A Study of Micro-Combustion in a Micro-Platinum Tube

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Introduction

With significant advances of MEMS technology in recent years, miniaturization of mechanical and electro-mechanical devices and systems has become a revolutionary thrust to pioneer a new world. In order to provide longer operational cycles and reduce the mass and volume fraction of power system, a new concept of micro-combustion is proposed to design micro-power systems. The power density of combustion is tens or hundreds times to a typical battery. However, to sustain combustion in a micro-size volume, becomes more difficult with decreasing characteristic length. The increasing surface to volume ratio leads more heat loss, radical depletion on wall and the shorter residence time leads low efficiency of fuel conversion. Some methods to overcome these problems were proposed, such as: fuel preheating[1], "excess enthaphy"[2], "Swiss Roll"[3-6] combustors and multi-ple-tube combustion[7]. An obvious reaction occurs in a quartz tube less than the quenching diameter with a platinum wire as the catalyst to stabilize the reaction was demonstrated[8]. The application of micro-combustion such as "thermoelectric power generation"[9] or "micro-propulsion"[10] is developed recently. The objective of this work is to study the ignition and combustion characteristics of catalytic micro-channels of platinum.

Experimental setup and numerical method

In order to study the ignition and combustion phenomenon in a micro-combustor and the size effects on chemical reaction, we use simple circular platinum tubes as the reaction chamber. The length of all tubes are 1cm, diameters are 200 μm, 500 μm, and 1mm, and purity is 99.9% (see Fig. 1). High purity hydrogen and air are controlled by mass flow-meter

and premixed in a simple mixer. An electric heater is used to preheat the mixture gas to 423K at the inlet of the platinum tube. A R-type thermocouple is used to detect the exit temperature. The experimental setup is shown schematically in Fig. 2. Numerical simulation of catalytic combustion in the micro-channel is developed to provide more detailed information of combustion and surface reaction in the micro-channel. The numerical model of the micro-catalytic combustion consists of the coupling of the flow field and the chemical reaction in the gas phase and on the catalyst surface. A flow model and the surface reaction mechanism of hydrogen on platinum is used to solve the governing equations including mass, moment, energy conservation equation and surface species[11].

Current results

We have tested and verified the feasibility of stable catalytic micro-combustion in the 200 μm and 500 μm diameter platinum tubes. The operational conditions for the tests are shown in table 1. Figure 3 shows that both 200 μm and 500 μm platinum tube will become red-hot when reaction temperature over 800K. Figure 4 shows the results of the exit temperature versus fuel concentration at different velocities for the 500 μm Pt tube. The exit temperature increases with increasing fuel concentration and velocity. When the velocity increases to 30m/s, an obvious temperature rise for high fuel concentration conditions can be observed. Figure 5 shows that some axial temperature profiles behind tube exit still remains at high temperatures for more than 12 tube-diameters in length. This result implies that gas phase reaction occurs near the exit and raises the temperature downstream obviously. The 200 μm-tube results, shown in Fig. 6, show different trends from those of 500 μm, such as: lower exit temperature, linear temperature raise with fuel concentration, and no gas phase reaction behind the exit. From the experimental results, one can find that the 500 μm platinum tube has better thermal efficiency than the 200 μm one.

The numerical simulation results as compared with experiments are shown in Fig. 7. Both experimental and numerical results on temperature are far below the adiabatic flame temperature. However, the simulation follows the same trend with the experiment. Simulation

also shows that gas phase reaction can occur in the 500 μm platinum tube for higher velocities and fuel concentrations. Figure 8 shows that the predicted OH concentration distribution in the tube depends on whether including the gas phase reaction mechanism in the simulation. When adding gas phase reaction mechanism, high concentration of OH is formed in the flow field, otherwise, OH is formed on the catalyst surface.

Discussion and future work

It has been demonstrated that micro-catalytic combustion can be sustained effectively in the 200 μm and 500 μm platinum tubes. Further modification of the numerical simulation to improve the prediction by including the detailed gas-phase kinetic mechanism is currently in progress. Measurements of the major species and temperature at the exit of the micro tube-reactor using Raman scattering spectroscopy will also be performed in the future to characterize the catalytic reaction in the tube and to verify the numerical predictions.

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Tables and Figures

	Tube Dia 200 μ m	Tube Dia 500 μ m
Velocity(m/s)	25~150	10~60
Fuel Concentration(%)	3~30	3~30
Preheat Temperature(K)	423	423

Table 1 Operational conditions for 200 μ m and 500 μ m pt tube.

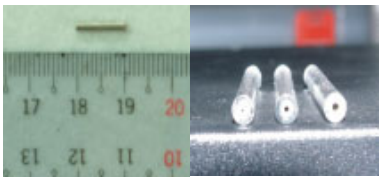

Fig. 1 The geometry of the pt tubes.

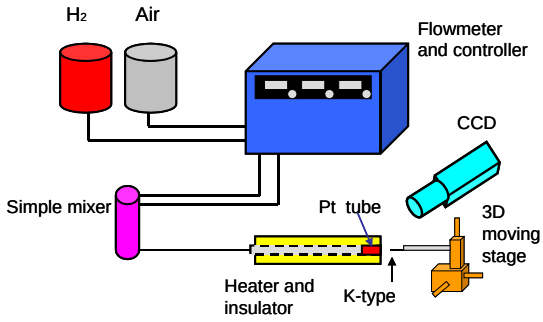

Fig. 2 Experimental setup

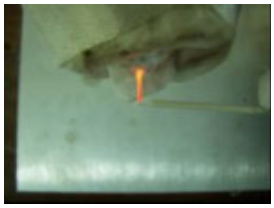

Fig. 3 Platinum tube with high temperature(>800K)

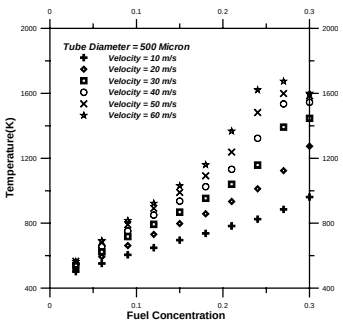

Fig. 4 Diameter =500 μ m, temperature versus fuel concentration for different velocity

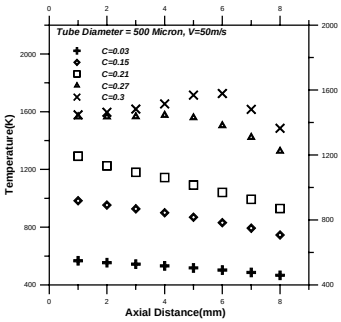

Fig. 5 Diameter=500 μ m, velocity=50m/s, axial temperature profiles behind the tube exit.

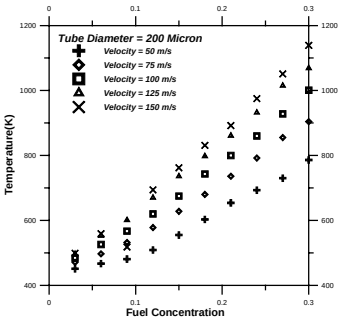

Fig. 6 Diameter =200 μ m, temperature versus fuel concentration for different velocity

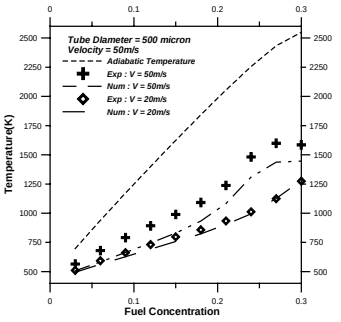

Fig. 7 Diameter =500 μ m, the compare of numerical simulation and experimental results

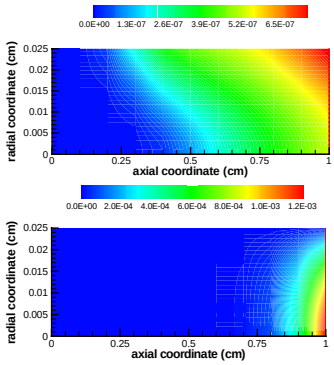

Fig. 8 Diameter=500 μ m, V=50m/s, fuel concentration=27%, OH distribution, upper: no gas reaction mechanism, lower: with gas reaction mechanism