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Original Research Article

Mechanism of viscosity increase in polyisobutylene succinimide during thermal storage

Qingyang Yuan, zuoxin Huang

SINOPEC Research Institute of Petroleum Processing Co., Ltd., Beijing, 100083, China

Abstract: Aiming at the problem of viscosity increase in polyisobutylene succinimide (PIBSI)-type ashless dispersants during thermal storage, this study integrates electronic science and technology to explore the mechanism. Methods such as Fourier transform infrared spectroscopy (FTIR), gel permeation chromatography (GPC), and reaction kinetics calculations were used to analyze the viscosity increase mechanism under thermal storage conditions. The effects of chemical structure changes on properties were evaluated through spot tests and simulated crankcase tests. The results show that the nucleophilic substitution reaction between the primary amine terminal group and the carbonyl carbon of the five-membered ring succinimide generates secondary amide, leading to an increase in relative molecular weight and kinematic viscosity. However, the changes in chemical structure and viscosity have no significant impact on dispersibility and high-temperature detergency. This study provides a theoretical basis for improving the viscosity increase problem and highlights the application value of electronic science and technology in fine chemistry.

Keywords: Succinimide; Ashless dispersant; Thermal storage; Kinematic viscosity

With the development of the automotive industry, ashless dispersants account for 80% of the usage of lubricating oil additives, whose core functions include emulsifying oil sludge, inhibiting soot agglomeration, and preventing abnormal viscosity increase[1]. Polyisobutylene succinimide (PIBSI) is the mainstream ashless dispersant, produced by thermal addition hydrocarbonation process and two-stage amination reaction[5-9]. A series of products such as T151 (excellent low-temperature dispersibility) and T154 (improved high-temperature stability) can be prepared by regulating the feed ratio[2, 11]. PIBSI has high viscosity at room temperature and needs to be stored under heating. However, long-term thermal storage can cause the viscosity of products like T151 and T161 to exceed the quality upper limit. At present, the mechanism of its viscosity increase has not been reported. This study aims to reveal the mechanism, evaluate the performance impact, and optimize the storage conditions[12].

1. Experimental Section

1.1. Key reagents

Polyisobutylene succinic anhydride (PIBSA1300, Yangzi Petrochemical), tetraethylenepentamine (TEPA, AR grade), 150SN base oil (Gaoqiao Petrochemical), etc.

1.2. Key points of T151 synthesis

Apparatus: 250 ml four-necked flask (equipped with water separator, condenser tube, etc.).

Procedure: Mix PIBSA1300 with base oil, add TEPA dropwise at 80°C, heat to 140°C and react until the acid anhydride peak disappears, then remove moisture at 150°C.

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1.3. Core analytical methods

Kinematic Viscosity: Measured at 100°C using an automatic viscometer, monitored during storage at 15–100°C (sampled every 48 hours).

FTIR Quantitative Analysis: Concentration changes were calculated via standard curves using characteristic peaks at 1700 cm^{-1} (succinimide) and 1650 cm^{-1} (amide) (measured every 2 days).

Gel Permeation Chromatography (GPC): THF as solvent, flow rate 1.0 mL/min, to determine molecular weight distribution before and after thermal storage.

2. Core results and analysis

2.1. Viscosity change patterns

Figure 1 shows that during storage at 80°C, the viscosity change rate exceeds 100% within the first 20 days, eventually stabilizing at 300 mm^2/s, which exceeds the standard upper limit (270 mm^2/s).

Figure 2 indicates that below 100°C, the higher the temperature, the faster the viscosity increase; however, after storing at 100°C for 50 days, the viscosity change is less than 30 mm^2/s.

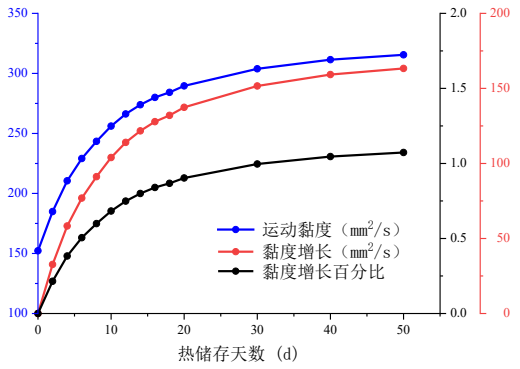

Figure 1. The trend of kinematic viscosity (at 100℃) of T151 with the number of days of thermal storage.

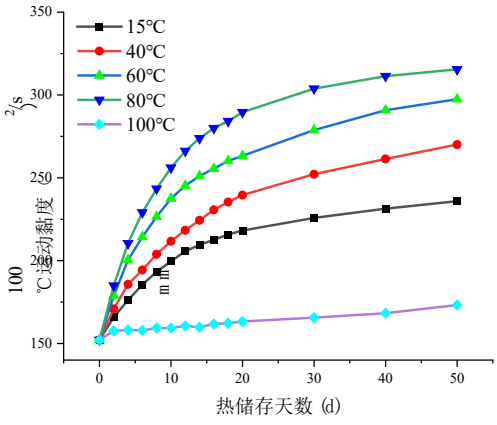

Figure 2. The trend of viscosity change under different storage temperatures.

2.2. Verification of Reaction Mechanism

Infrared Spectroscopy: During storage at 80°C, the absorption peak at 1700 cm^{-1} (succinimide) weakened, while that at 1650 cm^{-1} (amide) strengthened, confirming the conversion of succinimide to secondary amide (**Figure 3**). After high-temperature (>100°C) treatment, the succinimide peak reappeared and viscosity de-

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creased, indicating thermal instability of secondary amide (**Figures 4, 5**).

GPC Data: After 30 days of storage, the polydispersity index (PDI) increased from 1.297 to 1.388, and the weight-average molecular weight (Mw) rose from 3263 to 3768, confirming an increase in molecular weight (**Table 1**, **Figure 6**).

Kinetic Analysis: The reaction was second-order with an activation energy of 3.97 kJ/mol, occurring even at room temperature (**Figures 11, 12**).

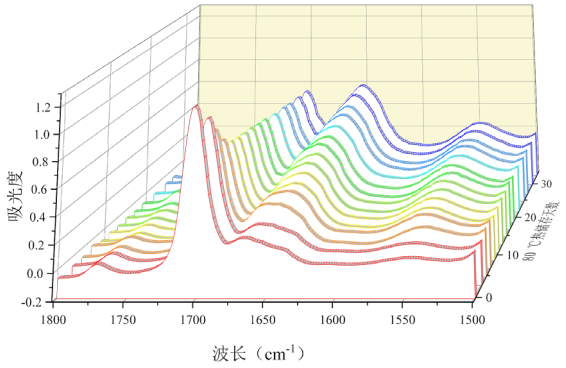

Figure 3. The waterfall plot of infrared absorption spectra as a function of the number of days of thermal storage.

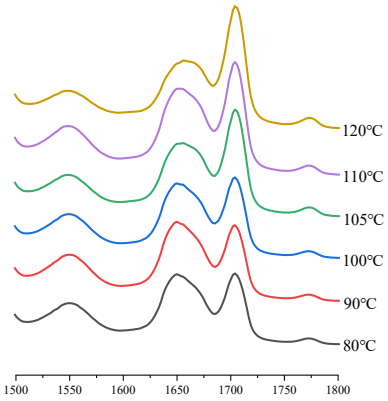

Figure 4. The variation in the content of succinimide after thermal storage, as indicated by changes in infrared characteristic absorption peaks at different temperatures.

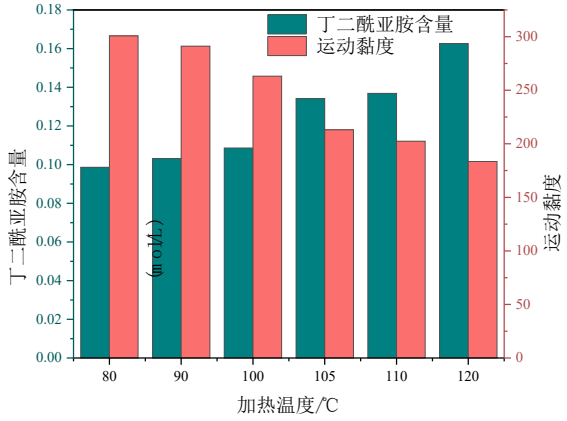

Figure 5. Changes in succinimide content and viscosity after thermal storage and subsequent reheating treatment.

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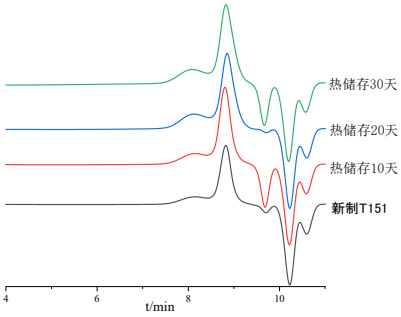

Figure 6. Comparison of GPC spectra after different days of thermal storage.

Table 1. The effect of thermal storage on the relative molecular weight of mono-polyisobutylene succinimide.

Thermal storage days	Mp	Mn	Mw	PDI
Freshly prepared T151	2531	2516	3263	1.297
Thermal storage for 10 days	2531	2639	3395	1.286
Thermal storage for 20 days	2684	2565	3420	1.333
Thermal storage for 30 days	2959	2714	3768	1.388

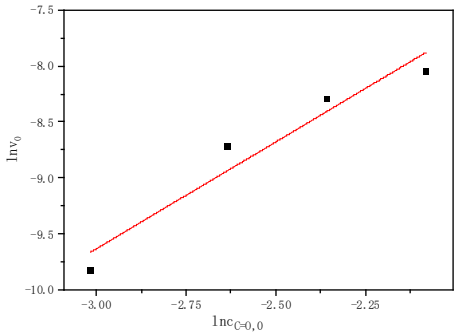

Figure 7. The linear relationship between $\ln c_{C=O,0}$ and $\ln v_0$

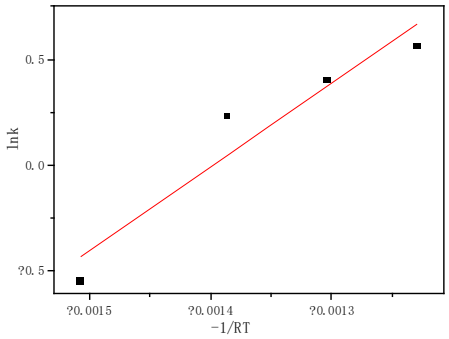

Figure 8. The linear relationship between-1/RT and lnk.

2.3. Performance impact

Dispersibility: The spot dispersion test (SDT) values showed small fluctuations (variance 0.009–0.012), indicating no significant difference in dispersibility before and after thermal storage (**Figure 10, 11**).

Detergency: In the simulated crankcase test, the weight of coke and lacquer formed showed no trend-based changes. At high temperatures, partial ring-closing of secondary amides to restore succinimide structure may counteract the impact (**Figures 12, 13**).

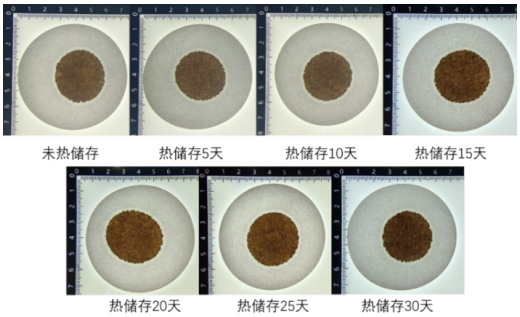

Figure 9. Spot dispersion test of CK4 15W-40 finished oil.

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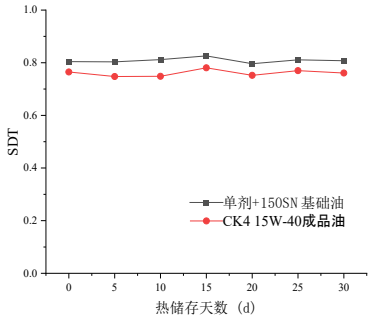

Figure 10. Spot dispersion test.

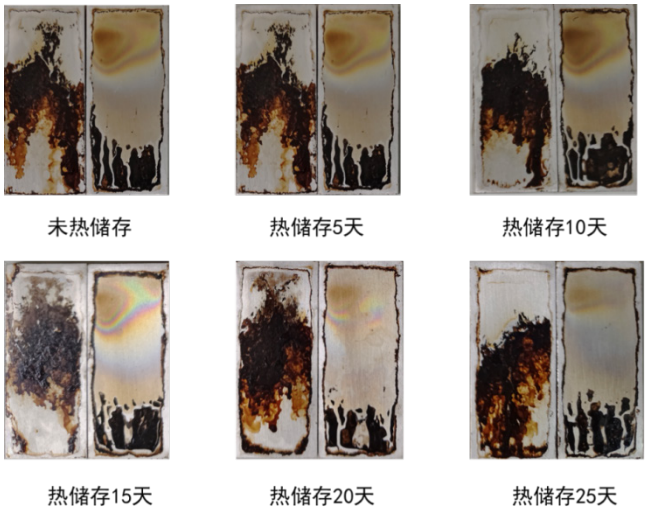

Figure 11. Simulation crankcase test of CK-4 15W-40 finished oil.

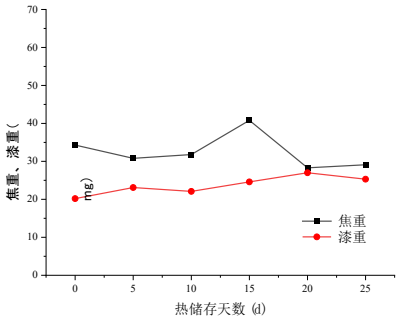

Figure 12. Comparison of the weights of coke and lacquer formed.

2.4. Results

2.4.1. The main reason for the viscosity increase of PIBSI during thermal storage is the nucleophilic substitution reaction between primary amines and succinimides, which generates secondary amides and leads to an increase in molecular weight.

2.4.2. The reaction has a low activation energy (3.97 kJ/mol), allowing it to proceed at room temperature. Above 100°C, the viscosity increase is limited due to the ring-closing reaction of secondary amides.

2.4.3. Changes in molecular structure have no significant impact on dispersibility and high-temperature de-

tergency.

3. Conclusions

This study systematically reveals the micro-mechanism of viscosity increase in PIBSI during thermal storage through technical means such as electronic spectral analysis, electronic data modeling, and automated detection. It confirms the critical supporting role of electronic science and technology in resolving reaction mechanisms, optimizing processes, and evaluating performance in the fine chemical industry, providing an innovative path for the intelligent production and storage of ashless dispersants.

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