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Abstract: Rotating Detonation Engine (RDE) has all the advantages including high-efficiency and high thrust density without compression stages for the future generation engine. Nevertheless, RDE is still at an infancy stage that need further study specifically to discover the best mixing scheme for combustion stability. Thus, the aim of this study is to develop and test the new mixing scheme of RDE using asymmetric vortex shape on small scale RDE to improve mixing and stability. Initiation strategy by using pre-detonator with 10bar of detonation pressure. RDE with asymmetric vortex shape was successfully operate with average pressure of 4.5bar and 6 kHz of frequency.

Keywords: Detonation; RDE; Rotating Detonation Engine

1. Introduction

Recently, RDE has become a very highly interested research field due to many advantages over the conventional combustor especially in thermodynamically efficiency [1)] and high thrust density without complex design[2)]. RDE promised technology for the new generation of propulsion engine[3–5)]. Significant progresses of RDE has been achieved in recent years [6–8)]. However, there are several challenges needed to be address for thorough investigation prior to industry application. Though, to develop workable RDE is a formidable task. The challenge is to successfully archive stable detonation using existing air-fuel supply system[9)].

In the past few years it can be seen that most of the combustion research community are aware of the limitations and finding the best remedy is still a challenge. Two main interested issues on RDE are mixing[6)] and stability[10)] of the detonation. Sufficient mixing is required for all combustion processes[11–13)], especially for RDE. Efficient mixing will improve thrust, stability, torque etc in combustion system[13)]. Basically, RDE requires a very fact mixing process in a very short period of time. It is because the combustion itself need to withstand the detonation wave inside it with the freshly reactant that supplied into it. Thus, high mass flow rate value of reactant is needed for the engine and this will produced a high pressure detonation combustion. To achieve this, it require a proper way of mixing between the reactants as well as the configuration of the mixing mode. Further clarification and explanation is needed[6)].

By research, the mixing scheme has a wide variety[12)], but those research doesn't include the effects of asymmetric vortex shape on RDE. Asymmetric vortex shape have the advantages on mixing and stability[14,15)] that can overcome RDE issues. Because RDE has a different combustion mode from that conventional combustor, it was considered that a characteristic of the subsequent channel flow is also different from that of a conventional. Therefore, investigation of the effect of the annular shape for mixing is one of the important factors in the practical use of an RDE.

The focus of the study is to produce a detonation combustion with high recirculation with a proper mixing. The design of RDE was modified based on Saqr[14)] asymmetric vortex combustor chamber as shown on Fig 1. This modified design includes a high recirculation for fast mixing. Basically, vortex flame will stabilize the reaction zone, thus it will provide flame stability that will made the mixing more faster and better between air and fuel upstream at the reaction zone[16,17)]. So the produced flame will demonstrate as premixed flame visually, although it is a non-premixed flame. Therefore, it will increase the stability while not effecting the premixed flame [18)].

Current research focuses on the development of asymmetric vortex for RDE, aiming for improving mixing and stability to be use as a thrust production engine with highly efficient system.

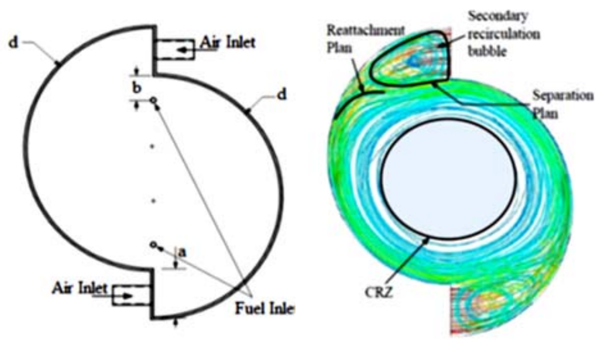

Fig. 1: Asymmetric vortex design and the simulated flow [14)]

2. Method and experiment setup

Fig. 2 shows the experimental setup done at High Speed Reacting Flow Laboratory (HiREF), School of Mechanical Engineering, Faculty of Engineering, Universiti Teknologi Malaysia. The setup consist of fuel and oxidizer supply system and control system. The experiment done in confine space for safety purpose. Control system locate inside control room separately from supply system and experimental area.

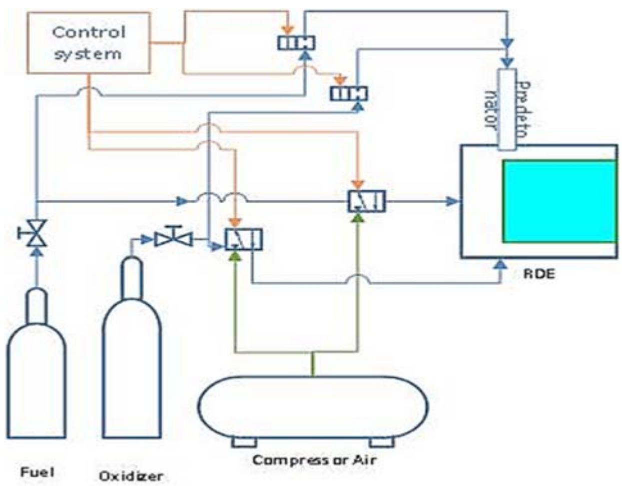

Fig. 2: Schematic diagram of RDE setup.

Two different design of RDE was used in this study. The first design is the regular circular shape as shown in fig. 3. The second RDE designed with asymmetric shape as shown in fig. 4. Both RDE was developed based on the guideline given by [19)]. A modular RDE was designed to make it easy to modify, fabricated and installed with outer diameter = 23mm, center body diameter= 28mm for both RDE. The shape of asymmetric vortex for the combustion chamber is the effect of offset of circular shape with 5mm suggested by Saqr [14)] as shown in fig. 1 and fig. 4.

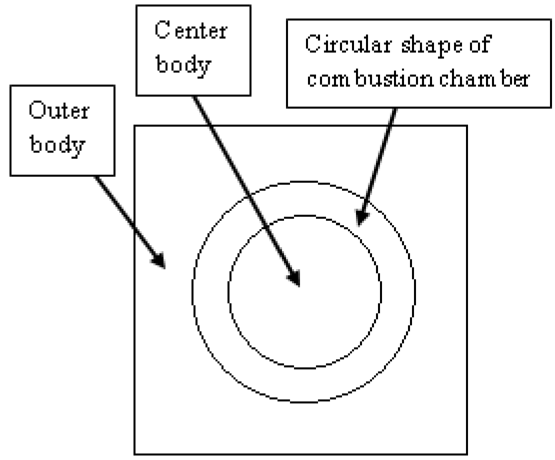

Fig. 3: Schematic of circular shape RDE from top view.

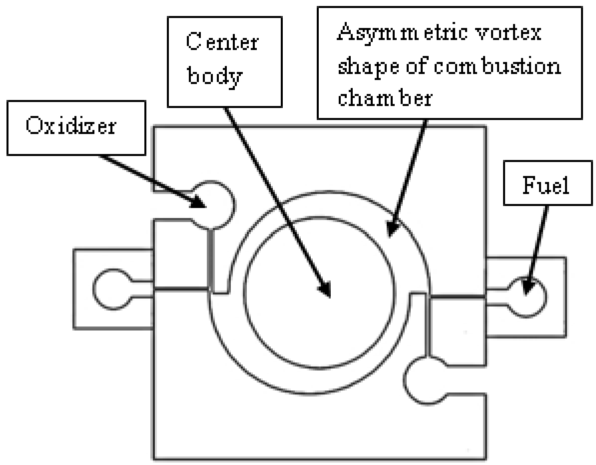

Fig. 4: Schematic of asymmetric vortex shape RDE from top view.

The chamber of RDE is made of mild steel. The fuel is injected from the bottom of engine through a hole with diameter 0.7mm. The oxidizer is injected tangentially to the body through four holes with diameter 1mm at both side. A pressure regulator is used to control the stagnation pressure and the flow rate of fuel and oxidizer. The selected fuel is pure methane and oxidizer is pure oxygen.

RDE was controlled distantly from the control room by using Arduino. The sequences is changeable, so it can manually edited to determine the best operation timing for success detonation of RDE. RDE timing sequence as an example is shown in Fig. 5. Firstly, a supply valve for pre-detonator will open along 0.5s then it close with delay 0.8s. At the same time, the main supply will also open until the end of operation period. The ignition system will initiate the pre-detonator to produce detonation to generate detonation inside RDE chamber after 1.3s from beginning. Lastly after 1s initiation, the main supply of fuel and oxidizer will cutoff. The initiator for pre-detonator ignites using spark plug. The energy of spark plug was generated from discharge capacitor. Detonation wave will develop at the end of pre-detonator tube. Then the detonation wave will initiate the RDE. The pressure profile of RDE was measured by using transducers brand Kistler 211B300 Piezotron with sensitivity 1.156 mV/psi to 1.168 mV/psi. The pressure transducers were equipped with water jacket to avoid from overheat or else may lead fatal on the transducers. The maximum working temperature of this transducer was 1210ºC. The data was recorded using data acquisition (DAQ) system from National Instruments. The digital inputs go to BNC-2120 then process by using LabVIEW program.

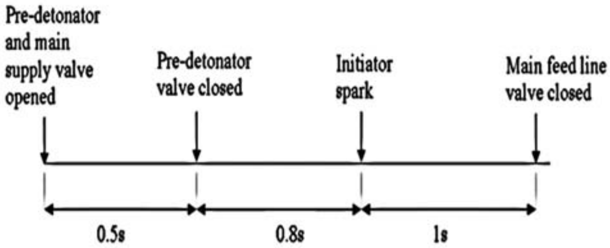

Fig. 5: Timing sequence of RDE system.

3. Result and discussion

The main result of this study is pressure pattern on RDE annulus chamber. The pattern of a pressure graph captured by transducer is shown either success or not to generate detonation. Before initiating the RDE, it is important to make sure the source of ignition (pre-detonator) was at detonation wave mode. After several times modify on the equivalence ratio and timing of pre-detonator, it produced the best detonation source at end of pre-detonator before initiate RDE as shown on fig. 6. Detonation wave produced by pre-detonator was 10bar. It was enough to initiate detonation wave inside RDE as long it was detonation wave. Pre-detonator is the best initiation strategy for RDE due to its consistency on repeatability and low energy requirement [20].

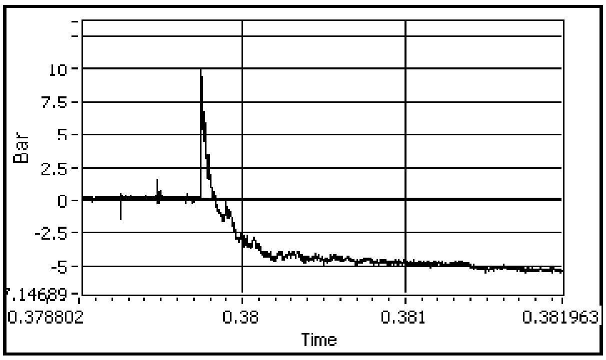

Fig. 6: 10bar detonation spike from pre-detonator.

Experiment was done using hydrogen as a fuel and oxygen as an oxidizer at equivalence ratio 1.1 for both type of RDE. Equivalence ratio 1.1 is the best detonation characteristic for hydrogen with the smallest cell size and higher pressure[21,22]. After abundant of trials and adjusting the timing sequence and modification was done, it shows the successful detonation inside the RDE with asymmetric vortex shape combustion chamber. The high-speed pressure data of RDE shown on Fig. 7. Fig. 8 shows the expanded view from Fig. 7 of the pressure profile of RDE. Asymmetric vortex shape RDE produced average pressure of 4.5 bar with 6kHz of frequency. The pressure pattern from zero bar to negative bar due the effect of thermal drift caused by higher temperature of detonation wave [23]. The pressure after 0.5 second shows that a thick line become thin line due the transition of detonation wave transforms to deflagration wave. During that point the main supply of fuel and oxidizer for RDE was cutoff. Graph pattern was same with other previous researcher [9,23,24].

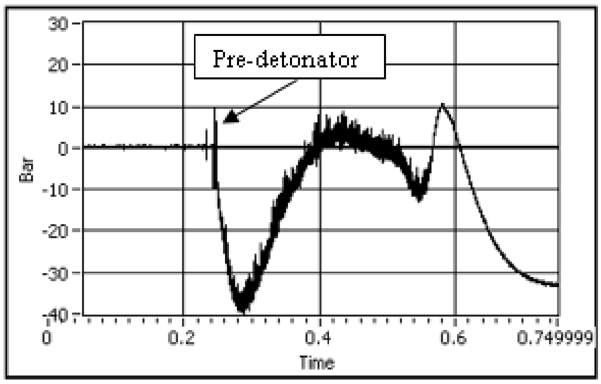

Fig. 7: Overall pressure profile on RDE chamber.

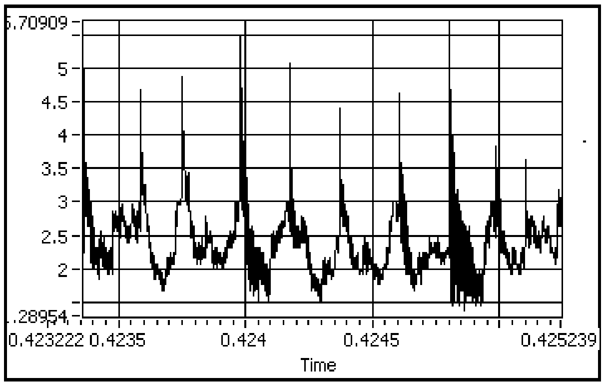

Fig. 8: Expanded view of detonation pressure from Fig. 7.

However, the result of regular circular shape of RDE showed unsuccessful detonation wave inside the combustion chamber. Although with same configuration setup with asymmetric vortex shape RDE. Fig. 9 shows the result of combustion happened inside circular shape RDE. Detonation wave inside the combustor cannot be maintained after receiving detonation wave inside the pre-detonator tube. There was no sharp rise spike of pressure pattern shown after the pre-detonator spike. This show that the time sequence of operation may require adjustment to make sure the propagation of detonation wave can be continuously maintained throughout the chamber of circular shape RDE. Moreover, addition delay in between each period is said to improve mixing of reactant before ignition.

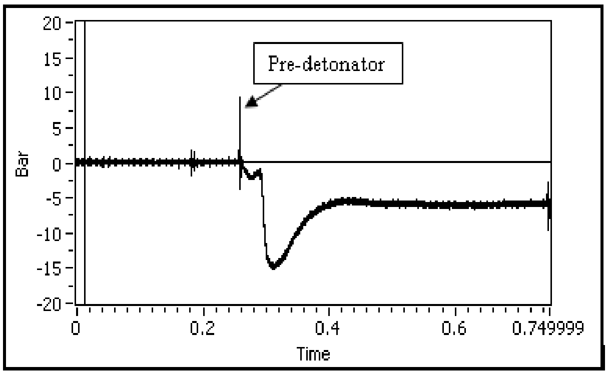

Fig. 9 Pressure pattern for circular shape RDE.

Unsuccessful detonation maybe happened due to the poor mixing issue lead to unstable combustion [25,26]. Asymmetric vortex shape have the advantages in term of vortex mixing that lead the swirl number [14,15]. RDE with asymmetric vortex shape is much easier to maintain detonation wave inside the combustion chamber compare to regular circular RDE due to the improvement on mixing of reactant inside the chamber. This modified design will produce a more stable flame that allows a more vigorous mixing between the reactant upstream of reaction zone [16,17].

4. Conclusions

The present study discussed the effect of RDE combustion shape on developing detonation wave inside the chamber. RDE was designed with two different shape which is circular shape and asymmetric shape. RDE with asymmetric vortex shape of annulus combustion chamber successfully generate detonation wave compare to circular RDE at the same fuel and equivalence ratio condition. RDE of asymmetric vortex generate the repeated detonation of 6 kHz with average pressure of 4.5 bar. This result will be used as a benchmark for further development on asymmetric vortex of RDE. For further understanding the performance of RDE, load cell will be used to measure thrust. The development of RDE using asymmetric vortex shape is expected to show enhanced output in comparison to conventional combustion.

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Nomenclature

RDE rotating detonation engine

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