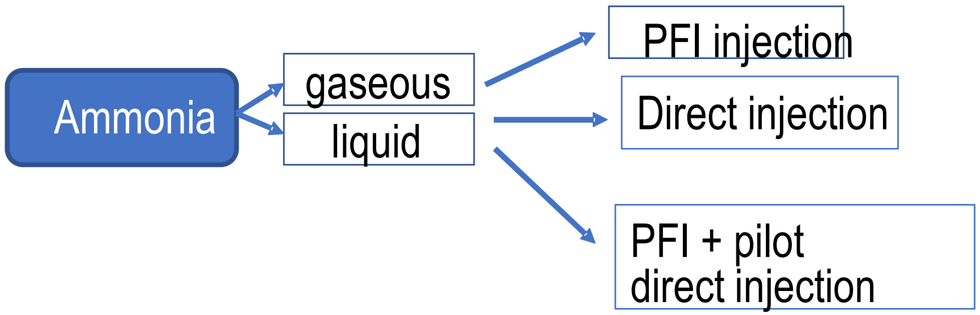
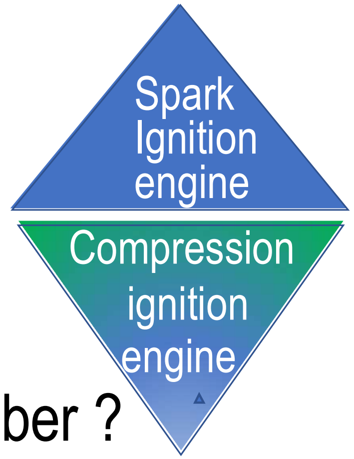
Best Possibilities to use ammonia (>95% !) in ICE ?

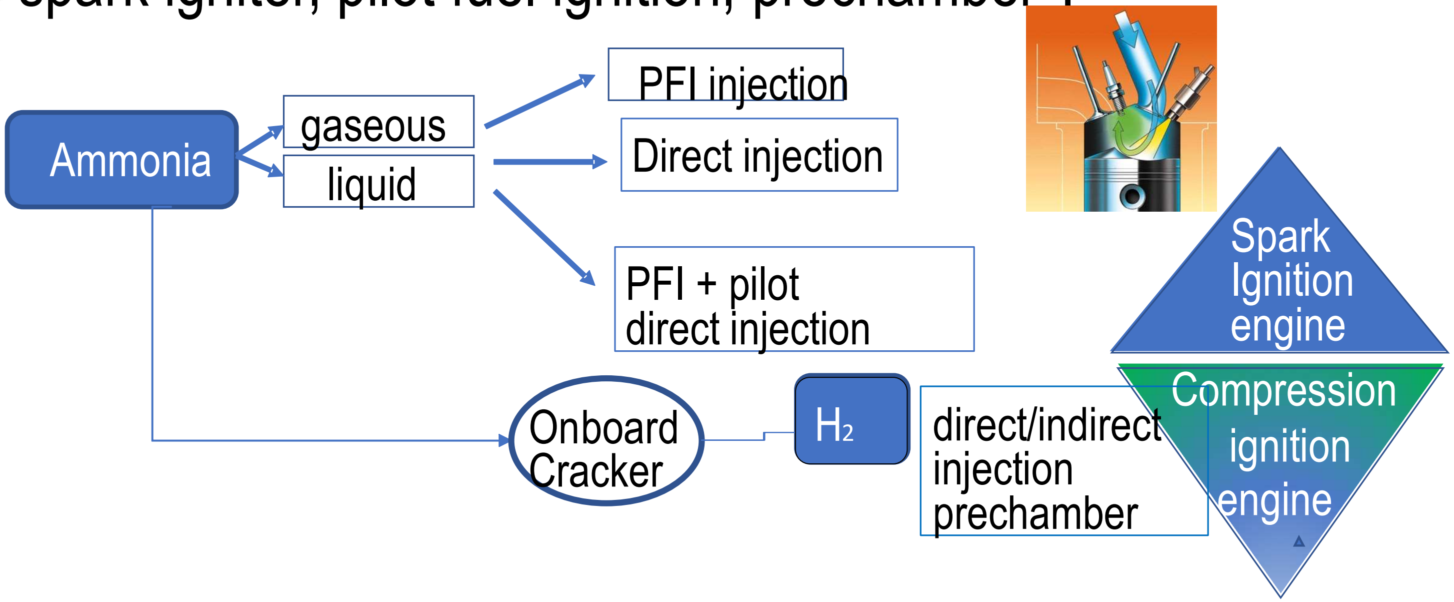




- Difficulties to auto-ignite NH_3
  - spark igniter, pilot fuel ignition, prechamber ?

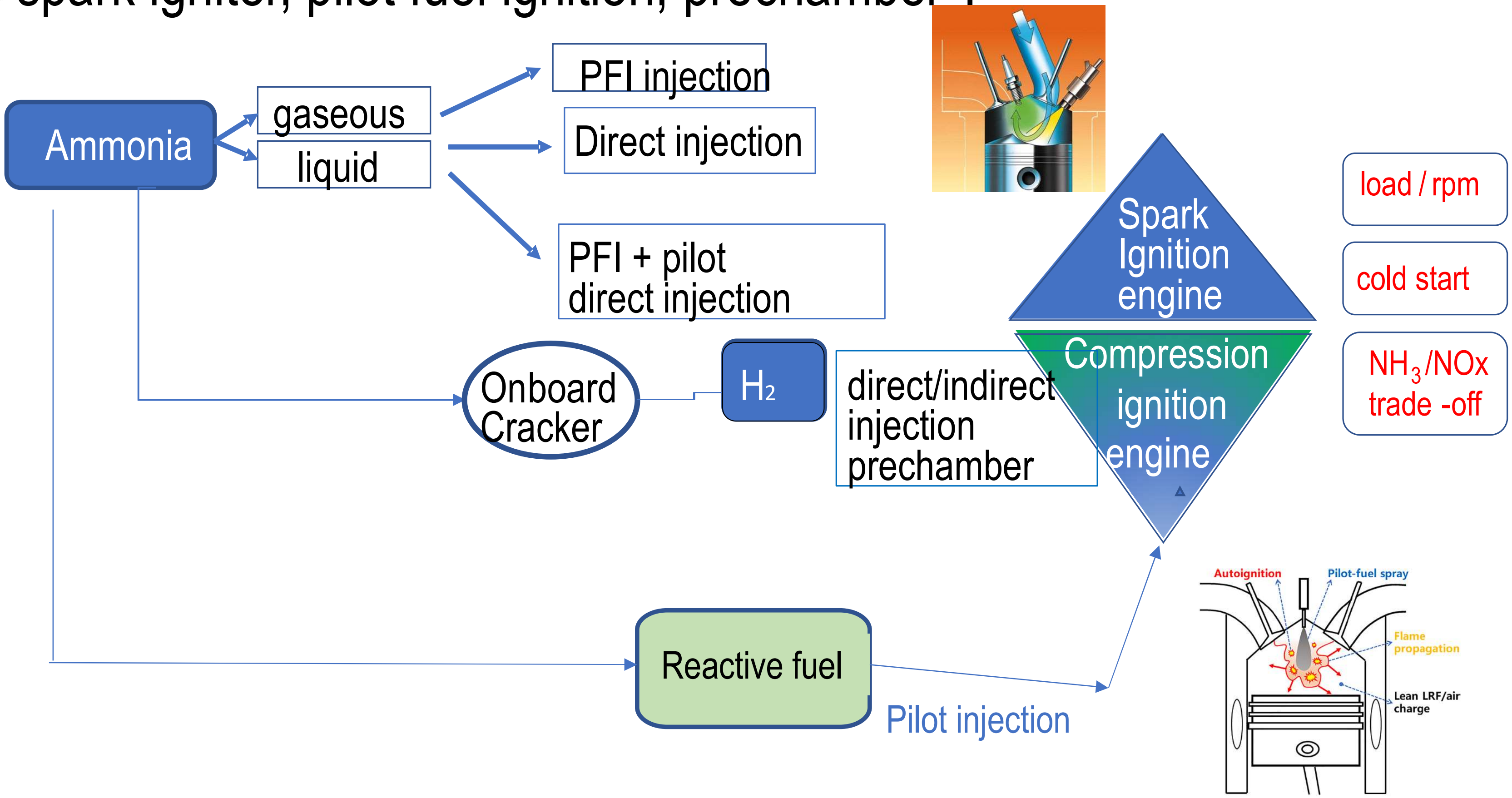
Best Possibilities to use ammonia (>95% !) in ICE ?

- Difficulties to auto-ignite NH_3
  - spark igniter, pilot fuel ignition, prechamber ?



Best Possibilities to use ammonia (>95% !) in ICE ?

- Difficulties to auto-ignite NH_3
  - spark igniter, pilot fuel ignition, prechamber ?



Yousefi, Amin; Guo, Hongsheng; Dev, Shouvik; Lafrance, Simon; Liko, Brian	A study on split diesel injection on thermal efficiency and emissions of an ammonia/diesel dual-fuel engine	2022	Fuel
Wang, Du; Ji, Changwei; Wang, Shuofeng; Yang, Jinxin; Wang, Zhe	Numerical study of the premixed ammonia-hydrogen combustion under engine-relevant conditions	2021	International Journal of Hydrogen Energy
Kurien, Caneon; Mittal, Mayank	Review on the production and utilization of green ammonia as an alternate fuel in dual-fuel compression	2022	Energy Conversion and Management
L… F…	…a spark-ignition engine by means of	2021	Proceedings of the Combustion Institute
W…	…mmonia/hydrogen mixtures on a marine	2021	International Journal of Hydrogen Energy
C… H…	…elled engines	2021	Energy Conversion and Management
W…	…ydrogen mixture under high-pressure	2021	International Journal of Hydrogen Energy
Zhang, Zhifei; Li, Tie; Chen, Run; Wang, Ning; Wei, Yijie; Wu, Dawei	Injection characteristics and fuel-air mixing process of ammonia jets in a constant volume vessel	2021	Fuel
Koike, Makoto; Suzuoki, Tetsunori; Takeuchi, Tadashi; Homma, Takayuki; Hariu, Satoshi; Takeu...	Cold-start performance of an ammonia-fueled spark ignition engine with an on-board fuel reformer	2021	International Journal of Hydrogen Energy
Ji, Changwei; Xin, Gu; Wang, Shuofeng; Cong, Xiaoyu; Meng, Hao; Chang, Ke; Yang, Jinxin			…onal Journal of …Energy
Oh, Sechul; Park, Cheolwoong; Kim, Seonyeob; Kim, Yongrae; Choi, Young; Kim, Changgi			
Yousefi, Amin; Guo, Hongsheng; Dev, Shouvik; Liko, Brian; Lafrance, Simon			
Liu, Long; Wu, Yue; Wang, Yang			
Cardoso, João Sousa; Silva, Valter; Rocha, Rodolfo C; Hall, Matthew J; Costa, Mário; Eusébio, Daniela	Ammonia as an energy vector: Current and future prospects for low-carbon fuel applications in internal combustion engines	2021	Journal of Cleaner Production
Böyükdipi, Ömer; Tüccar, Gökhan; Soyhan, Hakan Serhad	Experimental investigation and artificial neural networks (ANNs) based prediction of engine vibration of a diesel engine fueled with sunflower biodiesel – NH_3 mixtures	2021	Fuel
Berwal, Pragya; Kumar, Sudarshan; Khandelwal, Bhupendra	A comprehensive review on synthesis, chemical kinetics, and practical application of ammonia as future fuel for combustion	2021	Journal of the Energy Institute
Frost, James; Tall, Abdoulaye; Sheriff, Abubakar Mahmud; Schönborn, Alessandro; Hellier, Paul	An experimental and modelling study of dual fuel aqueous ammonia and diesel combustion in a single cylinder compression ignition engine	2021	International Journal of Hydrogen Energy

2021

More than 8 review papers

More than 12 research papers

12/2022-now (Science Direct, 0 SAE, 1 IJER)

30 research papers !!!

A lot of new interests but ..

A lot of papers based on simulation, especially for marine applications !

Table 6
Various CFD studies on ammonia combustion in ICEs.

Authors	Year	Case study	Experimental validation	Software/code
Boretti (2012)	2012	A 1-D model was used to explore a novel dual-fuel approach considering H_2 jet ignition followed by NH_3 direct injection.	Yes	GT-POWER
Kumar et al. (2014)	2014	Experimental and CFD analysis was employed to assess the ability of an SCR system with Urea or NH_3 as a reducing agent for NO_x emissions in a single-cylinder diesel engine.	Yes	AVL FIRE
Lauer (2017)	2017	An LES modelling approach was set to simulate injection designs and mixing sections for NO_x emissions reductions in a diesel engine.	Yes	Simcenter STAR-CCM+
Boretti (2017)	2017	A 1-D model was set to implement a novel dual-fuel approach considering diesel injection ignition followed by NH_3 direct injection.	No	GT-POWER; WAVE
Lamas and Rodriguez (2017)	2017	A CFD study was developed to compute the injection of NH_3 into the combustion chamber for NO_x emissions reduction.	Yes	OpenFOAM
Tay et al. (2017a)	2017	The effects of injection timing variation and multiple pilot fuels injection were investigated for the combustion of kerosene-diesel and NH_3 blends.	Yes	KIVA4
Lasocki et al. (2019)	2019	A 1-D model was set to gauge the feasibility of injecting a pilot dose of diesel fuel to ignite an NH_3-air mixture in a CI engine.	Yes	AVL BOOST
Galdo et al. (2020)	2020	A CFD approach was set to study NO_x emissions reduction through NH_3 injection in a commercial marine engine.	Yes	OpenFOAM
Frankl et al. (2020)	2020	A numerical CFD model approach was employed to assess NH_3 and H_2 as CO_2-free fuels for heavy-duty engines using a high-pressure-dual-fuel (HPDF) combustion process	Yes	CONVERGE CFD

INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 46 (2021) 14805–14812

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

Theoretical investigation of the combustion performance of ammonia/hydrogen mixtures on a marine diesel engine

Yang Wang*, Xiaohu Zhou, Long Liu

Fuel 351 (2023) 128906

Contents lists available at ScienceDirect
Fuel
journal homepage: www.elsevier.com/locate/fuel

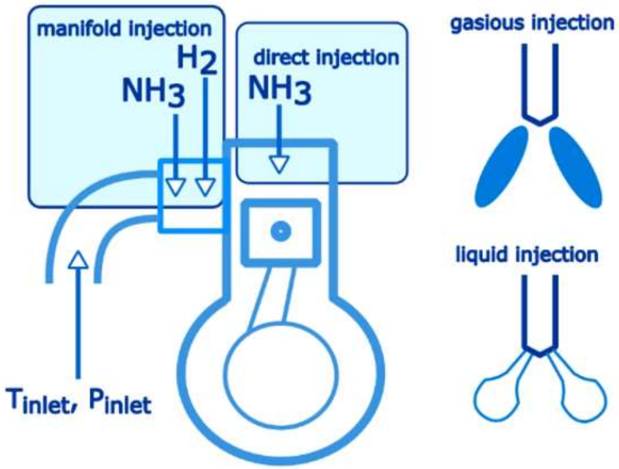
Full Length Article

CFD investigation the combustion characteristic of ammonia in low-speed marine engine under different combustion modes

Long Liu[a], Zan Wu[a], Fusheng Tan[a], Yang Wang[a,*]

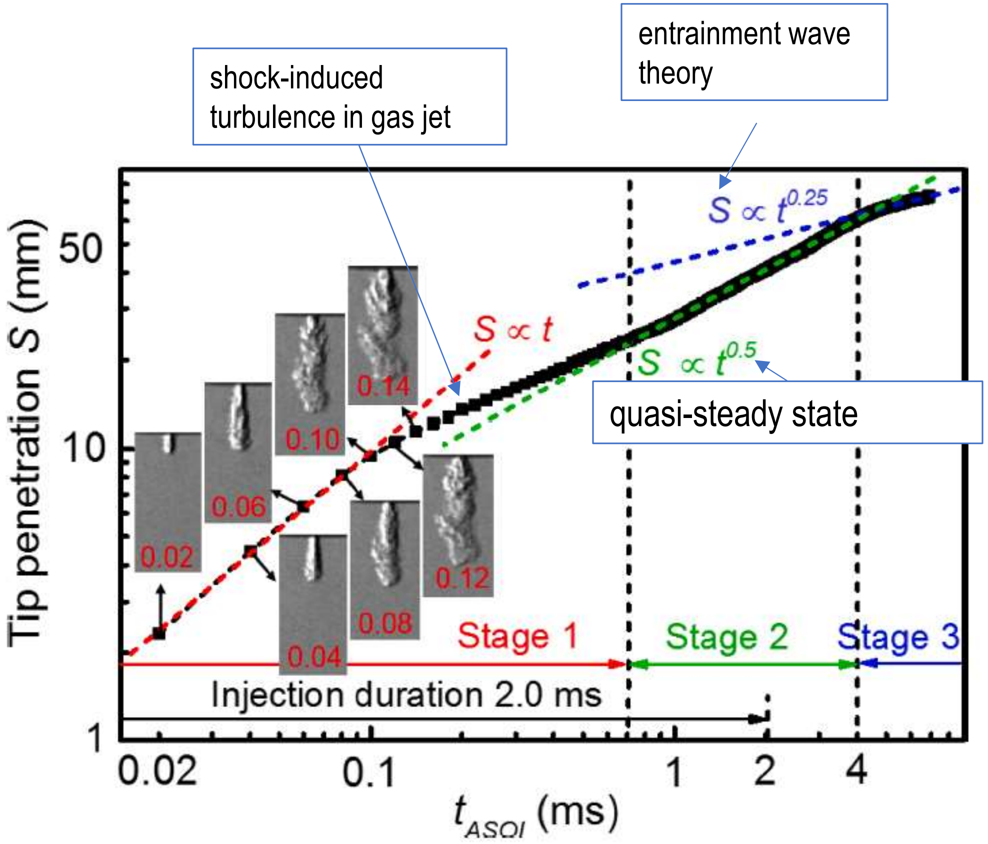
Ammonia and 'reactive' fuel injections

- Port-vapor fuel injection :
  - Displacement of the air supplied to the combustio
    - Reduction of volumetric efficiency of the engine.
- Direct-vapor fuel injection
  - Reduction of in-cylinder temperature (ammonia´s
- Liquid ammonia injection
  - better volumetric efficiency (no air displacement r and intake mixture cooling).



Ammonia gaseous injection

- Only 1 study for gaseous injection



Three-stage behavior of the tip penetration of ammonia jets. (P_{inj} = 8.0 bar, P_a = 2.0 bar, T_a = 298 K, τ = 2.0 ms).

Experimental conditions.

Fuel type	NH_3 (base), CH_4 (comparison)
Ambient temperature (K)	298
Ambient pressure (bar)	1.0–4.0
Injector hole diameter (mm)	0.93
Injection pressure (bar)	4.0–8.0
Injection duration (ms)	2.0
Room temperature (K)	298

Fuel 304 (2021) 121408

Contents lists available at ScienceDirect

Fuel

ELSEVIER

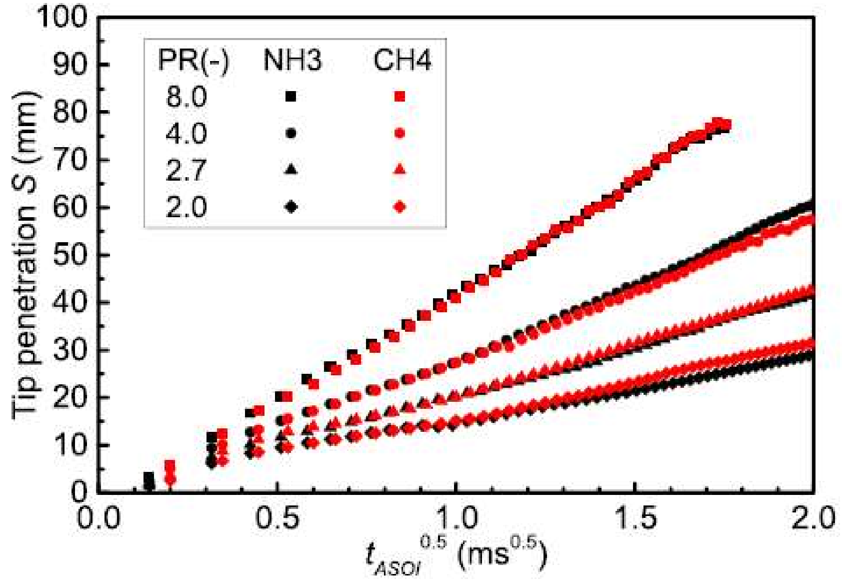
journal homepage: www.elsevier.com/locate/fuel

Full Length Article

Injection characteristics and fuel-air mixing process of ammonia jets in a constant volume vessel

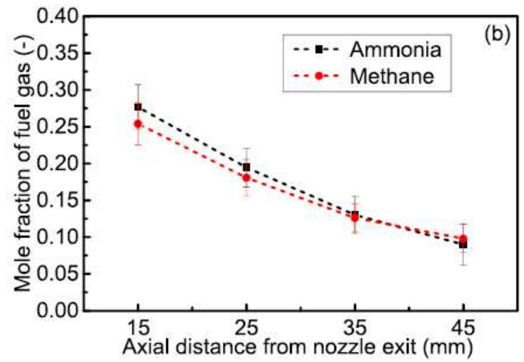
Zhifei Zhang[a], Tie Li[a,b,*], Run Chen[a,b], Ning Wang[a], Yijie Wei[a], Dawei Wu[c]

Ammonia injection : main results

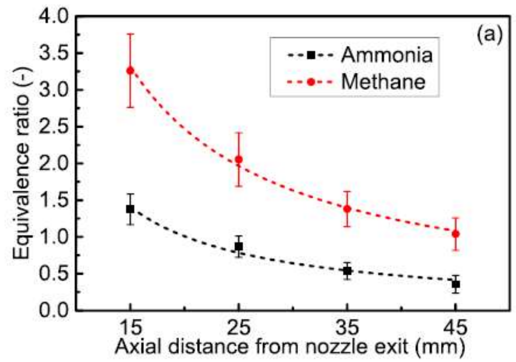


Comparisons of time evolutions of tip penetration between ammonia and methane jets at different PRs (T_a = 298 K, τ = 2.0 ms).

- Similar between ammonia and CH_4
  - CH_4 substitute for modelling ?
  - But strong difference on local equivalence ratio due to difference on A/F stoichio (6 instead of 14)!



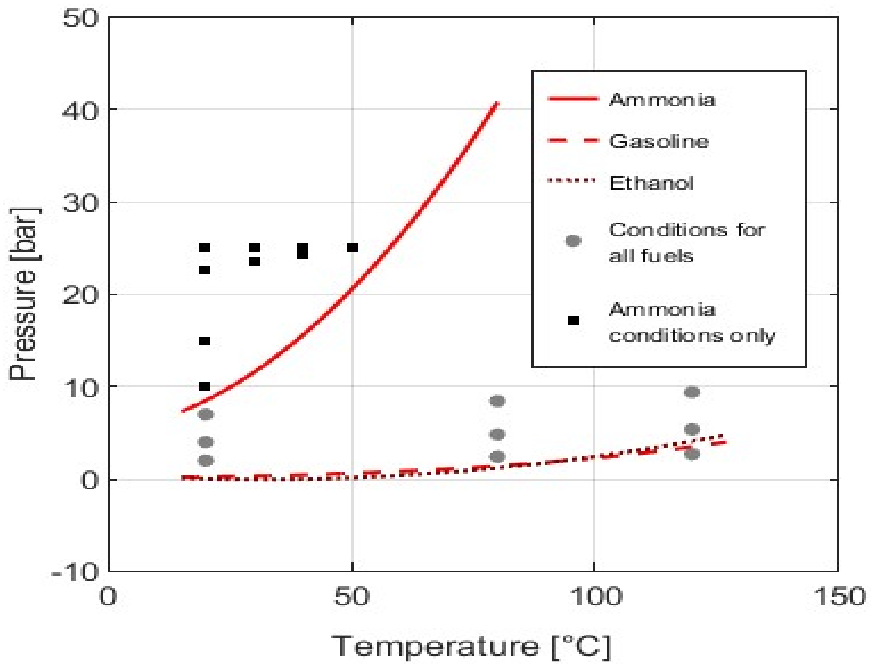
el mole fraction between ammonia and methane jets (P_{inj} = 8.0 bar, P_a = 1.0 bar,

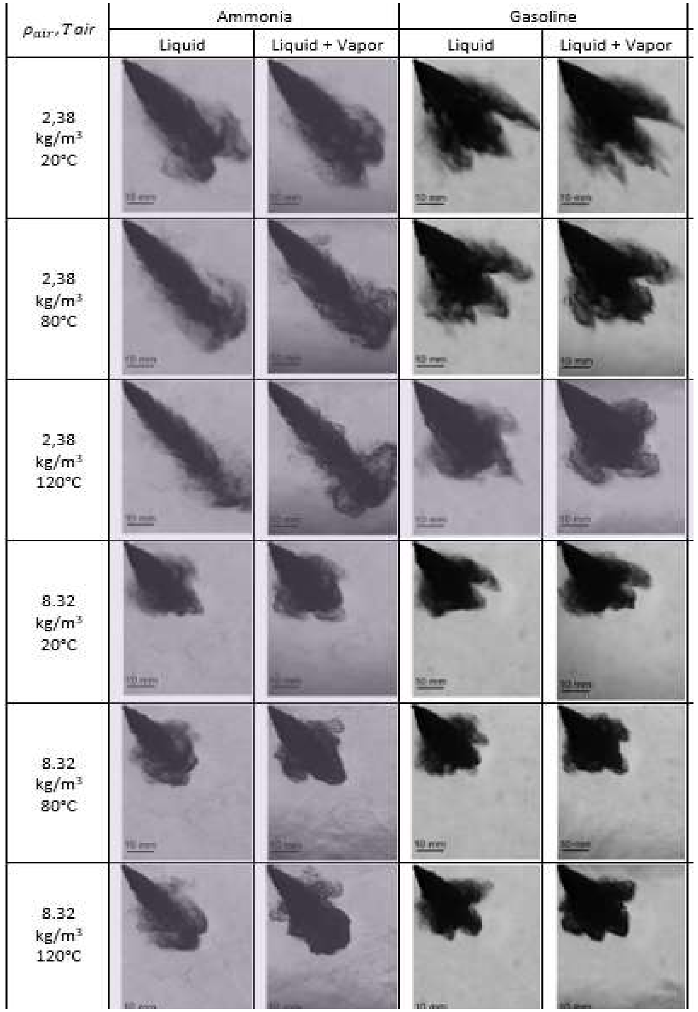


ıe comparisons of axial distributions of (a) equivalence ratio and (b) fı

Ammonia liquid injection

- More and more studies focused on liquid injection
- Flash-boiling specificities ?
- Accuracy of vaporization model/CFD





fuels

MDPI

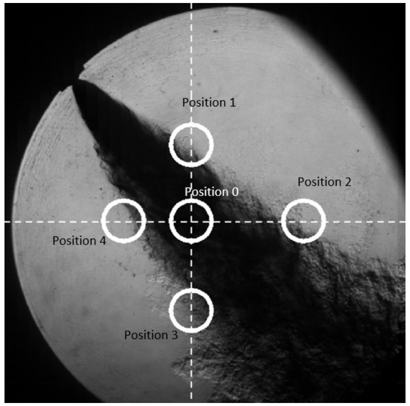
Article

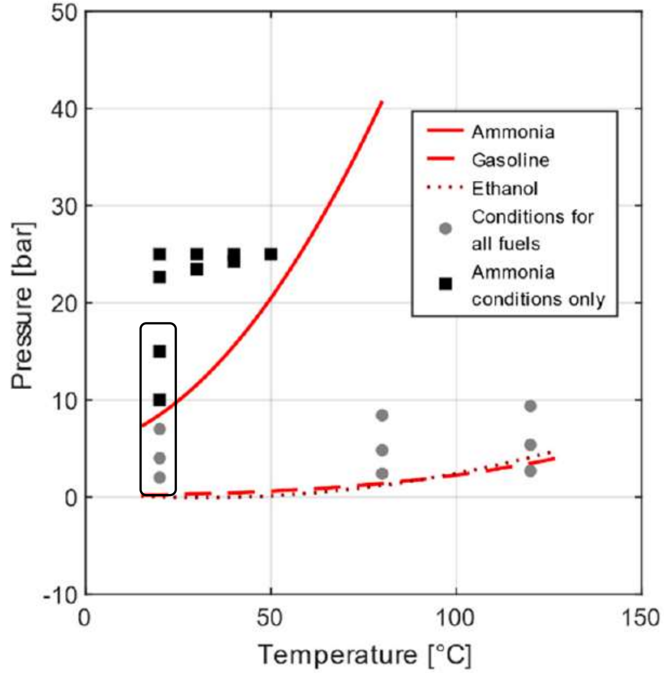
First Study on Ammonia Spray Characteristics with a Current GDI Engine Injector

Ronan Pelé [1,*], Christine Mounaïm-Rousselle [1,*], Pierre Bréquigny [1], Camille Hespel [1] and Jérôme Bellettre [2]

First measurement of droplet diameter

- Malvern droplet size analyzer
- Central point
  + 4 on the spray boundary close and far from the injector nozzle





➢ Sauter diameter D32 µm , Tamb. = 20° C

Position	2 bar	4 bar	7 bar	10 bar	15 bar
0	8.6	14.4	20.4	26.3	33.6
1	8.5	12.6	17.7	22.2	30.3
2	12.0	18.5	26.9	31.5	39.2
3	11.5	17.2	28.6	37.7	48.5
4	8.4	14.5	15.8	28.2	41.0


2023-01-0311 Published 11 Apr 2023

GDI Ammonia Spray Numerical Simulation by Means of OpenFOAM

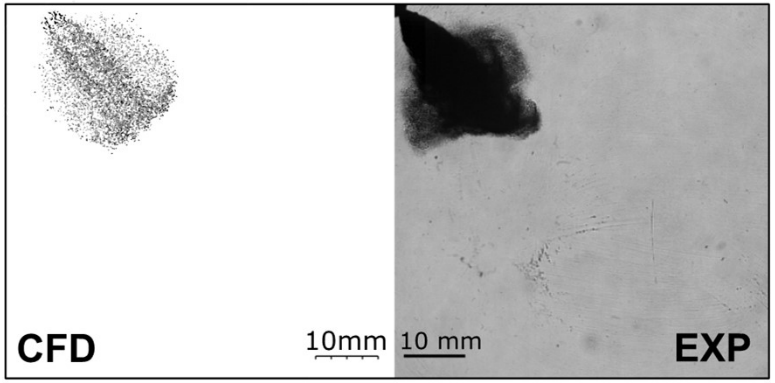
Adrian Pandal Universidad de Oviedo

Jacopo Zembi and Michele Battistoni Universita degli Studi di Perugia

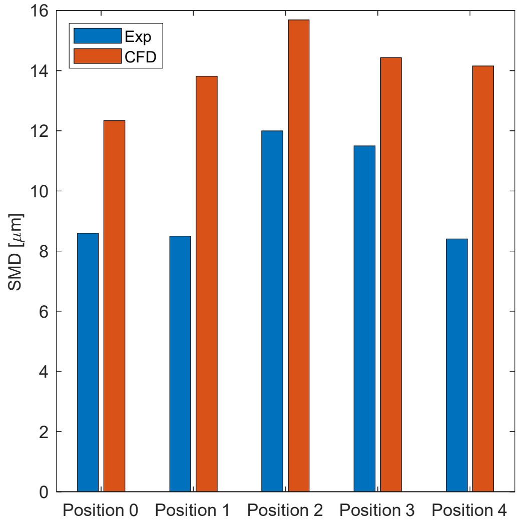
Camille Hespel, Ronan Pele, Pierre BREQUIGNY, and Christine Rousselle Universite D'Orleans

Citation: Pandal, A., Zembi, J., Battistoni, M., Hespel, C. et al., "GDI Ammonia Spray Numerical Simulation by Means of OpenFOAM," SAE Technical Paper 2023-01-0311, 2023, doi:10.4271/2023-01-0311.

First simulation : how classical models can predict



Spray morphology comparison at 1 ms. Pamb = 15 bar, Tamb = 20ºC.



SMD comparison in the different measured chamber positions. Pamb = 2 bar, Tamb = 20ºC.


2023-01-0311 Published 11 Apr 2023

GDI Ammonia Spray Numerical Simulation by Means of OpenFOAM

Adrian Pandal Universidad de Oviedo

Jacopo Zembi and Michele Battistoni Universita degli Studi di Perugia

Camille Hespel, Ronan Pele, Pierre BREQUIGNY, and Christine Rousselle Universite D'Orleans

Citation: Pandal, A., Zembi, J., Battistoni, M., Hespel, C. et al., "GDI Ammonia Spray Numerical Simulation by Means of OpenFOAM," SAE Technical Paper 2023-01-0311, 2023, doi:10.4271/2023-01-0311.

High Pressure liquid ammonia injection

- High pressure injection

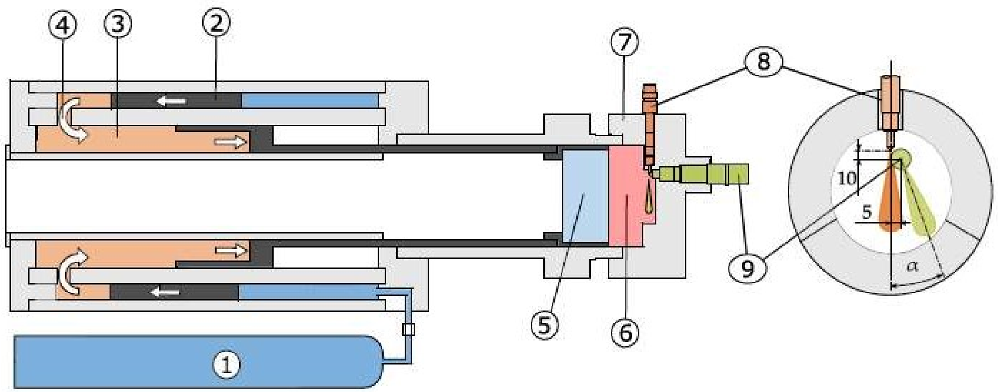


Figure 1: RCEM driving system and cylinder head: ① driving-air bottles, ② driving piston, ③ hydraulic fluid, ④ flow orifice, ⑤ working piston, ⑥ combustion chamber, ⑦ cylinder head, ⑧ diesel injector, ⑨ ammonia injector.

Table 4: RCEM specifications and injection parameters

Bore diameter [mm]	220
Start of diesel injection [ms BTDC]	2
Ammonia injection pressure [bar]	480 – 530
Ammonia nozzle diameter [μm]	940
Injected ammonia mass [mg]	210
Duration ammonia injection [μs]	2700
Relative ammonia injection timing [μs]	−1000 – +1500

- ➢ High pressure injection pump ?
  - ➢ Time life ? Add some 'lubricants' ?

Ignition and Combustion Characteristics of Diesel Piloted Ammonia Sprays

Valentin Scharl[a,*], Thomas Sattelmayer[a]

[a]Chair of Thermodynamics, Technical University of Munich, Boltzmannstraße 15, 85748 Garching