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Flameless Oxcydation in a Stirred Reactor

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Abstract

A stirred reactor was newly designed and the structure of the low Damkohler number flame was investigated. In the present study, the focus was placed on the reaction zone structure of the flameless oxidation in the well-stirred reactor regime. Ion current measurements and laseroptical measurements using OH laser induced fluorescence were carried out in a stirred reactor with highly preheated mixture up to 873 K. It was realized by a high speed jets from the injector into the surrounding combustion gases. The visual observation by schlieren photography does not indicate the occurrence of the thin laminar flame under low Damkohler number as proposed by Peters. In addition ion current was also measured in the reaction zone.

In the vicinity of the injector, ion current was low but not zero. Therefore, some reaction occurs. Ion current has no sharp peaks, which are typical feature of the thin laminar flame. From the cross-correlation of the ion current, it was found that the reaction zone was conjectured to be reacting gas lumps of the order of 4～5mm. These reacting eddies or gas lumps are transported by the mean convection velocity(80～100m/s) of the flow field.

Furthermore, OH-PLIF image in a well stirred reactor was taken. In a continuous wrinkled premixed flame, a sharp rise of OH should be observed, which is typical for the flamelet structure. However the OH distribution in a present burner becomes scattered. From these experimental results, it can be concluded that the flameless oxidation occurred in the well stirred reactor regime.

Combustion Chamber

Figure 1 shows the combustion chamber designed in the present study. Inner diameter of the combustion chamber was 80 mm and thickness of 10 mm. Preheated air and the fuel are mixed in the mixing chamber located at the bottom of the combustion chamber. Injector has 12 injection holes of which inside diameter is 1 mm. 12 exhaust ports were bored radially. The inside diameter of the exhaust ports is 4 mm. Both sides of the combustion chamber are fitted with quartz windows through which visual and schlieren observation are feasible.

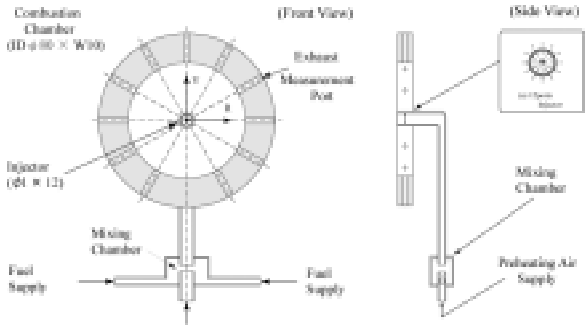


Fig. 1. Well Stirred Reactor(dimension in mm)

Power spectra of ion current in a stirred reactor

Figure 2 shows the power spectra of ion current at different radial positions for mixture jet velocity V_j = 403 m/s and equivalence ratio $\phi = 1.0$. The spectra of ion current fluctuation cannot correlate with the spatial vortical length scale directly. However, it can be considered as passage frequency of the eddy with a certain cycle, or reaction zone. That is, it is considered as an information on the reaction intensity in the place. Up to 200Hz, the each spectrum signal from (a) to (e) takes a flat waveform, and is decreasing abruptly after that. Moreover, the magnitude of a spectrum is increasing from (a) toward (e). In near injector, since ion current fluctuation is low, the spectrum appears low similarly. On the other hand, in near wall where ion current fluctuation is high, the spectrum shows high value. The tendency is in agreement with ion current signal (not shown in present paper), if it is considered as passage frequency of reaction zone. The burning field where the feature of a line spectrum was not seen and various gas lumps were formed. As the frequency increases, the reacting gas lumps become smaller and the fluctuating ion current decreases. At the low frequency, the ion current spectra have high value. Therefore, the relatively large reacting gas lumps include the small reaction zones. This fact shows that the reaction zone approaches to the homogeneity.

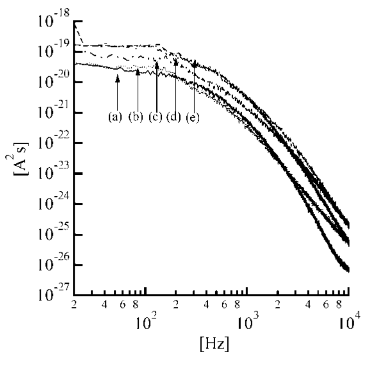


Fig. 2. Power spectra of ion current.

(a)R = 6 mm, (b) R = 11.5 mm, (c) R = 17 mm, (d) R = 28.5 mm, (e) R = 40 mm.

The cross-correlation function of the ion current

To measure the cross-correlation, two ion probes are installed in the combustion chamber with an appropriate distance. Figure 3 shows the cross-correlation functions at R = 17 mm with the probe separations of 1 mm, 3 mm, 5 mm, and 10 mm. The sampling rate was 1 μs and the number of averaging was 100. If a probe approaches, mutual interference will pose a problem. Both of ion current signal in d = 1 mm of probe distances are similar and it is thought that the influence by mutual interference is small. The slight periodicity is observed but we deems to be negligible.

The peak value decreases with the probe separation and appears at some delay time. From this delay time, the mean convection velocity of the reaction gas lumps can be calculated. The results are shown in Figure 4. The reaction gas lumps or thick reaction zones move with about 80 – 100 m/s. Moreover, since reaction intensity increases from (b) to (d), convection velocity increases slightly. The increase in convection velocity is considered to be the influence of expansion of reaction gas lumps by heat.

With the zero delay time, the cross-correlation coefficient decreases with the separation of two ion probes as shown in Figure 5. The correlation coefficient weakly depends on the radial distance. Therefore, the integral scale of the reacting gas lumps or thick reaction zones decrease from 5 mm to 4 mm with the radial distance. Therefore, the reaction gas lumps of the order of 4 – 5 mm move randomly in the combustion chamber on the mean velocity of 80 – 100 m/s. On the other hand, as shown previously, the integral time scale (not shown in present paper) is about 0.35 ms. If the convection velocity of the reacting gas lumps is 100 m/s, the integral length scale becomes 35 mm. This value coincides with the radius of the combustion chamber. Therefore, combustion reaction occurs in the entire chamber in the form of reaction lumps of the size of 4～5 mm.

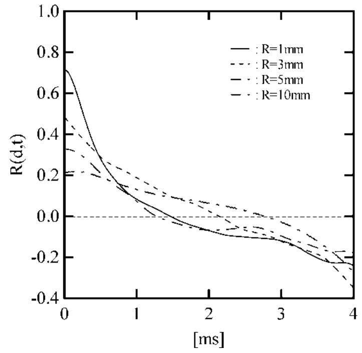


Fig. 3. Cross-correlation of ion current.

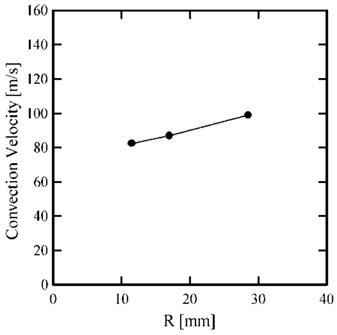


Fig. 4. Convection velocity.

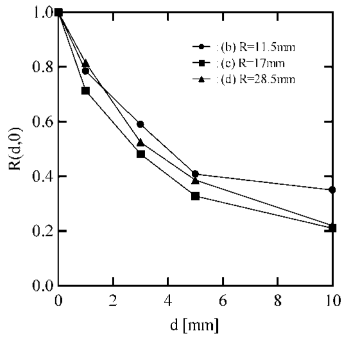
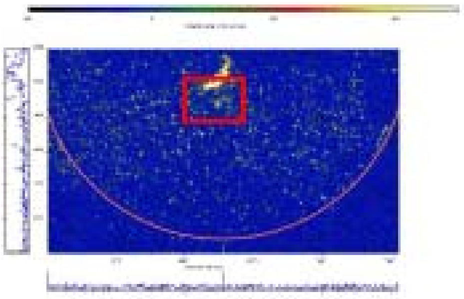


Fig. 5. Peak-cross-correlation of ion current.

OH laser induced fluorescence(OH-PLIF)

Figure 6 shows the OH-PLIF image in a well stirred reactor for $T_j = 873$ K ,$V_j = 403$ m/s and $\phi=1.0$. For the visualization of the combusting areas within the chamber, at lower position (35mm) of the chamber, OH-PLIF image was taken. The OH distribution in a well stirred reactor becomes uniformly scattered. In a wrinkled premixed flame, a sharp rise of OH could be observed, which is typical for the flamelet structure [1]. The dilution with exhaust gas increases the characteristics chemical time compared with the characteristics flow time.

This characteristics correspond to the results by Plessing et. al. [2], and this fact suggest that the flameless oxidation was realized in a present burner. A further detailed investigation will be needed for a complete analysis and classification of flameless oxidation.



Magnified Figure
(15 × 30mm)

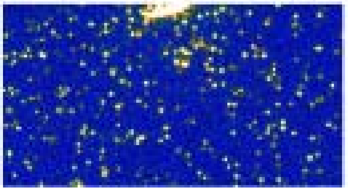


Fig.6 OH PLIF Image in a Well Stirred Reactor

Conclusions

In the present study, we designed a well-stirred reactor and characteristic features of the reaction zone formed in the reactor were studied.

The reaction gas lumps of the order of 4～5 mm move randomly in the combustion chamber on the mean velocity of 80 – 100 m/s.

In a wrinkled premixed flame, a sharp rise of OH could be observed, which is typical for the flamelet structure. However, the OH distribution in a well stirred reactor becomes uniformly scattered.

Consequently, flame structure showed a possibility of changing to flameless oxidation in the well stirred reactor.

References

1. A.Buschmann, F.Dinkelacker, T.Schafer, M. Schafer, and J.Wolfrum, “Measurement of the Instantaneous Detailed Flame Structure in Turbulent Premixed Combustion”, Proceedings of The International Symposium on Combustion, 26 (1996), The Combustion Institute, pp. 437 – 445.

2. Plessing, T., Peters, N., and J.,G. Wunning, “Laseroptical Investigation of Highly Preheated Combustion”, Proceedings of The International Symposium on Combustion, 27 (1998), The Combustion Institute, pp.3197-3204.