Detonation development induced by fuel concentration non-uniformity

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Abstracts

In spark ignition engines, the thermal efficiency can be improved through increasing the compression ratio. However, the increase in compression ratio can also induce engine knock which causes severe engine damage. According to the theory of Zel'dovich, reactivity gradient can lead to detonation development under certain conditions. This theory was confirmed by numerical simulations in previous studies. Most of previous studies considered a hot spot model with linear temperature distribution and detonation mode was observed at certain temperature gradient. However, besides thermal stratification, the fuel concentration stratification also induces reactivity gradient. Therefore, it is expected that concentration non-uniformity can also induce detonation development.

The objectives of the present work are to identify possible modes of reaction front propagation induced by concentration non-uniformity and to find the critical conditions for detonation development. One-dimensional simulations with detailed chemistry are conducted for n-heptane/air mixtures. The linear fuel concentration distribution is considered and the gradient of equivalence ratio is used to characterize the concentration non-uniformity.

It is found that negative gradient of equivalence ratio can lead to detonation development. In fact, the non-uniformity of equivalence ratio less than 0.02 in a stoichiometric n-heptane/air mixture is sufficient to cause a strong detonation. Therefore, similar to temperature non-uniformity, concentration non-uniformity also plays an important role in engine knock. The "C-shaped" detonation regime is plotted out in the ξ-ε diagram, with no "peninsula-like" structure is found. Furthermore, the detonation regimes for the same initial pressure of P_0=40 atm but different initial temperatures of T_0=750, 900 and 1000 K are studied. The detonation regime becomes broader as the initial temperature decreases. This is due to the facts that the volumetric energy density of the unburned mixture increases when the initial temperature decreases, and that detonation can be more easily developed at higher heat release. Besides, we propose a non-dimensional parameter η, which is equal to $\xi\varepsilon$. This parameter represents the ratio of the heat release rate and the speed of reaction front propagation in a given length. It is found that a necessary condition of η>20 must be satisfied so that detonation development can happen.

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