Technical Notes

Reduction of Catalyst Volume by Using Metal Mesh in Small-Scale H₂O₂ Thrusters

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I. Introduction

Propellant atomization is one of the most important aspects in monopropellant thruster systems. The atomization of propellants is closely related to the response time and catalyst bed volume. The performance of the thruster and perfect decomposition is affected by the catalyst, but the response time can be improved, and the catalyst bed volume can be reduced by fine atomization and fast vaporization of the propellant. The atomization of propellants occurs at the injector of the thruster in most cases. There are many types of injectors, and it is difficult to determine which one is the most suitable, because it is difficult to simply compare different types of injectors. The atomization and dispersion of propellants can be improved by using an impinging-type injector, but it is difficult to fabricate, and the technical expertise required for fabrication is relatively high for a small-scale thruster. The spray-type injector has improved mixing and atomization characteristics, but there should be enough space between the injector and catalyst where the propellant can spread; in addition, the spray-type injector has a relatively longer response time than the showerhead injector [1]. Therefore, it can be said that the showerhead-type injector is more appropriate for application to small-scale thrusters. Nevertheless, atomization of the showerhead-type injector is much poorer than that of other injector types. Therefore, the atomization characteristics of the showerhead-type injector should be improved. In this Note, a simple but effective method is introduced to improve the atomization characteristics of the showerhead-type injector applied to a small-scale hydrogen peroxide thruster.

II. Selecting Metal Mesh to Achieve an Atomization

The metal mesh, generally called a screen, is mounted on the injector to prevent the catalyst from entering the injector in the case of a hydrazine thruster, and it divides the propellant stream into not too much of a small size because of the detonation problem [2]. Therefore, the metal mesh can atomize the propellant finely in the case of propellants that are not overly affected by the detonation problem [2].

III. Thruster for Experiment

A large-sized thruster is not required, because only the effect of atomization is considered. In this case, a small-scale thruster with a design thrust of 1 N is enough to evaluate the effect of atomization on a small-scale hydrogen peroxide thruster. The chamber was designed considering the characteristic length and catalyst capacity. The catalyst capacity can be used to determine the maximum flow rate of a propellant per unit volume of the catalyst [3]. The diameter was 9 mm and the length was 12 mm. The value of \( L_1/D_1 \) was less than 2 without a metal mesh were compared, as shown in Fig. 1. The propellant stream was separated by a metal mesh, and the stream spread out. Therefore, it was believed that a metal mesh could be used to atomize the propellant, and its effectiveness should be evaluated by performing a thruster experiment.

IV. Propellant Atomization by Using Metal Mesh

A. Increase in Temperature Upstream of Catalyst Caused by Atomization

The showerhead-type injector is simple and can easily control the propellant at low-mass flow rates. However, the momentum of the propellant injected into the chamber is remarkably high in the axial direction, and the showerhead-type injector cannot atomize the propellant effectively. Therefore, upstream of the catalyst, which is near the injector, the propellant cannot be effectively decomposed. This poor atomization can be seen in Fig. 2, which shows the temperature profiles with a showerhead-type injector. The position of each thermocouple is shown in Fig. 3. The end tap of the thermocouple is not at the center of the thruster but at the chamber wall surface. The temperature at the chamber center was not measured, because if a thermocouple had been inserted at the center of the chamber, its volume would have been large enough to potentially affect the performance of the thruster and the flow pattern in the chamber.

Their reaction is affected by the catalyst, but the response time can be improved, and the catalyst bed volume can be reduced by fine atomization and fast vaporization of the propellant. Therefore, atomization is considerably important in a small-scale thruster to ensure the effective use of the catalyst. The volume of the catalyst required to decompose the propellant perfectly can be decreased if the propellant is atomized before it comes into contact with the catalyst. Here, the metal mesh was installed just downstream of the injector to atomize the propellant. Two mesh sizes were used: 50 mesh and 200 mesh. The atomization will be better with the 200 mesh, but the pressure drop will also increase. Figure 4 shows temperature profiles corresponding to the metal mesh.
The initial temperature of the catalyst bed was around 150°C. The temperature difference between T1 and T2 in the case without the metal mesh is relatively higher than in the cases with a metal mesh. This implies that T1 is increased owing to the decomposition of the propellant upstream of the catalyst, which can be accomplished by the atomization of the propellant through the metal mesh. The phenomenon can be understood more clearly from Fig. 3. Therefore, the volume of the catalyst can be decreased when the metal mesh is used. T2 in the 200 mesh case is less than that in the other cases because the quantity of mass flow rate remarkably decreased because of the metal mesh. Hence, the amount of released heat per unit time in the 200 mesh case was less than that in other cases; therefore, T2 and T1 both decreased. However, there was no significant difference between T1 and T2 in the 200 mesh case because of effective atomization.

B. Pressure Drop Through Metal Mesh and Catalyst

The pressure drop through the metal mesh is undesirable because it induces a performance decrease. Table 1 summarizes the pressure drop for each case. The chamber pressure in the 200 mesh case is much lower than that in the other cases. The $C_\text{e}$ efficiency is similar even though there was low-chamber pressure, because the mass flow rate also reduced. The mass flow rate decreased remarkably in spite of the high-pressure drop through the injector and mesh, because the metal mesh can play the role of an injector owing to its dense mesh and the fact that the pressure drop is mainly caused by friction.

<table>
<thead>
<tr>
<th>Case</th>
<th>Pressure drop, bar</th>
<th>Chamber pressure, bar</th>
<th>$C_\text{e}$ efficiency, %</th>
<th>Mass flow rate, g/s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Injector</td>
<td>Catalyst</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Without mesh</td>
<td>6.44</td>
<td>0.138</td>
<td>10.5</td>
<td>86.7</td>
</tr>
<tr>
<td></td>
<td>6.18</td>
<td>0.121</td>
<td>10.5</td>
<td>86.7</td>
</tr>
<tr>
<td></td>
<td>5.70</td>
<td>0.107</td>
<td>11.1</td>
<td>89.4</td>
</tr>
<tr>
<td>With 50 mesh</td>
<td>5.00</td>
<td>0.161</td>
<td>11.3</td>
<td>90.3</td>
</tr>
<tr>
<td></td>
<td>4.51</td>
<td>0.163</td>
<td>11.7</td>
<td>91.6</td>
</tr>
<tr>
<td></td>
<td>4.52</td>
<td>0.169</td>
<td>11.8</td>
<td>91.6</td>
</tr>
<tr>
<td>With 200 mesh</td>
<td>12.2</td>
<td>0.0766</td>
<td>4.56</td>
<td>90.0</td>
</tr>
<tr>
<td></td>
<td>12.1</td>
<td>0.0767</td>
<td>4.57</td>
<td>90.5</td>
</tr>
<tr>
<td></td>
<td>12.1</td>
<td>0.0773</td>
<td>4.59</td>
<td>90.9</td>
</tr>
</tbody>
</table>

This implies that T1 is increased owing to the decomposition of the propellant upstream of the catalyst, which can be accomplished by the atomization of the propellant through the metal mesh. The phenomenon can be understood more clearly from Fig. 3. Therefore, the volume of the catalyst can be decreased when the metal mesh is used. T2 in the 200 mesh case is less than that in the other cases because the quantity of mass flow rate remarkably decreased because of the metal mesh. Hence, the amount of released heat per unit time in the 200 mesh case was less than that in other cases; therefore, T2 and T1 both decreased. However, there was no significant difference between T1 and T2 in the 200 mesh case because of effective atomization.
Therefore, the size of the mesh is important and should be optimized to effectively atomize the propellant with a relatively low-pressure drop.

The pressure drop through the catalyst is the pressure difference between the T1 and T3 positions. If there are more regions where the flow phase is gas the pressure drop through the catalyst will increase. Higher-pressure drop through the catalyst implies that the less amount of catalyst is required for propellant decomposition. The ratio of pressure drop and upstream pressure is compared in Fig. 5. The ratio increased when 50 mesh was used, and it increased further when 200 mesh was used. The value of the pressure drop in the 200 mesh case was less than that in the other cases; this difference is caused by high-pressure loss through the fine metal mesh in the 200 mesh case. However, the ratio of pressure loss increased, because the gas phase region expanded owing to fine atomization. Therefore, the atomization evidently occurred owing to the metal mesh, and the quantity of catalyst required for decomposition could be decreased.

V. Conclusions

In this research, a simple and effective method for the atomization of propellants in small-scale hydrogen peroxide thrusters was suggested. The propellant, which is injected by a showerhead-type injector, was atomized by a metal mesh. This arrangement has the technical advantages of a simple structure and easy fabrication, and it can be used in every orifice, if there are more than two orifices. The effect of the metal mesh was evaluated by using a 1 N class hydrogen peroxide thruster. The temperature upstream of the catalyst increased when the metal mesh was mounted just after the injector. This implies that the propellant underwent decomposition more than atomization upstream of the catalyst. However, a pressure drop also occurred owing to the metal mesh, and the pressure drop increased as the mesh size decreased. Therefore, it is obvious that atomization of the propellant is a considerably important property of the thruster, and the use of a metal mesh is a simple and effective method for achieving atomization in small-scale hydrogen peroxide thrusters.

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References


L. Maurice
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