ARTICLE IN PRESS

INTERNATIONAL JOURNAL OF HYDROGEN ENERGY XXX (2018) 1–11

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/he

Investigation of rotating detonation wave fueled by "ethylene-acetylene-hydrogen" mixture

Yepan Zhong [a], Di Jin [b], Yun Wu [b,*], Xin Chen [b]

[a] School of Postgraduate, Air Force Engineering University, Xi'an, 710038, China
[b] Science and Technology on Plasma Dynamics Laboratory, Xi'an, 710038, China

ARTICLE INFO

Article history:
Received 18 March 2018
Received in revised form
24 May 2018
Accepted 30 May 2018
Available online xxx

Keywords:
Mixing gases
Rotating detonation
Instability
Thermoacoustic coupling

ABSTRACT

In this study, the stable operating range and basic characteristics including the pressure and speed of a rotating detonation are researched. The fuel is an "ethylene–acetylene–hydrogen" mixture, examined at three mixing ratios of 2:1:4, 2.2:1:4, and 1.8:1:4 (ethylene:acetylene:hydrogen). The pressure of the rotating detonation wave (RDW) increases when the equivalence ratio (ER) is near the stoichiometric ratio, but it is little affected by the flow rate. The detonation wave speed maintains at 1200–1400 m/s, approximately 70% of the Chapman-Jouguet (C-J) speed, which is hardly impacted by the ER and flow rate. The speed of the RDW in the long-duration tests is higher than in the short-duration tests, and the time taken for the formation of a stable RDW is longer. The stable operating range is broadened and speed is increased with the increase in the acetylene and hydrogen in the mixture. The instabilities in the RDW are found to be correlated with the planar acoustic waves, whereas the mechanisms of the decoupling and re-ignition of the RDW are explained from the perspective of thermoacoustic coupling.

Introduction

Presently, environmental problems resulting from emissions are becoming serious. Increasing the combustion efficiency is an efficient approach to reduce the fuel consumption rate and emissions. However, because of the limitations of high-temperature resistant materials, improving the combustion efficiency by the conventional mode of isobaric combustion is difficult. As a pressure-gain combustion mode, detonation provides a feasible method for improving the combustion efficiency. Therefore, it is important to investigate and establish a continuous and stable detonation-based thermal cycle in engines or other combustion devices. A typical pulsed detonation engine (PDE) closes one end of the detonation tube and opens the other; the fuel and oxidizer are filled and ignited again after the expansion of the previous products, which significantly limits the working frequency of the PDE and makes it difficult to meet the requirement of "a continuous cycle." In the late 1950s, Voitsckhovskii [1] first discovered rotating detonation using a disk setup, and subsequently, in the 1960s, Nicholls et al. [2] demonstrated the feasibility of a continuous detonation-wave using an annular combustor. Ignition is needed once by the rotating detonation engine (RDE), enabling it to install simpler ignition instruments compared with a PDE and allowing the RDW to sustain its propagation by itself. The aforementioned advantages of an RDE ensure its broad application prospects.

To date, hydrogen/air rotating detonation tests have been widely implemented globally and numerous research results

* Corresponding author.
E-mail address: wuyun1223@126.com (Y. Wu).
https://doi.org/10.1016/j.ijhydene.2018.05.174

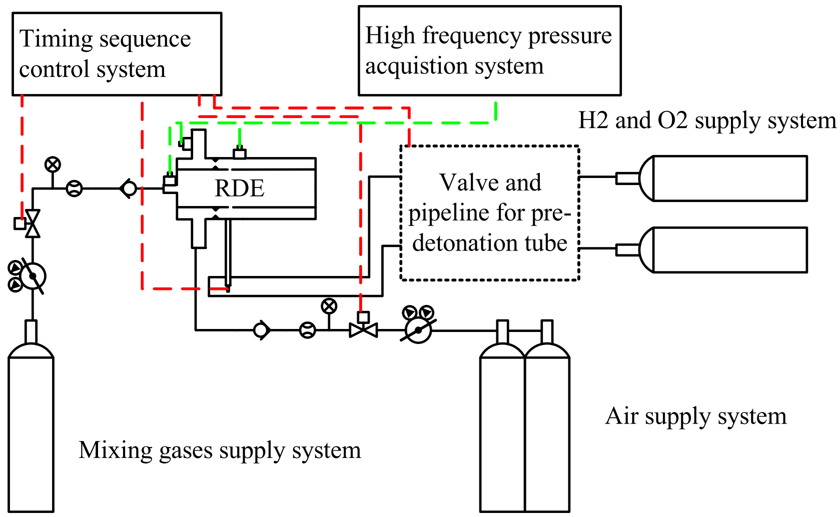

Fig. 1 – Sketch of the experimental system.

have been produced. Roy et al. [3] investigated the effect of preheating and back pressure on the performance of an RDE and found that an elevated preheat and back pressure promoted the mode switching of the RDW. Nagoya University implemented long-duration (6–10 s) hydrogen/air RDE tests in the background of a rocket engine, whose impulse reached 144 s [4]. Mid-infrared imaging was adopted in air force research laboratory (AFRL) to observe the hydrogen/air RDW structure [5]. Annad et al. determined the typical modes of a hydrogen/air RDW and also longitudinal pulsed detonation (LPD) [6,7]. Liu [8,9]and Ma et al. [10,11] examined the effect of the combustor geometry and mode transfer on a hydrogen/air RDW. Ma et al. [12] also implemented a test for the integration of a turbine and an RDE using a hydrogen/air mixture [12]. Frolov et al. tested a rotating detonation-based ramjet model under different stream conditions and demonstrated it in a wind tunnel [13,14]. Frolov et al. also conducted a large-scale test for a combustor and found that the total mass flow rates of the fuel components reached 7.5 kg/s [15]. Instead of an experimental study, Schwer and Kailasanth performed significant numerical investigation on the physics and fluid dynamics of an RDE [16,17]. Raman et al. described the nature of the detonation in terms of the shock front velocity and induction length [18]. Wang et al. analyzed the reacting paths and thermodynamic performance of the flow particles in an RDE by two-dimensional simulation [19].

In addition to hydrogen, hydrocarbon fuels are commonly used in combustion devices. The investigation of hydrogen and hydrocarbon mixtures is relevant for broadening the application of hydrogen because most of the global energy originates from fossil fuels [20]. Although hydrogen (H_2) is not directly contained in fossil fuels as a gas, H is one of the main elements of fossil fuels. Moreover, owing to its high activity, hydrogen plays an important role in the facilitation of the formation and propagation of an RDW. Wolansiki et al. [21] conducted RDE tests with three types of alkanes. Annad investigated the RDW mechanics and instability using an ethylene–air mixture in a hollow combustor [22]. Frolov et al. studied the self-ignition existing in a hydrocarbon–hydrogen mixture rotating detonation [23]. Falempin et al. successfully obtained a detonation wave with liquid kerosene–hydrogen mixtures and attempted to perform the RDE tests with a prevaporized hydrocarbon fuel [24]. Because it is difficult to form a detonation wave directly with hydrocarbon fuel/air mixtures, particularly for liquid fuels, it is necessary to investigate the rotating detonation characteristics of the hydrogen–hydrocarbon fuel mixtures to derive the basic characteristics of an RDW. Furthermore, the investigation of hydrogen–hydrocarbon fuel mixtures can deepen the understanding of the detonation mechanism and roles of the different components in the rotating detonation. In this study, before the tests, three main components are premixed with

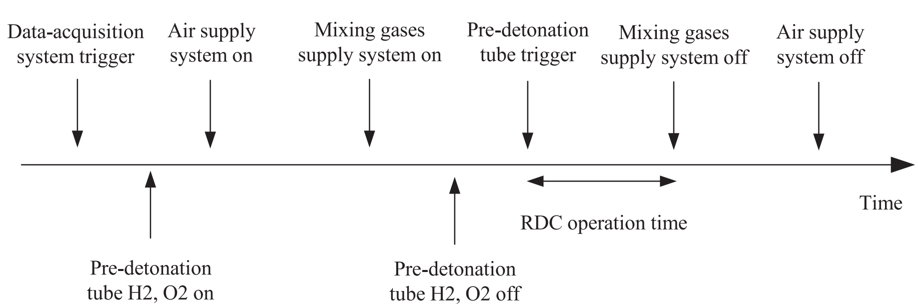

Fig. 2 – Time sequence of the experiments.

Please cite this article in press as: Zhong Y, et al., Investigation of rotating detonation wave fueled by "ethylene-acetylene-hydrogen" mixture, International Journal of Hydrogen Energy (2018), https://doi.org/10.1016/j.ijhydene.2018.05.174