Development of the "Micro Combustor"

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Small heat regeneration combustors have been developed for use as heat sources by applying excess enthalpy combustion technology. Two types of combustors have been manufactured for evaluation, a disk-type combustor and a tubular one. By tuning the surface-to-volume ratio, the CO emission of the disk-type combustor could be reduced to less than 45 ppm with high energy efficiency. For the tubular combustor, which has been operated in water, high energy efficiencies and CO concentrations below 35 ppm were confirmed. The tubular combustor also proved commercial levels of combustion properties in a test apparatus (fryer) built for kitchens. The combustor has attracted favorable attention at various fairs and exhibition events.

1. Introduction

In general, an electrical heater is used as a small-scale heat source, especially for instruments which need accurate temperature control. Although electricity is easy to use, it is produced by the heat generated in the combustion of fossil fuels, and the thermal efficiency of electric power generation can be as low as 36.6%.[(1)] This means that producing heat from electricity results in a larger amount of CO_2 emissions generated than if the heat were directly produced by combustion. If such electrical heating devices are replaced by small scale combustors, significant energy saving will be achieved.

It is well known that when combustors are scaled down, heat loss from the flame to its surroundings increases. This is a favorable property for a heating device if only thermal efficiency is considered. However, the down-sizing of a combustor generally causes incomplete combustion, resulting in higher CO (carbon monoxide) emissions. The new combustor presented here greatly alleviates this deficiency by utilizing excess enthalpy combustion technology. The concept of this technology is shown in **Fig. 1**. In excess enthalpy combustion, the fuel-oxidant premixed gas is heated to a high temperature by the exhaust gas before burning, thereby enabling better flame stability.

The Swiss-roll type micro combustor,[(2)] as shown in **Fig. 2**, consists of a pair of spiral channels with a combustion zone at their center, was developed at the first setout. Stable combustion and high thermal efficiency was achieved. The disk-type micro combustor (**Fig. 3**) was then developed to achieve double the thermal efficiency that the Swiss-roll type was capable of. The reduction of CO emissions and higher thermal efficiency has been confirmed.

This paper describes further reductions in CO emissions for practical use and the combustion characteristics of a demonstration device for kitchen fryers.

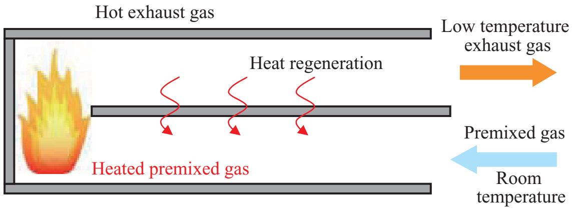


Fig. 1 Mechanism of excess enthalpy combustion

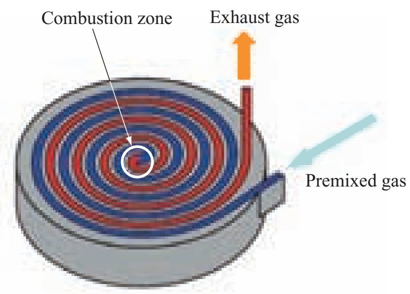


Fig. 2 Swiss-roll type micro combustor

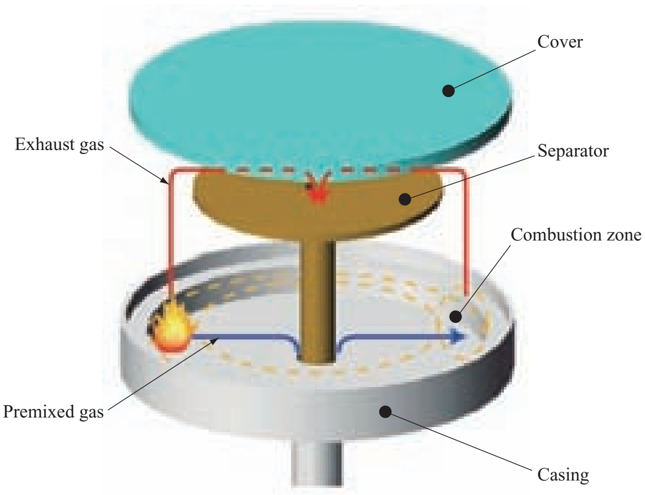


Fig. 3 Disk-type micro combustor

2. Experiment

The combustion characteristics of two types of micro combustors (jointly-developed with TOKYO GAS Co., Ltd.) were tested in an experiment. One of the micro combustors was a disk-type micro combustor with a water tank on its cover, and the other was a tube-type micro combustor for use in liquids. The experiment was carried out under water-cooled conditions so as to increase the heat loss from the combustor. This was done to confirm the performance of the combustors in conditions far worse than usual to evaluate their safety for commercial use.

2.1 Test equipment

Figure 4 shows a schematic drawing of the test equipment. The test equipment consists of a micro combustor, mass flow controller, thermocouple, and exhaust gas analyzer. Steady-state data was recorded 15 minutes after the conditions were fixed (including start-up time). This is because the temperature and exhaust gas compositions do not vary and are considered to be stable after 15 minutes have passed.

Methane or city gas (13A) was used as the fuel. Mass flow controllers were used to control the flow of fuel and air. Exhaust gas and water temperatures were measured by a thermocouple.

Five components of the exhaust gas were measured on a dry base (H_2O removed) in the experiment; namely THC (total hydrocarbon, as methane equivalent), CO, CO_2, NO_x, and O_2. In this study, CO concentrations were represented as O_2 0% equivalents.

The heat loss (Q_{Loss}) was calculated from Equation (1) based on the exhaust gas temperature. Since combustion efficiencies calculated from the exhaust gas compositions were more than 99.99%, combustion efficiency was assumed to be 100% in Equation (1).

$$Q_{Loss} = \frac{Q_E}{Q_F} \times 100 \quad \cdots\cdots (1)$$

Q_E : Sensible heat in the exhaust gas on a wet base (state in which the product is vapor)

Q_F : Combustion heat (lower heating value)

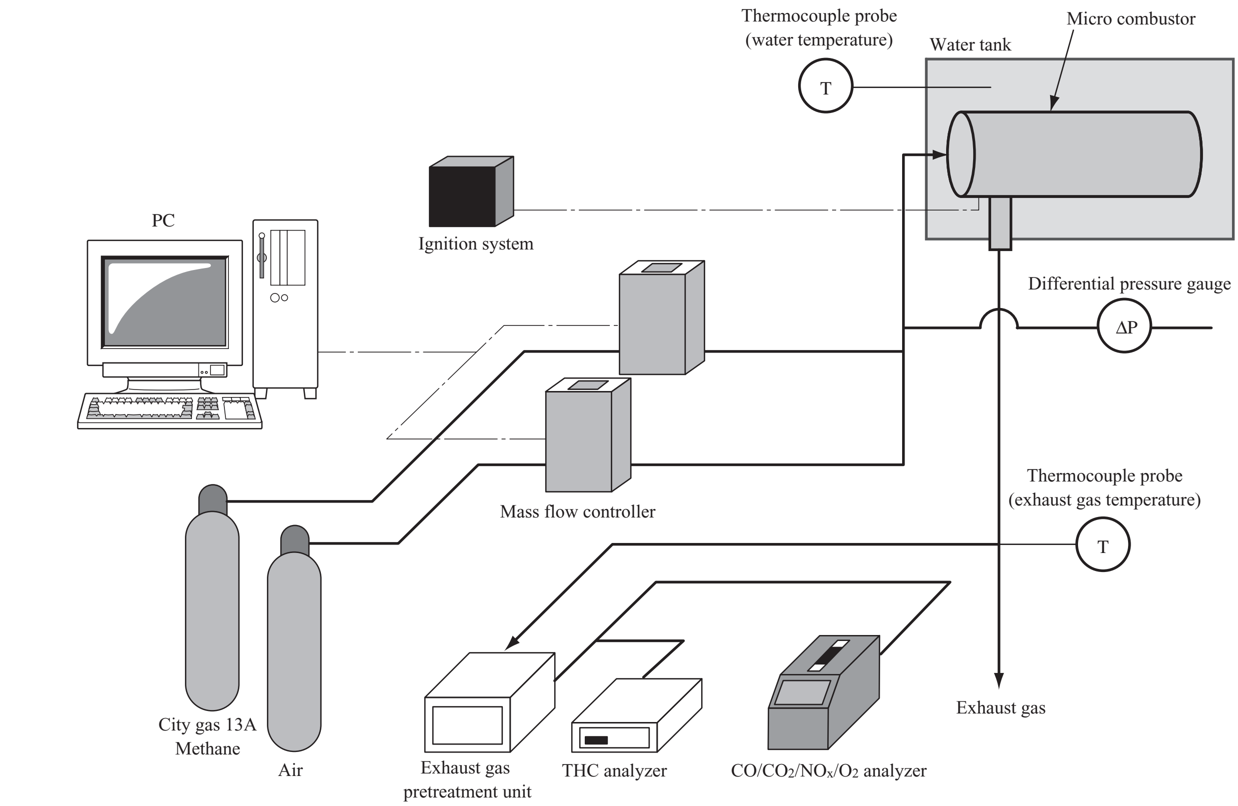


Fig. 4 Schematic drawing of test equipment

2.2 Disk-type micro combustor

The disk-type micro combustor consists of three parts: a casing, separator, and cover with a water tank. Air-fuel premixed gas (unburnt gas) is supplied between the casing and separator and spreads towards the periphery. The gas is burned in the combustion zone located in the peripheral part, and the exhaust gas passes between the cover and the separator and is discharged through the central tube. Heat from the exhaust gas is transferred to the premixed gas through the separator.

The test was performed with three kinds of disk-type combustors, each of which had a different sized gap between its cover and separator in order to vary the amount of heat loss (surface-to-volume ratio in the combustion zone).

2.3 Tube-type micro combustor

Figure 5 shows a schematic drawing of the tube-type micro combustor. The combustor consists of outer and inner tubes. The experiment was performed in water. The premixed gas passed through the inner tube and was injected into the combustion zone from a hole in its tip. The injected gas formed a stagnation point on the inner wall surface of the outer tube, and the flame was stabilized at that point.

The exhaust gas was then discharged through the annulus channel between inner and the outer tube. Heat was transferred through the inner tube wall. This type of combustor has two significant advantages: one is its simplicity and the other is that the heat transfer takes place through all of the outer tube surface.

An exciter (high-voltage generator) and ignition plug for domestic boilers were used as the ignition source. The flame was detected by a flame rod inserted into the combustion zone. Three combustors, all with different outer tube diameters, were tested to study the effect of the distance between inner and outer tube on the combustion characteristics.

3. Experiment results

3.1 Disk-type micro combustor

Figure 6 shows the correlation between input energy and CO concentrations for a disk-type combustor. The CO emissions of a water-cooled combustor is considerably larger than that of an air-cooled one. The amount of CO emitted also increases as the distance between the cover and separator decreases. For a distance of 4 mm, the combustor emits at least 1 500 ppm of CO, and cannot be put to practical use as a heat source.

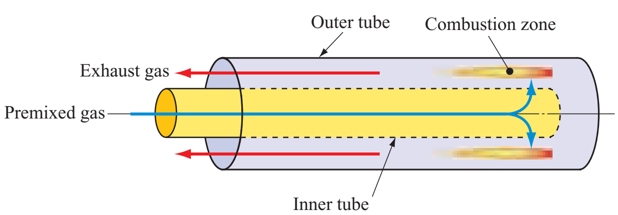


Fig. 5 Tube-type micro combustor

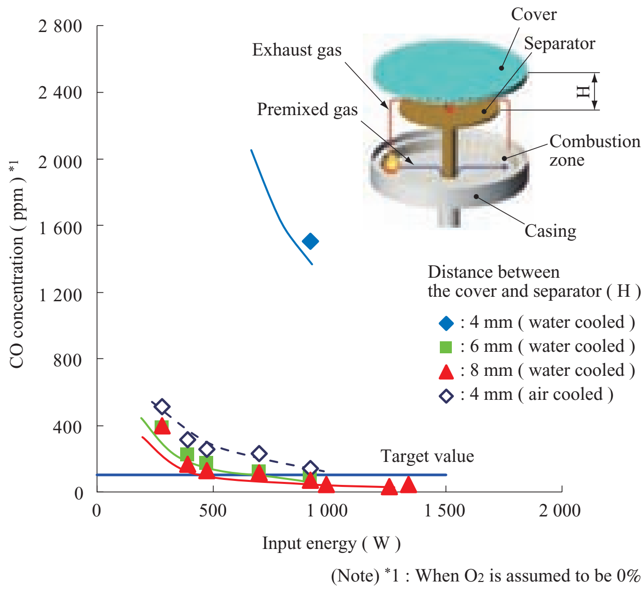


Fig. 6 Correlation between input energy and CO concentration

As the distance increases, the amount of CO concentrations falls below 100 ppm (which is the target for commercial use) when the input energy is increased. A likely reason for this is that the chemical reaction is prevented near the low temperature wall because of the higher heat loss, causing CO emissions to increase. The surface-to-volume ratio of the combustion zone is one parameter that indicates the degree of heat loss from burnt gas.

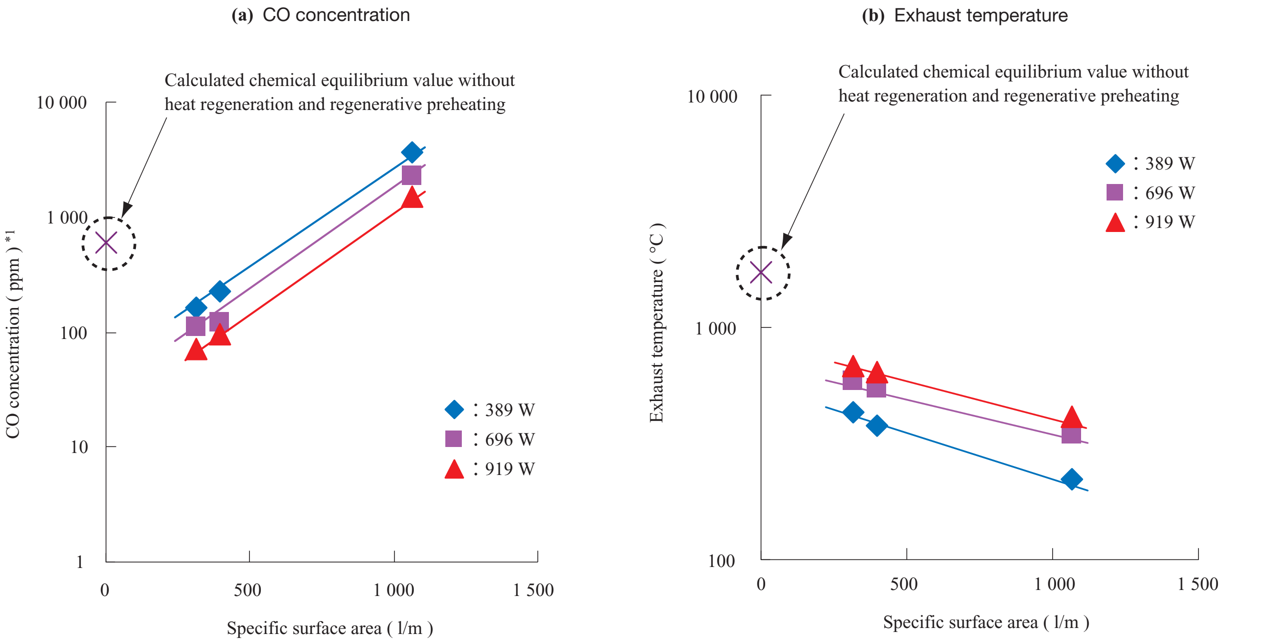
Figure 7 shows the relation between the surface-to-volume ratio and CO concentrations (**-(a)**), and the exhaust gas temperature (**-(b)**). Increasing the surface-to-volume ratio of the combustion zone causes a reduction in CO emissions and an increment in the exhaust gas temperature and heat loss. In addition, the CO concentrations can be reduced to below the chemical equilibrium values. It is supposed that the temperature of the premixed gas increased due to heat regeneration, promoting the oxidation of CO.

As a result, it was found that the CO emissions can be reduced by reducing the surface-to-volume ratio of the combustion zone, but at the same time, the exhaust gas temperature and heat loss increases, requiring the optimum shape to be identified.

3.2 Tube-type micro combustor

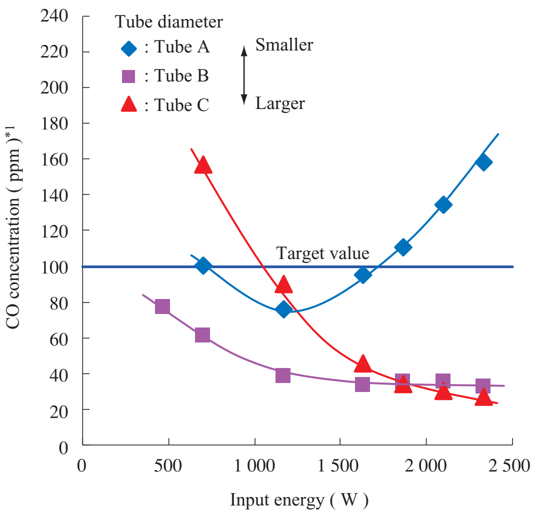
Figure 8 shows CO concentrations for different outer tube diameters. With outer tube B, the exhaust CO concentration can be kept below 100 ppm when the energy input is 500 to 2 300 W. With outer tubes A and C, the amount of CO concentrations exceeds 100 ppm depending on the energy input. Therefore, it is necessary to select appropriate sizes for the inner and outer tubes according to the operating conditions of the combustor.

Figure 9 shows how the equivalence ratio affects the CO concentration for outer tube B. The CO concentration is lowest when the equivalence ratio is 0.8, regardless of the input energy. In addition, the CO concentration is 100



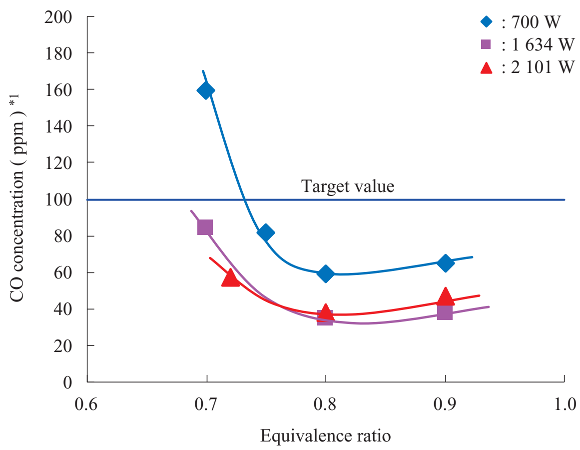
(Note) *1 : When O_2 is assumed to be 0%

Fig. 7 Effect of specific area on CO concentration and exhaust temperature



(Note) *1: When O_2 is assumed to be 0%

Fig. 8 Effect of outer-tube diameter on CO concentration



(Note) *1 : When O_2 is assumed to be 0%
With tube B

Fig. 9 Effect of equivalence ratio on CO concentration

ppm or less when the equivalence ratio is 0.75 to 0.9 and the input energy is 700 to 2 101 W. For practical use, it is important that the CO concentration does not change significantly even when the gas concentration changes, and the developed combustor was found to meet this requirement.

4. Prototype equipped with a micro combustor

4.1 Overview of the prototype combustor

Figure 10 shows a photo of the prototype fryer developed with TOKYO GAS Co., Ltd. A tube-type micro combustor has a small footprint, making it suitable for use with a fryer fluid tank. The prototype combustor is operated with a 100 VAC power supply and low pressure city gas, and is equipped with a gas supply section (gas valve and air fan), safety device, and exciter on the back, and a commercial gas controller on the front. In addition, it is equipped with a mass flow meter to monitor the fuel flow rate.

Two tube-type micro combustors were used to evaluate the prototype combustor. One of them was a movable-type combustor, and the other was a fixed-type combustor. The movable-type combustor is small and light enough to be installed in the tank, and it can be lifted up for cleaning. However, the lengths of the

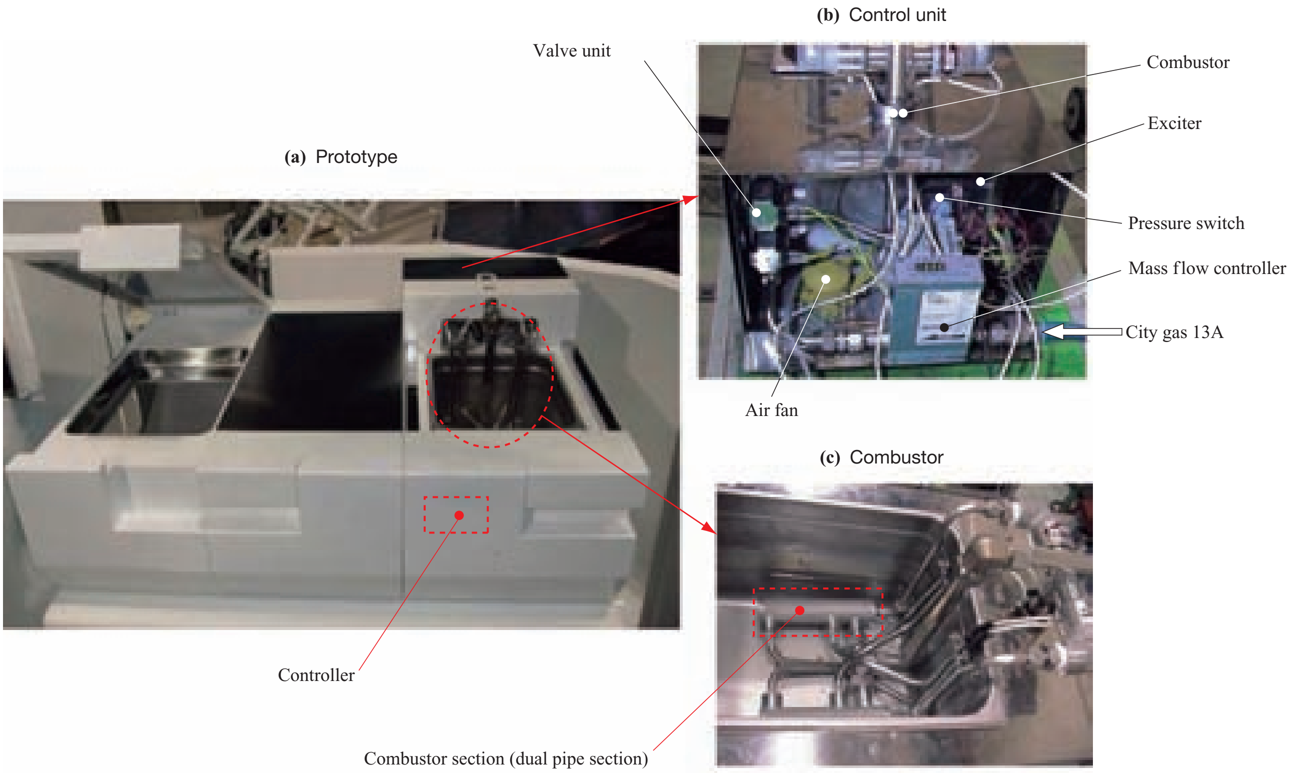


Fig. 10 Fryer prototype

movable-type combustor and its exhaust pipe are shorter than those of the fixed-type combustor because the movable-type combustor has a moving mechanism.

4.2 Performance of the prototype combustor

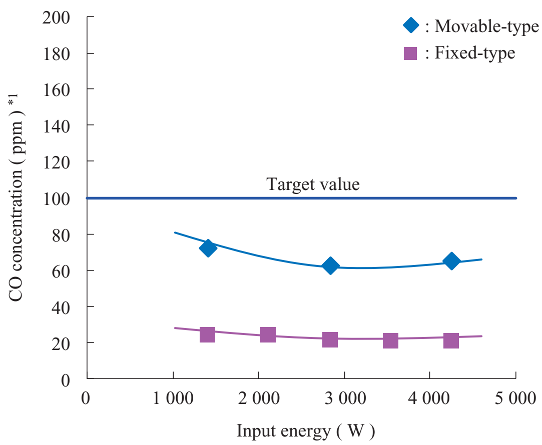
Figure 11 shows the CO emission characteristic of the prototype combustor. In this test range (1 400 to 4 200 W), the amount of CO concentrations for both the movable-type and fixed-type combustors were less than 100 ppm. However, the amount of CO concentration for the movable-type was higher than that for the fixed-type. The reason for this is likely to be that the movable-type is shorter than the fixed-type, and the degree of preheating is therefore lower.

Figure 12 shows the exhaust gas temperature of the prototype. With the movable-type combustor, the outlet temperature is as high as 480°C and the heat loss is 22.4% when the input energy is 4 200 W. With the fixed-type combustor, the outlet temperature is as low as 150°C and the heat loss is about 9%. The reason for this may be that the movable-type has a shorter exhaust pipe than the fixed-type combustor, resulting in insufficient heat transfer in water. With the fixed-type combustor, the temperature falls below 100°C when the input energy is low, causing water condensation. Therefore, it is necessary to select the appropriate exhaust pipe length according to the service conditions at the design phase.

4.3 Results of the exhibitions

Generally, a heat source like a burner cannot be lifted up to enable the fluid tank of an electric fryer, for example, to be cleaned. However, the micro combustor is small and light enough to be installed in the tank and to be lifted up.

The prototype combustor was exhibited at kitchen equipment exhibitions in cooperation with TOKYO GAS Co., Ltd. in order to survey opinions (Japan Food Service Equipment Show 2008: March 11 to 14, 2008; Energy & Environment Fair 2008: May 21 to 24, 2008; and 18th West Japan Professional Foodservice & Industry 2008: June 24 to 26, 2008). This new concept combustor attracted a great deal of attention at the exhibitions because of its higher performance, compactness and its movable mechanism.



(Note) *1 : When O_2 is assumed to be 0%

Fig. 11 Exhaust CO concentration in prototype commercial unit test

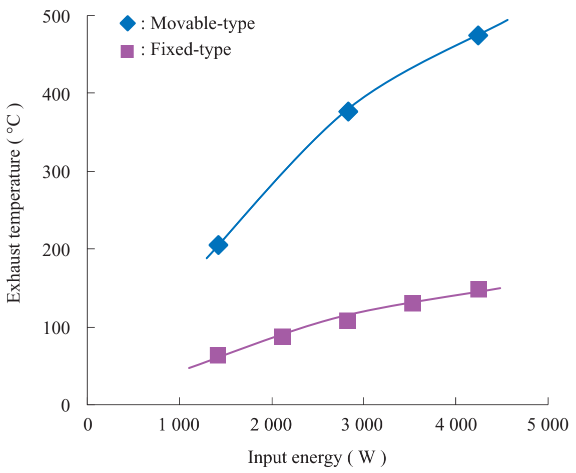


Fig. 12 Exhaust temperature in prototype commercial unit test

5. Conclusion

The combustion characteristics of the two types of combustors (disk- and tube-types) were tested under water-cooled conditions. In addition, a prototype combustor for use with fryer devices was developed using a tube-type micro combustor and its performance was evaluated. The results were as follows:

(1) For the disk-type micro combustor, increasing its surface-to-volume ratio of combustor causes a reduction in CO emissions and an increment in the exhaust gas temperature and heat loss. The reason for this could be that as heat loss increases (i.e. surface-to-volume ratio decreases), CO oxidation is prevented. Because of the trade-off relationship that exists between CO emissions and heat loss, it is necessary to find the optimal surface-to-volume ratio.

(2) For the tube-type micro combustor, the amount of CO emission depends greatly on the distance between the outer tube and inner tube. CO emissions are at their lowest when the equivalence ratio is 0.8.

(3) The CO emissions generated by the prototype fryer with the two tube-type micro combustors were less than 100 ppm. In addition, an exhaust temperature of 150°C and thermal efficiency of up to 93.3% were achieved.

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