High Pressure liquid Ammonia Injection ?

- Bosch solenoid injector with a convergent single hole nozzle (300 µm).
- High-pressure container, heated up to increase pressure
- Liquid ammonia extracted from the container, cooled down to prevent cavitation + fed into a high-pressure pneumatic pump.
- Return-leakage line : pressure increased up to 1MPa
- Injector holder with a cooling system with glycol (15ºC)

➢ Injection pressure of 80MPa.

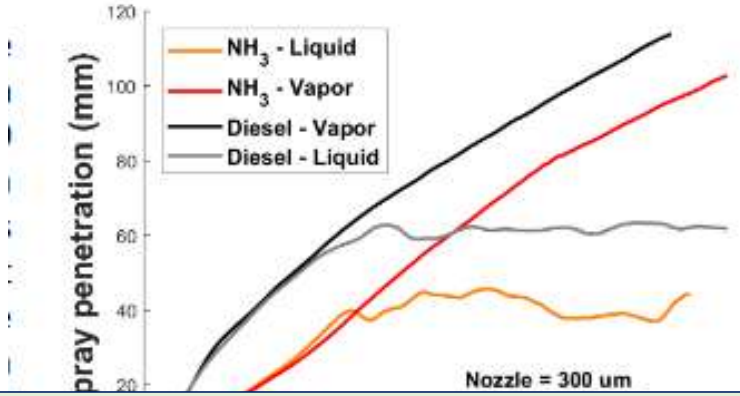


Figure 3. Liquid and vapor phase penetration at injection pressure of 60MPa. NH_3 and diesel comparison.

Accuracy of vaporisation model/CFD ? Diesel model consistant ?

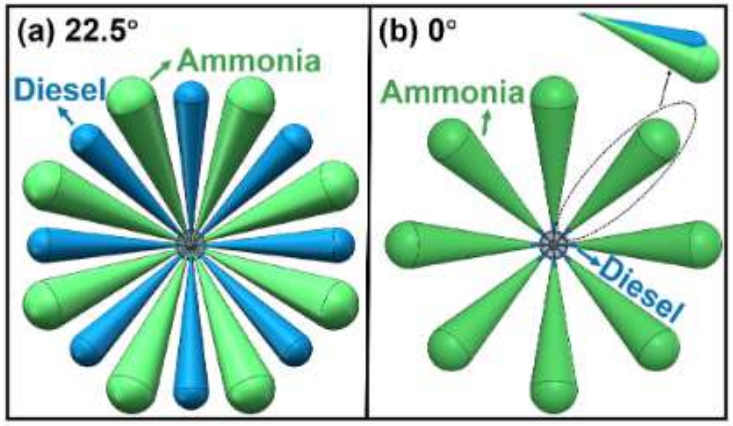
The Journal of Ammonia Energy

2nd Symposium on Ammonia Energy

Direct injection ammonia spray characterization under non-reacting diesel-like conditions

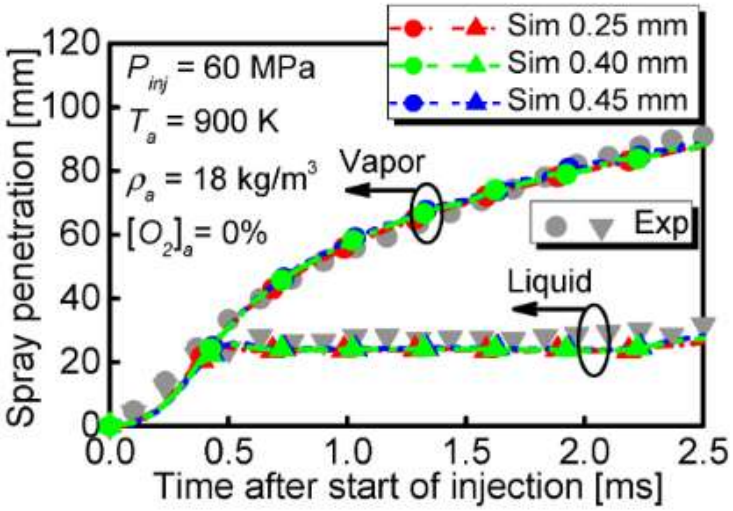
García, José María[a]; Bracho, Gabriela[a*]; de la Morena, Joaquín[a*]; Cao, Jiawei[a].

Best Ammonia / Reactive Fuel injections ?



lation. However, there is no available experimental data for high-pressure injection liquid ammonia spray under the thermodynamic conditions near the top dead center, while liquid ammonia has the rather different properties such as significantly lower boiling point and higher latent heat than liquid hydrocarbon fuels, causing calibration of spray sub-models very critical for engine combustion simulation.

tion, an in-house pressure accumulator capable of the maximum fuel injection pressure of 300 MPa and a single-hole diesel injector with the hole diameter of 0.22 mm were used for ammonia injection. For the fuel



For the HPDF mode, accurate predictions of the spray mixture formation processes are very critical, because the heat release rate will be controlled by the fuel-air mixing rate. As a result, the turbulence and

Renewable and Sustainable Energy Reviews 173 (2023) 113108
Contents lists available at ScienceDirect
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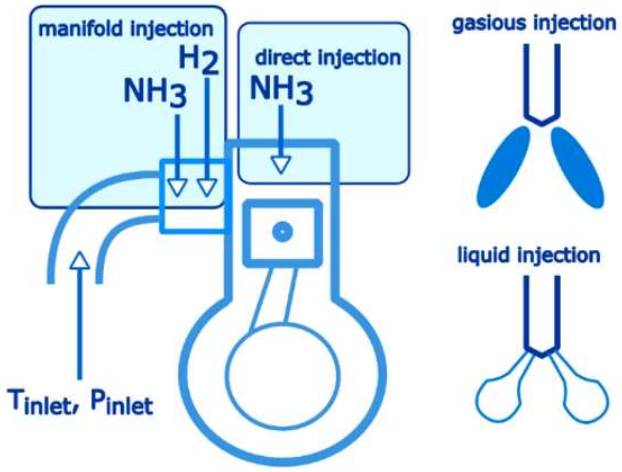
journal homepage: www.elsevier.com/locate/rser

Pilot diesel-ignited ammonia dual fuel low-speed marine engines: A comparative analysis of ammonia premixed and high-pressure spray combustion modes with CFD simulation

Xinyi Zhou[a,b], Tie Li[a,b,*], Ning Wang[b], Xinran Wang[b], Run Chen[a,b], Shiyan Li[a,b]

Ammonia as fuel for ICE engines



- Port-vapor fuel injection :
  - Displacement of the air supplied to the combustion chamber
    - Reduction of volumetric efficiency of the engine.
- Direct-vapor fuel injection
  - Reduction of in-cylinder temperature (ammonia´s high latent of heat)
- Liquid ammonia injection
  - better volumetric efficiency (no air displacement r and intake mixture cooling).
- Limited by narrow flammability limits and low flame speed
  - Uncomplete combustion ?
  - Misfire : ignition process ? Intrinsic flame instabilities ?
  - Ammonia more suitable for lower engine speeds due to its low flame speed ?
- One possible way to enhance mixing and thereby facilitate combustion of ammonia :
  - to increase turbulence in the combustion chamber ?

Example of SI Ammonia engine

- low flame speed + narrow flammable limits of ammonia
  = combustion instability (misfire)
- low combustion efficiency especially at low loads
  = more unburnt NH_3

Frigo et al. [15] investigated the cold start of a two-cylinder engine burning NH_3 with an external H_2 supply provided by a gas cylinder and concluded that the required flow rate of H_2 was 4.8 times larger than that of NH_3. The results of this prior work suggested that a H_2 sub-tank might be necessary in the case of cold starts.

Cold-start emissions remain a serious challenge associated with the use of NH_3 as a fuel. Specifically, unburned NH_3 will simply be released into the environment through the exhaust

INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 38 (2013) 1607–1615

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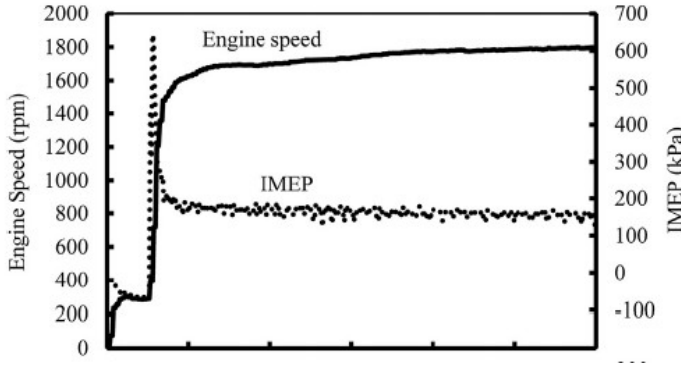
Analysis of the behaviour of a 4-stroke Si engine fuelled with ammonia and hydrogen

Stefano Frigo, Roberto Gentili* [1]



INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 46 (2021) 25689–25698

Available online at www.sciencedirect.com
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journal homepage: www.elsevier.com/locate/he

Cold-start performance of an ammonia-fueled spark ignition engine with an on-board fuel reformer

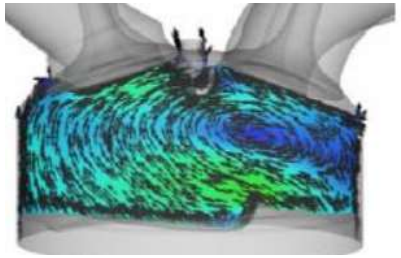
Makoto Koike [a,*], *Tetsunori Suzuoki* [a], *Tadashi Takeuchi* [b], *Takayuki Homma* [b], *Satoshi Hariu* [b], *Yoshitaka Takeuchi* [b]

[a] Toyota Central R&D Labs., Inc., 41-1 Yokomichi, Nagakute, Aichi, 480-1192, Japan
[b] Toyota Industries Corp., 8 Chaya, Kyowa, Obu, Aichi, 474-8601, Japan

One solution : increase the CR

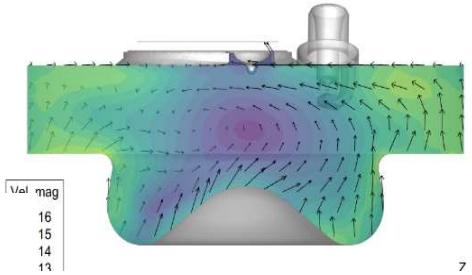
- Easy way : Compression Ignition engine with Spark Plug !
  - Retrofit ‘current’ Diesel engine (less expensive ..)
  - High Compression ratio : better for Ignition and Flame propagation
- But
  - No turbulence ? Only strong swirl motion ?
  - ‘classical piston bowl : unburnt ammonia ?

SI architecture



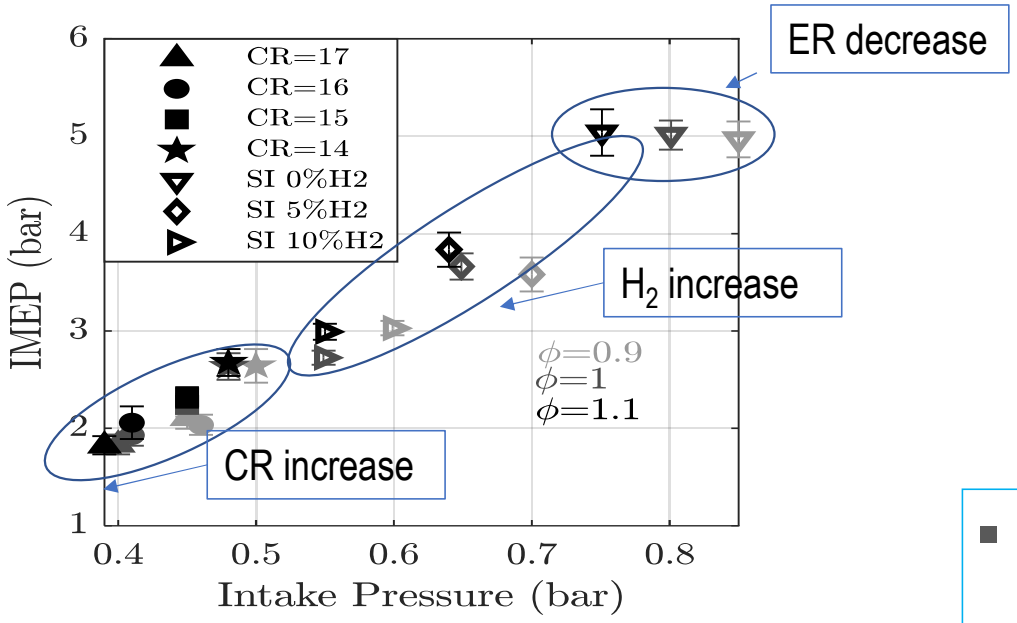
TKE+ Turbulent vortices

Diesel architecture



no TKE, no Turbulent vortices,
only big motion

One solution : increase the CR



Engine speed :1000 rpm

Engine Type	Current PSA EP6DT	SAD PSA DV6
Displacement Volume V_{cyl}	400 cm^3	400 cm^3
Compression Ratio	10.5	14 to 17
Valves	4	2
Tumble ratio	2.4	
Swirl ratio		2

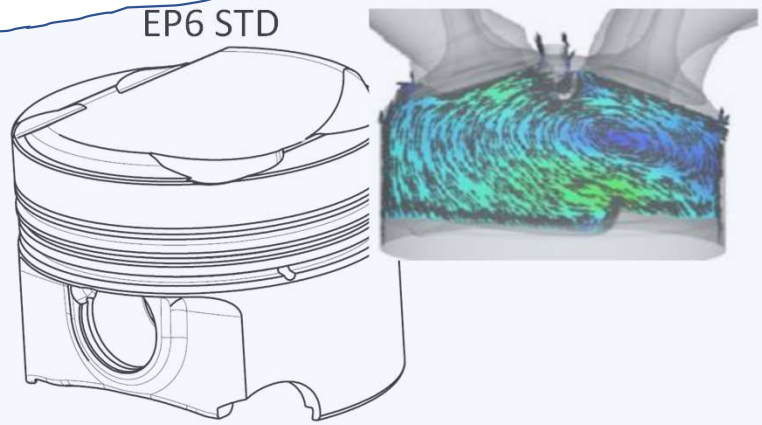
- Good improvement of NH_3 combustion with CR increase despite of flow field
- No H_2 needs
- Extension of low load limits
  - 1.7 b IMEP (as Koike et al. with Reformer)
  - CR 17, 650 rpm,
  - lower limit with slightly rich

areNH3a https://arenha.eu/

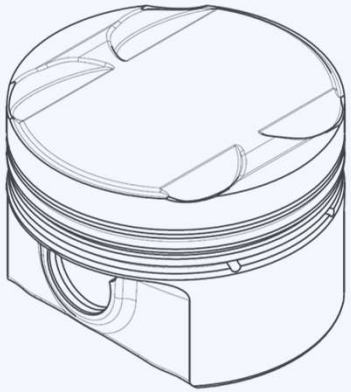
Other examples

SI engine

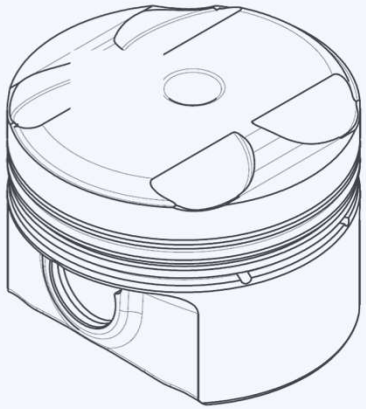
EP6 STD



EP6 CR 11.5

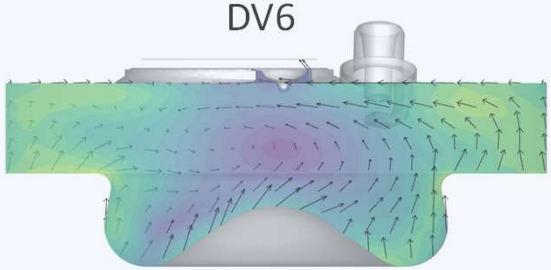


EP6 CR 14



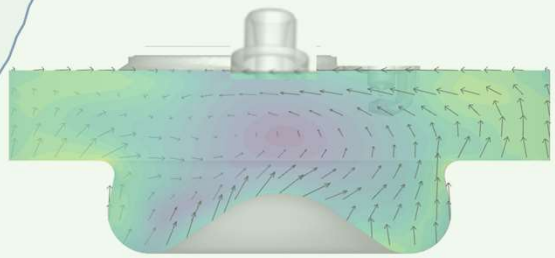
areNH3a https://arenha.eu/

DV6

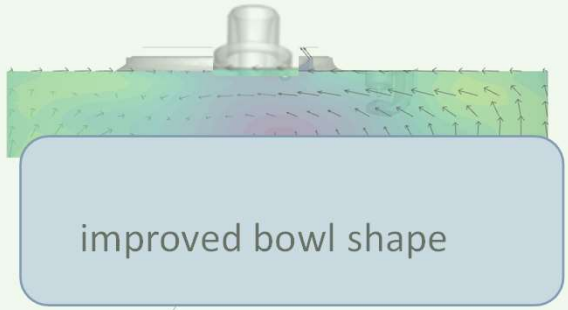


CI engine

DW10 REF



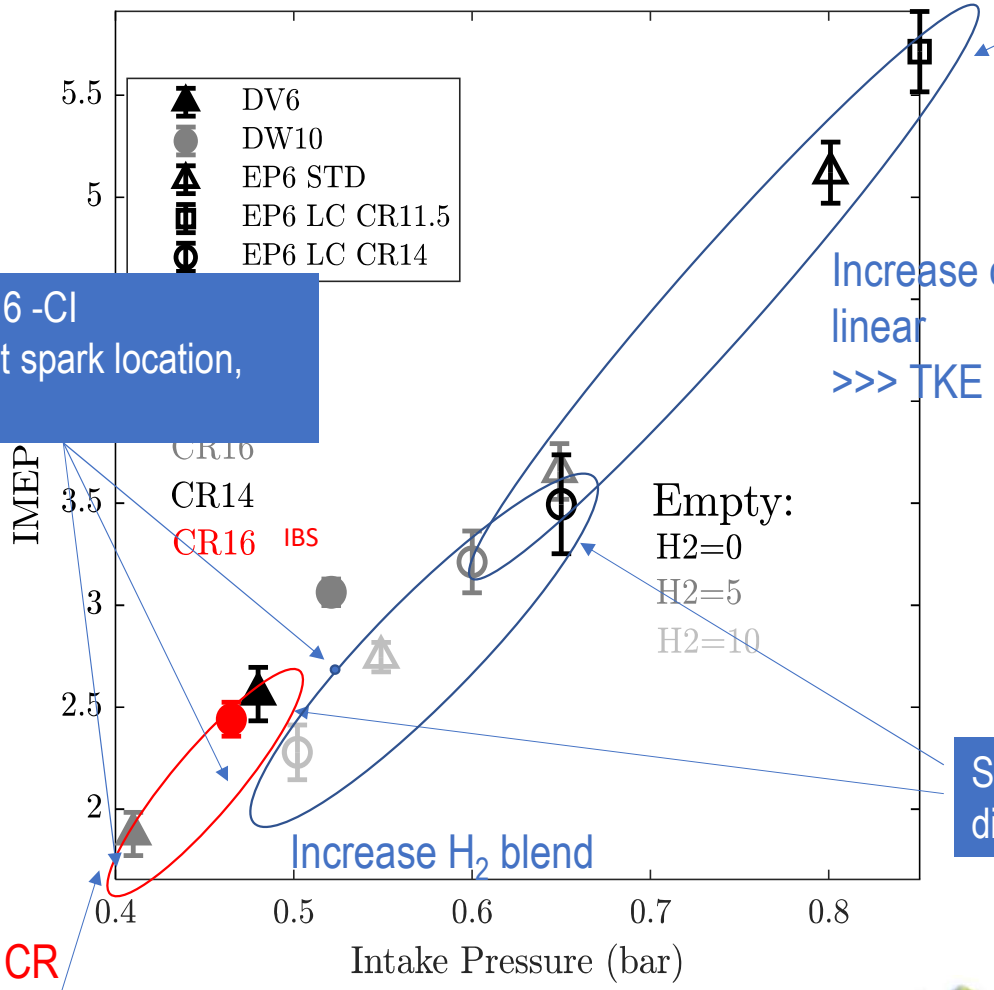
DW10 'IBS'



improved bowl shape

0.5l

Minimum IMEP @CovIMEP=5%



SI engine without H_2

Increase of CR ? Not linear
>>> TKE different

Same CR 16 -CI
But different spark location, bowl shape

Operating conditions:
- 1000 rpm
- Start of Ignition Timing = optimised
- Tintake ~50°C
- Equivalence Ratio =1

Same CR14
different engines : SI / CI

Increase H_2 blend

Increase of CR

DI with SI without H_2

PRISME

aramco

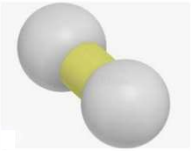
areNH3a

STELLANTIS

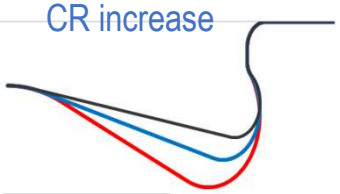
https://arenha.eu/

Other solutions ?

H_2 addition



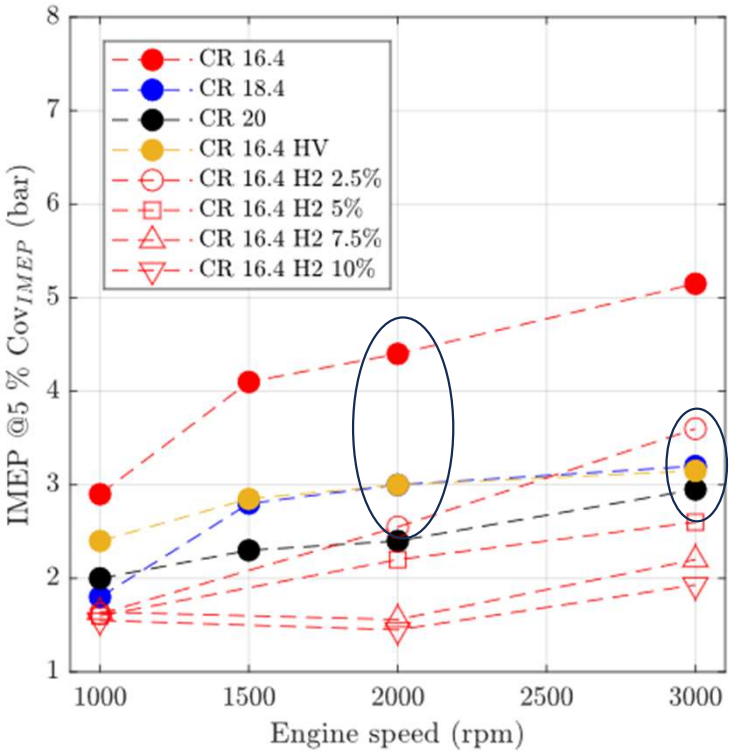
CR increase



HW Conf 01 : CR16
HW Conf 02 : CR18
HW Conf 03 : CR20

Ignition Improvement ?

30-60 mJ → 60-90mJ



lowest IMEP with high voltage SP
=
with high CR at all engine speeds

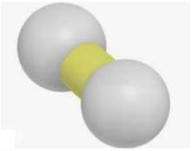
lowest IMEP with high voltage SP
=
4%vol. of H2 at high engine speed

Effect of compression ratio and ignition energy on ammonia pre-mixed combustion process in a single cylinder engine

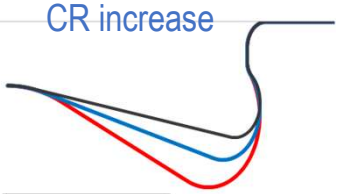
H. WON*, D. Kumar, V. Morel - Aramco Overseas Company B.V., Aramco Fuel Research Center, France
A. Mercier, C. Mounaïm-Rousselle - University of Orleans - Laboratoire PRISME, France
J. Bouriot, S. Houille and C. Dumand - STELLANTIS - Centre Technique Vélizy, France

Other solutions ?

H_2 addition



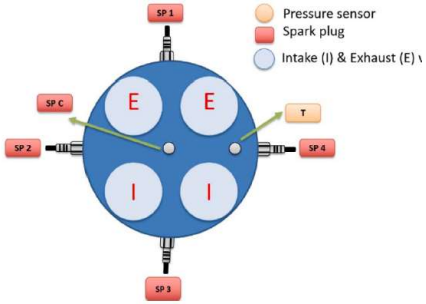
CR increase



HW Conf 01 : CR16
HW Conf 02 : CR18

Ignition Improvement ?

30-60 mJ → 60-90mJ



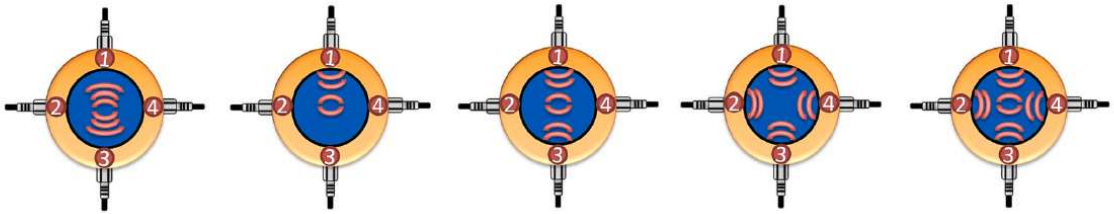
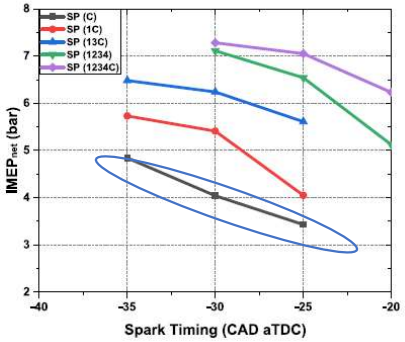
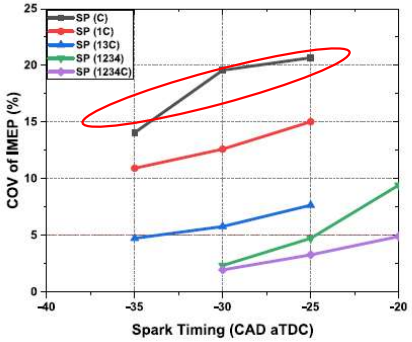


Fig. 2. Schematic of various spark plug locations and flame initiation.

IMEP @5 % Cov



(a) IMEPnet



(b) COV of IMEPnet

:age SP

speeds

:age SP

e speed

Fuel 349 (2023) 128741

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Full Length Article

A novel multiple spark ignition strategy to achieve pure ammonia combustion in an optical spark-ignition engine

Kalim Uddeen[a], Qinglong Tang[b,*], Hao Shi[c], Gaetano Magnotti[a], James Turner[a]

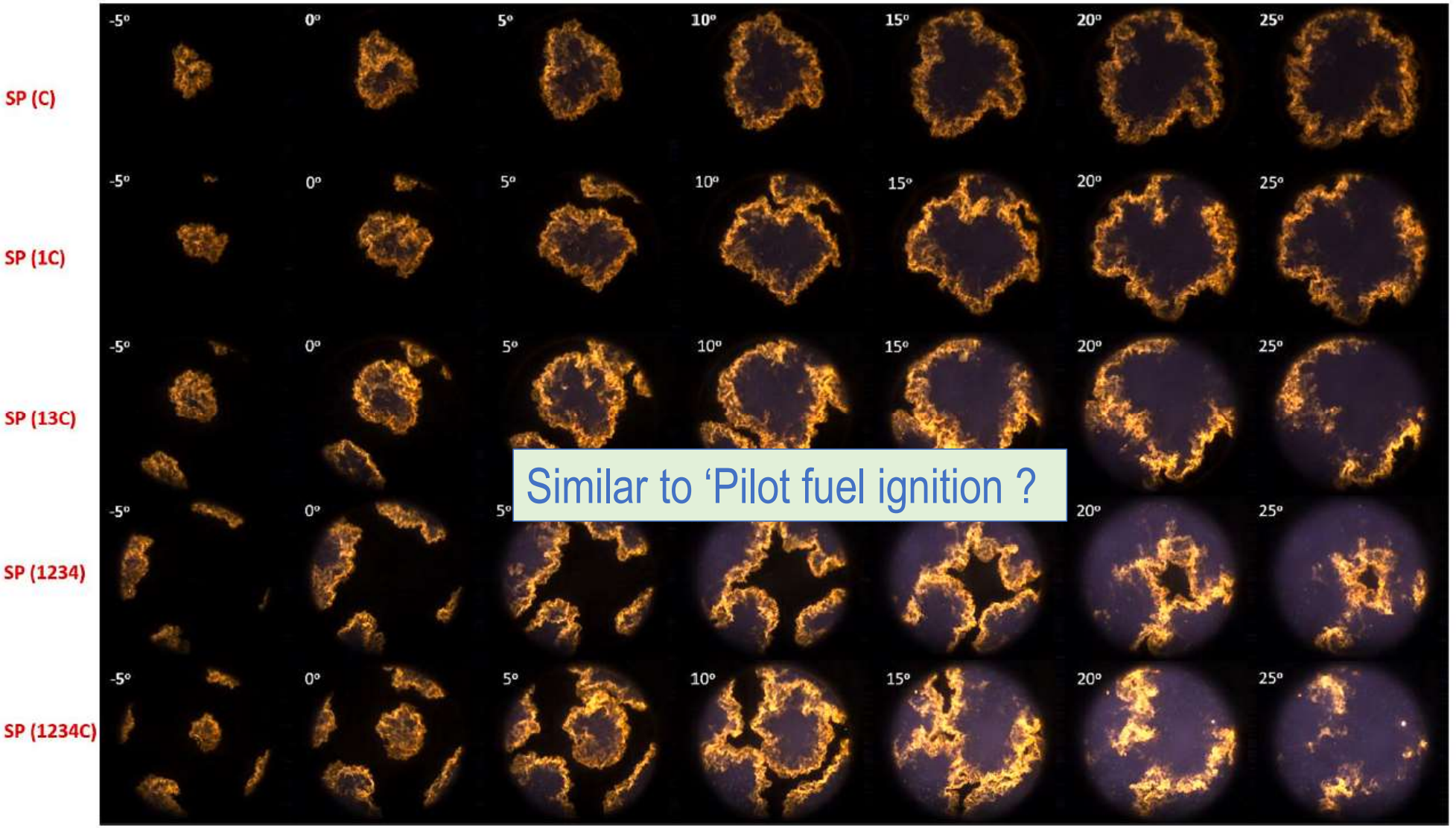
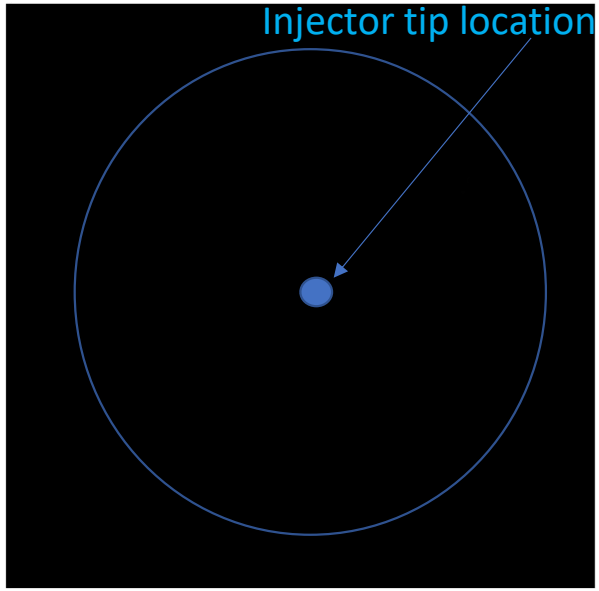


Fig. 8. High-speed NFL imaging for various ignition cases fired at a ST of −30 CAD aTDC for λ: 1.0 case.

Visualisation of ammonia flame propagation In ICE

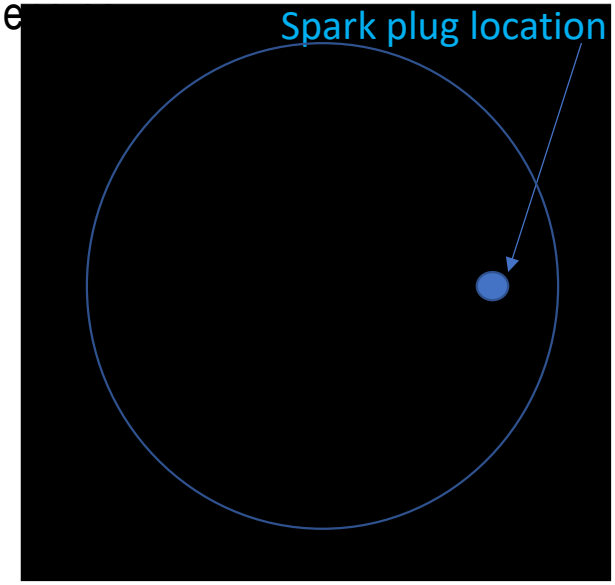
DUAL FUEL NH_3 -Decane



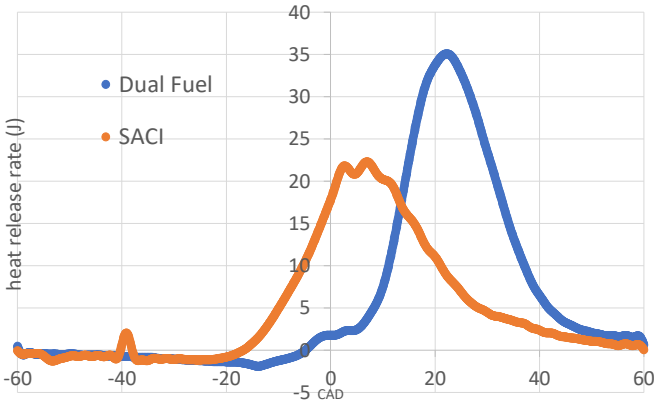
-10 CAD to 57 CAD ATDC

3 images/CAD

Spark Ignition in Compression Ignition e



-40 CAD to 27 CAD ATDC



- Start of Injection : -22 CAD, duration 6 CAD
- Pinj = 600 b,
  % decane/total fuel = 11% in Energy input
- E.R. total = 1.07, '*higher*' IMEP = 7.4 b

- Spark timing : -40 CAD
- IMEP = 6.7 b