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PRACTICAL DEVELOPMENT OF TUBULAR FLAMES

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ABSTRACT

Recently, tubular flame is attracting attention as an innovative combustion technology. The tubular flame is formed by tangentially injecting the fuel and the oxidant from a slit or slits into a cylindrical combustion chamber. The outside of the flame is covered with the unburned gas mixture and the inside is filled with the burned high-temperature gas. For practical use, this flame has many favorable characteristics such as being able to burn under almost all conditions between the flammable limits, forming an adiabatic flame, accepting some fuels that do not burn easily, expanding the turndown ratio, and decreasing the level of combustion noise. Gas appliances that make the best use of these features of the tubular flame have already been developed at Osaka Gas. Two such approaches will be introduced in this paper.

1) Steam generator

A cooking method that surrounds food with superheated steam can prevent food's oxidation and heat it up rapidly. A superheated steam oven that has a steam generator with a tubular flame burner is being developed. The oven blows the steam generated by the steam generator into the cooking chamber. At the same time, the oven overheats the steam with the assistance of electric heaters and adjusts the temperature and the heat distribution required for the cooking process. A super-compact steam generator has been developed by using the tubular flame burner. Thus, the oven developed has kept the size almost the same as the one with an electric steam generator.

2) Fireplace

An innovative fireplace by which users can enjoy the fire dancing and feel the flame radiating has been developed. The fuel is injected into the center of the burner, which is a gaseous zone of high temperature and low oxygen concentration. A luminous flame at high temperature and hardly exhausting soot can be formed easily even by natural gas fuel.

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2. INTRODUCTION

Combustion technology has been generally considered to be a matured one. But it is still an important technology to extract energy from fossil fuels. Therefore, research for a novel combustion system (e.g. investigating high-temperature air combustion that collects waste energy for preheating the combustion air[1] and micro-diffusion flames array combustion where the heat density per volume is high and can heat the body to be heated uniformly or arbitrarily[2]) has been executed consistently.

Recently, tubular flame is attracting attention as an innovative combustion technology. The tubular flame can be formed by letting a flammable gas permeate through a porous cylinder or by injecting a flammable gas tangentially from slits into a cylindrical combustion chamber[3]. The latter method (swirl type) can form the tubular flame with relative ease, because the pressure drop of the flammable gas is less than by the former method. Fig. 1 shows the structure of the tubular flame. As shown in Fig. 1, the tubular flame can be formed even if the fuel and the oxidant are injected from slits separately. The flame emerges at the position where the radial velocity of the fuel in the chamber balances its burning speed. The outside of the flame is covered with the unburned gas mixture and the inside is filled with the burned high- temperature gas.

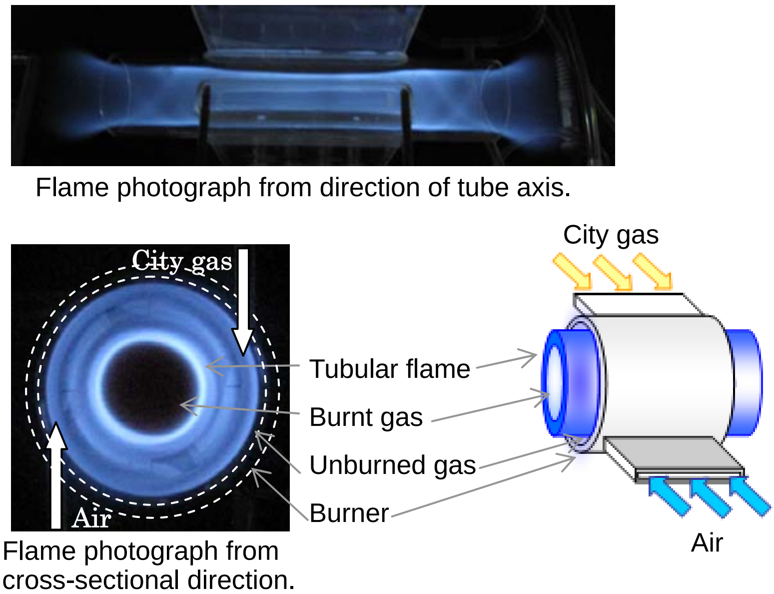

Figure 1 Structure of tubular flame

The tubular flame has been used to investigate flame characteristics under cylindrical coordinates. In other words, it has been used mainly for basic combustion studies. However, this flame has been found to have many favorable characteristics for practical use. Such advantageous characteristics for practical applications are as follows.

1) Burning under almost all conditions between the flammable limits

Rotating structure of the flame, which is covered with the unburned gas mixture and is filled with the burned high-temperature gas, is aerodynamically stable. Because the low-temperature unburned gas between the flame and the burner wall has an adiabatic -effect, the heat loss is minimized. As a result, the tubular flame can be formed under almost all concentrations between the flammable limits of the fuel. It brings about valuable advantages for developing practical appliances. Even when the fuel composition or the equivalence ratio changes, the effect may be restricted, and combustion can be maintained with stability in extremely lean condition where thermal NOx is hardly generated.

2) Realization of adiabatic flame

The heat loss by convection can be negligible at the tubular flame even though that by radiation cannot. Therefore, the tubular flame can achieve nearly the same temperature as an adiabatic flame. It is suitable to utilize it also for high-temperature applications such as generating superheated steam and building high-temperature furnaces for industrial use.

3） Burning with less combustible fuel

Because the insulating properties are high, steady combustion can be maintained with the fuel with low calorific value (which has high percentage of inert gases). For instance, a report shows that fuel of a low calorific value of 2.6 MJ/m3(LHV), which is a diluted by-product gas of ironworks (blast furnace gas) with nitrogen, can maintain combustion by using the tubular flame[(6)].

4) Wide turndown ratio

The tubular flame is formed at a position where the radial velocity of the gas mixture balances the burning speed. Because the radial velocity does not increase as compared with the tangential velocity even when the flow rate of the mixture is increased, the flame is hardly blown off. The flame only becomes longer in the direction of the tube axis. On the other hand, the lower limit of the combustion load may be defined when the flame cannot take a tubular shape because the tangential velocity of the gas mixture excessively decreases.

5) Low－level of combustion noise

The distribution of radial velocity in the tubular burner is continuous and is of 360-degree symmetry, so that the combustion produces a laminar flame. This flame structure does not change even when the flow rate is fluttered and the laminar flame can be maintained. It is an important feature if we consider that the noise level may limit the maximum output in existing household burners and commercial combustors for use in restaurants and so on.

On the contrary, if an inconvenience in practical use is to be mentioned, pressure drop of a flammable gas charge is higher than that in an existing burner. If the flammable gas is not injected with some speed in the tangential direction in the tube, the flame blows off from the burner, and the tubular flame cannot be formed.

3. DEVELOPMENT OF GAS APPLIANCES

Gas appliances that make the best use of these features of the tubular flame have already been developed at Osaka Gas. Two such approaches will be explained in the following.

3.1. Superheated steam oven

A cooking method that surrounds food with superheated steam for preventing oxidation and heats it up rapidly has come to attract much attention [7]. As the maximum capacity permitted for a household electrical installation is limited bellow about 1.5 kW, cooking time with an electric heater is usually long. Then, the development of a small steam generator with city gas as fuel was attempted. The steam is generated from 7.5 kW (HHV) input of city gas. The oven blows the steam into the cooking chamber. At the same time, the oven overheats the steam with assistance of electric heaters and adjusts the temperature and its distribution required for the cooking process. Fig. 2 shows the appearance of a superheated steam oven for commercial use that has a steam generator with a tubular flame burner. The steam generator is a kind of flue and smoke tube boiler. The inner diameter of the tubular flame burner is 60 mm and is attached to a 2” flue in a can that has many smoke tubes inside. The air for combustion is sent from two slits by using a sirocco fan, and city gas is supplied from two other slits by the pressure from a low pressure pipe line into the burner. A tubular flame burner shown in Fig.1 blows burned gas to both ends of the chamber. However, one end of the chamber is blocked in this tubular flame burner, because it is easy to connect it with the boiler. When the edge is closed, the flame tends to attach to the edge and overheats it. Therefore, an air layer is made between the flame and the blocked edge by adjusting air and fuel slit position. It thus prevents the edge from being overheated. Because the flame get close to the edge when the excess-air ratio changes from a set value to the stoichiometry, a safe control system which detects the blockage of the exhaust (because of decrease in the amount of air supply) has been built. A super－compact steam generator has been developed by Osaka Gas, using the tubular flame burner. Thus, the oven developed has kept its size almost the same as the one with an electric steam generator.

Figure 2 Photograph of superheated steam oven and generator.

Another boiler that makes superheated steam by using a center space of the tubular flame has been developed [8]. The auxiliary electric heater used for superheating can be omitted. The superheated steam boiler for demonstration whose can and burner are partly made of glass is shown in Fig. 3. The inside diameter of the burner is 40mm, and the blue lighting part in Fig. 3 is the tubular flame. The outside of the tubular flame is covered with unburned mixture. Evaporation, therefore does not occur around the tubular flame because heat is not transferred to boiler water. The saturated vapor is generated at the heat exchanger with internal fins, and is led to the super-heater tube installed at the burner center through the heat exchanger where the steam is superheated by the high-temperature burned gas at the flame center. There is a grate possibility that a smaller superheated steam boiler will be developed, because the high temperature area at the tubular flame center can help to make large temperature difference for heat transfer.

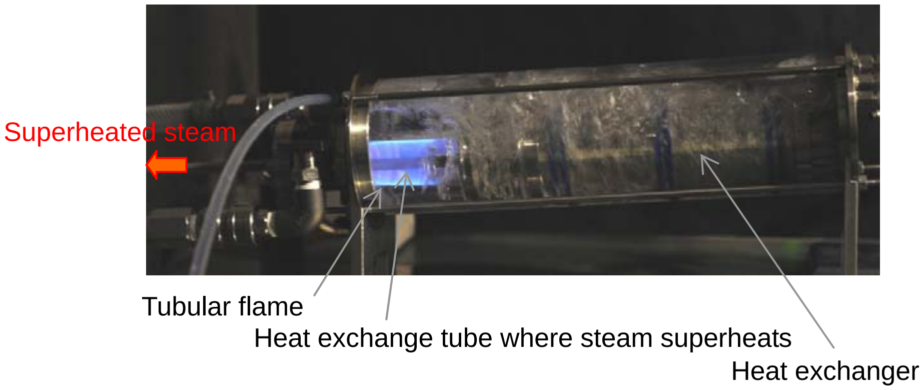

Figure 3 Photograph of superheated steam boiler for the demonstration.

3.2 Fireplace

An attractive fireplace by which users can enjoy the fire dancing and feel the flame radiating has been developed. Fig. 4 shows a photograph of the prototype and the schematic of the space heating system. The luminous flame of the fireplace has been realized by use of a tubular flame. The inner diameter of the burner is 30 mm, and a quartz tube 36 mm in diameter and 410 mm in length is attached downstream of the burner. The thermal output (HHV) of the system is about 9 kW in total.

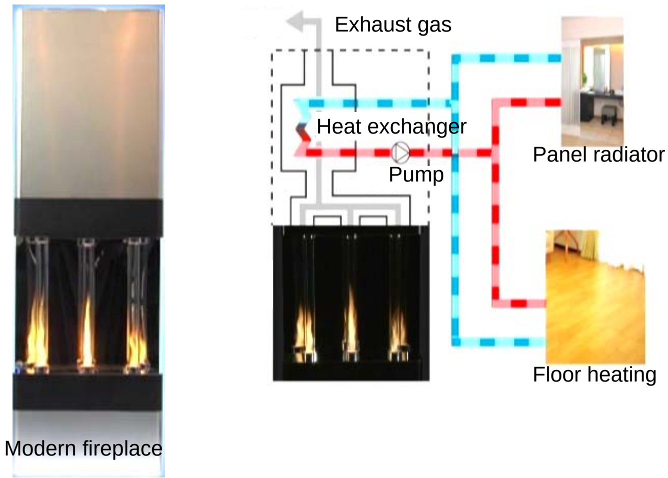

Figure 4 Photograph of the prototype and the schematic fireplace system.

1) Fireplace configuration

Space heating by a fireplace is commonly performed by the radiation from the flame and the chimney. Although there is age-old sentiment about the fireplace, its thermal efficiency is not necessarily high. This fireplace can produce hot water from wasted heat and use it as a heat source. The hot water can be supplied to heating appliances such as a panel radiator or a floor heating named "Nukku". Their thermal efficiency touches almost to that of the heating boiler called "Dan life". Comfort with high-temperature radiation by the luminous flame and low-temperature radiation by hot water can be realized when combined with the floor heating ("Nukku"). It also becomes possible to shorten the warm-up time of floor heating because the radiation from the luminous flame comes out immediately after igniting. Even after the floor heating get heated up, the radiation from the luminous flame is comfortable, and the movement of the dancing flame can be enjoyed.

2) Methodology of forming a luminous flame

A luminous flame at high temperature with little exhaust of soot can be made from natural gas by blowing it into burned gas at the center of the tubular flame, where the temperature is high and the oxygen concentration is low. Fig. 5 shows the method of forming a luminous flame by using the tubular flame. In the central region of the tubular flame, the burned gas at high temperature and low oxygen concentration flows down the stream and swirls slowly. For this reason, the natural gas blown in receives pyrolysis while being mixed with the burned gas. At that time, precursors of the soot are exposed to high temperature for a while, and get emitting solid radiation. In other words, the luminous flame (yellow flame) can be performed. Afterwards, the precursors of the soot burn out slowly swirling with the flow of the burned gas. Thus, a swirling and swinging flame named Spinning Flame is realized. A yellow flame (luminous flame) can be formed with natural gas by conventional diffusive combustion, but the temperature of the conventional flame is lower and it easily leads to incomplete combustion, exhausting a large amount of soot and carbon monoxide. When the color of the flame is yellow, it usually is considered as a sign of incomplete combustion. However, when the tubular flame is used, it heats up the luminous flame and prevents the direct contact to a low temperature wall, so that high temperature can be maintained until the precursors of the soot are completely burned out. As a result, complete combustion, where less carbon monoxide and soot are released, can be achieved even with a yellow flame. Incidentally, when the flow rate or the position of the natural gas that is blown into the central zone of the tubular flame is changed, flames of various shapes and brightness can be performed.

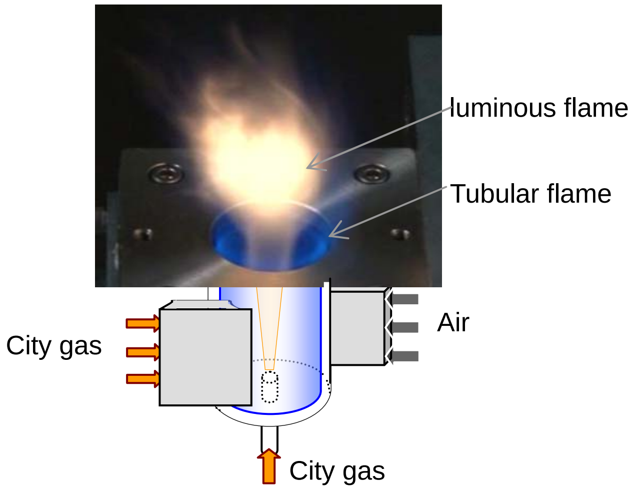

Figure 5 Method of forming luminous flame by using tubular flame.

4. CONCLUSIONS

Tubular flame has many favorable characteristics for practical use and is expected to have wide use. For example, an oxygen combustion burner for high-temperature heating and a super-lean combustion burner that hardly exhausts NOx. These are not, however, mentioned in this paper. We look forward to proposing new gas appliances by using these combustion technologies in the near future.

5. REFERENCES

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6. LIST OF FIGURES