INTERNATIONAL JOURNAL OF HYDROGEN ENERGY XXX (2014) 1–7

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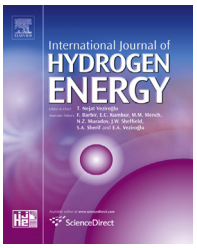

# The distinctive characteristics of combustion duration in hydrogen internal combustion engine

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ARTICLE INFO

*Article history:*
Received 12 November 2013
Received in revised form
27 February 2014
Accepted 2 April 2014
Available online xxx

*Keywords:*
Hydrogen internal combustion engine
Combustion duration
Location of 50% mixture combust up

ABSTRACT

As a practical solution to reduce the emission pollution and energy crisis, the research and development of HICE has been processed in several decades. The focus of this paper is trying to explore the new features of the combustion duration in HICE not only by engine experiment, but also by analysis of the physical properties of hydrogen, especially the obvious difference from that of gasoline. Firstly, the laminar flame speed difference between hydrogen and gasoline was studied and discussed. Secondly, a distinctive rule of combustion duration in HICE was discovered by analyzing the experiment data. Finally, as a key reference point to the HICE operation, a new characteristic of the location of 50% mixture combust up was proposed and analyzed, this will be helpful for the calibration of optimum ignition timing.



## Introduction

The automobile industry is facing the ultimate stage approaching zero regulated emissions as well as substantial reductions in $CO_2$ emissions. As the most plentiful element in the universe, hydrogen has long been recognized as a desirable fuel in engines [1]. Its combustion does not produce any of the major pollutants such as $CO_x$, HC and PM. $NO_x$ (oxides of nitrogen) is the single pollutant which needs to be carefully controlled. Thus, hydrogen is probably the unique versatile fuel which provides permanent solutions to fuel depletion and global environmental problems.

The HICE (Hydrogen Internal Combustion Engine) powered vehicles provide a practical approach for the companies to respond to environmental and market demands quickly.

### *Previous work*

Although a great number of research papers on HICE research have been published [2–12], most investigations focus on some issues based on the development of HICE and its advantages in high efficiency or low emission and corresponding vehicles development [13–15], rather than study HICE in-depth from the combustion characteristics of hydrogen fuel.

In only a few papers, the characteristics of combustion duration in HICE have been involved and discussed. Yaminhas made a comparative study of combustion duration between gasoline and hydrogen as a fuel in internal combustion engines by simulation based on a validated model [16]. Their results show that the combustion duration of hydrogen is much less than that of gasoline, and they attribute the high $NO_x$ emission as a disadvantage and significant reduction in the specific fuel consumption as an advantage of HICE to its

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http://dx.doi.org/10.1016/j.ijhydene.2014.04.013



Please cite this article in press as: Bai-gang S, et al., The distinctive characteristics of combustion duration in hydrogen internal combustion engine, International Journal of Hydrogen Energy (2014), http://dx.doi.org/10.1016/j.ijhydene.2014.04.013

short combustion duration. Their studies may be more reasonable if they had more experimental data on the lean concentration, which will offset their opinions on the combustion duration.

Verhelst proposed an optimum ignition timing map for HICE by experiment. Their results show that the ignition angle of HICE is about 50CA BTDC in very lean mixture [17]. However, their results could be better convinced if they explore that the main factor of such an early ignition is the result of the long combustion duration in a lean hydrogen–air mixture.

McTaggart-Cowan discussed the characteristic of combustion duration in hydrogen–methane internal combustion engine and their focus is the acceleration of combustion with the increase of hydrogen addition [18]. Although their research of combustion duration of hydrogen and methane blends as a fuel can give us some reference of the research on HICE, their conclusion could not be adapted to HICE directly.

Actually, the motivation of a majority of researchers to research and develop the HICE is the attraction of its low emission [19,20], as a result, authors proposed enough discussions on the methods to reduce $NO_x$ emission. However, little attention has been attempted to analyze the new features and conflicts of combustion duration between HICE and gasoline engine, which should be solved for the control of hydrogen engine and that is the focus of this paper.

### *Motivation and objective*

The difference between HICE and gasoline was chiefly induced by the difference of physical features between these two types of fuels. Compared with gasoline, the advantages of hydrogen, such as high flammability, low ignition energy, good homogenous combustion, high octane number and high thermodynamic efficiency, had been analyzed in most papers [8,19,21].

However, it is a two-edged knife that hydrogen has very wide flammable range and low ignition energy. As a positive effect, it is evidently that HICE is amenable to stable operation under highly dilute conditions, and the low ignition energy means less miss-fire, which allows much more feasibility over engine operation range for both emission and fuel consumption reduction. Nevertheless, as a negative effect, because the ignition energy of hydrogen–air mixtures are very small, the first obstacle regarding spark-ignited (SI) HICE combustion is backfire, pre-ignition and knocking, which limits the torque output of the engine [2]. As a result, the performance of HICE has to be limited by a certain concentration of the mixture. If the hydrogen mixture richer this value, the abnormal combustion will take place.

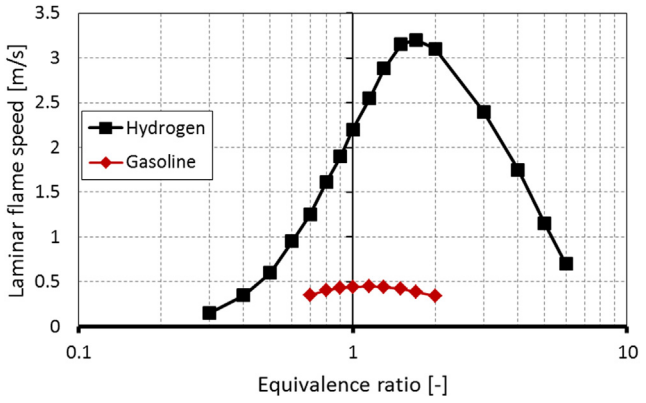


**Fig. 1 – The comparison of laminar flame speed between gasoline and hydrogen.**

The greatest difference between hydrogen and gasoline lies on the flammability range and flame speed. Therefore, the control of the combustion process in-cylinder should chiefly depend on these two points. Fig. 1 shows the laminar flame speed of hydrogen and gasoline in standard ambient temperature and pressure. There are two main differences between the hydrogen and gasoline on the laminar flame speed.

1. The laminar flame speed of hydrogen mixture near the stoichiometric condition is greatly higher than that of gasoline.
2. In the lean mixture, when the equivalence ratio less than 0.4, the laminar speed of hydrogen is lower than that of gasoline in its flammable zone.

Therefore, it is demand that the control of the combustion process should be different from gasoline and be adapted to this characteristic of hydrogen.

In a word, unlike most of the study of the HICE, we not only focus on the fast flame speed of the hydrogen, but also pay attention to the "slow" combustion characteristic in order to have a thoroughly understanding of the combustion characteristics in the HICE.

Consequently, a new feature of HICE, which was induced by the difference between hydrogen and gasoline, was investigated and discussed. As a result, a distinctive rule of combustion duration in HICE was discovered and analyzed. Moreover, further studies on a new strategy of ignition timing control based on this rule will be discussed in our next study.

## Materials and methods

The basic parameters of the BIT-HICE were shown in Table 1.

The engine experiment was carried out on different engine speed (from 1000 rpm to 5000 rpm at the interval 500 pm) with wide open throttle but different concentrations. The ignition timing was fixed at 15 °CA BTDC, and the injection timing was fixed at 350 °CA BTDC. The experiment starts from a lean mixture, and increases mixture concentration by adjusting

**Table 1 – Basic parameters of the BIT-HICE.**

| Specifications | Parameters |
|---|---|
| Characteristic | Two injectors per cylinder; four valves configuration |
| Bore (mm) | 86 |
| Stroke (mm) | 86 |
| Connecting rod length (mm) | 142.8 |
| Compression ratio | 10 |
| Displacement (ml) | 1998 |

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