

Department of Mechanical Engineering

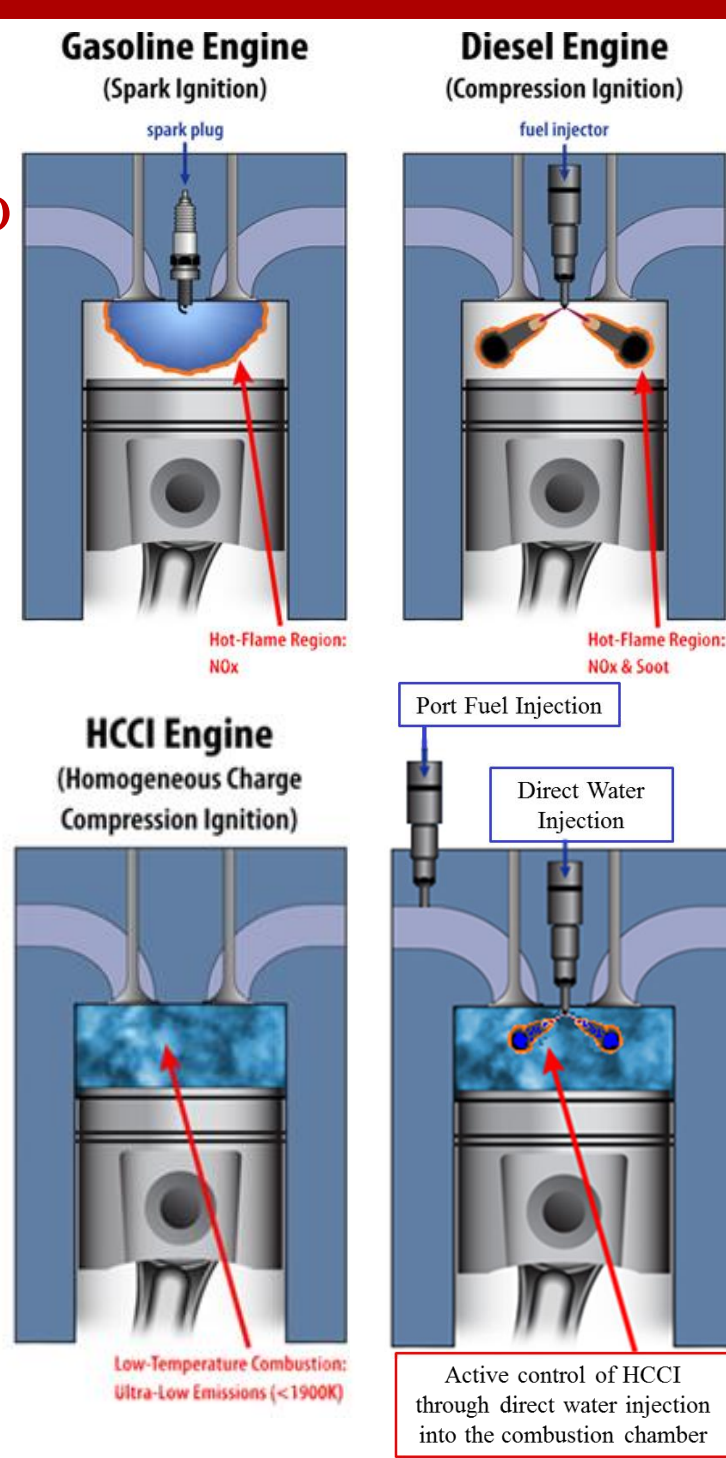
CFD Simulation of the Effect of Water Injection Spray on GM 2.0 Liter HCCI Engine

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Introduction

Gasoline engine: Homogenous, Lower emissions
 Diesel Engine: High compression ratio, Higher efficiency

HCCI Combines these benefits of gasoline and diesel engines



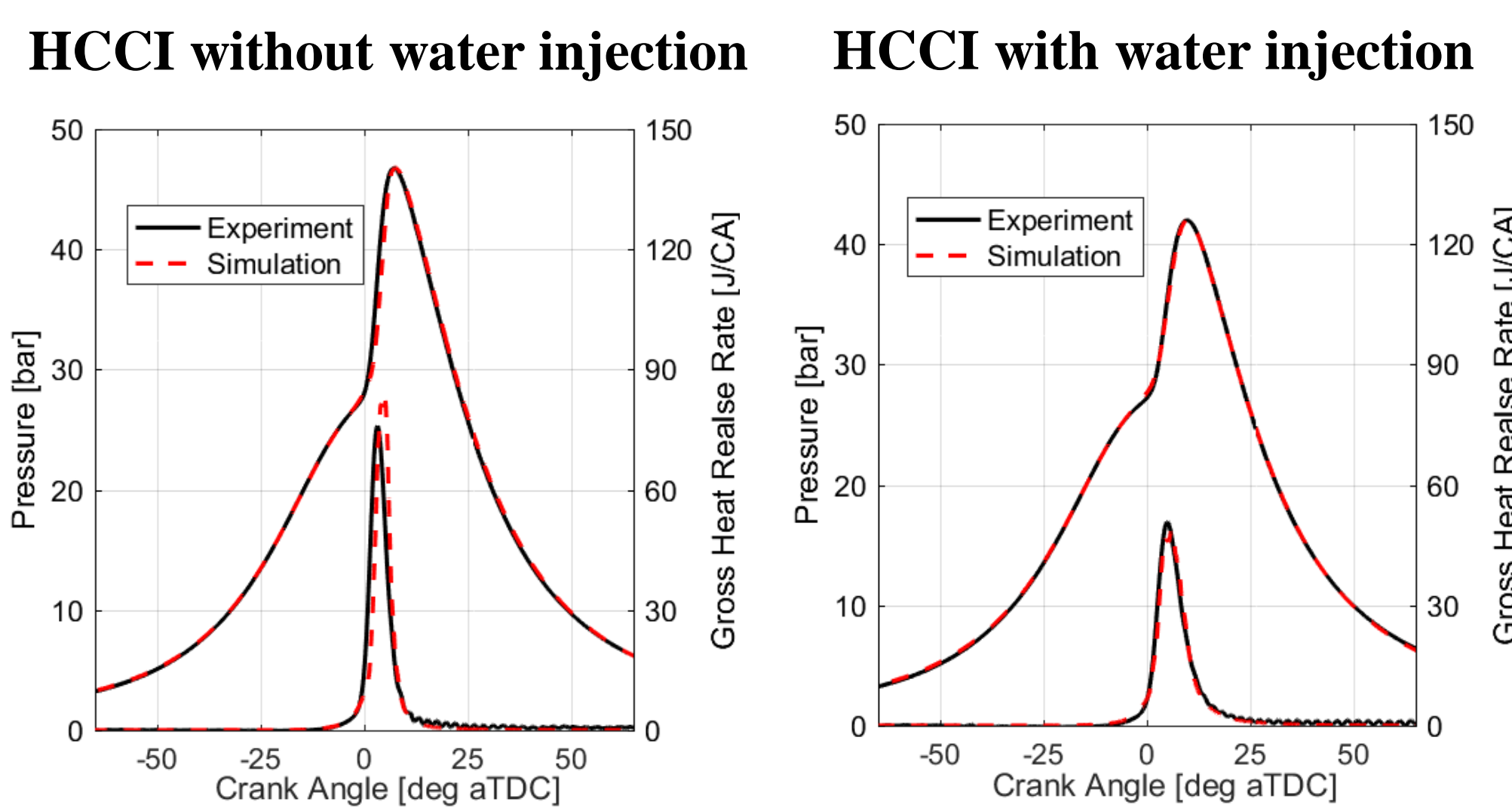
What are HCCI drawbacks?

1. High pressure rise rates which can damage the engine
2. Limited operating range
3. Lack of controllability

✓ Water injection can address these drawbacks

➤ Evaporative cooling adds controllability of pressure rise rates; expands the operating range

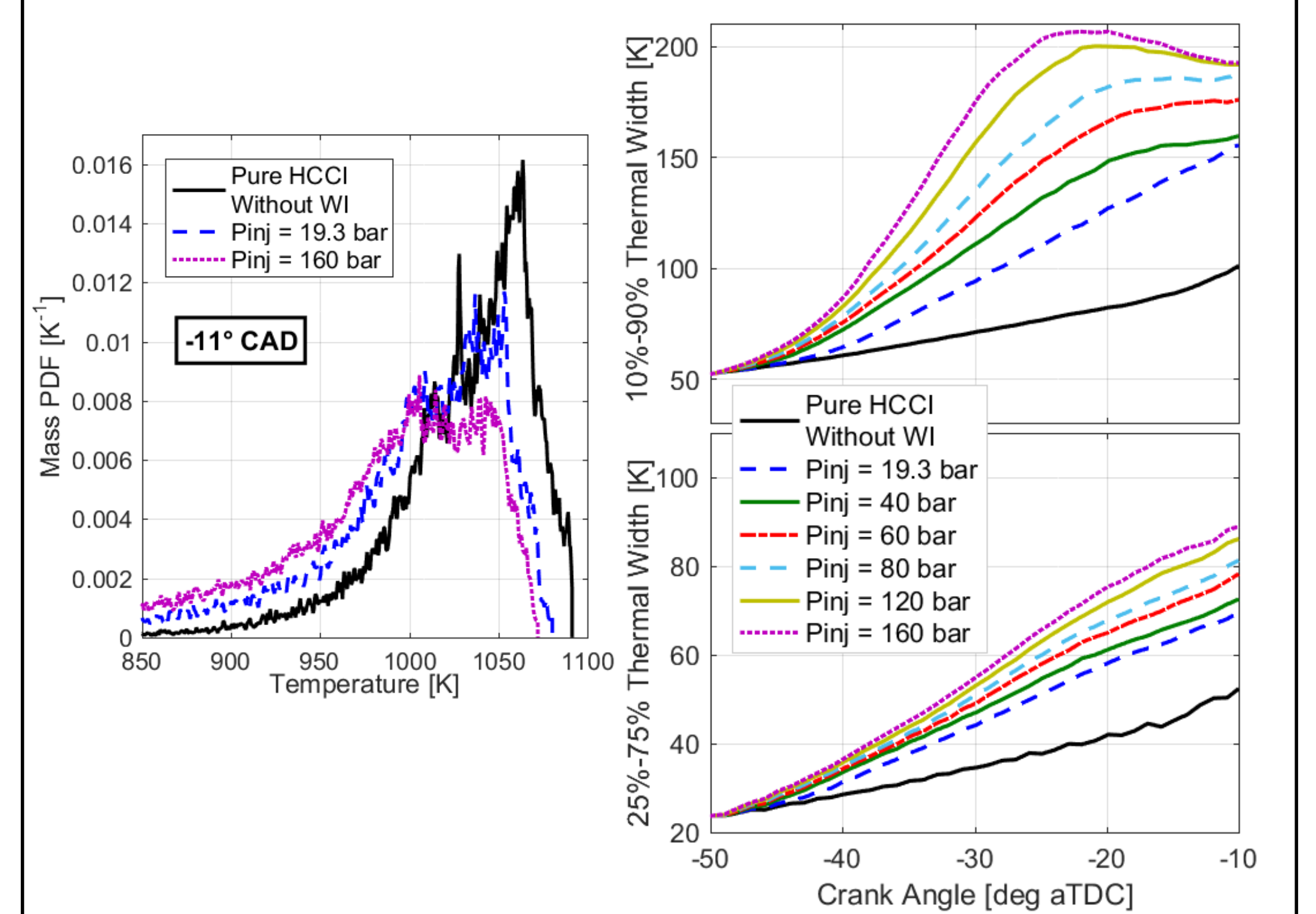
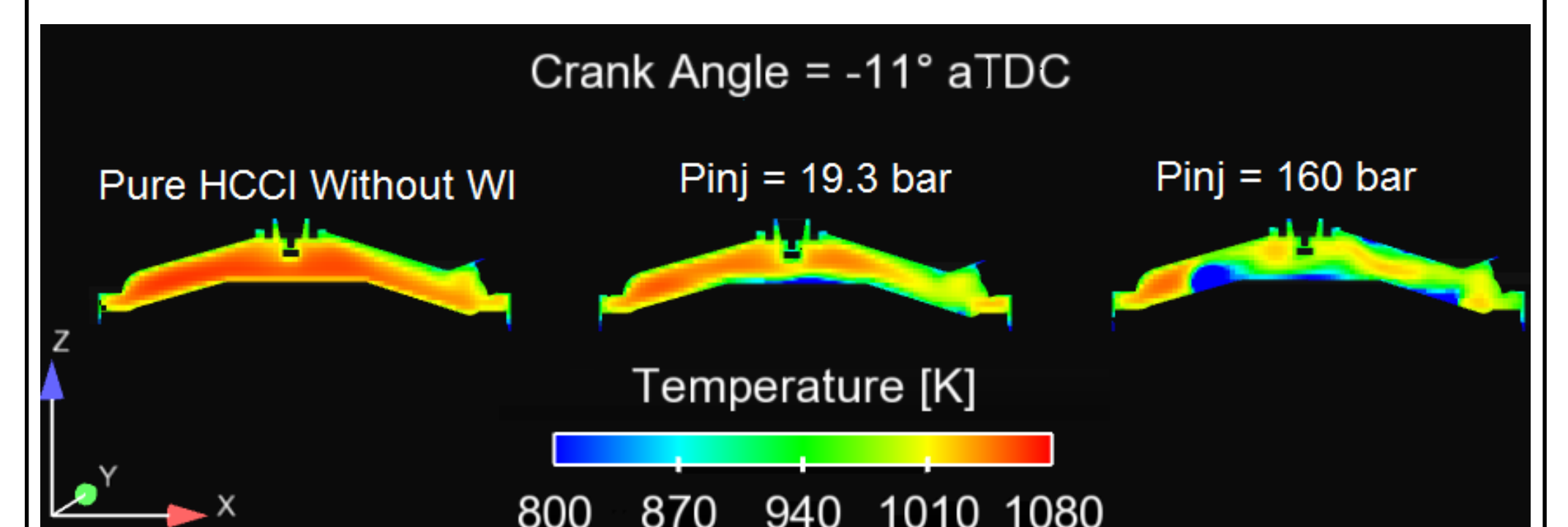
CFD Model Validation Against Experimental Data



- The CFD model has been validated against experimental data; showing good agreement between the CFD and experimental results
- The CFD model was calibrated based on the experimental data and some of the parameters have been adjusted, including compression ratio, EGR, and initial temperature

Thermal Stratification

- In HCCI almost all regions have the same temperature and ignite around the same time which results in high energy release rate
- Water injection creates regions with different temperature which ignite in sequential order, this technique is called thermal stratification
- Thermal stratification facilitates control of the combustion; increasing thermal stratification reduces the heat release rate



- Thermal width is another metric for better quantification of level of stratification and is defined as the temperature distance between the 10% and 90% (or 25% and 75% respectively) on the temperature distribution

Research Methods

- CFD is used to convert 3-D Navier-Stokes PDE equations into a set of algebraic equations

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho v_i)}{\partial x_i} = 0 \quad \text{Conservation of Mass}$$

$$\frac{\partial \rho v_i}{\partial t} + \frac{\partial(\rho v_j v_i)}{\partial x_j} = \frac{\partial \tau_{ij}}{\partial x_j} - \frac{\partial p}{\partial x_i} \quad \text{Conservation of Momentum}$$

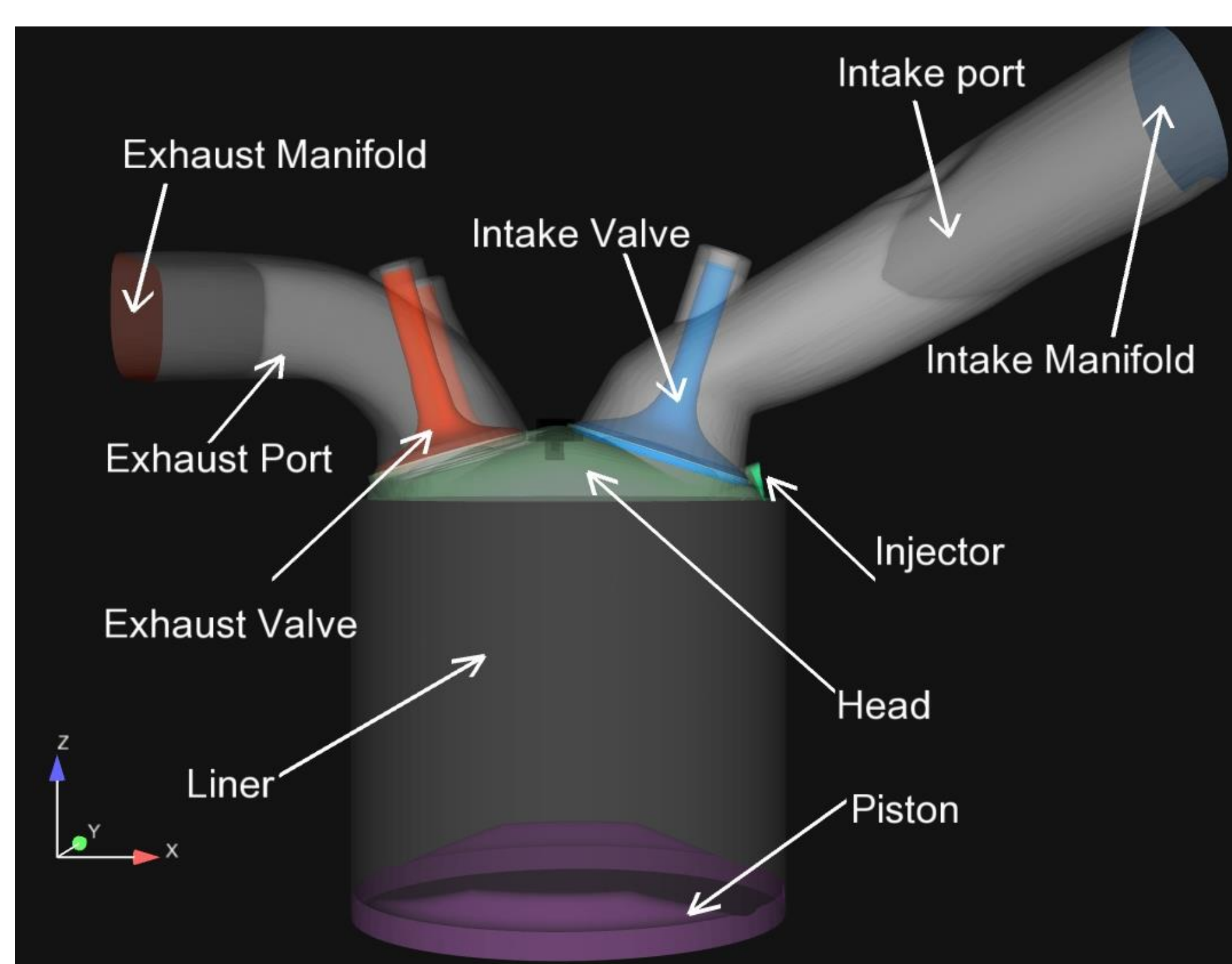
$$\frac{\partial(\rho E)}{\partial t} + \frac{\partial(\rho v_j E)}{\partial x_j} = \frac{\partial}{\partial x_j} \left(k \frac{\partial T}{\partial x_j} \right) + \frac{\partial}{\partial x_j} (\tau_{ij} v_i) \quad \text{Conservation of Energy}$$

- CFD also solves for chemical reactions through a chemical kinetic mechanism file

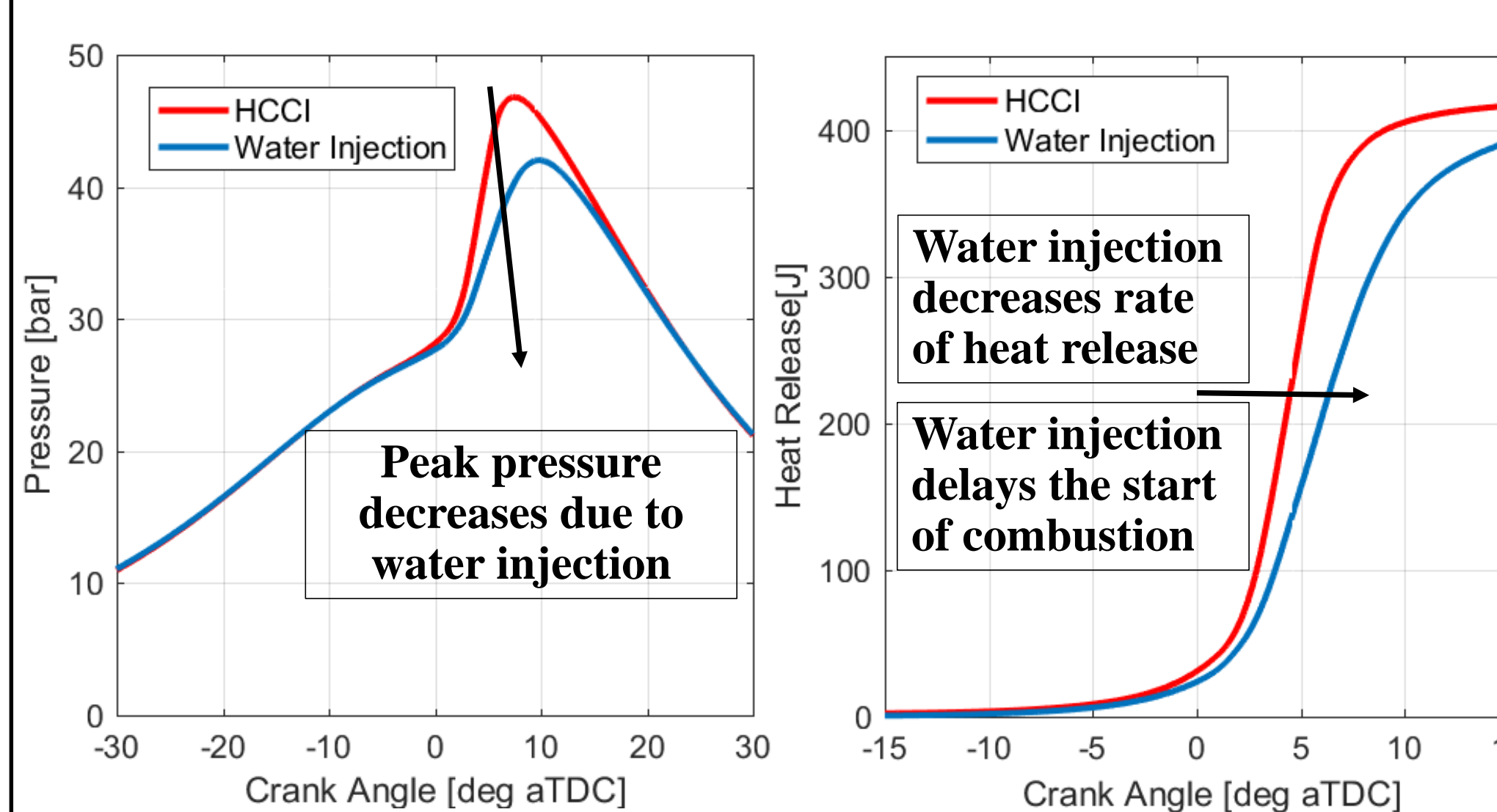
The i^{th} species mass fraction transport equation:

$$\frac{\partial}{\partial t} (\rho Y_i) + \frac{\partial}{\partial x_j} (\rho u_j Y_i) = \frac{\partial}{\partial x_j} \left(\rho D_i \frac{\partial Y_i}{\partial x_j} \right) + R_i + S_i$$

- This chemical kinetics mechanism file can consist of ~1,000 species and ~10,000 reactions
- The computational time for the combustion increases with the square number of species
- CONVERGE CFD performs 3-D simulations to provide insight into engine combustion
- It uses different sub-models for combustion, heat transfer, turbulence, and injection



Results-Effect of Water Injection on HCCI Combustion



Water injection :

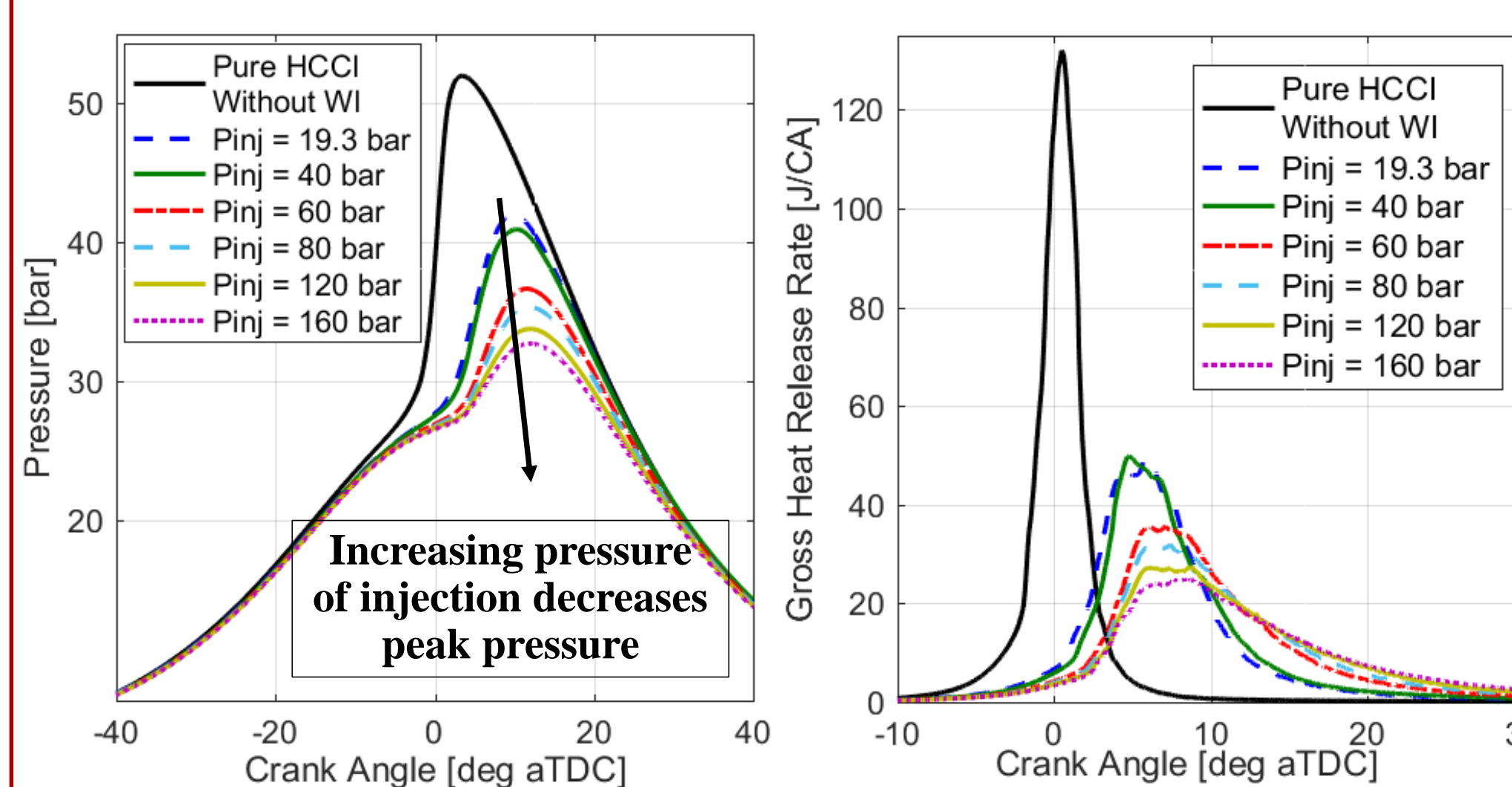
1. Reduces peak pressure and pressure rise rate
2. Provides control of the start of combustion
3. Provides control over the rate of energy release

IWM [mg]	0	6.7
Peak Pressure [bar]	52	42
Peak HRR [J/CA]	131	48

*IWM stands for Injected Water Mass

*HRR stands for Heat Release Rate

Results-Effect of Water Injection Pressure on Combustion



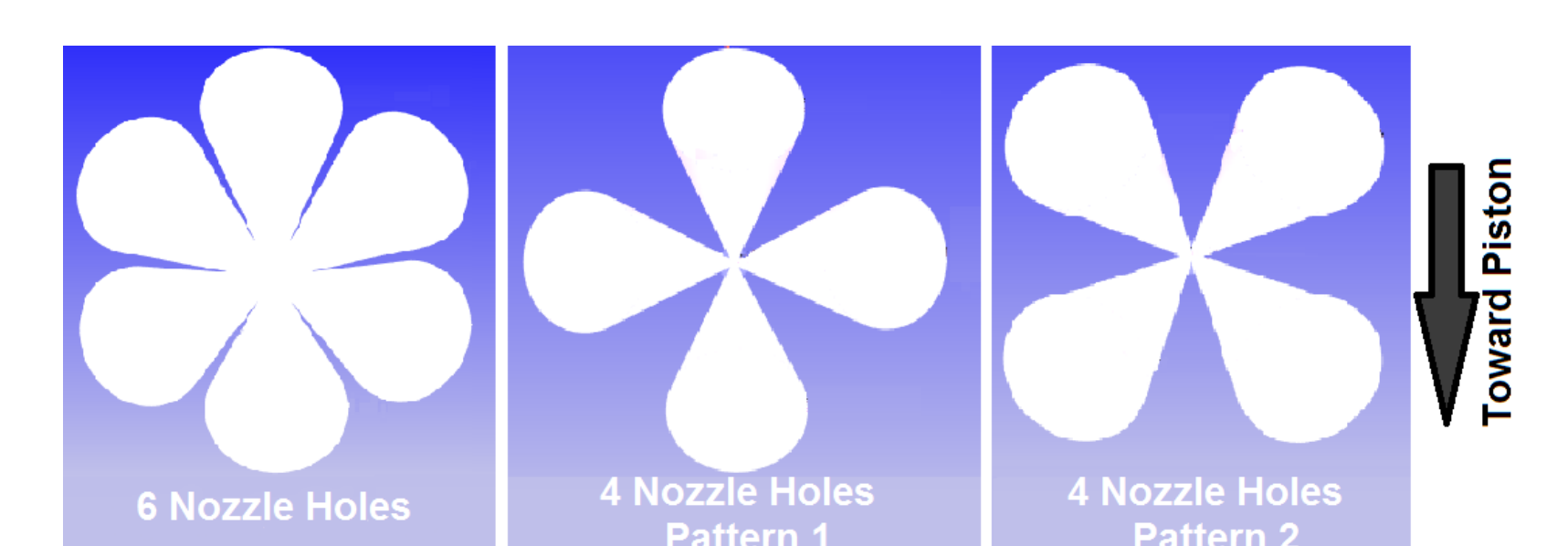
- Increasing water injection pressure results in lower maximum pressure and heat release rate

Conclusions

- HCCI offers many advantages over conventional SI and CI including less soot and NOX emissions and higher efficiency
- Water injection reduces the heat release rate and provides control over combustion due to thermal stratification
- Increasing pressure of injection results in less energy release rate and increases thermal stratification

Future Work

- The effect of spray pattern of water injection on combustion will be studied



- Turbulence model will be changed from RANS to LES