Experimental Investigation on Rotating Detonation Combustion Fueled by Kerosene

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1 Introduction

The application of rotating detonation combustion technology can greatly improve the performance of traditional aerospace propulsion and power devices, and thus has received extensive attention from the United States, Russia, and Europe in recent years. Based on numerous experimental and numerical studies on gaseous rotating detonation wave (RDW) with H_2 [1–3], CH_4 [4,5] and other gaseous fuels, the premilitary understanding are obtained on the propagation regimes of RDW[6–9]. These achievements have laid a foundation for multiple engineering applications of rotating detonation engines[10–12]. Compared to gaseous fuels, the liquid hydrocarbon fuels including kerosene is still the best choice in the field of aviation, and it is inevitable to adopt kerosene for the future rotating detonation engines. Nevertheless, the liquid hydrocarbon fuel has to undergo spray processes including atomization, evaporation and mixing before reaction. In the rotating detonation combustor, there may also be a complicated coupling between the spray processes and the detonation, which has negative effects on the initiation and stable combustion of rotating detonation.

Previous experimental studies have shown that it is difficult to obtain the stable and self-sustaining RDW using kerosene/air reactants at normal temperature [13,14]. In this study, the rotating detonation combustion process fueled by kerosene/oxygen-enriched air is experimentally investigated. The variation law of the propagation characteristics of kerosene two-phase rotating detonation wave and the combustion modes are illustrated.

2 Experimental Set-up

As shown in Figure 1, the rotating detonation combustor used in the study consists of oxidizer plenum, fuel plenum, injection plate, combustor and nozzle. The supplied fuel is RP-3, and oxidizer is oxygen-enriched air with oxygen volume fration of 40%. Thirty coaxial swirl atomizors are circumferentially placed on the injection plate. The inner and outer diameter of the combustor are 120 and 150 mm, respectively. The length of combustor is 200 mm. A high-speed camera is placed behind the combustor to capture the wave trajector in the annluar channel, and the frame rate is 30,000 fps.

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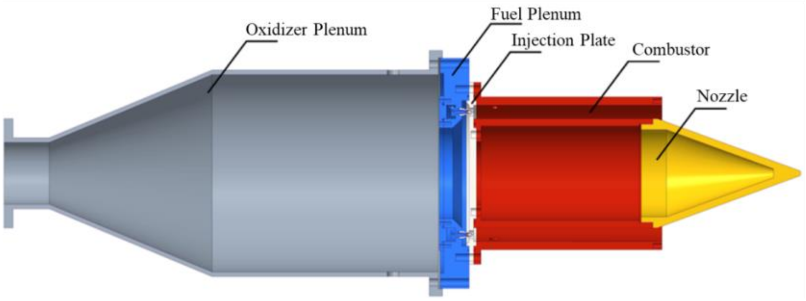

Figure 1: Structure schematics of two-phase rotating detonation combustor used in the study.

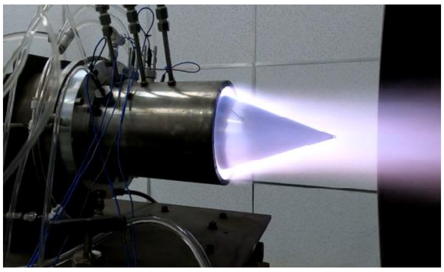

Figure 2: Photo of hot test of the rotating detonation combustor.

3 Result

As shown in Figure 3, complex combustion modes are observed in the experiments, including the counter two-wave mode, counter four-wave mode, unsteady mode and mode switch of two-wave to four wave. The evolution process and propagation characteristics of detonation waves are clearly illustrate by the wave trajectory diagrams.

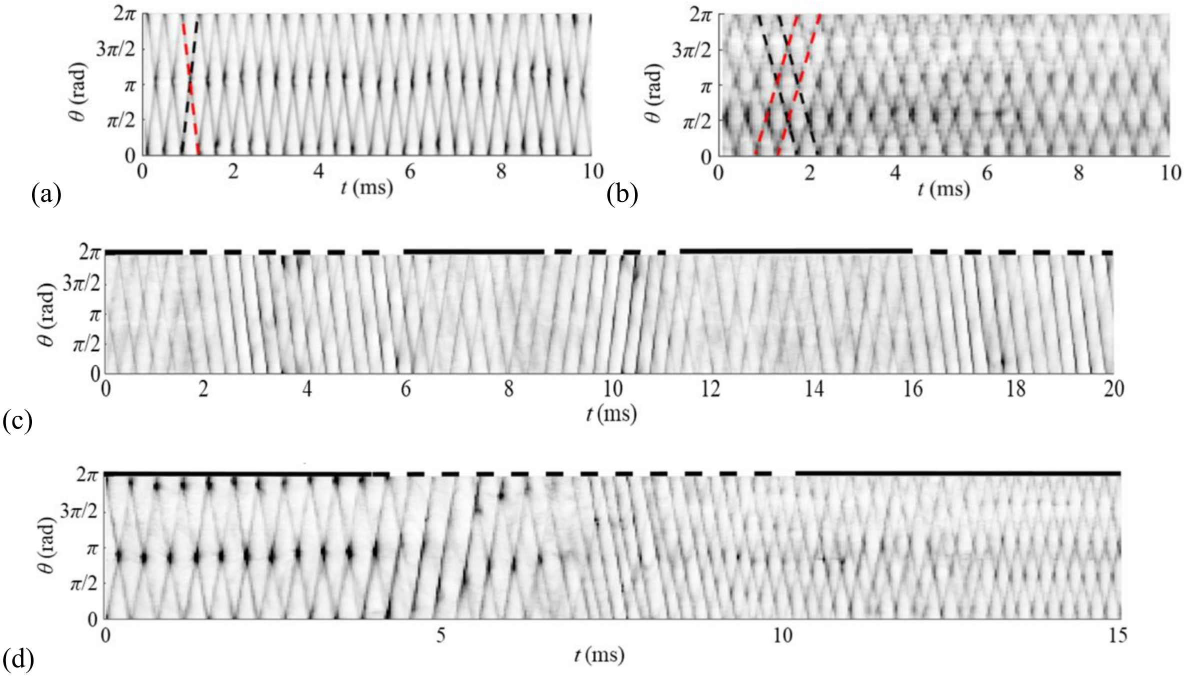

Figure 3: Typical combustion modes shown by wave trajectory diagrams: (a) counter two-wave mode, (b) counter four-wave mode, (c) unsteady mode and (d)mode switch of two-wave to four wave.

Besides, the mass flow rate of oxidizer is varied from 0.5 to 1.25 kg/s, and the equivalence ratio is varied from 0.5 to 1.0, to obtain the operation map of the given rotating detonation combustor. It is found that with the increase of oxidizer flow rate, the decrease of equivalence ratio, the combustion mode formed in the combustor gradually transits from the counter two-wave to counter four-wave mode. The mode switch occurs in the intermediate parameter region where the stable modes form. For the cases with low oxidizer flow rate and equivalence ratio, the detonation is failed.

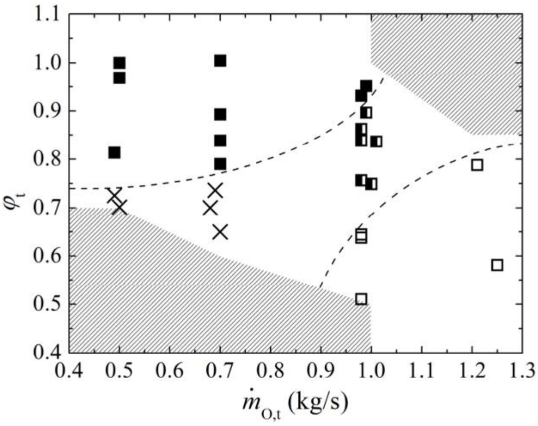

Figure 4: Operation map of rotating detonation combustor with kerosene/oxygen-enriched air:
■ couter two-wave mode, ◧ mode switch, □ counter four-wave mode, × ignition failure.

4 Conclusion

The combustion phenomena in the kerosene/oxygen-enriched air rotating detonation combustor equipped with coaxial swirl atomizors are experimentally studied. Various stable combustion modes such as one-wave and counter two-wave mode, as well as mode switches and three types of detonation quench are observed. The evolution process and propagation characteristics of detonation waves are illustrated. The study shows that with the increase of oxidizer flow rate, the decrease of equivalence ratio, the combustion mode formed in the combustor gradually transits from the counter two-wave to counter four-wave mode. The mode switch occurs in the intermediate parameter region where the stable modes form.

References

[1] Anand V, St. George A, Driscoll R, Gutmark E. Characterization of instabilities in a Rotating Detonation Combustor. Int J Hydrog Energy 2015;40:16649–59.

[2] Frolov SM, Aksenov VS, Ivanov VS, Shamshin IO. Large-scale hydrogen–air continuous detonation combustor. Int J Hydrog Energy 2015;40:1616–23.

[3] Rankin BA, Richardson DR, Caswell AW, Naples AG, Hoke JL, Schauer FR. Chemiluminescence imaging of an optically accessible non-premixed rotating detonation engine. Combust Flame 2017;176:12–22.

[4] Kasahara J, Kato Y, Ishihara K, Goto K, Matsuoka K, Matsuo A, et al. Application of Detonation Waves to Rocket Engine Chamber. In: Li J-M, Teo CJ, Khoo BC, Wang J-P, Wang C, editors. Detonation Control Propuls. Pulse Detonation Rotating Detonation Engines, Cham: Springer International Publishing; 2018, p. 61–76.

[5] Koch J, Chang L, Upadhye C, Chau K, Kurosaka M, Knowlen C. Influence of injector-to-annulus area ratio on rotating detonation engine operability. AIAA Propuls. Energy Forum Expo., 2019, p. 4038.

[6] Anand V, Gutmark E. Rotating detonation combustors and their similarities to rocket instabilities. Prog Energy Combust Sci 2019;73:182–234.

[7] Xie Q, Wen H, Li W, Ji Z, Wang B, Wolanski P. Analysis of operating diagram for H2/Air rotating detonation combustors under lean fuel condition. Energy 2018;151.

[8] Kindracki J, Kobiera A, Wolański P, Gut Z, Folusiak M, Swiderski K. Experimental and numerical study of the rotating detonation engine in hydrogen-air mixtures. Prog Propuls Phys 2011;2:555–82.

[9] Suchocki JA, Yu ST, Hoke JL, Naples AG, Schauer FR, Russo R. Rotating Detonation Engine Operation. 50th AIAA Aerosp. Sci. Meet., AIAA; 2012, p. 119.

[10] Liu S, Liu W, Wang Y, Lin Z. Free Jet Test of Continuous Rotating Detonation Ramjet Engine. 21st AIAA Int. Space Planes Hypersonics Technol. Conf., Xiamen, China: 2017, p. 2282.

[11] Frolov SM, Zvegintsev VI, Ivanov VS, Aksenov VS, Shamshin IO, Vnuchkov DA, et al. Hydrogen-fueled detonation ramjet model: Wind tunnel tests at approach air stream Mach number 5.7 and stagnation temperature 1500 K. Int J Hydrog Energy 2018;43:7515–24.

[12] Naples A, Hoke J, Battelle R, Wagner M, Schauer F. Rotating detonation engine implementation into an open-loop T63 gas turbine engine. AIAA SciTech Forum - AIAA Aerosp. Sci. Meet., 2017, p. 1747.

[13] Wolański P, Balicki W, Perkowski W, Bilar A. Experimental research of liquid-fueled continuously rotating detonation chamber. Shock Waves 2021;1:3.

[14] Kindracki J. Experimental research on rotating detonation in liquid fuel-gaseous air mixtures. Aerosp Sci Technol 2015;43:445–53.