Ultra Lean Combustion of Liquid Fuel Mist in a Hot Porous Solid

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Abstract

Ultra lean adiabatic combustion technology for the mixture of liquid fuel (Kerosene) mist and air in a simple perforated cylindrical hot porous ceramic burner was studied experimentally. During the steady lean combustion, high excess air ratios; 2.8 ~3.6 could be achieved through the range of fuel flow rate; 0.8 ~ 4 *g/min*. The emission levels of CO and NOx under the excess air ratios less than 2.0 were satisfactorily low. The effects of fuel flow rate on the emission levels and the mechanism of flame confinement in the hot porous ceramic were examined.

Introduction

From the point of view of the preservation of clean environment in the air and the energy saving, many combustion studies have focused their attention on the development of the technology for keeping exhaust burned gas clean. In particular, the technology for effective energy conversion by the excess enthalpy combustion of lean mixtures has been studied actively by using permeable solid since about twenty years ago. In the studies, thermal radiation characteristics due to the combustion in the hot porous media, and the propagation and stability of flame in the porous media have been examined experimentally and theoretically in detail **[1-7]**. We can see the excellent recent review by Howell et al.**[5]**. Many studies on the excess enthalpy combustion in the porous media, however, have focused on the gaseous fuels, and few studies on the liquid fuels have been reported **[1-4]**. Recently experimental and theoretical studies on the combustion of liquid fuels in a porous radiant burner have been reported by Kaplan and Hall **[3]**, and Tseng and Howell **[4]**. The present study aims to challenge to the lean limit of steady combustion of liquid fuels in our domestic combustors in the light of the concept of excess enthalpy combustion by a hot porous solid, and to examine the combustion characteristics in detail.

Apparatus and Procedure

Figure 1 shows the experimental setup. Liquid fuel (Kerosene) is transferred by magnet pump and vaporized in the heater cup (about 200 ^{o}C). The mixture of vaporized fuel mist and air is transferred into the perforated cylindrical porous ceramic (Inner dia.; 20mm, Outer dia.; 50 mm, Length 110 mm, Porosity; 0.82~0.83,Mesh; 9~20, namely pore size; 2.8~1.3 mm), and then the mixture ejected from the surface of porous ceramic is ignited by a small pilot flame. With increase in the temperature of the heated porous ceramic after several minutes, the distributed small flames formed on the surface regress into the hot porous ceramic owing to high heat flux from solid to the mixture. Thus, even an ultra lean combustible mixture can be burned steadily in the hot and bright porous ceramic.

The dependence of maximum excess air ratio on the fuel flow rate; 0.8~4 *g/min* (equivalent air flow rate; 9~46 *l/min*) was examined in detail. The temperatures in the hot porous ceramic were measured by R and K-type thermocouples. The emission levels in burned gas were measured by the constant potential electrolysis gas analyzer (Testoterm: GSV-350) with sampling probe at about 20 cm above the burner.

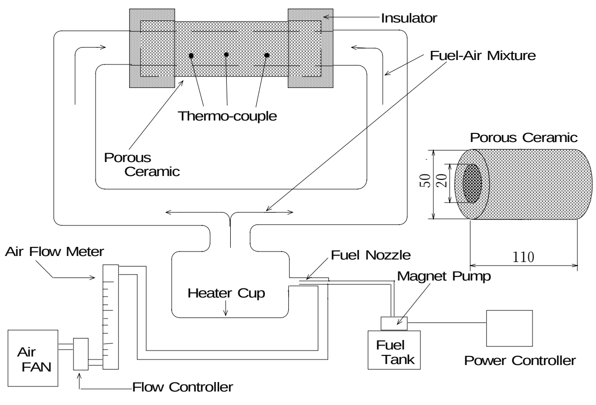

Figure 1: Experimental Setup

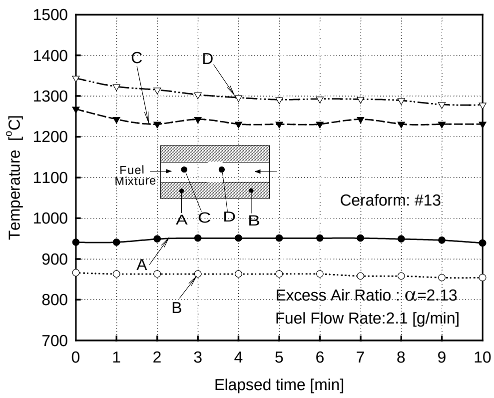

Figure 3: Temperatures in Hot Porous Ceramic.

Results and Discussion

We can see the very strong light and thermal radiation from the hot perforated cylindrical porous ceramic during steady combustion where the flame is confined completely.

The maximum excess air ratio for steady combustion attains 2.8～3.6 as shown in **Figure 2**, which is due to the successful ultra lean combustion of liquid fuel.

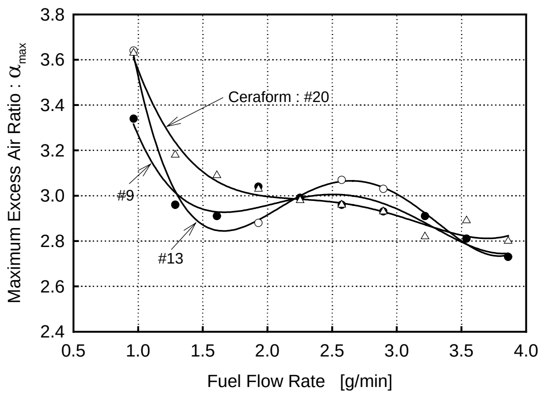

Figure 2: Dependence of Maximum Excess Air Ratio on the Fuel Flow Rate

Typical measured flame temperatures at high excess air ratio in the burner, shown as C and D in **Figure 3**, agree well with the calculated adiabatic flame temperatures of Kerosene, as shown in **Figure 4**. This is due to the high heat feedback from hot porous solid to the reaction zone, namely excess enthalpy combustion.

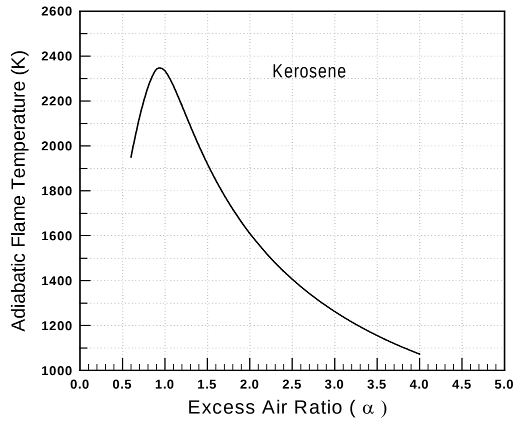

Figure 4: Calculated Adiabatic Flame Temperature.

Why can the flame be confined in the hot ceramic? From the calorific value of Kerosene; 10300 *Kcal/Kg*, fuel flow rate; 0.8~4 *g/min*, total inlet section area; 6.28 cm^2 and the equivalent air flow rate; 9~46 *l/min*, the inlet flow velocity of the mixture into the both ends of hot ceramic at the excess air ratio 2.8 can be estimated as 67~342 *cm/sec* approximately. This is very larger than the burning velocity of such the lean mixture of usual hydrocarbon fuels, and thereby the flashback can not occur.

In addition, as shown in **Figure 5**, due to the porosity of 0.82 of tube wall, and large thermal expansion effect, the radial exit flow velocity of the mixture from inner tube-like wall can be estimated as over 100 *cm/sec* at high excess air ratios. This is also the reason why the flame can be confined in the hot perforated cylindrical ceramic.

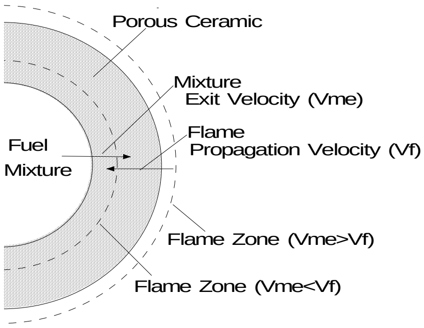

Figure 5: Schematic Model of Flame Position

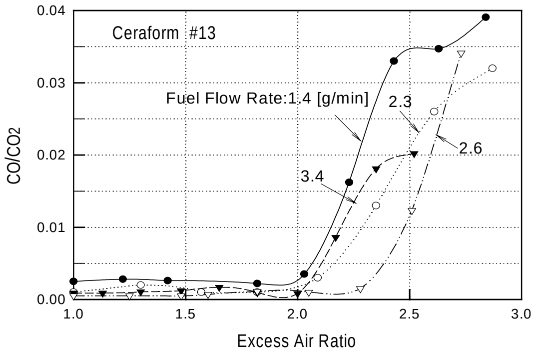

Figure 6: Effect of Excess Air Ratio on the Emission Ratio; CO/CO2

Typical dependence of the ratio; CO/CO2 and reduced NOx in the emissions on the excess air ratio and fuel flow rate are shown in **Figures 6** and **7**. The emission levels were satisfactorily very low when the excess air ratio is under about 2.0 through the range of fuel flow rates in this study. This is due to the effective lean adiabatic combustion in the hot porous solid.

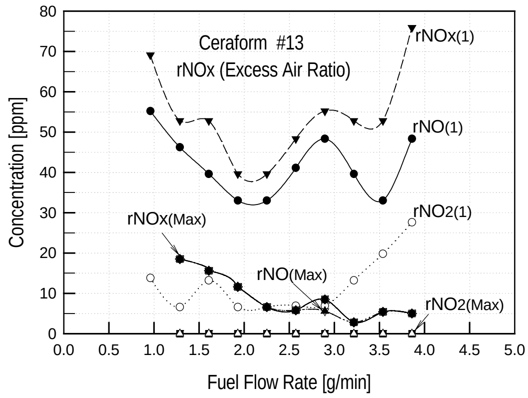

Figure 7: Dependence of reduced NO, NO2 and NOx Emissions on Fuel Flow Rate.

Concluding Remarks

(1) Ultra lean adiabatic combustion where the excess air ratio is over 3.0 for the mixture of liquid fuel mist and air can be achieved successfully by using the perforated hot porous ceramics.

(2) The adiabatic combustion method of liquid fuel mist in a hot porous ceramics can be promising combustion technology with many applications due to the ultra lean mixture condition, the strong light emission and thermal radiation.

(3) Successful reduction of CO and NOx in the emissions can be achieved under the excess air ratios less than 2.0, which may be due to the effective excess enthalpy combustion of lean mixture in the hot porous solid.

Acknowledgments

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