12TH ASIA-PACIFIC CONFERENCE ON COMBUSTION (ASPACC 2019)

1-5 JULY, 2019

FUKUOKA, JAPAN

SECOND CIRCULAR

Photo: Fukuoka City

The Asia-Pacific Conference on Combustion (ASPACC) is a biennial meeting sponsored by the Combustion Institute and organized by members of the Asia-Pacific regional sections. Its goal is to promote exchange of information and to elevate combustion science and technology through regional and global scientific partnership. The 12th ASPACC will be hosted by the Japan Section of the Combustion Institute, and will be held on July 1 to 5, 2019 in Fukuoka, Japan. The conferences will provide a forum for mutual exchange of information in the Asia-Pacific combustion community involved in both fundamental and application oriented research and development works.

PLENARY SPEAKERS :

Professor Evatt Hawkes, University of New South Wales
Unravelling engine combustion using large-scale computations

Professor Naian Liu, University of Science and Technology of China
Combustion of Fire Whirl : How much do we know?

Professor Kang Y. Huh, Pohang University of Science and Technology
Combustion Modeling and Simulation in Era of the Fourth Industrial Revolution

Professor Min Suk Cha, King Abdullah University of Science and Technology
Recent understanding with flames under external electric fields

Professor Yei-Chin Chao, National Cheng Kung University
Hydrogen Peroxide Revisited : the Role as an Energy-Saving Combusiton Enhancer and a Non-Toxic Green Propellant for Satellites and Hybrid Rockets

Speakers from Japan and India Sections are to be determined.

CONFERENCE VENUE :

Fukuoka International Congress Center
2-1 Sekijo-machi, Hakata-ku, Fukuoka 812-0032, JAPAN

IMPORTANT DATES :

Submission of full paper:	25th January 2019
Notification of paper acceptance:	1st April 2019
Conference dates:	1st - 5th July 2019

PAPER SUBMISSION :

Full length papers should follow the format given on the conference web site. The Program Committee will select papers for presentation on the basis of peer reviews of each paper. All selected papers should be presented by one of the authors. Technical papers are solicited in all areas of combustion science and technology including the following areas.

- Gas-Phase Reaction Kinetics
- Soot, Nanomaterials, and Large Molecules
- Diagnostics
- Laminar Flames
- Turbulent Flames
- Spray, Droplet, and Supercritical Combustion
- Detonations, Explosions, and Supersonic Combustion
- Solid Fuel Combustion
- Fire Research
- Stationary Combustion System and Control of Greenhouse Gas Emissions
- Internal Combustion Engines
- Gas Turbine and Rocket Engine Combustion
- New Concepts

YOUNG INVESTIGATOR AWARDS :

Young Investigator Awards will be awarded to the best performing young author-presenter from research students or postdoctoral researchers (or equivalent).

BEST PAPER AWARDS :

Best paper awards will be awareded to the best papers presented at ASPACC2019.

WOMEN IN COMBUSTION MEETING :

All women conference participants are invited to join together for a time to network and share their experiences. The interactive meeting will convene during the conference.

ORGANIZING COMMITTEE :

Chair: Toshiaki Kitagawa, Kyushu University
Co-chair: Fumiteru Akamatsu, Osaka University
Co-chair: Kenji Yamamoto, Mitsubishi Heavy Industries, Ltd.
In 2019, the Organizing Committee is spread in the community of the Asia-Pacific regional sections of the Combustion Institute, mainly the Japan Section.

PROGRAM COMMITTEE :

Chair: Masato Mikami, Yamaguchi University
Co-chair: Shuhei Takahashi, Gifu University

CONTACT :

For additional information please contact
Contact address: aspacc19@combustionsociety.jp
Website: http://www.combustionsociety.jp/aspacc19/

Full length paper submission will be available in early December on the conference web.

Room 10 (503)

OS12-01. Gas Turbine and Rocket Engine Combustion

Tue., 2 Jul., 10:00 - 11:20, Room 10 (503)

Chair: **Hiroshi Gotoda** (Tokyo University of Science, Japan)

ASPACC2019-1037	**Combustor Modeling and Design Modification of a Micro Gas Turbine with a Rotating Casing for H2-rich Syngas Fuel** Maaz Ajvad, Hsin-Yi Shih (Chang Gung University, Taiwan)
ASPACC2019-1143	**KINETICS MODELING STUDY OF A STAGED COMBUSTOR CONCEPT FOR DIRECT-FIRED sCO2 OXY-COMBUSTION** Wenkai Qian, Haoyang Liu, Suhui Li, Min Zhu (Tsinghua University, China)
ASPACC2019-1279	**NOx Emission of Two-stage Combustor for Ammonia/Natural Gas Co-Fired Gas Turbine** Shintaro Ito, Masahiro Uchida, Toshiro Fujimori (IHI corporation, Japan), Hideaki Kobayashi (Tohoku university, Japan)

OS12-02. Gas Turbine and Rocket Engine Combustion

Tue., 2 Jul., 11:40 - 12:40, Room 10 (503)

Chair: **Masahiro Uchida** (IHI corporation, Japan)

ASPACC2019-1086	**Combustion Stability of Nonpremixed Oxygen/Hydrogen Coaxial Jet Flames** Young Hoo Kim (Sungkyunkwan University, Korea), Tae Young Kim (Research Institute of Industrial Science & Technology, Korea), Yeong Jong Ahn, Sun Choi, Oh Chae Kwon (Sungkyunkwan University, Korea)
ASPACC2019-1141	**A Novel Type of Tubular Flame Burner with Multi-stage and Partially-Premixing Features** Yiran Feng, Wenyuan Qi, Yuyin Zhang (Shanghai Jiao Tong University, China)
ASPACC2019-1176	**Numerical Investigation on the Syngas Composition Effects on a Model Gas Turbine Combustor** Jaehyun Nam, Younghun Lee, Jack Jai-Ick Yoh (Seoul National University, Korea)

12th Asia-Pacific Conference on Combustion,
Fukuoka International Congress Center, Fukuoka, Japan
1st -5th July 2019.

Numerical Investigation on the Syngas Composition Effects on a Model Gas Turbine Combustor

Jaehyun Nam[1], Younghun Lee[1], Jack J. Yoh[1*]

[1]Department of Mechanical and Aerospace Engineering, Seoul National University

1 Gwanakro, Gwanakgu, Seoul, 151-742, Republic of Korea

Abstract

Simulations are carried out on a hydrogen-enriched partially premixed model gas turbine combustor. Synthetic gas consisted of methane and hydrogen is considered as the working fuel and the influence of hydrogen composition in combustor is investigated. The nozzles of the combustor are composed of 14 swirl channels (swirl number = 0.83) and partial premixing of the fuel and the oxidizer takes place in a short region of about 3 mm inside the nozzle. For accurate simulation of the swirl-stabilized flame inside the combustor, large-eddy simulation (LES) with 23-step chemical kinetics is applied within the OpenFOAM framework. Comparisons are made with experimental flame images and combustion instability data for verification. Simulation results show that the flame shape changes drastically depending on the hydrogen content. The combustion instability in the combustion chamber is also found to vary with the hydrogen content, and the pertaining analysis is developed.

1 Introduction

Synthetic gas, which is a compound composed of H2/CO/CH4, has advantages in reduction of greenhouse gas emission and performing stable combustion. The characteristics associated with its composition have been actively studied over the past few decades. Nobel et al. [1] have reported flashback and blowout characteristics according to the composition of syngas. Burbano et al. [2] analyzed the effect of H2/CO/Air mixture composition on laminar flame speed and Lewis number in nozzle burner. Issues related to auto-ignition [3] and combustion stability [4] according to the composition of syngas have also been reported. Furthermore, it has been reported that the composition of the syngas has a notable influence on the combustion instability occurring in the combustor. Davis et al. [5] considered pure CH4, CH4/H2 gases and analyzed H2 effect on dynamic response of thermoacoustic oscillation in gas turbine combustor. Allison et al. [6] conducted experiments on various syngas/hydrocarbon gases and analyzed the effect of laminar flame speed on instability modes. Still, such topics are limited to experimental approach, and elaborate numerical analysis is in demand for further understanding the effects of various fuel and combustor conditions.

In this study, we perform numerical simulations on a partially premixed gas turbine combustor, and CH4/H2 syngas is considered as the working fuel. LES turbulence model and turbulence-chemistry interaction model were implemented in the governing equations to describe the strong turbulence in the combustor. Total three syngas compositions are considered in simulations, and the syngas composition effects in combustor are investigated.

Corresponding author. Fax: +82-02-882-1507
E-mail address: jjyoh@snu.ac.kr

2 The test case

2.1 Gas turbine combustor

A 1/3-scale GE7EA model gas turbine combustor, shown in Fig. 1, was selected to study the syngas composition effects.

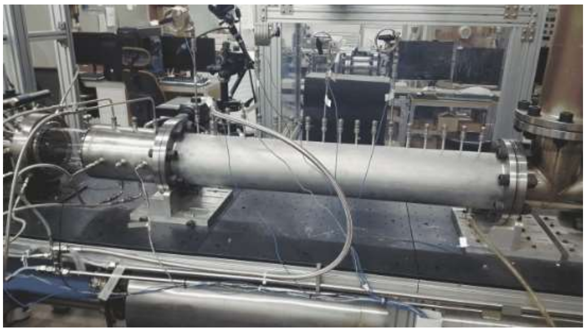

Figure 1: Model gas turbine combustor [7]

The combustor had a length of 0.13m in the radial direction, 1.41m in the axial direction. A swirl nozzle was located at the entrance of a combustor to generate the swirling flame. A water-cooled plug nozzle was located at the outlet of the combustor to achieve an acoustic boundary. The air is supplied to the swirl nozzle at a temperature of 200 ° C and partial premixing with syngas takes place in the 3mm-length short mixing zone in the nozzle. After the mixing process, air and syngas are spark-ignited in the combustor and unstable flame is generated. Experimental measurements were performed inside the combustor and the results about dynamic pressure, flame structure were used to verify the calculation results. In the simulation, the mole fraction of H2 in CH4/H2 syngas was considered to be 0.5, 0.75, and 1 while the total amount of heat input was fixed at 40kW. The test conditions of simulated cases are tabulated in Table 1.

Case	A	B	C
H2 ratio (Mole fraction)	0.5	0.75	1
Equivalence ratio	0.552	0.529	0.480
Fuel flow rate (slpm)	102.00	139.78	222.00
Air flow rate (slpm)	1100		

Heat input (kW)	40

Table 1: Initial conditions of the simulated cases

2.2 Numerical setup

Large-eddy simulation was performed for describing turbulent combustion in the combustor. Compressible governing equations consisted of mass, momentum, energy, and species were calculated for reactive flow simulation. Sub-grid scale modeling was performed using WALE proposed by Nicoud et al. [8] and turbulence-chemistry interaction model (PaSR) [9] was additionally considered to accurately simulate sub-grid scale chemical reactions. A reaction mechanism [10] consisting of 15 species and 23 reaction steps was applied to analyze the reaction rate of CH4/H2 synthesis gas. An STL file was additionally produced based on the design of the gas turbine for 3D simulations. STL file and mathematical models are implemented in the open-source CFD toolbox OpenFOAM. In order to accurately calculate the mixing process in the nozzle, we used a fine unstructured grid of about 0.3mm length in that section. In the combustor, a relatively fine grid was applied in the flame-generating zone and a course grid was applied in the non-reacting zone. In addition, a 1mm length grid was applied near the wall region to simulate small eddies in that region. A schematic and grid distribution of the gas turbine geometry is described in Fig. 2.

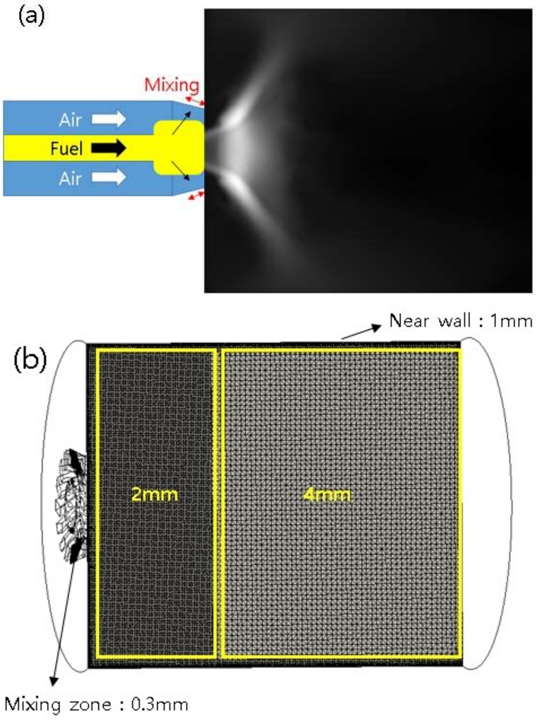

Figure 2: (a) Schematic of the gas turbine combustor and (b) the different grid sizes used inside the combustor

The total number of hexahedral cells used in the calculation was approximately 2.5 million and the computation was performed by parallel computation using 196 cores.

3 Results and discussion

3.1 Flame structures and flow fields

Multiple flames and flow fields in combustor were calculated according to the composition of syngas. Flame structures were compared with the experimental results, and it was confirmed that the simulation reproduced the experimental results well (Fig. 3).

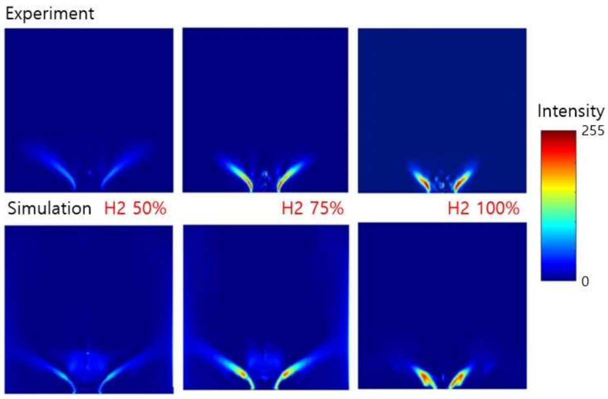

Figure 3: Flame images for various syngas compositions [7]

Results show that the flame structure changed drastically depending on the content of hydrogen in the syngas. As the hydrogen content increases, flame height decreased and high content of OH radical was produced in a narrow region. Furthermore, the flame was formed close to the swirl nozzle when the hydrogen content increased. High reactivity, fast ignition of hydrogen gas affected on those phenomena. Changes in syngas composition and consequent changes in the flame structure also affect the thermoacoustic instability generated in the combustor. The verification process with the experimental results also proceeded with the velocity field in the combustor. Experimental measurements were performed using a particle image velocimetry (PIV) technique in a quartz tube located in a combustor. Since the measurement region is defined as a part of the combustor, the comparison with the simulation result is made in the corresponding section (Fig. 4).

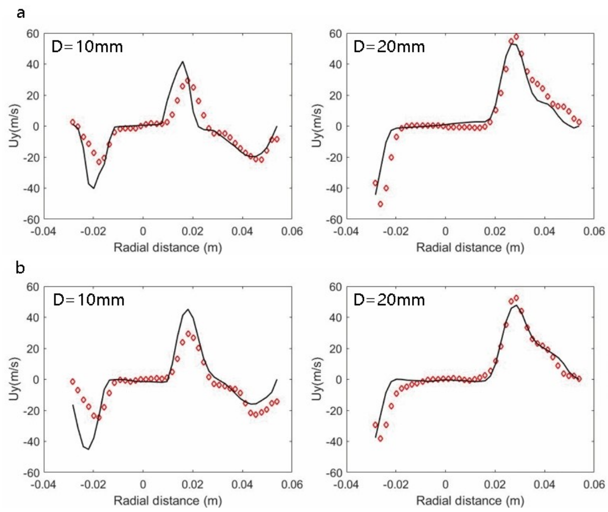

Figure 4: Profiles of the time-averaged Uy velocity components in 50% H2 (a) and 75% H2 (b) syngas compositions for the experiments [10] (symbols) and simulations (lines)

Figure 4 shows the y-axis velocity distributions at 10 mm and 20 mm axial directions (D) from the nozzle location. The results indicate that the simulation accurately predicts the experimental results. Unlike the flame structure, the distribution of the velocity field remains relatively constant with changes in hydrogen content. This is because the velocity field is mainly determined by the constant air injection rate which was remained constant in every cases.

3.2 Combustion instability

Simulations of the combustion instability due to thermos-acoustic coupling in the combustor were progressed. The flow analysis in the previous section is based on the calculation results of 0.05 seconds, whereas the combustion instability analysis is based on the results calculated up to 0.3 seconds. Because of the high computational cost, two-dimensional analysis was performed prior to the three-dimensional analysis. The simulation simplifies the nozzle part, and assumes the cylindrical combustor as rectangular. The FFT (fast Fourier transform) results of the combustion instability analysis under the hydrogen composition of 50% are shown in Fig. 5.

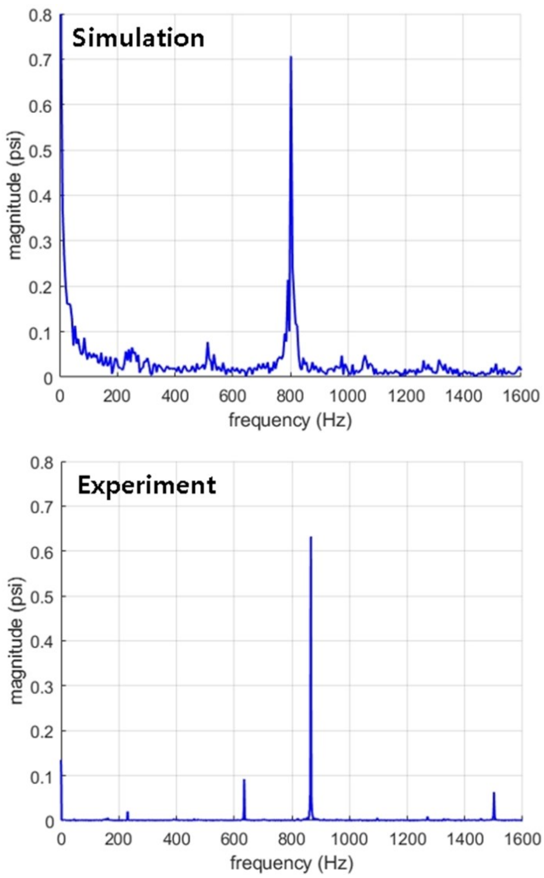

Figure 5: 2D Simulation (top) and experimental [10] (bottom) FFT results of combustion instability for H2 50% syngas composition

From the results, we confirmed that the numerical analysis can similarly predict the combustion instability observed in the experiments. Experimental results show that dominant oscillation occurs at about 800 Hz, which corresponds to the third mode of the combustor, and relatively weak oscillation occurs at 600 Hz, 1500 Hz. The simulation successfully predicted the dominant resonance occurring at the 800 Hz state, while the interpretation of the resonance occurring at the 1500 Hz states was relatively inaccurate. Calculation was also carried out under the conditions of 25% and 75% of hydrogen composition to verify the effect of syngas composition on combustion instability (Fig. 6).

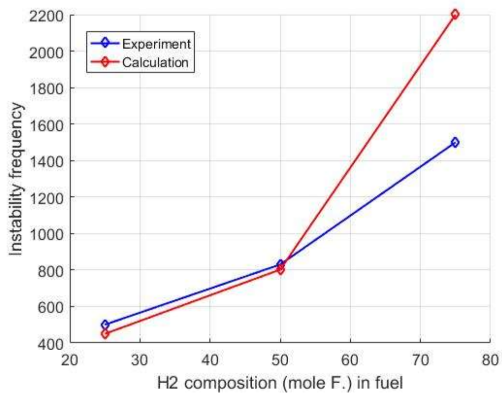

Figure 6: Instability frequency change due to hydrogen composition

Figure 6 is a graph showing the most dominant resonant frequency observed in both simulation and experiment. The results show that the resonant frequency of the combustion instability increases in proportion to the content of hydrogen in the syngas. The same trend was observed in previous experiments and these phenomena are attributed to the high laminar flame speed of hydrogen as analyzed by Allision et al. [6]. In contrast to the hydrogen composition of 25% and 50%, the numerical results predicted a higher frequency range than the experiment under the condition of 75% H2 composition. A related study [11] suggests that a frequency mode jump may occur as the laminar flame speed of the fuel increases. Therefore, it is estimated that the mode jump occurs in 75% H2 condition because the laminar flame speed is calculated to be somewhat higher than the actual value in the simulation.
The combustion instability analysis in 3-D is also performed under the condition of H2 50%, and the results are shown in Fig. 7.

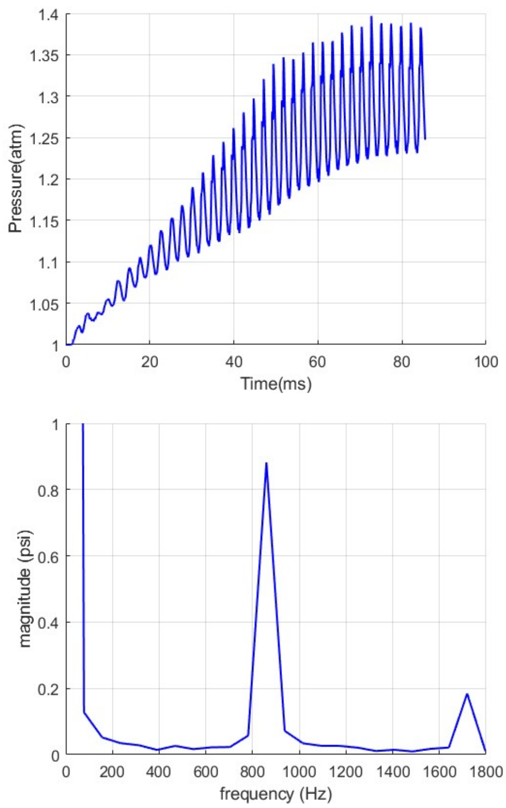

Figure 7: 3D simulation of dynamic pressure profile (top) and its FFT result (bottom) in H2 50% syngas composition

The dynamic pressure profile of Fig. 7 shows that the growth of instability occurs for about 60 ms. During this time, the pressure increases gradually due to the partially-closed combustor outlet. After 60 ms, a relatively constant oscillation is observed. The FFT result is based on the dynamic pressure profile after 60 ms. According to FFT results, it can be seen that a more accurate oscillation frequency is calculated than the two-dimensional calculation. Also, it is shown that the relatively inaccurate oscillation amplitude is calculated in 3D condition. Compared with the two-dimensional results, the three-dimensional setup can accurately calculate the mode in the radial direction. Therefore, it is assumed that the resonance occurring at 1500 Hz may coincide with the radial mode of the combustor.

From those results, it is shown that numerical analysis can be used to calculate the thermoacoustic instability vary with hydrogen content. In two-dimensional calculations, it is concluded that the dominant instability modes in the combustor can be satisfactorily calculated. Still, two-dimensional calculations do not accurately predict all the instability frequencies generated in the combustor, and three-dimensional calculations are progressing as follow up. Since the calculated time in three-dimensional cases is insufficient, the results of more progressed results are needed and will be reported.

4 Conclusions

Numerical investigations were made on the combustion characteristics in a hydrogen-enriched partially premixed combustor. Three different cases of varying syngas compositions were considered. The results showed that the flame structure changed significantly as the hydrogen content changed. Then, the effect of syngas composition on thermoacoustic instability in the combustor was investigated.

5 Acknowledgment

This work was financially supported by the Advanced Research Center (NRF-2013R1A5A1073861), contracted through the Next Generation Space Propulsion Research Center at Seoul National University. Authors are thankful to Prof. Y. Yoon for providing the experimental data.

References

[1] D.R. Noble, Q. Zhang, A. Shareef, J. Tootle, A. Meyers, T. Lieuwen, Syngas mixture composition effects upon flashback and blowout, Proceedings of GT2006 ASME turbo expo 2006, Barcelona, Spain, 2006.

[2] H.J. Burbano, J. Pareja, A.A. Amell, Int. J. Hydrogen Energy 36 (4) (2011) 3232-3242

[3] E.L. Petersen, D.M. Kalitan, A.B. Barrett, S.C. Reehal, J.D. Mertens, D.J. Beerer, R.L. Hack, V.G. McDonell, Combust. Flame 149 (12) (2007) 244-247

[4] R. Schefer, D. Wicksall, A. Agrawal, Proc. Combust. Inst. 29 (2002) 843-851

[5] D.W. Davis, P.L. Therkelsen, D. Littlejohn, R.K. Cheng, Proc. Combust. Inst. 32 (2013) 3135-3143

[6] P.M. Allison, J.F. Driscoll, M. Ihme, Proc. Combust. Inst. 34 (2013) 3145-3153

[7] J. Yoon, S. Joo, M.C. Lee, J.G. Lee, Y. Yoon, Proc. Combust. Inst. 36 (2017) 3753-3761

[8] F. Nicoud, F. Ducros, Flow Turb. Combust. 62 (3) (1999) 183-200

[9] V. Golovitchev, N. Nordin, R. Jarnicki, K. Chomiak, SAE Technical Paper 2000-01-1891 (2000)

[10] F.N. Egolfopoulos, P. Cho, C.K. Law, Combust. Flame 76 (34) (1989) 375-391

[11] M.C. Lee, J. Yoon, S. Joo, J. Kim, J. Hwang, Y. Yoon, Proc. Combust. Inst. 35 (2015) 3263-3271