N_2O 단일 추진제 추력기 개발을 위한 촉매 분해 시험

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Catalytic decomposition of N_2O to develop monopropellant thruster

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ABSTRACT

Catalytic decomposition of nitrous oxide was investigated experimentally. Two noble metal catalyst (Pt, Ir) were chosen to decompose nitrous oxide. Each catalyst was tested with different chamber pressure and preheating temperature. Ir decomposed N_2O at lower temperature (230℃) and suitable for N_2O decomposition. In addition, the minimum required preheating temperature decreased as the chamber pressure increased. However, deactivation of Ir catalyst was observed during the experiments.

초 록

친환경 추진제인 N_2O 단일추진제 추력기 개발을 위하여 N_2O 촉매 분해 시험을 수행하였다. 백금(Pt), 이리듐(Ir)을 알루미나 펠렛에 코팅한 촉매를 삽입하여 압력을 달리하고 분해 반응이 시작되는 최저 예열 온도를 측정하였다. 실험 결과 Ir이 N_2O 분해 반응에 더 적합하며 최저 요구 예열 온도도 낮게 나타났다. 또한 요구 예열 온도는 챔버 압력이 증가함에 따라 감소하였다. 그러나 지속적인 분해 반응시험을 통해 Ir의 산화 반응에 의한 반응성 저하 현상이 나타남을 실험적으로 확인하였다.

Key Words: Nitrous oxide(아산화질소), Catalytic decomposition(촉매 분해), Monopropellant(단일추진제), Thruster(추력기)

1. Introduction

Recently, nitrous oxide(N_2O), widely known as laughing gas, attracts many researchers' attention due to its green, non-flammable, non-explosive and storable characteristics. N_2O is being investigated as an oxidizer of hybrid rocket[1] or liquid bipropellant rocket[2], and as a green monopropellant[3]. However, flight heritage of N_2O propulsion system was rarely reported. N_2O resistojet thruster (Mark-IV) developed by Surrey Space Center

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Table 1. Comparison of N_2O and H_2O_2

	N_2O	90% H_2O_2
I_{SP} (theoretical), s	181*	205*
$T_{adiabatic}$, K	1904	1022
Storage density	745**	1347
Storable temp., ℃	-34 ~ 60	-7 ~ 38
Melting point, ℃	-90.86	-12
Boiling point, ℃	-88.48	146

* I_{SP} data obtained for A_e/A_t=200 (as monopropellant)
** Liquefied gas at 52.4 bar and 21℃

was boarded on the UoSAT-12 in 1999, and tested in-orbit[3]. First successful flight was achieved in 2004 by SpaceShipOne which was propelled by N_2O/HTPB hybrid rocket [4].

$$N_2O \rightarrow N_2 + 0.5O_2 + heat \quad (1)$$

Table 1 presents comparison of green-propellants N_2O with hydrogen peroxide (H_2O_2) as a monopropellant. N_2O can be decomposed into O_2 and N_2 by catalytic or thermal decomposition (Eq. (1)).

Due to high adiabatic decomposition temperature N_2O has higher I_{SP} than that of H_2O_2 due to its higher adiabatic decomposition temperature. N_2O can be liquefied by pressurizing. Due to high vapor pressure (52.4 bar at 21℃) of N_2O, additional propellant expulsion system is not required in N_2O thruster system (self-pressurizing). Storage temperature for N_2O is wide, and N_2O is compatible with common materials.

N_2O is able to be thermally decomposed at 520℃[4]; however, the gas in a reaction chamber should be heated over than 1000℃ to maintain the enough reaction rates as propellant. This required temperature can be reduced by adapting catalyst, and Surrey Space Center insisted that the minimum required temperature was 200℃[3]. However, the information about catalyst was not reported.

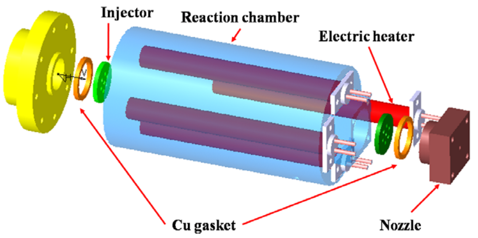


Fig. 1. Schematic of thruster

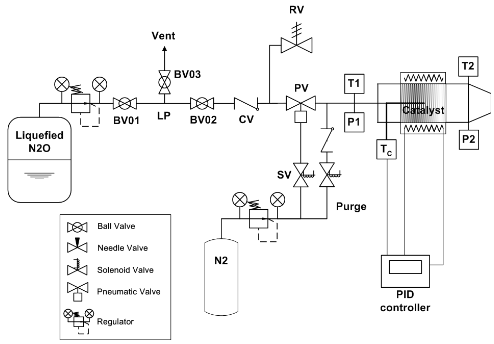


Fig. 2. Experimental setup

In the present study, N_2O decomposition test were carried out with different catalyst to light suitable catalyst for further development of N_2O thruster. Precious metal catalyst such as Pt and Ir were chosen since this study is just in the beginning stage.

2. Thruster design and preparation of catalyst

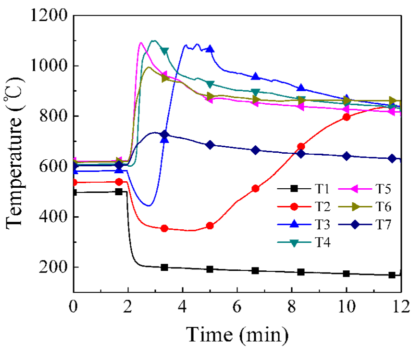
2.1 Schematic view of thruster and experimental setup

The schematic view of the thruster is shown in Fig. 1. Due to preheating requirement of catalyst for decomposition N_2O; four cylindrical electric heaters (O.D. 10 mm, 95 mm long) were inserted into the wall of the reaction chamber. Diameter and length of the reaction chamber were 15 mm and 100 mm, respectively. The nozzle was designed separately from the reaction chamber to be able to it in the future work. In the present study a converging nozzle with throat diameter 1 mm was used. Temperature distribution was obtained by measuring temperature at seven points along the chamber with distance bewteen two adjacent thermocouples 15 mm.

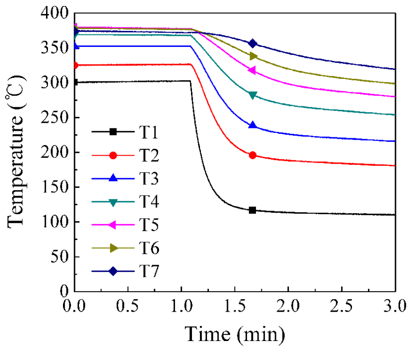
The outline of experimental setup is shown in Fig. 2. N_2O injection was controlled by solenoid valve and its remote control system.

2.2 Preparation of catalyst

In the present study, Pt and Ir were chosen and inserted into the reaction chamber after coating them on the commercial alumina (Al_2O_3) pellets by wet-impregrnation methods using metal chloride (MCl_x or H_xMCl_y) aqueous solution [5]. The concentration of metal on supports is important parameter in catalytic reaction. In the present study, the concentrations were 15~18 wt% for all catalysts.



(a) 500℃



(b) 300℃

Fig. 3. Variation of temperature with different preheating temperature (P_C : 2 bar, Pt)

3. Results and discussions

3.1 Pt catalyst

Pt is widely used catalyst in various reaction such as combustion, decomposition of hydrogen peroxide. When the chamber pressure is 2 bar, the reaction was initiated at 500℃. If the preheating temperature is below 500℃, temperature in the reaction chamber decreases continuously.

The required temperature to initiate decomposition of N_2O decreased by increasing chamber pressure (400℃ at 10 bar). However, comparing with literatures, the required preheating temperature is too high for Pt catalyst. As a result, experimental results reveals that Pt is not appropriate for N_2O decomposition.

3.2 Ir catalyst

The N_2O decomposition was initiated with 230℃ of preheating temperature at 2 bar. This required temperature much lower than that for Pt catalyst, and it is comparable with data reported in other literatures. After first successful reaction, the thruster was cooled-down and retested with same preheating temperature; however, the reaction was not initiated and higher preheating temperature was required. Figure 4 shows the variation of temperature in second firing test. The minimum required preheating temperature was 300℃ otherwise it was 230℃ at the first firing test.

Comparing with Pt catalyst, Ir shows more stable reactivity than Pt in N_2O decomposition. In addition the reaction zone was formed at the far downstream from the injecting point at the beginning, and this reaction zone was propagated to upstream.

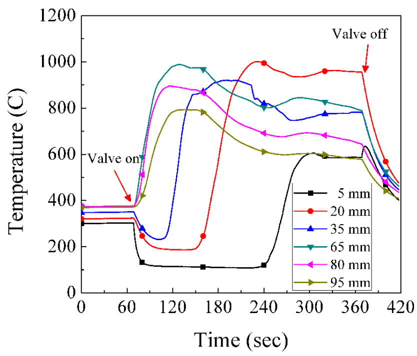


Fig. 4. Variation of temperature (P_C = 2 bar, Ir)

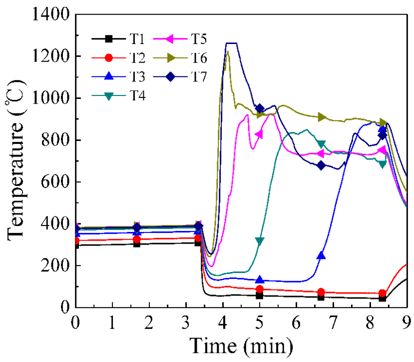


Fig. 5. Variation of temperature (P_C = 10 bar, Ir)

Even though the reaction was initiated with Ir at low temperature, temperature during decomposition was lower than adiabatic decomposition of N_2O. Figure 5 shows the results obtained with 10 bar of chamber pressure. T7 reached higher limit of K-type thermocouple as shown in Fig. 5; however, this temperature decreased rapidly due to deactivation of catalyst. Deactivation can be explained oxidation of Ir. Ir is easily oxidized and changes to IrO_2 which is volatile. Therefore, Ir catalyst is deactivated due to its oxidation and vaporization. The used catalyst was reduced for 12 hours and retested. In the experiment, we found that the required minimum preheating temperature decreased and recovered to lower value after reduction.

4. Conclusion

In order to develop N_2O monopropellant thruster catalytic decomposition of N_2O were carried out with two noble metal experimentally. Ir decomposed N_2O at lower temperature and suitable for N_2O decomposition. However, Ir should be modified to be used in monopropellant thruster due to its deactivation characteristics.

As a future work, other catalyst such as Ru will be tested and new support which can be maintained at high temperature will be considered to develop catalyst for N_2O decomposition.

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