Development of a High Test Hydrogen Peroxide (HTP) Micro-Thruster

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Introduction

In the present study, a sub-mesoscale high test hydrogen peroxide (HTP) micro-thruster for reactive control systems (RCS) in micro and pico-satellites is developed. The goal of this effort is to develop a method to overcome the difficulties which liquid monopropellant chemical thruster systems may experience when reducing the reactor size into mesoscales. Using HTP in sub-meso and micro-scale reactors, two latent heat thresholds (liquid water and liquid peroxide at 373.15 K and 423.15 K respectively) impede the decomposition progression and significantly degrade the performance. Once the combustor system gets over the hydrogen peroxide boiling temperature, gasified hydrogen peroxide vapor will decompose rapidly on the catalyst surface in milliseconds in the micro channel. In order to gasify the liquid hydrogen peroxide as fast as possible, large catalytic surface is imperative in the small volume of HTP thruster. Moreover, we need design a more efficient channel to recover the decomposition heat from the enhanced heat loss due to size-downing and get a better performance of thrust.

In recent years, high test hydrogen peroxide attracts renewed attention as a safer and environmentally friendly green monopropellant which becomes a potential alternative of the hazardous hydrazine. With the outstanding features of non-toxicity and high energy density, HTP can be applied in the propulsion systems ranging from large scale rocket engine to milli-Newton level attitude control system of nano-satellites, whether decomposes alone or reacts with other fuel as a bipropellant propulsion [1-6].

The surface area to volume ratio increases as the reactor size is decreased. This is beneficial to apply catalyst to decompose hydrogen peroxide in a catalytic reactor which makes up of a ignition-free combustor for the chemical micro-propulsion system [7]. However, the enhanced heat loss than the conventional propulsion system due to larger temperature gradient near the boundary results in quench or lower thrust in the performance of the micro-thruster. Hence, external heating may be needed. Hitt et al. [8] presented a MEMS-based hydrogen peroxide micro-propulsion prototype constructed of numerous Pt catalytic pillars in the combustion chamber and the target thrust level of this chip is about 500 μN with a specific impulse of 140~180s. Experimental results revealed incomplete decomposition at the nozzle exit but they believed that once the decomposition problem is solved, the target thrust could be achieved.

Incomplete decomposition of hydrogen peroxide is a serious difficulty in micro-propulsion systems. In this research, we look for a solution to effectively overcome the incomplete decomposition problem by electro-spray to diminish the droplet diameter to the size suitable for sub-mesoscale reactor channel. By this way, the goal of initial tests has been accomplished and some remarkable phenomena which could be positive references for future design are observed in a sub-mesoscale cylindrical catalyst bed.

Experimental Setup

Figure 1 shows the schematic of experimental setup in the preliminary experiments. Since the adiabatic decomposition temperature of 92% HTP may exceed the melting temperature of silver, it is not applicable using silver as HTP decomposition catalysts. The reactors are made of catalytic microtubes with different diameters fabricated by pure (99.9%) platinum. The platinum tube is placed within the quartz tube and resistance coils surrounds the quartz tube as the heater for startup. Because the cylindrical tube has the smallest surface to volume ratio, we choose this geometry to determine the maximum fuel consumption flow rate in the same volume space and residence time. The quartz tube is well insulated and fine thermocouples (25μm R-type) with non-catalytic coating are used to measure the outlet temperature. A CCD camera is used for qualitative observation of the reaction process. High test (concentration) hydrogen peroxide is fed by high pressure nitrogen and a mass flow meter is used to control the 95% HTP flow rate. In this experiment, the material of all the valves and fittings should be 316 steel which is inert to HTP. Other materials that could result in HTP decomposition reaction and produce small bubbles in the system interfere the performance and accuracy of the experiment. Any decomposition in flowline may lead to the instability of flow rate. A venting facility is necessary to avoid contact of the corrosive HTP vapor.

Results and Discussion

In the preliminary experiments, the 5cm cylindrical catalytic bed with two diameters-1mm and 500μm- is tested with 95% HTP. In the experiment, the feeding valve and the auxiliary electrical power are turned on simultaneously at selected flow rate. Figure 2 shows the reactor exit temperature at different flow rates and power input. We can see that below certain input power level, the reactor exit temperature is below 100℃. If we increase the input power and the exit temperature exceeds 100℃, one can find pluming products emitting. The decomposition reaction is rapidly built up and the system reaches a steady temperature in about 30 sec if the exit temperature exceeds 150℃ which is just equal to the boiling point of HTP. We call this “built up” process as “ignition”. For 1mm diameter catalytic reactor with 1cc/min flow rate, 13W power input is required to ignite and for 2cc/min needs about 27W. The large auxiliary power may due to the latent heat of water and HTP.

HTP enters catalytic bed in liquid phase, then electrical power supplies additional heat to increase the HTP temperature. In this step, decomposition rate is low because low diffusivity of liquid and inactive reaction with Pt due to low temperature. Self-sustained decomposition can’t propagate until the heating power helps the system to overcome the “latent heat of water” barrier. In this situation, no gaseous products at the exit can be found. When exit temperature exceed 100℃, all liquid water is vaporized and partial decomposition of HTP release decomposition heat to system. The foggy plume at the exit reveals incomplete decomposition. Once the exit temperature goes beyond 150℃, “ignition” takes place quickly and the outlet gas becomes invisible. We believe that the decomposition of HTP is almost complete with a exit temperature above 450℃, which suggest that homogenous reaction dominate [10].

Pressure feedback is another important phenomenon when decomposition reaction is built up. The chamber pressure increases with the reaction, and the pressure wave may go back upstream and affect the flow rate which may result in instability. Moreover, the heat of decomposition communicating upstream may give rise to pre-decomposition or vaporization of HTP liquid. These decomposition bubbles are the source of instability resulting in mass flow flogging [11]. A fine spray using the electrospray system is proposed to resolve "flogging" and "pressure feedback" problems and to enhance the reaction and performance of the micro-thruster, but the exciting voltage for HTP may be too high to suit practically space application. Figure 3 shows that proper thermal insulation reduces the power needed for ignition and yields higher exit temperature.

Conclusions

In the design of a micro-propulsion system using HTP, large latent heat of water and HTP is a main block decreasing decomposition rate and the performance. Lower decomposition efficiency than normal also originates from shorter the resident time and enhanced heat loss when reducing the size of the reactor down to sub-meso-scales. If we want to achieve a short response of pulse thrust, additional heat supply must be needed. For the improvement of instability due to flow rate flogging and pressure feedback, a fine spray atomization system may be the solution. The design of the catalytic reactor with a higher surface area to volume ratio is a key point to accelerate the decomposition rate for a micro-thruster.

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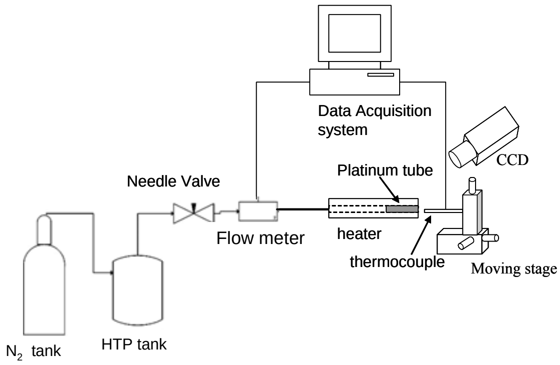


Fig 1: Experimental facility schematics

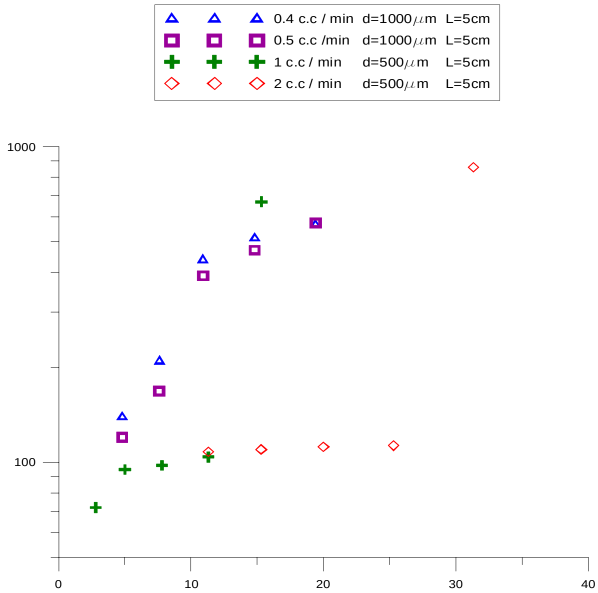
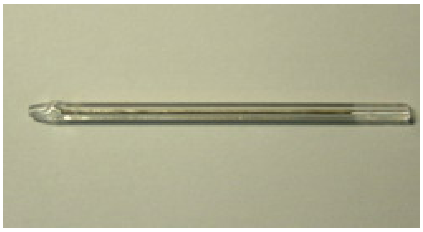


Fig 2: catalytic bed exit temperature versus auxiliary power with different flow rate



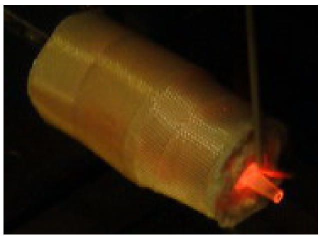


Fig 3: (a) Catalyst chamber, D=1mm and L=50mm (b) The ignition of decomposition reaction at 95% HTP flow rate 0.6 cc / min, the auxiliary power is 11W and exit temperature 978 K.