# Structure of Swirler Flame in Gas Turbine Combustor

Y. Kurosawa, S. Yoshida, T. Yamamoto K. Shimodaira, M. Gomi and K. Suzuki National Aerospace Laboratory of Japan

## 1. Introduction

Turbulent combustion is widely utilized for various devices, internal combustion engines, boilers and burners. Here we deal this subject applying it to gas turbine. The combustor of gas turbine is required to have high combustion efficiency, low pollutant emission and wide stability. Turbulent flow field is formed in a combustor and plays a very important part in forming flame. And another important factor is how fuel is supplied into combustor and mixed with air. In designing combustor, these two factors should be controlled effectively to meet these demands.

This research has two objectives. One is to know how turbulent flow field affects the combustion performance and the emission characteristics. It was difficult to measure a flow velocity field with combustion, but it can be successfully done here by the optical method, the particle image velocimetry (PIV). Another purpose is to investigate how fuel should be supplied to get high performance and low pollutant emission. As concerns fuel injection, we have conducted experiments of both diffusion combustor and pre-mixed combustion in order to compare them.

#### 2. Experimental Facilities

Swirling flow is often used in gas turbine combustor to stabilize flame. The experimental facility is shown in Fig.1. This is composed of pre-mixing tube, swirlers and combustion chamber. This model has two swirlers, which have the same direction of rotation, in order to investigate the interaction between neighboring ones. The vane angle is 45 degrees. The four walls of chamber are made of quart glass plates so that an optical method, PIV can be used for measuring a reacting flow field. Fuel can be injected at two positions, one is located upstream of pre-mixing tube to get the pre-mixed condition and other is at center of swirlers to give the diffusion condition. Several twisted plates are put in the pre-mixing tube to promote turbulent for well mixing. Methane gas is used as fuel.

The distributions of concentration are measured by traversing a gas-sampling probe in the combustor. The particles for PIV is added upstream of electric heater. The particles do not affect combustion.



Fig.1 Experimental Facility

### **3. Experimental Results**

The flames are shown in Fig.3. The pre-mixed flame is attached at swirler vanes and compact. The streaks are observed at swirler exit. The diffusion flame is detached from the swirler. These features can be well understood by flow fields and chemical species distributions measured here.

The flow velocity fields are shown in Fig.4 for both pre-mixed and diffusion flames, which are measured by PIV. The measured area in combustion chamber is given in Fig.2. It is just downstream region of swirler, which is important to make turbulent flow and stabilize flame. PIV can give 2-dimensional fields here. In pre-mixed flame, the re-circulation zone is well formed and its size is larger. And the reverse velocity is higher than in diffusion flame. This means that the high temperature burned gas can be well carried back to ignite fresh mixture.



Fig.2 Measured Area



(a) Pre-mixed Flame



(b) Diffusion Flame









Colors in the figures indicate the velocity components in stream direction, blue region presents a re-circulation zone. In diffusion flame, this region is smaller and the reverse velocity is lower. In order to see the 3-dimensional structure of flow field, the 2-dimensional flow profiles are measured at Z=30,20,10,0,-10,-20, -30. They are shown in Fig.5 and can give the complicated flow near the swirlers.

Many separated jets are observed at Z=20,-20. It should be noted that other re-circulation region is formed in the space near wall between swirlers. In this place, flame is formed and stabilized, this bring out the problem of durability.

Comparison between reacting flow and cold flow is presented in Fig.6. In cold flow, the



Fig.6 Comparison between Reacting Flow and Cold Flow

re-circulation zone is not well formed and smaller than diffusion flame. The reverse velocity in this region is also lower. This means that a sufficient re-circulation zone can be made when combustion can start just at the swirler exit as in pre-mixed flame.

Contour graphs of NOx distribution are shown in Fig.7 for pre-mixed flame and diffusion flame. They are measured in planes of swirler axis and perpendicular to it. The velocity vectors are drawn over this NOx contour graph. In the pre-mixed flame, almost NOx is formed in the re-circulation region. The value is maximum at X=80mm and decreases in downstream. The contour of y-z plane also gives a clear feature that high NOx concentration is observed in the re-circulation zone. In the case of diffusion flame, NOx concentration remains low in the upstream of Z=60mm. But it continues to increase gradually to downstream. This value becomes much higher than in pre-mixed flame at Z=100. To the contrary, it tends to decrease in downstream beyond Z=100 for pre-mixed flame. It is estimated that the NOx emission by diffusion flame becomes much higher at combustor exit. By the y-z contour, small flames are stabilized near the wall. They are not desirable from the viewpoint of durability and reliability.



Fig.7 NOx Distribution



Fig.8 Contour of O2 Distribution

The contours of O2 are presented in Fig.8. The O2 distribution can present how combustion progresses spatially. The gradient of O2 along the streamline gives the consumption of O2, which is caused by combustion progress. In pre-mixed flame, it is shown that the mixture is entrained into the re-circulation region with consuming O2. In this region, the O2 concentration reaches to the minimum value calculated from equivalence ratio. This is observed in the y-z distribution. The fuel is burned completely in short time and this results in low NOx emission. In diffusion flame, O2 is not consumed in the re-circulation region.

The y-z distribution is measured at Z=40mm and show well that O2 remain in high value in this region and combustion does not progress.

The x-y distribution of unburned HC is shown in Fig.9. The white-colored region in this graph is too much high to be measured in normal range. It can be pointed that HC in the re-circulation is burned completely in pre-mixed flame, but not in diffusion flame. The CO distribution is shown in Fig.10. The formation of CO is complicated, but the contrary tendency to NOx is observed if the combustion efficiency is high in a certain degree. NOx is relatively low in the region where CO is high.



#### 4. Summary

The experimental results of reacting flow field and chemical species distribution in swirl flames are presented here. The difference of flame structure between pre-mixed and diffusion combustion could be made clear in details. They are summarized as follows.

- In pre-mixed flame re-circulation zone is well formed by swirler and combustion is proceeded in this region.

- In diffusion flame re-circulation zone is small and the reverse flow velocity is also low. And combustion does not take place so much in this region.

- The combustion progress can be known by the streamline in a flow vector field and the gradient of O2 distribution. In pre-mixed flame, combustion can be completed in the re-circulation zone.

- NOx emission is higher in diffusion flame. Pre-mixed flame forms most of NOx in re-circulation zone, but diffusion flame continue to form it in downstream region.