Comparative oxidation study of aviation lubrication oil

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Abstract. The kinematic viscosity, lubricity, acid number of 928 and 50-1-4Φ aviation lubrication oils are investigated in this paper. Oil samples were oxidized at 150 and 175°C for 120 h to evaluate their performance variation. The results suggest that 928 lubrication oil is easily oxidized and generates acidic products, which increase its acid number. The comparative analysis revealed that 928 lubrication oil tends to react in oxidizing atmosphere, which increases its viscosity, acid number, and weight-bearing performance. Meanwhile, wear scar diameters of both oxidized oil samples were found to be nearly the same.

1. Introduction

The import and domestic aviation lubrication oils exhibit significant differences under harsh conditions, such as high temperature, oxidative atmosphere, and high loads, which can be very harmful for the flight safety [1-3]. Noteworthy is that the Russian-made aircraft engine is used in the third-generation fighters in China, while the Russian-produced 50-1-4 Φ aviation lubricating oil is the main lubricant used in those engines. In order to realize the localization of main lubricants, China has developed 928 aviation lubrication oils, as an alternative to the Russian-produced 50-1-4 Φ. However, users reported that 928 aviation lubrication oil had some problems, such as color deepening and oil pressure instability [4]. As a result, its key performance should be investigated to reveal any differences with that of 50-1-4Φ oil, and find the reasons for this deviation. Consequently, the domestic 928 and Russian-produced 50-1-4Φ aviation lubricant oils were used as research objects in this paper. The ASTM D4636 standard test method was used to simulate the oxidation process of 928 and 50-1-4Φ main lubricants. The kinematic viscosity, lubricity, and acid number of the oil samples were comparatively analyzed and the reasons for the performance deterioration were discussed.

2. Experimental Section

The 928 and 50-1-4Φ aviation lubrication oils are commercially available in the Henan Hangcai Science and Technology Co. Ltd., China. Other chemicals used in this paper are analytically pure and applied as they are received.

As shown in figure 1, all of the 928 and 50-1-4Φ aviation lubrication oils are treated in the appliances for the comparative oxidation studies. The oxidation glass tube is made by Tianchang City Instrument Company, according to the ASTM D4636 standard.
3. Results and discussion

3.1. The kinematic viscosity variation

The results from tables 1 and 2 imply that the oxidation process of 928 and 50-1-4 Φ at 150°C had a very low oxidation rate, resulting the kinematic viscosity slowly changing with temperature and time. On the other side, the performance indexes of 50-1-4 Φ were relatively stable after the oxidation temperature increased to 175°C, while 928 had a significant change after the oxidation time reached 120 h. The maximum increment of kinematic viscosity of 928 lubrication oil, which was oxidized for 120 h at 175 °C, was 17.69%, i.e. much higher than that (2.32%) of 928 lubrication oil, which was oxidized under the same conditions. Comparatively, the kinematic viscosity of 50-1-4 Φ lubrication oil has a relative small change even at 175 °C, when it was oxidized for 120 h (7.51%). The kinematic viscosity variation study of 928 and 50-1-4 Φ lubrication oil indicates the kinematic viscosity of 50-1-4 Φ lubrication oil is much more stable, as compared to the 928 lubrication oil.

Table 1. The 100°C kinematic viscosity ($\nu_{100°C}$) variation of aviation lubrication oils oxidized at 150°C for various time periods (0 to 120 h).

| Oxidation time (h) | 928 Viscosity (mm$^2$/s) | 928 Increment (%) | 50-1-4Φ Viscosity (mm$^2$/s) | 50-1-4Φ Increment (%) |
|-------------------|--------------------------|-------------------|----------------------------|------------------------|
| 0                 | 3.84                     | 0.00              | 3.11                       | 0.00                   |
| 24                | 3.84                     | 0.20              | 3.10                       | -0.32                  |
| 48                | 3.86                     | 0.21              | 3.12                       | 0.32                   |
| 72                | 3.87                     | 0.75              | 3.13                       | 0.64                   |
| 96                | 3.90                     | 1.26              | 3.13                       | 0.64                   |
| 120               | 3.93                     | 2.32              | 3.14                       | 0.96                   |

Table 2. The 100°C kinematic viscosity ($\nu_{100°C}$) variation of aviation lubrication oils oxidized at 175°C for various time periods (0 to 120 h).

| Oxidation time (h) | 928 Viscosity (mm$^2$/s) | 928 Increment (%) | 50-1-4Φ Viscosity (mm$^2$/s) | 50-1-4Φ Increment (%) |
|-------------------|--------------------------|-------------------|----------------------------|------------------------|
| 0                 | 3.84                     | 0.00              | 3.11                       | 0.00                   |
| 24                | 3.85                     | 0.19              | 3.11                       | 0.00                   |
| 48                | 3.87                     | 0.92              | 3.12                       | 0.32                   |
| 72                | 4.02                     | 4.39              | 3.15                       | 1.23                   |
| 96                | 4.24                     | 10.17             | 3.20                       | 2.59                   |
| 120               | 4.54                     | 17.69             | 3.36                       | 7.51                   |

3.2. The friction and wear property variation

Four-ball friction and wear testing machine is applied to evaluate the two kinds of aviation lubricating oil oxidation anti-wear performance test [5]. The sample before and after grinding by preliminary
experiments found that lubricating oil before and after oxidation spot diameter changed, so choose 150 and 175°C, respectively. Under 72 and 120 h of oxidizing, the same anti-wear performance experiment was carried out, considering the test error are two repeated trials, explore the oxidation reaction of two kinds of lubricating oil anti-wear performance impact. According to data in table 3 and figure 2, the 928 aviation lubricating oil with a 50kg-load in a 30 min-long grinding experiment, the grinding spot with average diameter of 0.473 mm was obtained. A typical picture of wear scar of aviation lubrication oil samples in the lubricity testing is shown in figure 3. Meanwhile, the 50-1-4 Φ grinding test spot diameter was 0.488 mm. As shown in Table 3, the spot diameter for the 928 oil was slightly less than that of 50-1-4 Φ, shows that 928 anti-wear performance is better than that of the 50-1-4 Φ, but the difference is small.

Table 3. The wear scar diameters of four-ball tested oxidized oil samples at 150 and 175°C (mm).

| Temperature / Time | Wear scar diameter for 928 oil | Wear scar diameter for 50-1-4Φ oil |
|-------------------|--------------------------------|-----------------------------------|
|                   | Mean value | Increment % | Mean value | Increment % |
| Untreated         | 0.453 | 0.493 | 0.473 | --- | 0.491 | 0.485 | 0.488 | --- |
| 150°C/72h         | 0.460 | 0.495 | 0.478 | 1.1 | 0.472 | 0.531 | 0.502 | 2.9 |
| 150°C/120h        | 0.462 | 0.505 | 0.484 | 2.3 | 0.481 | 0.505 | 0.493 | 1.0 |
| 175°C/72h         | 0.470 | 0.492 | 0.481 | 1.7 | 0.495 | 0.500 | 0.498 | 2.0 |
| 175°C/120h        | 0.475 | 0.483 | 0.479 | 1.3 | 0.523 | 0.478 | 0.501 | 2.7 |

Figure 2. The maximum anti-seizure duty (Pb) of the oxidized 928 and 50-1-4 Φ oils oxidized at 150 and 175 °C with various oxidation times.

Figure 3. The typical picture of wear scar of aviation lubrication oil samples in the lubricity testing.
As shown in figure 2, the untreated 928 aviation lubricating oil had the maximum anti-seize duty as high as ~73 kg, while that of 50-1-4 Ф was about 61 kg [6]. The maximum anti-seize duty of 928 was by 12 kg higher than that of 50-1-4 Ф oil. At the oxidation time of 120 h, the maximum anti-seize duty of the 928 oil increased to 87 kg, while that of 50-1-4 Ф oil was only 67 kg (i.e., higher by 6 kg than that of the untreated oil). Thus, the increment was 9.8%, as compared with the untreated 50-1-4 Ф oil. Since the maximum anti-seize duty of oxidized 928 oil samples could reach as high as 107 kg versus 67 kg of 50-1-4 Ф oil, the former oil exhibits the best weight-bearing performance even after being oxidized for 120 hours at 175°C.

3.3. The friction and wear property variation

The untreated 928 and 50-1-4 Ф aviation lubrication oils have very low acid numbers, namely 0.07 and 0.05 mgKOH/g, respectively [7, 8]. After thermal oxidation process, the acid number of 50-1-4 Ф was much lower than that of 928 lubrication oil, as shown in figure 4. For both aviation lubrication oils, the acid number grows with oxidation time almost linearly but the acid number of 928 grows much faster than that of 50-1-4Φ.

![Figure 4](https://example.com/figure4.png)

**Figure 4.** The acid number variation of the oxidized 928 and 50-1-4 Ф oil samples which have been oxidized at 150 °C and 175 °C for certain time.

As shown in figure 4, the acid number of 928 lubrication oil at 150 °C is higher than that of 50-1-4 Ф at 175°C. The acid number of oxidized 928 lubrication oils at 150 °C for 120 h increased from 0.073 mgKOH/g to 0.403 mgKOH/g, which is 5.5 times higher than that of untreated 928 oil. The acid number of 50-1-4 Ф is relatively low at 150°C after a 120h-oxidation, since it is only 0.115 mgKOH/g, or 2.5 times higher than that of untreated one. If the oxidation temperature was elevated to 175°C, the acid number of 928 lubrication oil samples would increase to 0.779 mgKOH/g, which is 10.7 times higher than that of the untreated oil. On the other hand, the acid number of 50-1-4 Ф lubrication oil only increased to 0.318 mgKOH/g, which is 6.9 times higher than that of the new oil under the same test conditions. Thus, the acid number of 928 lubrication oil is nearly 2.4 times higher than that of the 50-1-4Φ oil samples at high temperature. The results suggest that the 928 lubrication oil is easily oxidized and generate acidic products, which raise its acid number.

4. Conclusions

The maximum increment of kinematic viscosity of the domestic 928 lubrication oil oxidized for 120 h at 175°C is 17.69%, which is much higher than that of 50-1-4 Ф lubrication oil under the same test conditions (7.51%). The lubricity test shows the average wear scars for 50-1-4 Ф and 928 lubrication oils detected after a 30min-grinding under 50 kg load were nearly the same (0.488 and 0.473 mm, respectively). However, while the maximum anti-seize duty of oxidized 928 oil samples could reach
as high as 107 kg, that of 50-1-4 Ф oil was only 67 kg. Thus, the 928 lubrication oil showed much better weight-bearing performance even at 175°C after being oxidized for 120 hours. The acid number of 928 lubrication oil is nearly 2.4 times higher than that of 50-1-4Ф oil at high temperature. The results suggest that the 928 lubrication oil is easily oxidized and generates acidic products, which raise its acid number. The comparative analysis results strongly suggest that the 928 lubrication oil tend to react in oxidizing atmosphere, which would increase its viscosity, acid number, and weight-bearing performance, but not affect its wear scar diameter.

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References
[1] Terence C 1987 Role of additives and transition metals in lubricating oil oxidation Ind. Eng. Chem. Res. 26 1888-95
[2] Wu Y X, Li W M, Zhang M and Wang X B 2013 Oxidative degradation of synthetic ester and its influence on tribological behavior Tribol. Int. 64 16-23
[3] Wu T H, Wu H K, Du Y and Peng Z X 2013 Progress and trend of sensor technology for on-line oil monitoring Technol. Sci. 56 2914-26
[4] Owrang F, Mattsson H, Olsson J and Pedersen J 2003 Investigation of oxidation of a mineral and a synthetic engine oil Thermochim. Acta 413(1-2) 241-8
[5] Minami I and Mimura K 2004 Synergistic effect of antiwear additives and antioxidants in vegetable oil Lubr. Sci. 21(3) 193-205
[6] Wu Y X 2013 The preparation and properties research of high performance synthetic ester lubrication oil (China: Lanzhou Institute of Chemical Physics)
[7] Ahmad I, Ullah J, Ishaq M, Khan H, Khan R, Ahmad W and Gul K 2017 Oxidative stability of base lubricant oil monitored by gas chromatography–mass spectrometry: influence of sawdust-derived antioxidants Energ. Fuel. 31(7) 7653-61
[8] Singh R K, Kukrety A, Sharma O P, Poddar M K, Atray N and Ray S S 2017 Synthesis of a novel efficient antioxidant for use in lubes and biodiesel Petrol. Chem. 57(1) 100-5