INVESTIGATION OF AUTO-IGNITION OF HEPTANE-CNG MIXTURE IN HCCI ENGINE

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Abstract—HCCI operating principals have been widely investigated yet the uncontrollable combustion of HCCI is the major obstacle in its development. This paper is trying to increase the understanding on the auto-ignition and combustion process of several fuels to be applied in HCCI combustion system. This paper investigates variation of fuel composition between heptane and compressed natural gas (CNG) with the composition ranges from 10-100\% heptane/CNG. The investigation was done in a constant volume chamber with elevated temperature (800°C). Three lambdas were tested for each fuel, namely 0.8, 1, 1.2 and 2. From the results, it is found that the mixture composition highly affects the output of the combustion of dual fuel where CNG is able to suppress heptane combustion at CNG percentage more than 40\%. Furthermore, homogeneity level highly determines the types of combustion produced by the mixture, distributed or propagation flame.

Introduction

Stringent emissions regulations and significant increase of fuel price highly affecting the growth rate of automotive technology development with the objective of reducing fuel consumption and improving engine efficiency. Controlled autoignition based combustion system such as homogeneous charge compression ignition (HCCI) \cite{1,2}, stratified charge combustion ignition (SCCI), and premixed charge compression ignition (PCCI) are the recent engine development with high efficiency, low emissions and fuel consumption.

Fuel type is the most significant parameters in the auto ignition behavior of a mixture \cite{3-8}. A significant number of experiments and simulations in order to improve the understanding of the auto ignition process has been done. Most of the investigations used primary reference fuel (PRF) composition that had similar ignition delay properties as gasoline to get a better understanding of the auto ignition process \cite{9}. The most common PRF are n-heptane and iso-octane. Low temperature reaction is dominant in n-heptane auto ignition showed by cool flame phenomena and the existence of negative temperature coefficient (NTC) \cite{10-11}. While on the other hand, high temperature reaction is dominant in iso-octane autoignition process \cite{12-13}.

Methodology

The study performs extended experimental investigation on the auto ignition behavior of dual fuel (heptane-CNG). A probe heater was used to increase the temperature inside the combustion chamber with set point temperature 800°C in order to get the autoignition. Furthermore, oxygen with purity 99.5\% is used as the replacement of air in order to reduce the complexity of the reaction and increasing the autoignition occurrence probabilities.

In the experiment, combination of two fuels namely heptane and CNG. The combustion data for these fuels were obtained for various lambdas (0.8, 1, 1.2 and 2) in order to get the effect of lambda to the combustion of the fuel. The injector used is Siemens Deka 4 with 3 bars injection pressure and 4.3 g/s delivery rate (manufacturer specification and fueled with gasoline). A calibration process is carried out in the ambient condition for each file to measure the actual delivery rate of the injector fuelled with heptane. The calibration results are shown in Table 1.
Figure 1. Constant volume chamber.

Figure 2. Fuel injector and heater arrangement in the CVC.

Table 1. Injector delivery rate for each fuel

<table>
<thead>
<tr>
<th>Fuels</th>
<th>Injector delivery rate (g/s)</th>
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<tbody>
<tr>
<td>N-Heptane</td>
<td>4.6 @ 3 bar</td>
</tr>
<tr>
<td>CNG</td>
<td>7.2 @ 7.5 bar</td>
</tr>
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Lambda was generated by calculating the stoichiometric reaction between the fuels and oxygen. From the calculation, the required fuel amount of constant volume was determined and was translated to the injector opening by dividing the total fuel required with the injector delivery rate.

Results and Discussions

The effect of injection gap at various fuel compositions at lambda 0.8, 1, 1.2 and 2 are shown in Figure 3. The mixture composition gives significant changes to the combustion of the fuel mixtures. The combustion efficiency and total heat release rate shows increasing trend from 10 – 60% heptane and decreases as the heptane percentage increase mixture composition and decreasing as the heptane percentage increase. While on the other hand, the maximum pressure kept increasing with the increase of heptane percentage yet shows very low results for heptane as single fuel (100% heptane).

There is an increasing trend on the combustion efficiency, maximum pressure, total heat release rate and decreasing trends on the combustion delay as the heptane percentage increasing in the mixture. Furthermore, the combustion properties between the two injection gaps show almost similar behavior with the fuel composition variations.

20 ms injection gap has different mixture distribution compared to 0 ms injection gap. During the heptane injection process, heptane is able to reach the upper side of the chamber closing in to the hot region of the chamber before CNG is introduced. This configuration creates stratified regions near the heater and prolong the combustion delay for 20 ms injection gaps.

In order to get a clear picture of the combustion process of the dual fuel mixture, combustion visualization is done on 70-30 mixture composition at lambda 1. The combustion profile for this mixture is depicted in Figure 4. It can be observed that the 0 ms injection gap generates higher pressure compared to 20 ms injection gap and pure heptane. Furthermore, it is also seen that the profile of pressure and pressure rise rate (PRR) for both injection gaps is the same for the first 10 ms which is the initial stage of the combustion yet different at the later stage of the combustion.

The main reason for high PRR of 0 ms injection gap to happen is the existence of distributed flame. Figure 5 shows the combustion sequence of this mixture for the first 2 ms. It shows that the combustion of the mixture is started with cold flame from the middle part of the chamber (around the heater) as seen on 0.5 ms and followed by distributed flame behind the cold flame boundary. This distributed flame can be recognized with its fish scale like shape which can only be seen with 0 ms injection gap.
Figure 3. Effect of injection gap in the combustion of heptane-CNG mixtures at lambda (a) 0.8, (b) 1, (c) 1.2 and 2.

The existence of the distributed flame in the 0 ms injection gap combustion makes the initial stage of the combustion evenly distributed around the chamber while for 20 ms injection gap and single fuel initial flame is started at a single point and propagate throughout the chamber as the combustion happen.
Figure 4. Pressure rise rate, pressure profile and mass fraction burned at 70/30 Heptane/CNG, lambda 1 for 0 and 20 ms injection gaps

Figure 5. Combustion sequence of 70/30 heptane/CNG mixture.

The distributed flame can also be identified in the PRR profile. The trendline of 0 ms distinctively divided into two gradient where on 20 ms injection gap and single fuel cannot be observed (Figure 5). The border between two gradient occurs at 0.8 ms. Higher gradient is observed after 0.8 ms which probably the initial stage of the distributed flame to occurs in the cold flame. It is seen that
the initial combustion rate of 0 ms is slower compared to 20 ms injection gap and changes after 0.8 ms where 0 ms injection gap combustion is faster than 20 ms injection gap combustion. It is safe to say that the distributed flame is the main reason for this to happen.

The occurrence of distributed flame may occur due to the homogeneity level of the mixture. As shown in Figure 5, the mixture at the start of combustion (0 ms) with 0 ms injection gap is homogeneous (no intensity difference) which is very different with 100% heptane and 20 ms injection gap. This homogeneous mixture may also be the reason of slower combustion rate at the early stage of the flame development. While on the other hand, higher stratification level will creates a single hot spot to be the combustion starter. Higher stratification level also the main reason for 20 ms injection gap has longer combustion delay owing to droplet heating and evaporation process of the liquid fuel.

Conclusions

From the results, it shows that mixture composition is highly determining aspects in the autoignition properties of the mixture as well as the properties of each constituent, fuel with lower octane number is used to be the igniter for the higher octane number fuels. Furthermore, the homogeneity level of the mixture could affect the behavior of the dual fuel combustion of where homogeneous mixture could produce distributed flame in contrary with stratified mixture that produce propagated flame.

The injection gap between the two fuels will affect the level of homogeneity in the mixture. 20ms injection gap produce better combustion compared to 0ms injection gap for most of mixture compositions.

References:


