A Green High-Energy Liquid Fuel: DMAZ

Jie Huang, XuanJun Wang, Ying Li and Lan Ma

ABSTRACT

Dimethylaminoethylazide (DMAZ) is a new green liquid fuel. The fuel has attracted much attention as a replacement for monomethylhydrazine (MMH) and unsymmetrical dimethylhydrazine (UDMH) for its non-toxic and high performance. This paper reviews recent performance and applications of DMAZ. Furthermore, more attention should be paid to the prospects of the amino-azides.

1 INTRODUCTION

At present, monomethylhydrazine (MMH) and unsymmetrical dimethyl hydrazine (UDMH) are widely used in liquid missile and spacecraft propulsion system. However, the corrosiveness, high toxicity[1] and high cost of hydrazine type fuels cannot be ignored. When the problem of environment is becoming more and more serious nowadays, the concepts of designing the green high-energy propellant fuel are being paid more and more attention.

Dimethylaminoethylazide (DMAZ) is a kind of small molecular weight of azido-amine compound. Its molecular structure is simple and the synthesis path is short. It has become a focus of high-energy liquid fuel research. The latest data confirm that DMAZ is not carcinogenic and relatively non-toxic[2]. It is expected to replace the MMH. In the late 1990s, the United States using DMAZ in bipropellant rocket engines and some research for monopropellant propellant greatly promoted the development of the DMAZ [3-5]. Then DMAZ came to the attention of European Space Agency[6]. After about ten years, the domestic scholars have noticed DMAZ. And a primary research was conducted on the synthetic process and ignition performance[7-9].

2 BASIC PROPERTIES

DMAZ, is one kind of relatively stable organic azide, which is achromatic color or light yellow transparent liquid[7]. It has low adherence, volatility and pungent odor[10]. The basic properties of DMAZ and MMH are compared in Table I.
Azide compounds are usually unstable. It is very necessary to consider the safety of the study and application of this compound. S.G. Pakdehi, Iran, uses CHETAH software to carry out a theoretical risk assessment of DMAZ and MMH (see Table II). Due to the higher decomposition heat and release potential, DMAZ and MMH are classified as hazardous materials by CHETAH software[10].

<table>
<thead>
<tr>
<th></th>
<th>Molecular Weight</th>
<th>Boiling Point/°C</th>
<th>Freezing Point/°C</th>
<th>Flash Point</th>
<th>Density /g·cm⁻³</th>
<th>Viscosity /cp</th>
<th>Heat of Formation/cal/g</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMAZ</td>
<td>114</td>
<td>135.6</td>
<td>-68.9</td>
<td>29.4</td>
<td>0.933</td>
<td>2</td>
<td>580</td>
</tr>
<tr>
<td>MMH</td>
<td>46</td>
<td>86.7</td>
<td>-52.8</td>
<td>0.88</td>
<td>0.775</td>
<td>276</td>
<td></td>
</tr>
</tbody>
</table>

A series of sensitivity tests of DMAZ also did by S.G. Pakdehi. The results showed that DMAZ is insensitive to impact, direct flame and shock wave. Sensitivity threshold of DMAZ to static electricity is also less than 525 mJ. Thus, the safety feature of DMAZ with respect to electrostatic spark should be considered in production, handling and storage of DMAZ. Moreover, DMAZ sensitivity to heat in confined volume is medium[10].

Barrie Mellor[6] also gave some sensitivity data of DMAZ: impact sensitivity is 165 kg·cm⁻¹, friction sensitivity is 500psi.

3 PROPELLION PERFORMANCE

For liquid propellants, specific impulse (Isp) and ignition delay (ID) time are two important parameters.

3.1 Specific impulse (Isp)

The Isp is defined as the produced thrust per weight flow rate of the propellant consumed in a combustion chamber that is representative of potential chemical energy in the liquid propellant[11]. Isp can be calculated by computer codes or empirical methods.

D. Thompson (U.S. Army) gave a conclusion that the DMAZ/IRFNA has an Isp of 287 lbf*s/lbm while MMH/IRFNA has an Isp of 284 lbf*s/lbm at 2000 psi at their respective optimum oxidizer-to-fuel(O/F)ratio. DMAZ has a density specific impulse (DIsp) of 13.77 lbf*s/in³ while MMH has a maximum DIsp of 13.36 lbf*s/in³[3]. M.J. McQuaid (U.S. Army) calculated Isp by Gaussian98 (G98) suite of quantum chemistry codes. The result shows that the DIsp of DMAZ /IRFNA is 4.3% higher than
MMH/IRFNA[12]. Kokan T. (Georgia Institute of Technology) calculated Isp of DMAZ/LOX (liquid oxygen) under an expansion ratio of 50 for a chamber pressure of 20.69MPa. It can deliver an Isp of 367.9s and a DIsp of 342.15 s·g·cm\(^{-3}\)[13,14]. NASA report gave results that DMAZ has an Isp of 308.2s at an O/F ratio of 2.25 while MMH has an Isp of 313s at an O/F ratio of 2.275[15]. S.G. Pakdehi examined the performance of DMAZ with the most common liquid oxidizers by NASA-CEC-71 software (see Table III)[11].

<table>
<thead>
<tr>
<th>Pair</th>
<th>Optimum O/F ratio</th>
<th>(d_{\text{propellant}})</th>
<th>Optimum Isp(s)</th>
<th>DIsp (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMAZ/IRFNA</td>
<td>2.5</td>
<td>1.274</td>
<td>272.7</td>
<td>347.5</td>
</tr>
<tr>
<td>DMAZ/HNO(_3)</td>
<td>2.5</td>
<td>1.278</td>
<td>270.7</td>
<td>346.4</td>
</tr>
<tr>
<td>DMAZ/N(_2)O(_4)</td>
<td>2</td>
<td>1.215</td>
<td>283.1</td>
<td>344</td>
</tr>
<tr>
<td>DMAZ/MON-10</td>
<td>2</td>
<td>1.216</td>
<td>283.3</td>
<td>344.5</td>
</tr>
<tr>
<td>DMAZ/H(_2)O(_2)</td>
<td>3.5</td>
<td>1.283</td>
<td>280.8</td>
<td>360.2</td>
</tr>
<tr>
<td>DMAZ/LOX</td>
<td>1.5</td>
<td>1.047</td>
<td>305.8</td>
<td>320.3</td>
</tr>
</tbody>
</table>

It is also reported that DMAZ/N\(_2\)O\(_4\) has an Isp of 284.2s and a DIsp of 265.8 s·g·cm\(^{-3}\) at an O/F ratio of 2.5 while MMH/ N\(_2\)O\(_4\) has an Isp of 288.3s and a DIsp of 254.6s·g·cm\(^{-3}\) at an O/F ratio of 2.6[8].

The data above shows that DMAZ has the similar Isp with MMH, but DMAZ has the better DIsp than MMH. From an energy point of view, DMAZ can be used as a substitute for hydrazine fuels.

### 3.2 Ignition delay (ID) time

The ID time is the time between the instant at which the fuel and oxidizer come in to contact with each other and the time at which a flame appears. A short ignition delay characteristic is important since a long ignition delay of approximately 25 millisecond or longer causes fuel and oxidizer to accumulate in the combustion chamber. Over pressurization in the combustion chamber can be severe enough to destroy the rocket motor and negate achievement of the mission objective[16]. And then, accurate and reliable ID time can provide a reliable basis to the design of the engine dimension.

S. G. Pakdehi observed ignition of DMAZ with various oxidants by the cup test. Respective tests with DMAZ and oxidizers of H\(_2\)O\(_2\), IRFNA, LOX show that this combinations are not self-igniting. DMAZ/HNO\(_3\) (\(\geq\)99.5wt%) has an ID time of 156.94 milliseconds. DMAZ/MON-10 (10wt% of nitric oxide in N\(_2\)O\(_4\)) has an ID time of 135.4 milliseconds. DMAZ/N\(_2\)O\(_4\) has an ID time of 68.05 milliseconds. The author predicted that DMAZ–N\(_2\)O\(_4\) may be suitable for space programs[11]. William H. compared the ID time of MMH/IRFNA and DMAZ /IRFNA by drop test. MMH/IRFNA has an ID time of 3~15 milliseconds (depending on test techniques) while DMAZ/IRFNA has an ID time of 26 milliseconds. And the addition of some TMEDA to DMAZ can promote a shorter ID time of 9~10 milliseconds (depending on proportion)[16]. B. Mellor performed ignition tests with MON3 and DMAZ by an experimental method using
impinging jets. The tests show that this combination is not self-igniting, and even the addition of some MMH to the DMAZ failed to promote a hypergolic reaction while MMH has an ID of ~1 millisecond[17].

Thus, we can arrive at the conclusion that DMAZ has a longer ID time than MMH. To solve this problem, scientists began the catalyst research. The main catalysts used for DMAZ are Iridium-based, iron-based and composite catalyst. A new type of iron phosphotungstate catalyst was developed by Mach. I, the distributor of 3M company[9]. This catalyst is characterized by lower costs, higher activity and stability, as well as renewable exposed to the air. Using 8% cobalt butyrate in DMAZ/H\textsubscript{2}O\textsubscript{2} (HF-57J) can obtain ID on the order of 1-2 milliseconds, this fuel showed long-term storage stability and also yielded smooth ignition[18]. Ramona E.A. Hallit of the Boeing Company has also studied the ignition performance of DMAZ/H\textsubscript{2}O\textsubscript{2} and cobalt ethylhexanoate catalyst[19]. Thus, it is feasible to reduce ID time and improve the ignition performance by adding catalysts.

4 DISCUSS

DMAZ is a new type of green liquid fuel which has good prospect. This fuel is expected to replace the expensive, toxic hydrazine fuels due to its high propulsion performance, low toxicity. Many special researchers of the U.S., Europe and Iran pay much attention to this fuel. D. Thompson of U.S. Army used DMAZ added gels and additive as bipropellant and monopropellant in rocket engines[3,4]. Edotek Ltd. of Britain considered DMAZ/(N\textsubscript{2}O/H\textsubscript{2}O\textsubscript{2}) combination is suitable for small satellite orbit transfer engine and the pressurization gas generator[3]. S.G. Pakdehi of Iran gave a conclusion that DMAZ–H\textsubscript{2}O\textsubscript{2} might be considered for use in the first stage of a multistage rocket and DMAZ–N\textsubscript{2}O\textsubscript{4} may be suitable for space programs.

Research of azido-amine liquid fuels such as DMAZ is placed in the stage of beginning in our country, and application is still in the blank stage. The possible reason is that we don’t have the ability of mass production, which limit its research and application process. In the next step of research, first synthesis process should be solved. And then, a series of azido-amine compounds which have the similar structure with DMAZ could become an important research content. Furthermore, we must independently develop a number of new structures of those green liquid fuels to support the development of liquid propellants.

REFERENCES