Catalytic decomposition of N₂O to develop monopropellant thruster

Jungkun Jin* · Assylkhan Kosdauletov** · Sungyong An** · Sejin Kwon***

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 N₂O at lower temperature (230°C) and suitable for N₂O decomposition. In addition, the minimum required preheating temperature decreased as the chamber pressure increased. However, deactivation of Ir catalyst was observed during the experiments.

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

1. Introduction

Recently, nitrous oxide(N₂O), widely known as laughing gas, attracts many researchers’ attention due to its green, non-flammable, non-explosive and storable characteristics. N₂O 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 N₂O propulsion system was rarely reported. N₂O resistojet thruster (Mark-IV) developed by Surrey Space Center...
Table 1. Comparison of N₂O and H₂O₂

<table>
<thead>
<tr>
<th></th>
<th>N₂O</th>
<th>90% H₂O₂</th>
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</thead>
<tbody>
<tr>
<td>Iₛₚ (theoretical), s</td>
<td>181*</td>
<td>205*</td>
</tr>
<tr>
<td>Tₐdiabatic, K</td>
<td>1904</td>
<td>1022</td>
</tr>
<tr>
<td>Storage density</td>
<td>745**</td>
<td>1347</td>
</tr>
<tr>
<td>Storable temp., °C</td>
<td>-34 ~ 60</td>
<td>-7 ~ 38</td>
</tr>
<tr>
<td>Melting point, °C</td>
<td>-90.86</td>
<td>-12</td>
</tr>
<tr>
<td>Boiling point, °C</td>
<td>-88.48</td>
<td>146</td>
</tr>
</tbody>
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* Iₛₚ data obtained for A₁/A₂=200 (as monopropellant)
** Liquefied gas at 52.4 bar and 21°C

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 N₂O/HTPB hybrid rocket [4].

\[ N₂O → N₂ + 0.5O₂ + \text{heat} \]  (1)

Table 1 presents comparison of green-propellants N₂O with hydrogen peroxide (H₂O₂) as a monopropellant. N₂O can be decomposed into O₂ and N₂ by catalytic or thermal decomposition (Eq. (1)).

Due to high adiabatic decomposition temperature N₂O has higher Iₛₚ than that of H₂O₂ due to its higher adiabatic decomposition temperature. N₂O can be liquefied by pressurizing. Due to high vapor pressure (52.4 bar at 21°C) of N₂O, additional propellant expulsion system is not required in N₂O thruster system (self-pressurizing). Storage temperature for N₂O is wide, and N₂O is compatible with common materials.

N₂O is able to be thermally decomposed at 520°C[4]; however, the gas in a reaction chamber should be heated over than 1000°C 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°C[3]. However, the information about catalyst was not reported.

In the present study, N₂O decomposition test were carried out with different catalyst to light suitable catalyst for further development of N₂O 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 N₂O, 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 between two adjacent thermocouples 15 mm.

The outline of experimental setup is shown in Fig. 2. N₂O 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 (Al₂O₃) pellets by wet-impregnation methods using metal chloride (MClₓ or HₓMClₓ) 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.

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°C. If the preheating temperature is below 500°C, temperature in the reaction chamber decreases continuously.

The required temperature to initiate decomposition of N₂O decreased by increasing chamber pressure (400°C 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 N₂O decomposition.

3.2 Ir catalyst
The N₂O decomposition was initiated with 230°C 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°C otherwise it was 230°C at the first firing test.

Comparing with Pt catalyst, Ir shows more stable reactivity than Pt in N₂O 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.
Even though the reaction was initiated with Ir at low temperature, temperature during decomposition was lower than adiabatic decomposition of N₂O. 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 IrO₂ 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 N₂O monopropellant thruster catalytic decomposition of N₂O were carried out with two noble metal experimentally. Ir decomposed N₂O at lower temperature and suitable for N₂O 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 N₂O decomposition.

Acknowledgement

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