FVV Autumn Conference, Würzburg, 27th – 28th September 2018

Water Injection in Spark-Ignition Engines

Numerical Analysis of the Impact of Water Injection on Combustion and Thermodynamics using Detailed Chemistry

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Project Work Flow

		WP1 Mixture Formation	WP2 Reaction Kinetic	WP3 Mixture & Reaction Sim	WP4 Thermodynamic Investigation	WP5 After-treatment	WP6 FVV Cylinder Module
VKM	TU Berlin	Optical Tests			Thermodynamic Tests	Synthetic Gas Tests	
tdtvt	B-TU Cottbus-Senftenberg	Optical Tests	Mechanism Generation	3D-CFD QD-SRM	QD-SRM	1D-CFD	
IVK	Universität Stuttgart			3D-CFD 1-cyl. Engine	3D-CFD Full Engine		1D-CFD FVV Cyl. Module

Introduction

In this numerical study, we investigate the effect of water on the chemical and the thermodynamic processes using 3D CFD RANS with detailed chemistry. In the first step, the influence of different amounts of water vapor on ignition delay time, laminar flame speed and heat capacity is investigated. In the second step, the impact of water vaporization is analyzed for different injection strategies, such as port and direct injection. Therefore, the water mass flow and the injection pressure are varied. A steady state, medium speed, high-load engine operating point is investigated with focus on the effect of water injection on knock tendency and exhaust temperature.

Detailed Chemistry

The oxidation chemistry in the unburned zone is modelled using the Ethanol Toluene Reference Fuel (ETRF) reactions scheme by Seidel [1] that allows for a flexible surrogate definition. This scheme was developed taking the core model from Seidel et al. [3], and reduced following the methodology in [3]. Netzer et al. [4, 5] showed that the prediction of auto-ignition in the unburned zone and laminar flame speed using this ETRF reaction scheme are sensitive to the research / motored octane number (RON/MON) rating of the surrogate and to the spark ignition timing. For the analysis in this work, a surrogate that represents a typical European gasoline fuel with a RON/MON of 94.5/88.8 is chosen. The surrogate is composed of 49.5% *iso*-octane, 12.7% *n*-heptane and 37.8% toluene by mass. Even though the reaction scheme can treat an ETRF surrogate, a TRF surrogate is chosen to reduce the number of influencing factors in the present study.

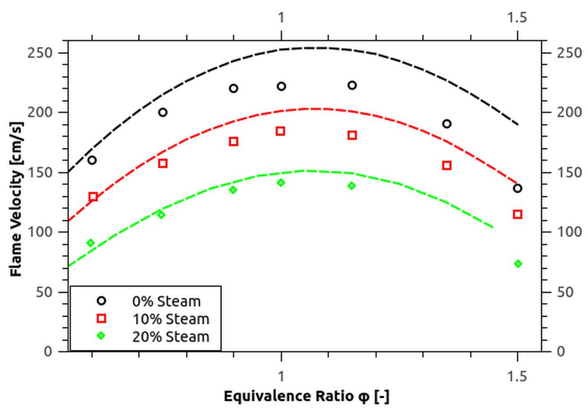

Figure 1: Laminar flame speeds over different equivalence ratios of methane and water vapor addition at 1 atm, 373 K and air as oxidizer. Symbols: Experiments by Mazas et al. [6]. Dashed lines: Simulations using the ETRF mechanism by Seidel [1].

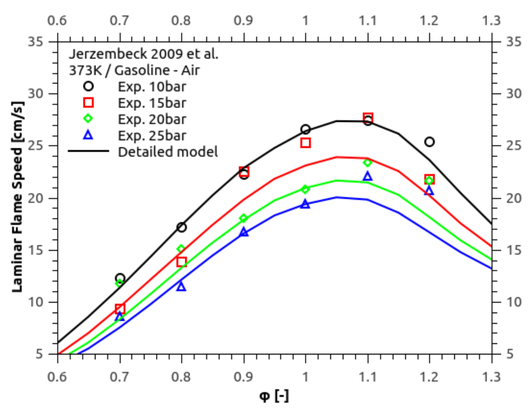

Figure 2: Laminar flame speeds over different equivalence ratios and pressures of gasoline at 373K and air as oxidizer. Symbols: Experiments by Jerzembeck et al. [7]. Lines: Simulations using ETRF mechanism by Seidel [1].

Combustion Modelling Approach

The combustion is predicted using the G-equation [9] and well stirred reactors [10] in the unburned zone to predict auto-ignitions. Auto-ignitions and laminar flame speed are predicted applying the ETRF reaction scheme from Seidel [1]. The laminar flame speed is calculated and stored in look-up tables using LOGEresearch [11].

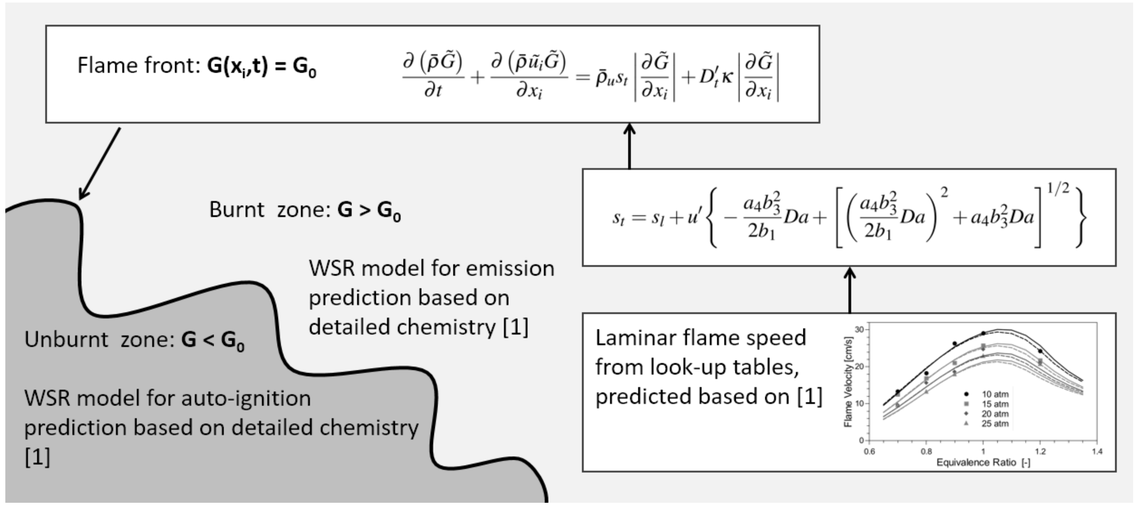

Figure 3: Schematic illustration of the combustion modelling approach.

Knock Evaluation

To find the KLSA a spark timing sweep is performed. If one of the ignition kernels is found to be in the developing detonation regime, the KLSA is exceeded. Therefore, we define as KLSA the earliest spark timing for that all ignition kernels are in deflagration or non-knocking regime (beyond the upper limit of the peninsula).

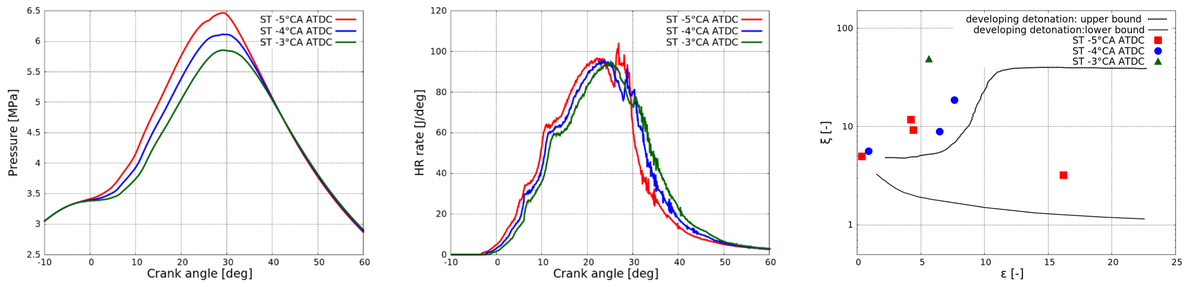

Figure 4: Predicted mean pressure, apparent heat release rate and auto-ignitions for the spark timing sweep from –5°CA to –3°CA ATDC [12].

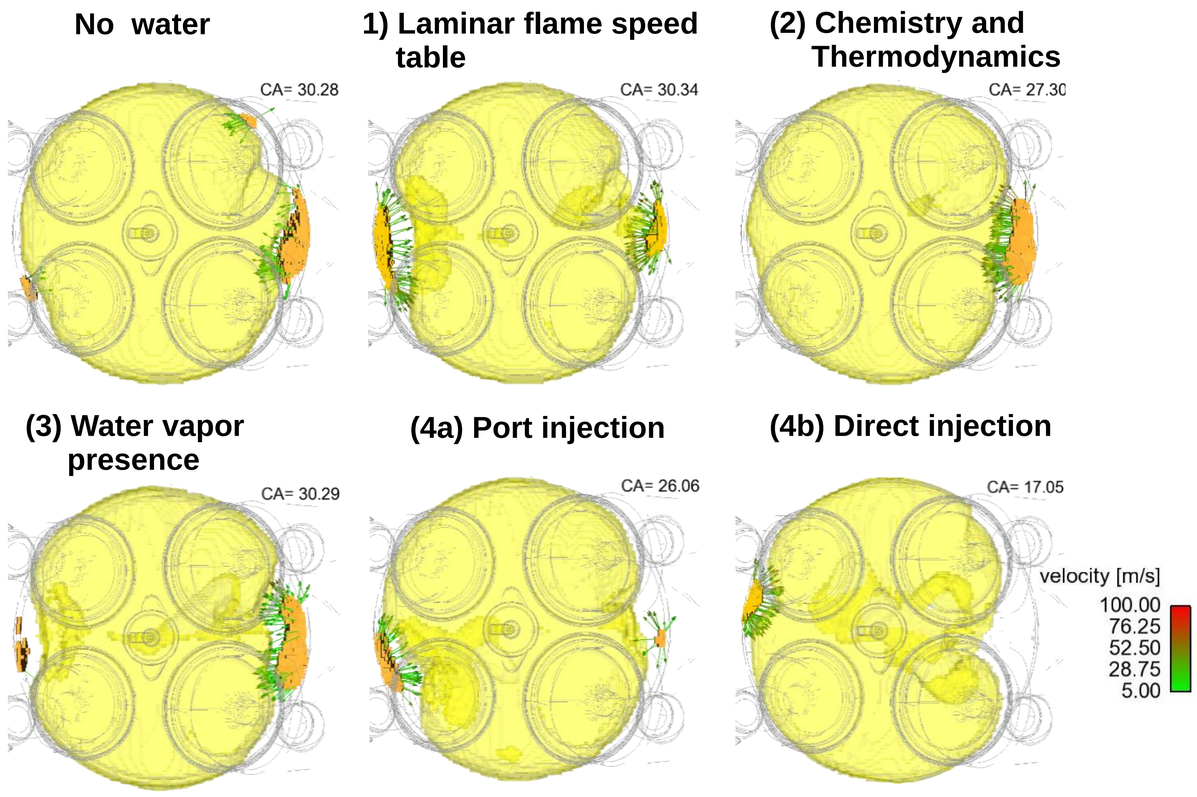

Figure 5: Predicted ignition kernels at the KLSA for no added water and the parameter studies (1)-(4) for 50% water/fuel ratio. View from top. Main flame colored in yellow, ignition kernels colored in orange. Arrows represent the gas velocity resulting from the ignition event [12].

Exhaust Temperature

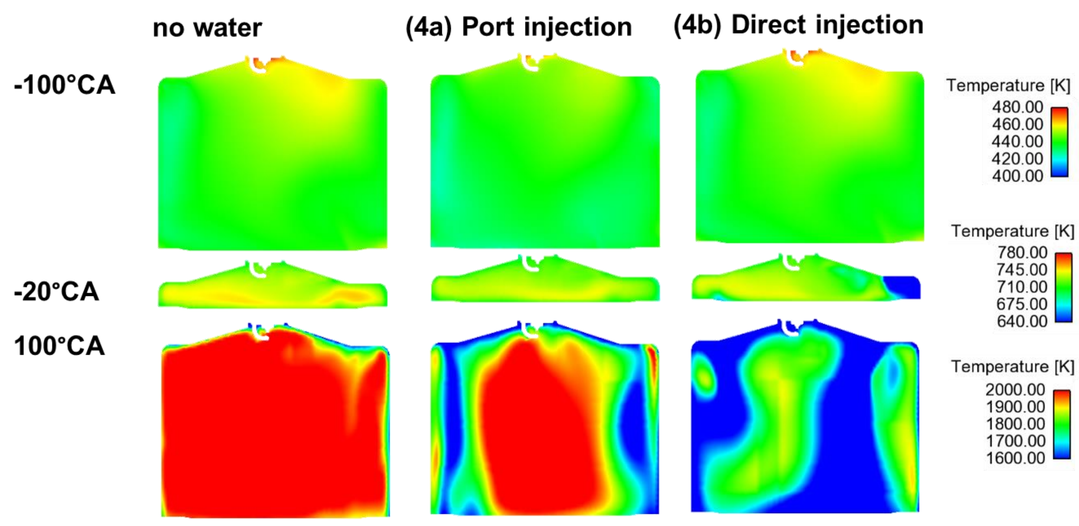

Figure 5: Local temperature distribution for no injected water, 50% water port injection (4a) and 50% water direct injection (4b), for –100°CA ATDC, –20°CA ATDC and 100°CA ATDC [12].

Conclusions

The analysis shows that for a prediction of water injection it is essential to apply a flame speed model and a chemical reaction scheme that accounts for the increasing water amount [12].

Analyzed property	Water/fuel ratio		
	20%	50%	80%
Laminar flame speed	3°CA	4°CA	5°CA
Ignition delay time > 950K	0°CA	0°CA	0°CA
Third body efficiency	-	1°CA	-
Chemical equilibrium	-	2°CA	-
Heat capacity	-	2°CA	-
Water vaporization intake port	0°CA	1°CA	1°CA
Water vaporization cylinder	1°CA	3°CA	3°CA

1. **Laminar flame speed**
2. **Heat of vaporization**
3. **Chemical equilibrium**
4. **Water vapor heat capacity**
5. **Third body efficiency**
6. **Ignition delay time**

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