Characteristics of combustion of Rich-Lean Flame Burner under Low-Load Combustion

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Introduction

The development of gas burner used for the domestic hot water generator for room heating and hot water supply has been curried on seeking higher efficiency, lower emission of pollutants, such as NOx, and compactness. The rich-lean flame burner developed in 1995 showed outstanding combustion characteristics in terms of low NOx emission to the conventional Bunsen burner. Therefore, it has been widely used as gas burner of the domestic hot water generator. In 2004, top runner system concerning the efficiency under full-load combustion was decided to be applied to the domestic hot water generator to meet the requirement of CO_2 reduction in Japan. In the future, the efficiency under not only full-load combustion but also low-load combustion would be conscious considering actual life. To meet the future requirement, a new type of rich-lean flame burner with a novel combustion mechanism realizes low-load combustion.

The most successful burner for low NOx combustion is the rich-lean flame burner consists with a layered structure of rich flame and lean flame, as shown in Fig. 1. The air ratio m defined $Q_{supplied}$ / $Q_{stoicheometric}$ where $Q_{supplied}$ is supplied air volume, $Q_{stoicheometric}$ is stoicheometric air volume is set about 0.4-0.6 for the rich flame and about 1.4-1.5 for the lean flame. Each flame length at 6.7kW input is about 3mm for the rich flame and about 8mm for the lean flame respectively to form united flame. As a result, the combustion is stabilized. And thermal NO formation is offset due to the split flames avoiding stoicheometric combustion, as inferred in Fig. 2 (1).

So far, several efforts have been made to investigate the characteristics of combustion including the mechanism of low NOx emission of the rich-lean flame burner under full-load combustion (2, 3). However the characteristics about the low-load combustion condition have not been investigated. Because of the insufficient TDR (turn down ratio), the conventional rich-lean flame burner is operated over half of full-load combustion.

In this paper, first, the characteristics of combustion of the conventional rich-lean flame burner under low-load combustion were investigated to figure out breakthrough points to realize the higher TDR. Second, the advanced rich-lean flame burner with novel structure which works even under lower-load combustion to the conventional rich-lean flame burner was proposed.

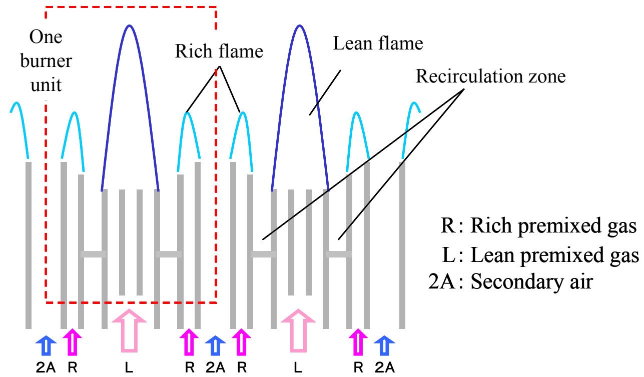

Fig. 1 Schematic figure of the conventional rich-lean flame burner

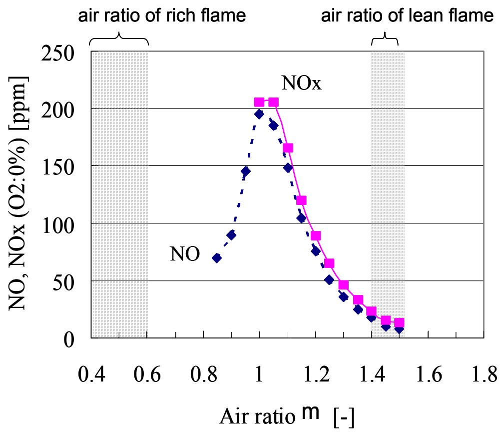

Fig. 2 NOx emission of premixed combustion at various air ratio *m*

Experimental results and discussions

Combustion characteristics of conventional rich-lean flame burner

Figure 3 shows the experimental setup which was designed to investigate the characteristics of combustion of conventional type rich-lean flame burner under low-load combustion. The burner consists of 6 burner units, as shown in Fig. 4. One burner unit has layered structure of slit shape ports for rich flame and lean flame (see Fig. 1). Experimental fuel gas is consisted with 85vol% CH_4 and 15vol% C_3H_8, and the oxidizer is air. The flow rate of fuel gas is controlled by gas valve and measured by wet gas meter, and the flow rate of air is controlled by changing the revolution of air supply fan. The water circulated by a water pump through heat exchanger retrieves generated heat by combustion. The number of working burner unit (6 : all sides or 3: half side) can be controlled in this experimental setup. In all sides combustion mode, all 6 burner units work. And only 3 burner units work in the half side combustion mode. Each temperature of hot water at inlet and outlet of heat exchanger is measured by thermocouple. The efficiency is evaluated by the measured flow rate of circulating water and the temperature change of hot water through the heat exchanger. The concentrations of NOx, CO and CO_2 in the exhaust gas are analyzed by gas chromatography. As shown in Fig. 5, the temperature of the rich burner plate and the temperatures of inside and outside of lean burner plates are measured. The temperature of the burner plate is dominant factor in particular under the low load combustion to prevent the thermal deformation of the burner plate. The flame is located at the closer position to the burner plate under low-load combustion than full load combustion because of the decrease of gas flow rate. As a result, the burner plate temperature is raised and the plate deformation occurs. Eventually, the minimum load of combustion is decided.

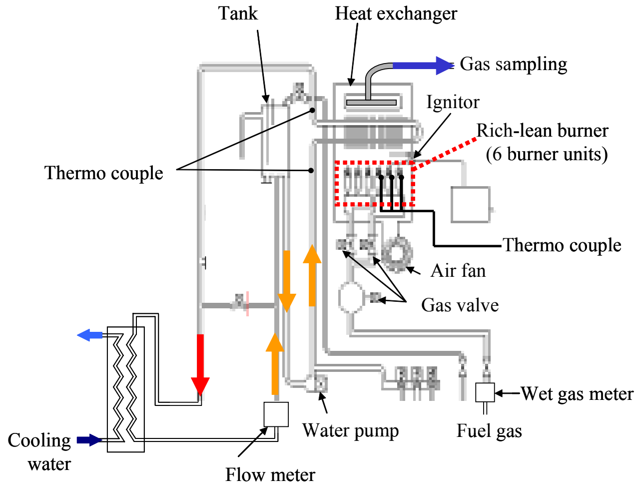

Fig. 3 Experimental setup

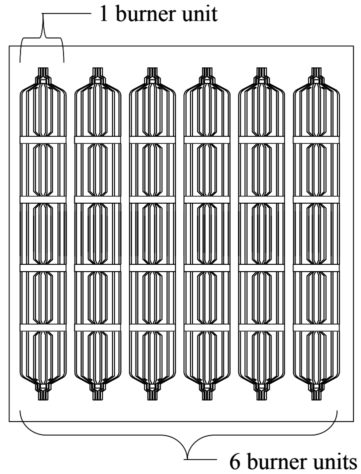

Fig. 4 Top view of the conventional rich-lean flame burner

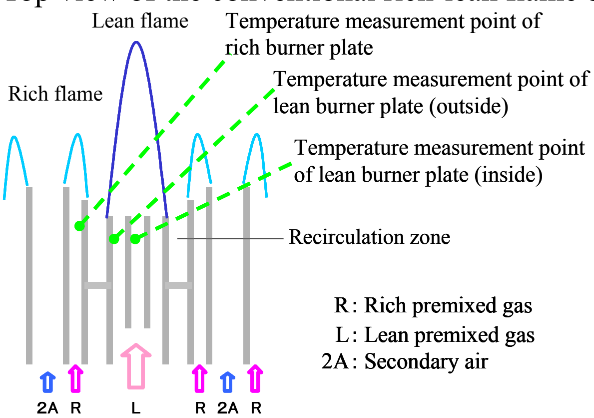

Fig. 5 Schematic figure of the points of measuring temperature

Table 1 shows the experimental conditions and results. Total load fraction is defined by the ratio of the consumed fuel gas of whole burners consisted with 6 burner units under full-load combustion to partial load combustion. And burner load fraction is also defined by the ratio of the consumed fuel gas of each burner unit under full-load combustion to partial load combustion. In the hot water generator with conventional rich-lean flame burner, both fuel gas volume and the number of working burners are controlled to achieve low-load combustion. In addition, the working burner operation time is controlled by alternating the working mode and un working mode. With all these controls, the 1/9-load combustion is achieved. Actually, the efficiency under the combustion of total load fraction of 1/9 is lower than the one of under full-load combustion by 5.2% (see Table 1 case No.1 and 5). On the other hand, the efficiencies under the condition of all burners are working are nearly same (see Table 1 case No.1, 2and 3). The efficiency decrease under total load fraction of 1/9 is due to the heat exchanger cooling effect by the unburned air passing through the un working burner ports. The concentrations of NOx and CO/CO_2 under all combustion conditions of all burners working have same tendencies and good combustion ranges (see Figs. 6 and 7). However the temperature of the burner plates gradually increase according to the decrease of the input, and show steep increase under burner load fraction of 1/3, as shown in Fig. 8. During the low-load combustion, the burner plate is deformed due to overheating.

The conventional rich-lean flame burner didn't show any differences in terms of the efficiency and gas concentration of NOx and CO/CO_2 under the combustion of burner load fraction of 1/3. But has a critical problem on durability of burner plates due to overheating. To prevent the burner plate thermal deformation due to overheating is a technological issue to extend the lower range of combustion range.

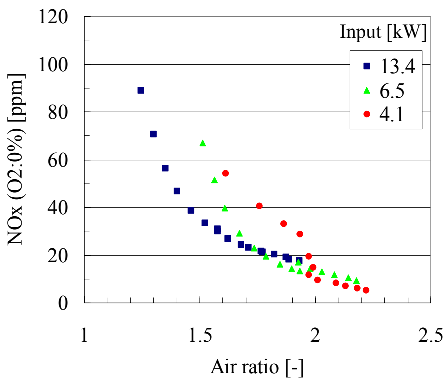

Fig. 6 NOx emission under the condition with all burners working

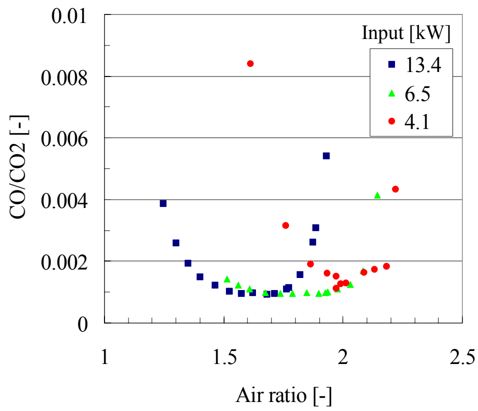

Fig. 7 CO/CO_2 under the condition with all burners working

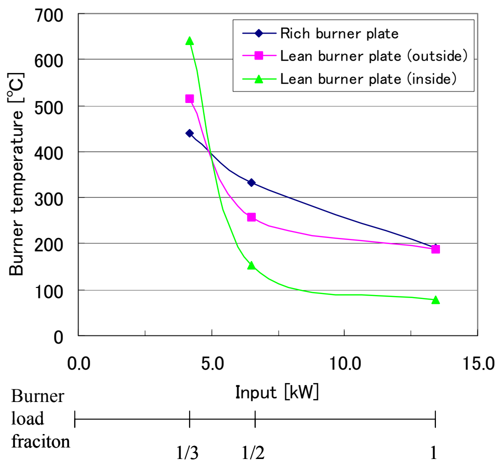

Fig. 8 Temperature of burner plates under the condition with all burners working

Table 1 The efficiency of the conventional rich-lean flame burner

Case No.	1	2	3	4	5
Input (kW)	13.4	6.5	4.1	3.6	1.6
Total load fraciton (–)	1	1/2	1/3	1/4	1/9
Burner load fraction (–)	1	1/2	* 1/3	1/2	–
The number of working burner	6	6	6	3	3
burner control	continious working				alternating working and un working
Efficiency (%)	73.7	74.9	74.6	72.8	68.5

* = out of the operating range of burner load fraction

Combustion characteristics of advanced rich-lean flame burner with a novel structure

Based on a conventional rich-lean flame burner, advanced rich-lean flame burner with a novel structure which enables the auxiliary air supply to the recirculation zone between the rich flame and the lean flames was developed expecting the cooling effect of the burner plate, as shown in Fig.9. The flow rates of the fuel gas and the air passing through the each inlet port are precisely controlled in order to examine the combustion characteristics. The temperature of each burner plate under low-load combustion is successfully decreased at the experimental conditions, as shown in Table 2.

Figure 10 shows the effect of the air flow rate passing through recirculation zone on the temperature of inside of lean burner plate. By increasing the air flow rate, the temperature is decreased immediately. At air flow rate of 0.155 m/s, the maximum temperature of burner plate is below 200ºC even under burner load fraction of 1/5.5 which is out of the operation range of the conventional the burner. Furthermore, the heat efficiencies are not validated if the air flow rate of recirculation zone increases, while both the concentrations of NOx and CO/CO_2 in the exhaust gas are decreased as shown in Fig. 11.

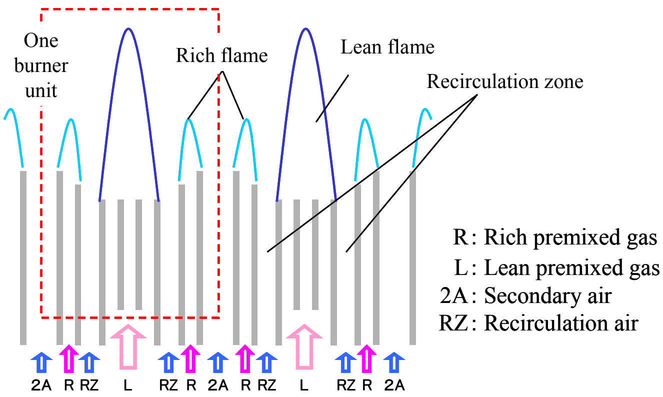

Fig. 9 Schematic figure of new type of rich-lean flame burner

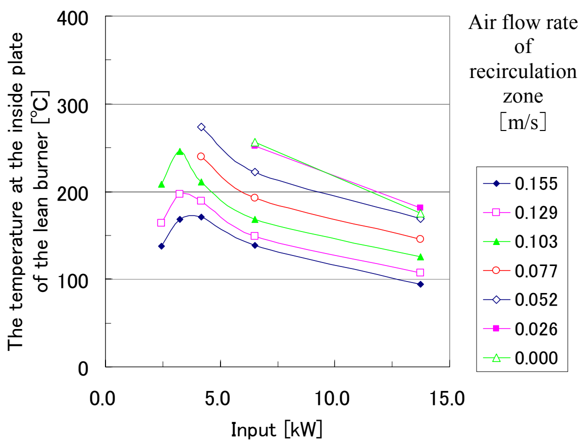

Fig. 10 The temperature of inside of lean burner plate

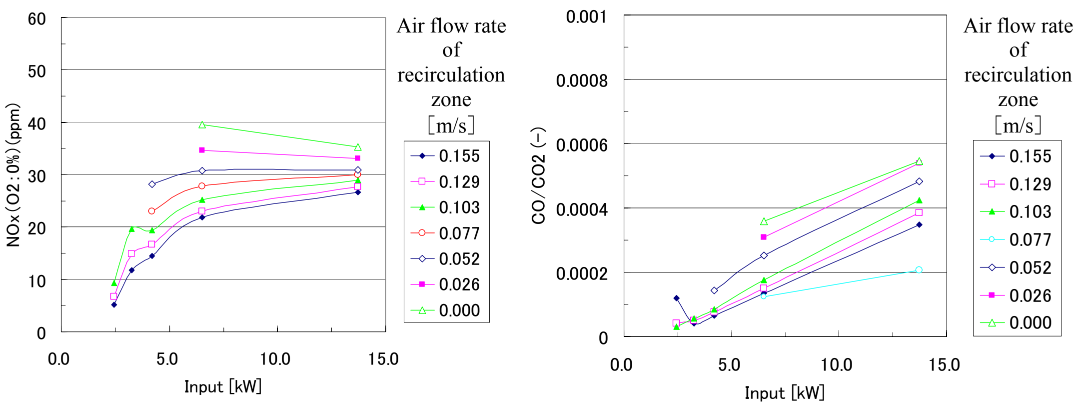

Fig. 11 Effect of the air flow rate of recirculation zone on the concentration of NOx and CO/CO_2

Table 2 Experimental condition

Case No.	1	2	3	4	5
Input (kW)	13.7	6.5	4.2	3.3	2.4
Burner load fraction (−)	1	1/2	∗ 1/3	∗ 1/4	∗ 1/5.5
Rich−lean gas input ratio	30 : 70				
Air ratioof rich premixed gas (−)	0.49				
Air ratioof lean premixed gas (−)	1.46				
recirculation zone air speed (m/s)	0.000～ 0.155	0.000～ 0.155	0.052～ 0.155	0.103～ 0.155	0.103～ 0.155

∗ = out of the operating range of burner load fraction

To examine the mechanism of auxiliary air supply effect, the temperature was measured at the cross section of the downstream of each rich and lean burner plate under burner load fraction of 1/2, and auxiliary air flow rate of 0.0, 7.7×10^{-2}, and 1.55×10^{-1} m/s respectively (see Fig. 12). The radiation effect and the conduction effect on the temperature of thermo couple are not taken into account.

Figure 12 shows the temperature of the burned gas in the downstream of the lean flame decreases with the increase of the air flow rate at recirculation zone. As a result, the formation of thermal NOx in the lean flame zone is suppressed due to flame temperature decrease. Eventually the concentration of NOx decreases. On the other hand, the temperature of the burned gas in the downstream of the rich flame increases. It shows that the perfect combustion in the rich flame is enhanced and CO production and CO/CO_2 in the rich flame zone are suppressed because of the promotion of the perfect combustion.

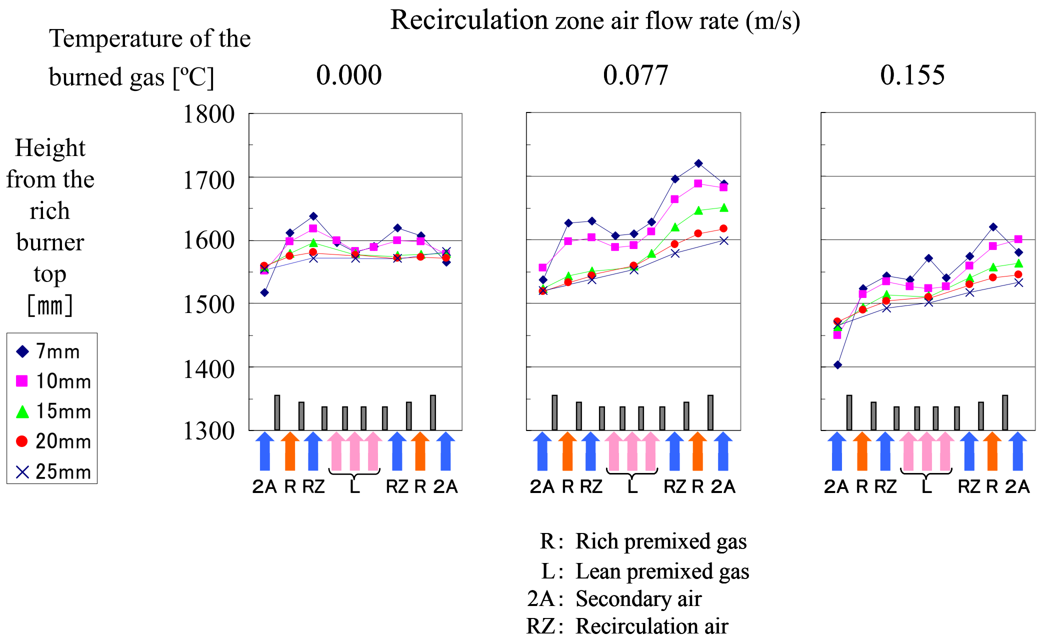

Fig. 12 Effect of air flow rate of recirculation zone on temperatures of burned gas

Conclusions

(1) The conventional rich-lean flame burner used in domestic hot water generator for room heating and hot water supply didn't show any problem on the efficiency and the gas concentration of NOx and CO/CO_2 but has a critical problem on deformation of burner plates due to overheating under the combustion of burner load fraction of 1/3.
(2) Supplying the auxiliary air with the flow rate 0.155 m/s to the recirculation zone, the temperature of burner plate can be decreased under threshold temperature; 200ºC to avoid the thermal deformation by overheating even under the combustion of burner load fraction of 1/5.5 which is out of operating range of conventional rich-lean flame burner. The auxiliary air successfully extended the operation range of combustion load approximately 2.7 times to that of conventional rich-lean flame burner.
(3) The formation of thermal NOx in the lean flame zone is suppressed by decreasing the flame temperature. In addition, CO generation in the rich flame zone is also decreased due to the promotion of perfect combustion.

References

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