production industry of NH_3 is well matured, and life cycle analysis (LCA) shows that it can be produced from air, water, and non-conventional energy sources.
- Burning pure ammonia fuel is difficult due to its low flammability, high ignition energy, low burning velocity, and consequent large cycle-to-cycle variation.
- This study used a multiple-spark-plug approach to burn pure ammonia gas with reduced combustion duration and higher engine power output. The natural flame luminosity (NFL) imaging method was used to capture the multiple flames initiated by various ignition sites
- Firing a single central spark plug generated unstable combustion with higher combustion duration at low compression ratio.
- Adding more spark plugs increased the cylinder pressure generation and HRR along with creating shorter combustion duration for the same operating conditions.

Experimental setup



Description	Specification
Swept volume	511 cc
Engine speed	1200 rpm
Intake pressure & Temperature	1 bar & 25 °C
Relative air/fuel ratio (λ)	1
Spark timing (ST)	-30 CAD aTDC
Camera type	Photron- SA4
Frame rate	36000, fps
Compression ratio	10.5
Image resolution	320 x 272
Ammonia injection pressure	4 bar

Methodology

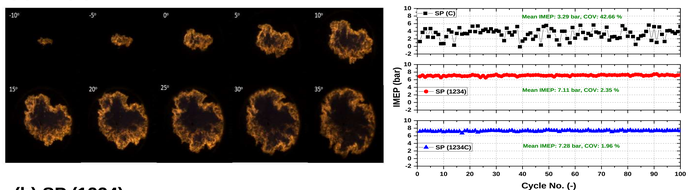


Representation of ignition cases

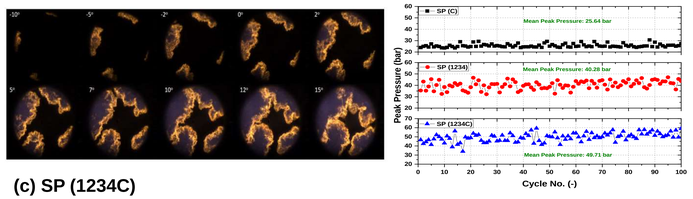
Results

Case 1: Combustion characteristics at λ = 1.0 and ignition timing -30 CAD aTDC

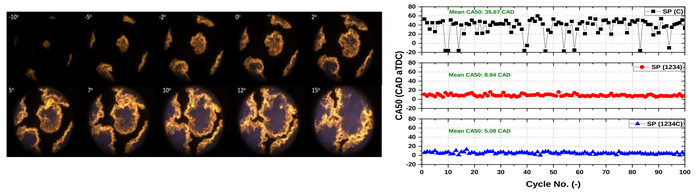
(a) SP (C)



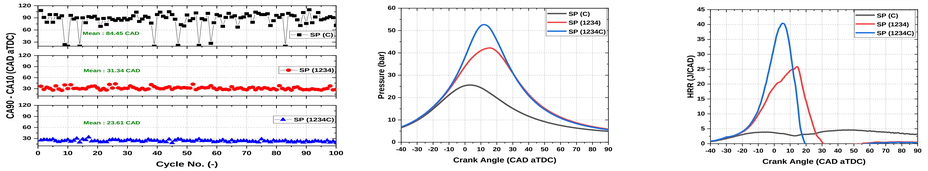
(b) SP (1234)



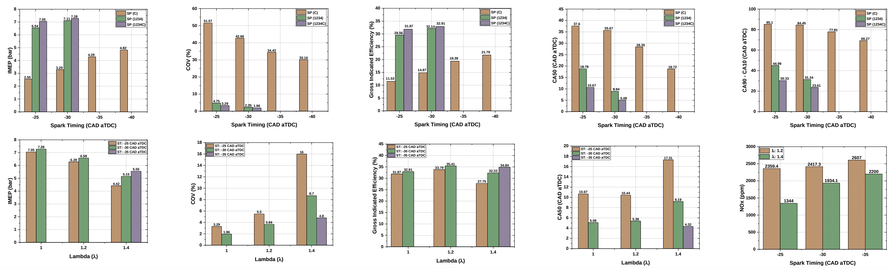
(c) SP (1234C)



Results



Case 2: Effect of ST and relative air-fuel ratio (λ)



Summary

- Compared with the traditional single sparking method in conventional SI engines, multiple ignition sites produce higher in-cylinder pressure and HRR for the same operating conditions.
- Cycle-to-cycle variation shows that multiple ignition sites reduce the CA50 and increase the IMEP values, together with providing a lower coefficient of variation of indicated mean effective pressure (COV of IMEP).
- Single spark ignition "SP (C)" case showed multiple misfire cycles with a COV of IMEP higher than 42%. However, the SP (1234) and SP (1234C) cases generated very stable combustion with COVs of IMEP of 2.36% and 1.96% respectively.
- Earlier spark timing showed higher engine power output and shorter combustion duration due to the higher in-cylinder pressure and temperature generated by early compressed flame.
- The highest gross indicated efficiency was obtained while triggering multiple spark ignition cases due to higher cylinder pressures. The mean efficiencies obtained were 32.2%, 31.5%, and 14.5% for the cases of SP (1234C), SP (1234), and SP (C) , respectively.
- Adding more spark plugs produced shorter combustion duration with more-advanced combustion phasing (50% mass fraction burned point, or CA50). The lowest CA50 of 5.1 CAD was recorded for the SP (1234C) case. However, the single plug SP(C) case produced a later CA50 of 35.7 CAD aTDC.
- Multiple ignition sources allow ammonia fuel to be burnt at lean conditions even at the low compression ratio used here. The SP (1234C) case permitted the use of a lean λ value of 1.4 with acceptable COV of IMEP of 4.8%.
- Furthermore, firing multiple spark plugs produced higher NOx emission than the single spark plug case due to the higher in-cylinder temperatures generated by multiple flame kernels. At λ = 1.2, higher NOx emission were obtained, because greater amounts of oxygen in the air-fuel mixture permit the oxidation of nitrogen (present in the fuel) into NOx. Further moving to λ = 1.4, reduces the NOx emission due to the lower in-cylinder temperatures generated by leaner mixtures.

Ongoing Work

- Analyze the combustion of ammonia fuel by using other liquid fuels such as gasoline, methanol, ethanol, etc.
- Investigate the combustion phenomena of ammonia gas by using gaseous fuels such as Methane (CH4) and Hydrogen (H2).
- Optical investigation of ammonia fuel in SI engine by capturing various species, such as NOx, NH* etc.