# Effect of azide amine on combustion characteristics of certain hydrocarbon fuels

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***ABSTRACT.*** *In this paper, azidoamine DMAZ is used as a fuel aid, and an oxygen bomb calorimeter is used to simulate the high-altitude environment. The influence of the fuel aid on the combustion performance of a hydrocarbon fuel under different working conditions is investigated. Studies have shown that DMAZ and the fuel are mutually soluble at 20°C, and the mixed fuel after compounding has azide groups that can support combustion. The higher the residual gas coefficient, the higher the fuel combustion heat value and combustion efficiency. The combustion-supporting effect of the combustion-supporting agent is not only related to the content of the combustion-supporting agent, but also related to the residual gas coefficient. When the residual gas coefficient is 1.0, the combustion-supporting effect of DMAZ with a volume content of 0.5% can reach the maximum. When the volume content is greater than 0.5%, the combustion-supporting effect of DMAZ will decrease.*

***KEYWORDS:*** *azidoamine DMAZ, combustion characteristics, hydrocarbon fuels*

## 1. Introduction

With the continuous progress of science and technology and the increasing complexity of the international situation, people have put forward higher requirements for the speed, range, and payload of aircraft [1]. Under the condition that the weight and volume of the engine and fuel tank are limited, how to effectively improve the speed, range, load and other performance of the aircraft? The first is to use high-density and high-calorific value hydrocarbon fuels; the second is to add high-energy particles or other substances that can increase the fuel's density and calorific value to the fuel; the third is to use some combustion aids to improve fuel combustion efficiency.

Azideamine has the characteristics of high density, high burning rate, high heat generation, and clean combustion products, and can be used as a fuel [2-3]. Its three nitrogen atoms form a typical azide group. The N-N bond in the middle of this group is extremely easy to break, thus releasing heat and generating nitrogen. Because the

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azide compound has the typical characteristics of this low-temperature liquid phase decomposition heat and good physical and chemical properties [4-5], it is widely used as a combustion-supporting agent for fuels such as ordinary fuels and jet fuels. It is used to improve the atomization and combustion characteristics of fuel. Generally, azide compounds are unstable and explosive, but because DMAZ has a relatively stable near-ring structure and has good stability, it has also become the most promising azidoamine compound [6].

In this paper, traditional hydrocarbon fuel (replaced by R in this article) is used as the research object, and DMAZ is used as a new type of combustion aid to compound mixed fuels with different volume contents. The compatibility of DMAZ with traditional hydrocarbon fuels is characterized by appearance and Fourier infrared (FTIR). The Parr6200 oxygen bomb calorimeter was used to simulate the high-altitude combustion environment, and the influence of DMAZ content on the combustion performance of the fuel was judged by measuring the combustion heat value and combustion efficiency of different mixed fuels.

## 2. Experimental part

### *2.1 Experimental principle*

It is necessary to add DMAZ as a combustion-supporting agent to hydrocarbon fuels to form a mixed fuel that meets the needs of use. It is necessary to study the mutual solubility of the two. If the two fuels cannot form a uniform and stable state, it will inevitably bring about instability of combustion, which is very dangerous for the aircraft. Fuel miscibility refers to the compatibility of fuel components without stratification. It has an extremely important effect on the normal and stable operation of the mixed fuel in the combustion chamber [7].

Combustion efficiency refers to the ratio of the combustion heat measured under given experimental conditions to the combustion heat measured when the fuel is completely burned. The combustion-supporting effect of the combustion-supporting agent can be expressed by the percentage increase of the combustion efficiency. The more the percentage increases, the better the combustion-supporting effect of the combustion-supporting agent is [8].

The residual air coefficient refers to the ratio of the actual air flow rate to the theoretical air volume required for complete fuel combustion when the engine is running. Because the oxygen content in the air does not vary with temperature and altitude, the residual gas coefficient can be simplified as the ratio of the actual amount of oxygen to the theoretical amount of oxygen required when the fuel is completely burned [9].

The traditional hydrocarbon fuel studied in this article is a mixture. According to the research report [10], it can be known that its theoretical molecular formula is $C_{10.5}H_{22}$, and the combustion reaction equation can be obtained by using its molecular formula. By fixing the amount of oxygen to change the amount of

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combustion sample, using the chemical reaction equation to obtain the theoretical amount of oxygen, and then different residual gas coefficients can be obtained.

### *2.2 Experimental method*

(1) Prepare DMAZ/R with different volume content and characterize the mutual solubility:

Under the condition of 20℃, add a certain amount of R fuel and DMAZ to a 20mL container according to Table 1, and compound DMAZ/R mixed fuel with different content. Let it stand, observe whether there is "delamination" phenomenon, and use Fourier infrared to characterize the main groups. In the early stage, the 5% DMAZ/R mixed fuel was characterized, and it was found that the FTIR characteristic peak of the mixed fuel was extremely inconspicuous. The analysis reason was caused by too little combustion aid content. Therefore, 20% DMAZ/R mixed fuel was reconfigured, and infrared characterization was performed to observe whether the azide group that plays a role in supporting combustion exists.

*Table 1 The volume of R and DMAZ in different content*

| Volume fraction (%) | R volume (mL) | DMAZ volume (mL) |
|---|---|---|
| 0% | 20.00 | 0 |
| 0.1% | 19.98 | 0.02 |
| 0.3% | 19.94 | 0.06 |
| 0.5% | 19.90 | 0.1 |
| 1% | 19.80 | 0.2 |
| 2% | 19.46 | 0.4 |
| 3% | 19.40 | 0.6 |
| 5% | 19.00 | 1.0 |

(2) Determination of experimental conditions:

The theoretical formula of R is $C_{10}H_{16}$, and the formula for combustion with oxygen is:

$$C_{10.5}H_{22} + 16\ O_2 = 10.5\ CO_2 + 11\ H_2O \quad (1)$$

It can be seen from the equation that when the ambient temperature is 300K and the residual gas coefficient is 1.0, 0.5 g R requires 0.05405 mol of oxygen. The capacity of the hyperbaric oxygen bomb in this experiment is 240mL, and the required oxygen pressure (p/Mpa) in the oxygen bomb tank under this condition can be calculated as:

$$p=nRT/V=(0.05405\times 8.314\times 300)/240\approx 0.5618Mpa$$

This experiment initially set the oxygenation pressure to 3Mpa, but after a series of failed attempts, the final experimental conditions were: the mixed gas output

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pressure was 2Mpa, the oxygen content was 40%, and the nitrogen content was 60%. It can not only simulate mixed air, but also meet the needs of residual air coefficient changes within a certain range.

Considering the original air in the 0.1 Mpa oxygen-nitrogen tank and the 1.9 Mpa mixed gas filled, the partial pressure of oxygen is 0.78(1.9×0.4+0.1×0.2) Mpa, and the number of moles of oxygen in the oxygen bomb is 0.0751(0.78×240÷8.314÷300) mol. According to the chemical equation (1), when the mass of R is m=0.0751/16×148.29=0.6960 g, the residual gas coefficient of R in the oxygen bomb is 1. When the mixed gas pressure is 2Mpa, the experimental dosage of R under five residual gas coefficients is shown in Table 2 below:

*Table 2 Fuel consumption under different residual gas coefficients*

| Residual gas coefficient | Experimental dosage/g |
|---|---|
| 0.6 | 1.1600 |
| 0.8 | 0.8700 |
| 1 | 0.6960 |
| 1.2 | 0.5800 |
| 1.4 | 0.4971 |

(3) Calorific value measurement experiment

Before measuring the calorific value of the mixed fuel, the instrument needs to be calibrated. After the calibration is completed, the calorific value of the mixed fuel can be measured.

In the process of calorific value measurement, the output pressure of the mixed gas is controlled to 2 Mpa, the fuel consumption is weighed according to Table 2, and the calorific value measured under each condition is subjected to more than 3 parallel experiment to reduce the relative error. Values with larger errors are excluded. Each experiment operation strictly follows the prescribed steps.

## 3. Results and discussion

### *3.1 Characterization of mutual solubility*

When the DMAZ droplets are just added to the R, the R in the container becomes a little turbid, but this turbidity will gradually improve over time and become clear within 24 hours, as shown in Figure 1 and 2. After the mixed fuel was allowed to stand for 10 days, it was found that the solution did not delaminate.

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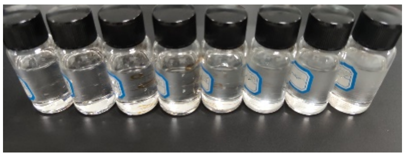

*Figure. 1 When DMAZ/R is just mixed*

*Figure. 2 24h after DMAZ/R mixing*

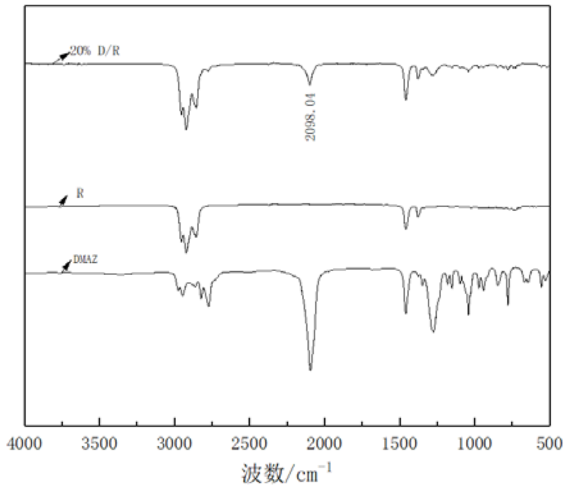


*Figure. 3 FTIR diagram of three fuels*

The FTIR spectra of DMAZ, R and DMAZ/R are shown in Figure 3, where a strong asymmetric stretching vibration peak of the azide group is found in DMAZ at 2098.045 cm-1. In the mixed fuel, the amount of DMAZ added to R is 20%. By comparison, it can be found that the FTIR spectrum of DMAZ/R is basically the same as that of R. However, there is an asymmetric stretching vibration peak of the azide group near 2098.045 cm-1. It shows that in the DMAZ/R mixed solution, the azide group still exists stably, and no other characteristic peaks are generated, indicating that the two have good compatibility and no chemical reaction occurs.

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***3.2 The influence of residual gas coefficient on combustion heat value and combustion efficiency***

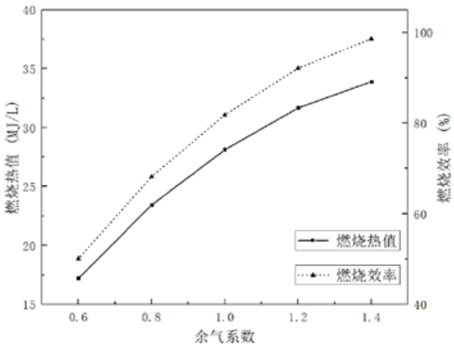


*Figure. 4 The influence of residual gas coefficient on the combustion performance of R under the condition of 0% DMAZ*

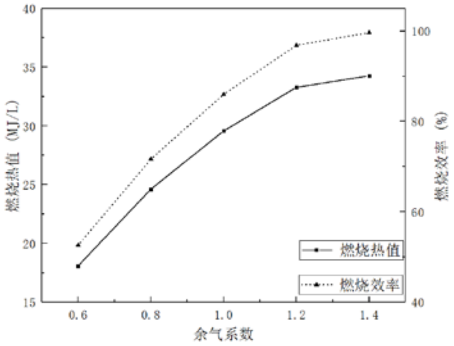


*Figure. 5 The influence of residual gas coefficient on the combustion performance of R under the condition of 0.1% DMAZ*

It can be seen from Figure 4 that under the condition of 0% DMAZ, the heat of combustion of R fuel increases from 17.22 to 33.9MJ/L, and the combustion efficiency increases from 50.09% to 98.6%. The effect of residual gas coefficient on combustion performance is almost linear.

Figure 5 shows that under the condition of 0.1% DMAZ, the heat of combustion of R fuel increases from 18.09 to 34.26 MJ/L, and the combustion efficiency increases from 53.01% to 99.64%. The effect of residual gas coefficient between 0.6 and 1.2 on combustion performance is almost linear.

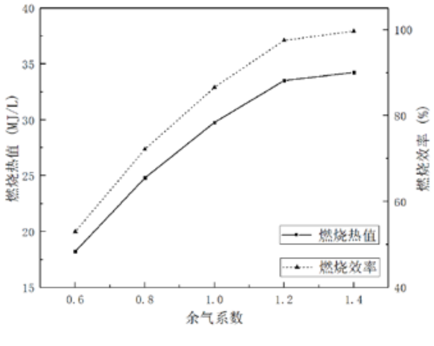


*Figure. 6 The influence of residual gas coefficient on the combustion performance of R under the condition of 0.3% DMAZ*

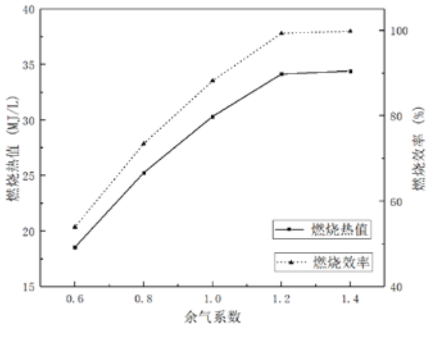


*Figure. 7 The influence of residual gas coefficient on the combustion performance of R under the condition of 0.5% DMAZ*

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It can be seen from Figure 6 that under the condition of 0.3% DMAZ, the heat of combustion of R fuel increases from 18.22 to 34.25 MJ/L, and the combustion efficiency increases from 53.01% to 99.64%. The effect of residual gas coefficient between 0.6 and 1.2 on combustion performance is almost linear.

It can be seen from Figure 7 that under the condition of 0.5% DMAZ, the heat of combustion of R fuel increases from 18.56 to 34.42 MJ/L, and the combustion efficiency increases from 53.98% to 99.82%. The effect of residual gas coefficient between 0.6 and 1.2 on combustion performance is almost linear.

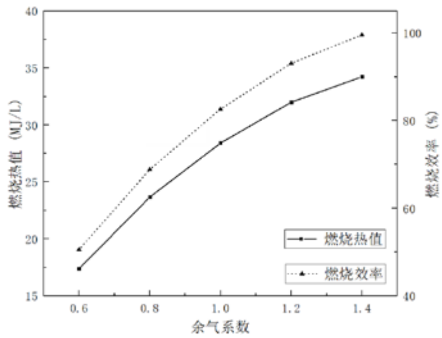


*Figure. 8 The influence of residual gas coefficient on R combustion performance under 1%DMAZ condition*

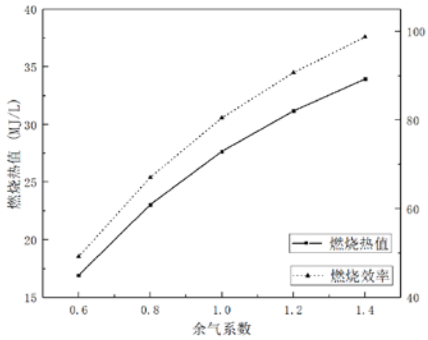


*Figure. 9 The influence of residual gas coefficient on the combustion performance of R under 2%DMAZ conditions*

Figure 7 shows that under the condition of 1% DMAZ, the heat of combustion of R fuel increases from 17.39 to 34.23 MJ/L, and the combustion efficiency increases from 50.58% to 99.55%. The effect of residual gas coefficient between 0.6 and 1.2 on combustion performance is almost linear.

It can be seen from Figure 8 that under the condition of 2% DMAZ, the heat of combustion of R fuel increases from 16.93 to 33.95 MJ/L, and the combustion efficiency increases from 49.24% to 98.77%. The effect of residual gas coefficient between 0.6 and 1.2 on combustion performance is almost linear.

From Figures 4 to 9, it can be seen that the residual gas coefficient has an effect on the combustion performance and combustion efficiency of R fuel: the larger the residual gas coefficient, the higher the combustion heat value and combustion efficiency of the fuel. It reaches the maximum at 1.4, which is close to the theoretical value. ; The residual gas coefficient is between 0.6 and 1.2, the gain range and the residual gas coefficient are almost linear, and the gain range decreases after being greater than 1.2.

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### *3.3 Influence of DMAZ content on combustion heat value and combustion efficiency*

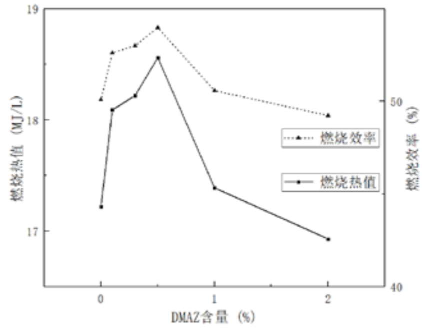


*Figure. 10 Under the condition of 0.6 residual gas coefficient, the influence of DMAZ content on the combustion performance of R*

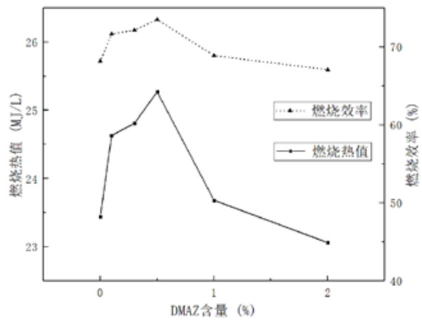


*Figure. 11 The influence of DMAZ content on the combustion performance of R under the condition of 0.8 residual gas coefficient*

It can be seen from Figure 10 that under the condition of a residual gas coefficient of 0.6, the combustion heat value of R fuel increases first and then decreases. The minimum value is 17.22 MJ/L and the maximum value is 18.56 MJ/L. The combustion efficiency reaches the maximum when the DMAZ content is 0.5%, which is 53.98%, and the combustion efficiency is 4.75% higher than that without the addition of combustion aid.

It can be seen from Figure 11 that under the condition of a residual gas coefficient of 0.8, the combustion heat value of R fuel increases first and then decreases. The minimum value is 23.06 MJ/L and the maximum value is 25.27 MJ/L. The combustion efficiency reaches the maximum when the DMAZ content is 0.5%, which is 73.50%. The combustion efficiency is 6.42% higher than that without the addition of combustion aid.

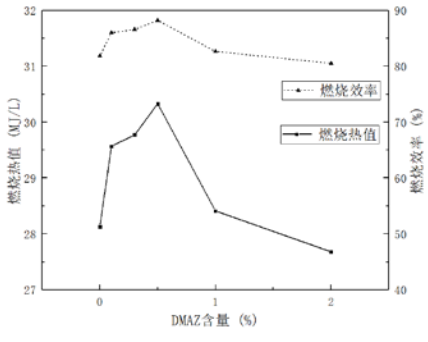


*Figure. 12 Under the condition of 1.0 residual gas coefficient, the influence of DMAZ content on the combustion performance of R*

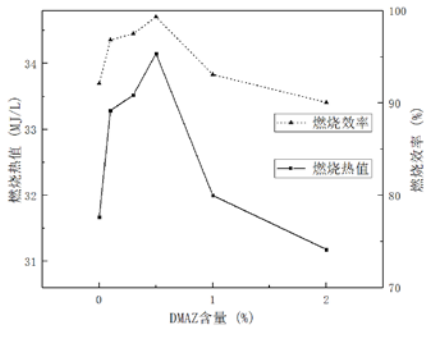


*Figure. 13 Under the condition of 1.2 residual gas coefficient, the effect of DMAZ content on the combustion performance of R*

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It can be seen from Figure 12 that under the condition of a residual gas coefficient of 1.0, the combustion heat value of R fuel increases first and then decreases. The minimum value is 27.68 MJ/L, and the maximum value is 30.33 MJ/L. The combustion efficiency reaches the maximum when the DMAZ content is 0.5%, which is 88.22%. The combustion efficiency is 7.70% higher than that without the addition of combustion aid.

It can be seen from Figure 13 that under the condition of a residual gas coefficient of 1.2, the combustion heat value of R fuel increases first and then decreases. The minimum value is 31.18 MJ/L and the maximum value is 34.15 MJ/L. The combustion efficiency reaches the maximum when the content of DMAZ is 0.5%, which is 99.33%. The combustion efficiency is 9.26% higher than that without the addition of combustion aid.

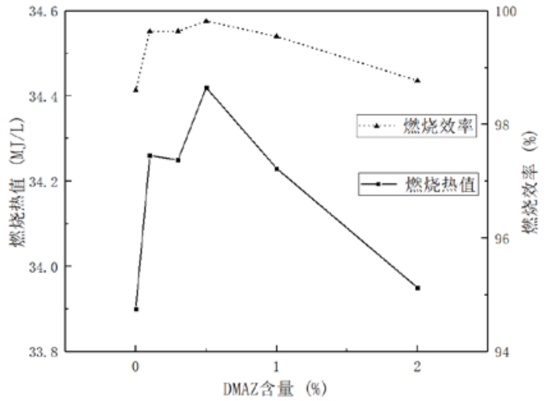


*Figure. 14 The influence of DMAZ content on the combustion performance of R under the condition of 1.4 residual gas coefficient*

It can be seen from Figure 14 that under the condition of the residual gas coefficient of 1.4, the combustion heat value of R fuel increases first and then decreases. The minimum value is 33.90 MJ/L and the maximum value is 34.42 MJ/L. The combustion efficiency reaches the maximum when the DMAZ content is 0.5%, which is 99.82%. The combustion efficiency is 1.22% higher than that without the addition of combustion aid.

From Figures 10 to 14, the combustion-supporting effect is not only related to the content, but also related to the residual gas coefficient; when the content of DMAZ is 0.5%, the combustion-supporting effect reaches the best; under different residual gas coefficients, the combustion-supporting effect of the combustion-supporting agent is different. Before the residual gas coefficient is less than 1.2, the combustion-supporting effect of 0.5% of the combustion aid is gradually increased, and reaches the maximum at 1.2. After the residual gas coefficient is greater than 1.2, the combustion-supporting effect of the combustion-supporting agent is smaller.

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## 4. Conclusion

(1) DMAZ combustion-supporting agent can be miscible with traditional hydrocarbon fuel R. When DMAZ droplets are dripped into R fuel, some turbidity will be produced, but it can return to a clear and transparent state within 24 hours. And no stratification occurred within 10 days of mixed fuel; FTIR showed that no new functional groups were generated in the mixed solution of the two, indicating that no chemical reaction occurred.

(2) The residual gas coefficient plays a role in supporting the combustion of R fuel. The greater the residual gas coefficient in a certain range, the better the combustion performance of the fuel; when the residual gas coefficient reaches a certain level, the fuel can exert theoretical performance.

(3) When the content of DMAZ combustion-supporting agent is less than 0.5%, the combustion-supporting effect on R fuel reaches the maximum. When the content is less than 0.5%, the combustion-supporting agent content increases, and the combustion-supporting effect becomes better and better. When the content is greater than 0.5%, the combustion-supporting effect shows a downward trend. The combustion-supporting effect of the combustion-supporting agent is also affected by the residual gas coefficient. When the residual gas coefficient is 1.2, the combustion-supporting effect is the best.

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