



Article Isomerization Properties of Pt/SAPO-11 Catalysts for the Production of Bio-Aviation Kerosene

Sangni Yang ¹, Xuejun Liu ^{1,*}, Xin Zhang ¹, Wuji Sun ¹, Qiqi Ma ¹, Nianhua Song ¹, Meizhen Lu ¹ and Jianming Hu ²

- ¹ Zhejiang Province Key Laboratory of Biofuel, School of Chemical Engineer, Zhejiang University of Technology, Hangzhou 310014, China; y2448750713@163.com (S.Y.); 15615633853@163.com (X.Z.); lqs434272@gmail.com (W.S.); 2112101123@zjut.edu.cn (Q.M.); m15979944753@163.com (N.S.); luzhen726@zjut.edu.cn (M.L.)
- ² Zhejiang Jieda Technology Co., Ltd., Huzhou 313300, China; 13185206325@163.com
- * Correspondence: liuxuejun@zjut.edu.cn; Tel.: +86-188-5716-1950

Abstract: The hydroisomerization of *n*-alkanes is an important step in the production of high-quality bio-aviation kerosene. A SAPO-11 molecular sieve was synthesized using the hydrothermal synthesis method, and a 0.5 wt% Pt/SAPO-11 catalyst was prepared using the impregnation method. The crystal phase, pore structure, acidity, and morphology of Pt/SAPO-11 were characterized via X-ray diffraction, N₂ adsorption-desorption, NH₃ temperature-programmed desorption, scanning electron microscopy, and transmission electron microscopy, respectively. The hydroisomerization performance of the catalyst was evaluated with bio-*n*-hexadecane as the model compound. The results showed that temperature and space velocity had significant effects. Under the conditions of 340 °C, 1.5 MPa, WHSV = 1.0 h^{-1} , $V(H_2)$: V(n-hexadecane) = 1000:1, the conversion of *n*-hexadecane and the selectivity of *i*-hexadecane were 81.8% and 86.5%, respectively.

Keywords: Pt/SAPO-11; hydroisomerization; n-hexadecane; bio-aviation kerosene



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1. Introduction

Sustainable aviation fuel (SAF) is recognized as a short-to medium term solution toward the overall reduction of greenhouse gas emissions. It can achieve a 50% reduction in carbon emissions by 2050 compared to 2005. At present, the most important SAF is bio-aviation kerosene (BAK), which is a synthesized paraffinic kerosine produced from hydroprocessed esters and fatty acids. BAK is a synthetic blending component for aviation turbine fuels in civil aircraft and engines. BAK is mainly obtained through the hydrodeoxy-genation of esters and fatty acids. The ester and fatty acid hydrogenation route has some advantages, such as being abundant in raw materials, relatively mature in technology, and having a high yield. Therefore, the hydrogenation route is an effective method to prepare bio-aviation fuel [1]. The products obtained by hydrodeoxygenation from ester and fatty acid hydrogenation have a high content of *n*-alkanes, resulting in poor low-temperature fluidity in bio-aviation kerosene. The hydroisomerization of *n*-alkanes is one of the most effective methods to improve the low-temperature fluidity of biofuels.

The hydroisomerization reaction of *n*-alkanes is usually carried out on bifunctional catalysts. Therefore, developing catalysts with high *i*-alkane yield and reaction stability is crucial for producing high-quality bio-aviation kerosene [2]. Among common catalysts, for the hydroisomerization of strong Bronsted [3], *Y* zeolite, and MCM-41 catalysts, the conversion of *n*-decane is about 78% and 30%, respectively [4,5]. For the hydroisomerization performances of ZSM-22 and ZSM-48 catalysts, the conversion of dodecane is about 40% and 52%, respectively [6,7]. Due to the shape-selective isomerization effect, monobranched isomeric alkanes are obtained in higher yields on 10-membered ring zeolite [8]. The typical catalyst is a bifunctional catalyst for alkane hydroisomerization and has been

widely researched. The *n*-alkane first adsorbs to the metal active site and then undergoes a dehydrogenation reaction to form an olefin. The resulting olefin diffuses from the metal active site to the acidic site, where it is protonated to produce an alkyl carbon carbocation. At the acidic site, olefins and alkyl carbocation undergo competitive adsorption-desorption. Subsequently, the alkyl carbocation starts skeletal isomerization or cracks into a new olefin and a new carbocation. Finally, the carbocation deprotonates to an olefin, which diffuses from the acidic site to the metal active site to prepare hydrogenation to an alkane and then desorbs.

In terms of the influence of the carrier, it is mainly the pore distribution of the carrier and the acidity strength that affect the catalyst's activities. Protonation, isomerization, and cracking reactions take place on the acid carrier. Different molecular sieves have different pore distributions, amounts of acid, and acidity distributions, resulting in different isomeric performances of the catalysts. The carbocation reaction generated from isomerization or cracking is an acid catalytic reaction that is mainly influenced by the acidity of the molecular sieve, the distribution of acid sites, and the structural characteristics. The stronger the acid, the more intense the carbocation reaction is, and the resulting conversion is higher. With the increase in acidity, the isomerization reaction intensifies to a certain extent, but not as much as the cracking reaction. Therefore, to obtain more isomerized products and reduce excessive cracking, molecular sieves with weak and moderately strong acids should be selected. Metals are loaded on molecular sieves to provide mainly hydrogenation or dehydrogenation functions. A stronger hydrogenation function of a metal results in a higher conversion rate. In addition, the strong hydrogenation ability of metals can suppress carbon deposition during the reaction. Thereby, the lifetime of the catalyst can be improved.

The SAPO-11 molecular sieve is one of the most promising acidic carriers due to its one-dimensional 10-membered ring pore structure and suitable acidity [9,10]. Pt metal is often used as a metal site for bifunctional catalysts due to its stronger hydrogenation activity, while SAPO-11 molecular sieves provide acidic centers [11,12]. Thus, the selectivity of isomeric alkanes mainly depends on the metal and acidic sites [13], and the appropriate balance between these variables is closely related to determining the reactivity and selectivity of bifunctional catalysts. Xiaojun Dai et al. synthesized SAPO-11 molecular sieves through a two-step crystallization method. Under the reaction conditions of 360 °C, 2 MPa, 1.5 h⁻¹, and a 600 volume ratio of H_2/n -C₁₆, the conversion of *n*-hexadecane was 90% and the selectivity of *i*-hexadecane was 80% [14,15]. Yuchao Lyu et al. prepared a Ni/SAPO-11 bifunctional catalyst for the hydroisomerization of *n*-hexane. Under the reaction conditions of 340 °C, 2 MPa, 1.0 h⁻¹, and a 4.0 volume of H_2/n -C₆, the conversion of *n*-hexane was 75% and the selectivity of *i*-hexane was 90% [16]. Lili Geng et al. studied Pt/SAPO-11 molecular sieves under the reaction conditions of 320 $^{\circ}$ C, 0.1 MPa, 4.0 h⁻¹ and a 15.0 mole ratio of H_2/n - C_{12} ; the resulting conversion of *n*-dodecane was 76% and the selectivity of *i*-dodecane was 80% [12].

In this study, in order to prepare bio-aviation kerosene, the SAPO-11 molecular sieve was synthesized by the one-step hydrothermal synthesis method. Additionally, 0.5 wt% Pt/SAPO-11 was prepared by loading Pt. The physicochemical properties were characterized using instruments. The catalytic performance was investigated in the *n*-hexadecane hydroisomerization.

2. Results and Discussion

2.1. Physicochemical Properties

Figure 1 shows the XRD patterns of the samples SAPO-11 and Pt/SAPO-11. It can be seen from the figure that the characteristic diffraction peaks of the SAPO-11 molecular sieve were observed at $2\theta = 8.1^{\circ}$, 9.4° , 13.1° , 15.6° , 20.3° , and 21.2° for the crystalline sample, indicating that the impregnation process of Pt has no significant effect on the crystallinity of SAPO-11, and the loaded Pt/SAPO-11 had good crystallinity and no heterocrystals and still maintained a good AEL structure [17]. Besides the typical characteristic peaks of SAPO-11, Pt/SAPO-11 has a weak peak at $2\theta = 59^{\circ}$ (marked by \downarrow) due to loaded Pt.



Figure 1. XRD patterns of SAPO-11 and Pt/SAPO-11.

Figure 2 shows the N₂ adsorption-desorption isotherms and pore diameter distribution of the SAPO-11 molecular sieve and Pt/SAPO-11. Table 1 shows the corresponding pore structure parameters. The SAPO-11 molecular sieve is a typical type-I isotherm, indicating that the SAPO-11 sample is a microporous molecular sieve. Pt/SAPO-11 is a type-IV adsorption-desorption isotherm and a type-H₄ hysteresis loop. The pore diameter distribution of the SAPO-11 molecular sieve is obvious from 1 nm to 12 nm, and the Pt/SAPO-11 molecular sieve mainly has a pore size distribution in the range of 2–20 nm. As can be seen from Table 1, the specific surface area of the catalyst decreased significantly compared with the SAPO-11 molecular sieve when loaded with 0.5 wt% Pt. The specific surface area decreased from 145.4 m²·g⁻¹ to 103.0 m²·g⁻¹. This is due to the interaction between the active component Pt and the molecular sieve after loading, which occupies a portion of the surface area and results in a decrease in surface area. In addition, agglomeration of grains in the pore channel occurred, which blocked the molecular sieve pore channel, causing a decrease in surface area and microporous pore capacity.



Figure 2. N₂ adsorption–desorption isotherms and BJH pore size distribution curves of SAPO-11 and Pt/SAPO-11.

Samples	Surface Area (m ² ·g ⁻¹)		Pore Volume (cm ³ ·g ⁻¹)	
	BET Surface Area	Micropore	Total	Micropore
SAPO-11	145.4	130.5	0.31	0.069
Pt/SAPO-11	103.0	93.1	0.29	0.039

Table 1. Pore structures of SAPO-11 and Pt/SAPO-11.

Figure 3 shows the SEM image of SAPO-11 and Pt/SAPO-11. 1–2 shows the SEM image of SAPO-11, and 3–4 shows the SEM image of Pt/SAPO-11. 1 and 3 show the morphology at the scale of 50 μ m, and 2 and 4 show the morphology at the scale of 20 μ m. It can be seen from the figure that the SAPO-11 molecular sieve has spheroidal particles with relatively rough surfaces. The particle size is about 20–35 μ m. The SAPO-11 molecular sieve synthesized by the hydrothermal method has high crystallinity and a relatively uniform particle diameter. The microscale structure of the SAPO-11 is influenced little by Pt loading. Additionally, uniform particle size distribution, high crystallinity, and smooth pore channels facilitate the diffusion of reactants and products in the isomerization reaction.



Figure 3. SEM images of SAPO-11 and Pt/SAPO-11. (**1**,**2**) are SEM images of SAPO-11, and (**3**,**4**) are SEM images of Pt/SAPO-11.

Figure 4 shows the TEM image of SAPO-11 and Pt/SAPO-11. 1–2 shows the TEM image of SAPO-11, and 3–4 shows the TEM image of Pt/SAPO-11. 1 and 3 show the morphology at the scale of 50 μ m, 2 and 4 show the morphology at the scale of 100 μ m. It can be seen from the figure that the black spots on the TEM photograph of the catalyst are loaded platinum particles. The particle size is about 10–25 nm. The platinum particles were successfully loaded on the molecular sieve, both dispersed on the outer surface of SAPO-11 and partially dispersed inside the pore channel, and the loaded particles were evenly distributed with good dispersion and no obvious agglomeration of large particles. Similarly, the microscale structure of the SAPO-11 is influenced little by Pt loading. This is because the hydroisomerization performance of the catalyst is affected by the synergistic effect of both the pore structure and the acidic and metal active sites [18]. Platinum is loaded using

an equal-volume impregnation method supplemented by ultrasound to evenly distribute platinum particles on the SAPO-11 molecular sieve. Therefore, with the better dispersion of Pt, the catalyst is not easily blocked in the pore.



Figure 4. TEM diagram of SAPO-11 and Pt/SAPO-11. (**1**,**2**) are TEM images of SAPO-11, and (**3**,**4**) are TEM images of Pt/SAPO-11.

NH₃-TPD is obtained as a TPD detection signal through NH₃ adsorption and temperature-programmed desorption. Figure 5 shows the NH₃-TPD spectra of the SAPO-11 and Pt/SAPO-11 samples. It can be seen from the figure that the molecular sieve had one desorption peak concentrated at 50–200 °C, which corresponds to the weak acidic site, and another peak concentrated at 200–400 °C, which corresponds to the medium to strong acidic site. Additionally, the area of the low-temperature desorption peak was larger than that of the high-temperature desorption peak. This indicates that the catalyst is dominated by weak acid centers. The loading of platinum had little effect on the acid intensity distribution and the weak and medium-strong acid centers [19]. During the hydrogenation of *n*-hexadecane, the acidic strength had a significant influence on the performance of the catalyst [20], with medium-to-strong acid centers inducing dimerization and cracking reactions and weak acid centers favoring the isomerization of alkanes [21–23]. Table 2 shows the amount of acid in SAPO-11 and Pt/SAPO-11 through integration calculations. The Pt/SAPO-11 molecular sieve's amount of weak and medium acid decreased slightly compared to the SAPO-11 molecular sieve, possibly due to the metal occupying the acidic site.

Table 2. The amount of acid distribution of SAPO-11 and Pt/SAPO-11.

Samples	Amount of Weak Acid (µmol/g)	Amount of Medium Acid (µmol/g)	Total Acid (µmol/g)
SAPO-11	0.795	0.303	1.098
Pt/SAPO-11	0.737	0.452	1.189



Figure 5. NH₃-TPD profiles of SAPO-11 and Pt/SAPO-11.

2.2. Hydroisomerization of n-Hexadecane

In order to prepare bio-aviation kerosene, the effects of reaction temperature, weight hourly space velocity, the ratio of H_2/n - C_{16} , reaction pressure, and metal loadings were considered. Meanwhile, the influence of reaction conditions on conversion and selectivity was studied.

2.2.1. Effect of Reaction Temperature on the Isomerization Performance

The influence of reaction temperature on the hydroisomerization performance of the Pt/SAPO-11 catalyst is shown in Figure 6. Under the reaction conditions of 1.5 MPa pressure, $1.5 h^{-1}$ of weight hourly space velocity, and 1000 of volume ratio of H₂/*n*-C₁₆, with the increase in temperature, the conversion of *n*-hexadecane increased obviously. With the increase in conversion, the selectivity and yield showed a trend of increasing and then decreasing. When the temperature increased from 340 °C to 380 °C, the conversion increased from 81.8% to 85.12%, and the selectivities were 86.5% and 71.2%, respectively. When the reaction temperature exceeded 340 °C, the isomeric olefin intermediates did not desorb in time, and a portion of the carbocations carried out β fracture, and then carbocations occurred with varying degrees of cracking, resulting in a decrease in the selectivity of *i*-C₁₆ with the increase in conversion [24].

2.2.2. Effect of Weight Hourly Space Velocity on the Isomerization Performance

Figure 7 shows the influence of weight hourly space velocity on the hydroisomerization performance of the Pt/SAPO-11 catalyst. The conversion of *n*-hexadecane decreased, and the selectivity of *i*-hexadecane increased with the increase in weight hourly space velocity. When the space velocity increased from 1 h^{-1} to 3 h^{-1} , the conversion decreased from 81.7% to 17.5%, and the selectivity increased from 86.8% to 98.1%. With the increase in space velocity, the residence time of *n*-hexadecane in the active center of the catalyst became shorter, the reaction was insufficient, and the conversion decreased. Although the product selectivity was higher at higher space velocity, the conversion was lower and not conducive to improving the quality of the product.



Figure 6. Effect of reaction temperature on isomerization performance. Reaction conditions: P = 1.5 MPa, WHSV = 1.0 h⁻¹, $V(H_2)$: V(hexadecane) = 1000.



Figure 7. Effect of weight hourly space velocity on the isomerization performance. Reaction conditions: $T = 340 \degree \text{C}$, P = 1.5 MPa, $V(\text{H}_2)$: V(hexadecane) = 1000.

2.2.3. Effect of the Ratio of $H_2/n-C_{16}$ on the Isomerization Performance

Figure 8 shows the effect of the ratio of $H_2/n-C_{16}$ from 600 to 1400 on the isomerization performance. It can be seen that the conversion of *n*-hexadecane and the selectivity of *i*-hexadecane on Pt/SAPO-11 almost did not change when increasing the ratio. When the ratio of $H_2/n-C_{16}$ was 600, the conversion of *n*-hexadecane was 79.5% and the selectivity of *i*-hexadecane was 85.5%. When the ratio of $H_2/n-C_{16}$ was 1400, the conversion of *n*-hexadecane was 86.2%. A higher $H_2/n-C_{16}$ ratio can increase the hydrogen partial pressure, which is conducive to improving the hydroisomerization of the catalyst.



Figure 8. Effect of the ratio of $H_2/n-C_{16}$ on the isomerization performance. Reaction conditions: $T = 340 \degree C$, P = 1.5 MPa, WHSV = 1.0 h⁻¹.

2.2.4. Effect of Reaction Pressure on the Isomerization Performance

Figure 9 shows the effect of reaction pressure from 1.0 MPa to 3.0 MPa on the isomerization performance. It can be seen that the conversion of *n*-hexadecane and the selectivity of *i*-hexadecane changed only slightly, with insignificant effects. When the reaction pressure was 1.0 MPa, the conversion of *n*-hexadecane was 80.3% and the selectivity of *i*-hexadecane was 86.9%. When the reaction pressure was 3.0 MPa, the conversion of *n*-hexadecane was 83.1% and the selectivity of *i*-hexadecane was 72.5%. Increasing the partial pressure of hydrogen resulted in a slight increase in the conversion of the hydroisomerization reaction and a decrease in selectivity.



Figure 9. Effect of reaction pressure on the isomerization performance. Reaction conditions: T = 340 °C, WHSV = 1.0 h⁻¹, $V(H_2)$: V(hexadecane) = 1000.

Figure 10 shows the effect of metal loadings from 0.2 wt% to 1.0 wt% on the isomerization performance. It can be seen that the active components of precious metals have a great influence on the hydroisomerization reaction by the Pt/SAPO-11 catalyst. When the active component loading increased from 0.2 wt% to 0.8 wt%, the conversion of *n*-hexadecane increased to 82.43% and the selectivity of *i*-hexadecane increased to 87.3%. However, when the active component loading increased from 0.8 wt% to 1.0 wt%, the conversion of *n*-hexadecane decreased to 63.56% and the selectivity of *i*-hexadecane decreased to 81.6%. On the one hand, this may be due to excessive Pt occupying partial acidic sites of the catalyst. On the other hand, some Pt may block the pores of the carrier.



Figure 10. Effect of metal loadings on the isomerization performance. Reaction conditions: $T = 340 \degree C$, P = 1.5 MPa, WHSV = 1.0 h⁻¹, $V(H_2)$: V(hexadecane) = 1000.

2.3. Isomeric Product Distribution

Table 3 shows the product distribution of the Pt/SAPO-11 catalyst. In order to reflect the data more intuitively, Figure 11 is drawn. The influence of reaction temperature on the distribution of mono/multi-branched isomers is shown in Figure 12. The ratio of mono-branched chain isomeric products to multi-branched chain isomeric products decreased gradually with the increase in conversion. At high conversion, the multi-branched isomeric products were greater than the mono-branched isomeric products.

Temperature (°C)	Conversion (%) –	Yield (%)		Cracked
		MoBC ₁₆ ¹	MuBC ₁₆ ²	Product (%)
300	43.81	31.05	2.6	23.2
320	63.57	41.84	7.3	22.7
340	81.80	56.36	14.4	13.5
360	83.66	28.00	35.0	24.7
380	85.12	10.11	50.5	28.8

Table 3. Product distributions using Pt/SAPO-11.

¹ MoBC₁₆, Mono-branched hexadecane isomers. ² MuBC₁₆, Multi-branched hexadecane isomers.



Figure 11. Effect of reaction temperature on hydroisomerization. Green line represents yield.



Figure 12. Effect of reaction temperature on distribution of mono/multi-branched isomers.

The conversion sequence of *n*-alkanes on the catalyst is as follows: $n-C_{16} \rightleftharpoons mono$ $branched chain; <math>i-C_{16} \rightleftharpoons multi-branched chain; and <math>i-C_{16} \longrightarrow cracking product$ [24]. At low conversion, the main reaction products were mono-branched chain $i-C_{16}$. With the increase in reaction temperature, the mono-branched chain $i-C_{16}$ was converted to the multi-branched chain $i-C_{16}$ and further cracked into short-chain alkanes. The reaction mechanism of the mono-branched isomer is shown in Figure 13. First, the alkanes at the Pt center are dehydrogenated to form olefin molecules and diffused to the acidic site. Then olefin molecules converted to alkane carbocation at the B-acid center. Subsequently, the carbocation undergoes skeletal isomerization to form a new carbocation. After that, the carbocation deprotonates to olefin. Finally, the mono-branched isomer is formed by hydrogenation on the Pt center.



Figure 13. Reaction mechanism of mono-branched isomers [25,26].

2.4. Stability of Catalyst

Figure 14 shows the conversion of the Pt/SAPO-11 catalyst and the selectivity of i-hexadecane over time. From the graph, it can be seen that the conversion and selectivity of isomeric hexadecane changed smoothly with the development of reaction time. The conversion of the Pt/SAPO-11 catalyst and the selectivity of isomeric hexadecane remained above 80%. Research has shown that molecular sieves have large specific surface areas and mesoporous volumes and are conducive to increasing the carbon deposition resistance of SAPO-11 catalyst, thus improving the activity of the catalyst and extending its service life. The Pt/SAPO-11 catalyst can run continuously and stably for more than 60 h under the abovementioned conditions.



Figure 14. Activity stability evaluation of the Pt/SAPO-11 samples. Reaction conditions: $T = 340 \degree C$, P = 1.5 MPa, WHSV = 1.0 h⁻¹, $V(H_2)$: V(hexadecane) = 1000.

3. Materials and Methods

3.1. Synthesis of SAPO-11

The SAPO-11 molecular sieve was synthesized by hydrothermal synthesis. The specific synthesis steps were as follows: Pseudo-boehmite (Al₂O₃·nH₂O) and phosphoric acid (H₃PO₄) were dissolved in deionized water, stirred for 2 h in a constant temperature water bath at 35 °C, and then di-n-propylamine (DPA) and acid silica sol (mSiO₂·nH₂O) were added to the abovementioned solution and stirred continuously for 2 h. The molar

composition was 1.25 DPA:1.0 Al₂O₃:0.8 P₂O₅:0.4 SiO₂:50 H₂O gel. The synthesized sample was transferred to a stainless-steel autoclave lined with polytetrafluorethylene and crystallized in a drying oven at 180 °C for 24 h. The product was cooled to room temperature, and the required sample was obtained after centrifuging, washing, and drying. The sample was placed in a muffle furnace and calcined at 600 °C for 5 h to obtain SAPO-11 to remove the template.

3.2. Preparation of Catalyst

The forming and metal loading of the catalyst were carried out by pressing and dipping methods, respectively. The abovementioned calcined SAPO-11 powder was pressed and formed by a tablet press, screened to 20–40 mesh, and a 10 g sample was taken and placed in a surface dish with a diameter of 10 cm.

Afterward, 0.1 g of H_2PtCl_6 solid powder was weighed and dissolved in 10 mL deionized water, adding the H_2PtCl_6 precursor solution dropwise onto the SAPO-11 molecular sieve, ultrasonicating for 30 min, and then left to stand at room temperature for 24 h. Afterwards, it was dried at 105 °C for 12 h and finally calcininated in a Muffle furnace at 550 °C for 3 h.

3.3. Characterization

The determination of the crystal phase structure was performed as follows: we used the X'Pert Pro automatic powder diffractometer from Panaco, Netherlands, with a working voltage of 30 kV and a working current of 30 mA, using a Cu target, a K α radiation source, a wide angle scanning range of $2\theta = 5^{\circ}-40^{\circ}$, and a scanning rate of $2^{\circ}\cdot\min^{-1}$. For N₂ adsorption–desorption, we used a 3H-2000PS1 specific surface area and pore diameter analyzer from Beijing Besser Instrument Technology Co., Ltd., Beijing, China. The samples were degassed for 3 h under vacuum conditions at 300 °C, and data were collected under a high-purity N₂ atmosphere. The obtained data were analyzed by the BET method, the t-plot method, and the BJH method.

Morphology determination was performed as follows: a SIGMA-type field emission scanning electron microscope from Zeiss (Jane, Germany) was used. The working voltage of the instrument was 2.0 kV, and it was necessary to spray gold before testing to increase the conductivity of the molecular sieve. A transmission electron microscope of the Tecnai G2 F30 S-Twin type from Philips-FEI, The Netherlands, was used for observation. The determination of NH₃-TPD was performed with an Auto Chem II 2920 program temperature chemisorption instrument. First, the sample was pretreated with helium at 550 °C for 0.5 h, then adsorbed at 70 °C for 0.5 h. After that, the physically absorbed NH₃ was removed in helium for 0.5 h, then the sample temperature was increased to 700 °C at a rate of 10 °C·min⁻¹ to obtain a TPD detection signal.

3.4. Catalytic Performance Tests

Bio-*n*-hexadecane (*n*-C₁₆) was obtained by hydrodeoxygenation of fatty acid methyl esters (biodiesel) and distillation, with a purity > 99%. We used bio-*n*-hexadecane as a model compound to evaluate the isomerization property of the Pt/SAPO-11 catalyst. The reaction was carried out continuously in an XL-RL-type tube fixed-bed reactor from Haian Petroleum Scientific Research Instrument Co., Ltd., Nantong, China. The inner diameter of the reaction tube was 1 cm, and the length was 45 cm. Next, 6 g of catalyst was loaded into the reaction tube, and both ends were filled with quartz sand. The ends of the reaction tubes were blocked with asbestos mesh to prevent the loss of quartz sand. A temperature-measuring tube was inserted in the middle of the bed. After filling, we tightened both ends of the reaction tube and mounted it on the experimental setup. Hydrogen and *n*-hexadecane were fed through a mass flow controller and a liquid chromatography metering pump, respectively. Hydrogen pressure was controlled through a cylindrical reducing valve and a backpressure valve.

Before running the device, the gas tightness of the device was checked with soapy water to ensure that the experimental device was gas-tight. Prior to the reaction, the loaded Pt/SAPO-11 catalyst was reduced at 380 °C for 4 h in a high-purity H₂ atmosphere. Then, the temperature was decreased to the reaction temperature, and the reaction parameters were controlled to carry out the hydroisomerization of *n*-hexadecane. The hydroisomerization properties of n-hexadecane were evaluated at a reaction temperature of 300 °C to $380 \,^{\circ}$ C, a reaction pressure of 1 MPa to 3 MPa, a weight hourly space velocity of 1 h⁻¹ to $3 h^{-1}$, and the ratio of H₂/*n*-C₁₆ from 600 to 1400. After leaving the reactor, the product entered the gas-liquid separator, and the liquid product was separated and collected by two continuously arranged gas-liquid separators in order to minimize the interference caused by collecting and to increase the liquid yield. In order to ensure the comparability of the data, the samples were taken at a stationary time interval. Additionally, the liquid in the gas-liquid separator was emptied after the collection was completed to avoid interference with the next group of data. The experiments were conducted by changing different reaction conditions in order to obtain product data over a large conversion range. After each change in conditions, we waited for the system to stabilize before starting product collection and sampling. However, the minimum stabilization time of the system varied according to the changes in gas and liquid velocities, and in actual operation, a large time interval elapsed before emptying and sampling.

The products were qualitatively and quantitatively analyzed by Agilent GC-MS and Shimadzu GC-2014 gas chromatographs, respectively. The GC-MS ramp-up program was held at 50 °C for 3 min and subsequently increased to a maximum temperature of 300 °C at a rate of 20 °C·min⁻¹. It was held for 2 min, with a total program time of 17.5 min. The GC-2014 was performed on a Rtx-5 capillary column (30 m × 0.32 mm × 0.25 µm) and a FID detector. First, 50 °C was held for 3 min, then increased from 50 °C to 300 °C at a rate of 20 °C·min⁻¹ and held for 2 min.

Formulas (1) and (2) were used to calculate the conversion of n-hexadecane (x) and the selectivity (s) of i-hexadecane, respectively.

$$x = \frac{m_1 - m_2}{m_1} \times 100\%$$
 (1)

$$s = \frac{m_3}{m_1 - m_2} \times 100\%$$
 (2)

In the formulas, m_1 and m_2 represent the mass of *n*-hexadecane in the raw materials and products, respectively, *g*; m_3 represents the mass of the isomerized product in the products, g.

4. Conclusions

The catalytic performance of Pt/SAPO-11 was evaluated with bio-aviation kerosene (*n*-hexadecane) by a hydroisomerization reaction. The SAPO-11 molecular sieve synthesized by the hydrothermal synthesis method exhibited regular columnar crystal aggregation, forming a spherical shape. The load of Pt did not affect the AEL structure of SAPO-11, and the Pt/SAPO-11 molecular sieve exhibited an obvious mesoporous structure and acid content. The reaction temperature and weight hourly space velocity had significant effects on the conversion of *n*-hexadecane and the selectivity of *i*-hexadecane, whereas the reaction pressure and the ratio of H₂/*n*-C₁₆ had no obvious influence. Therefore, the Pt/SAPO-11 molecular sieve had a high hydroisomerization rate for *n*-hexadecane, which is beneficial for improving the low-temperature fluidity of bio-aviation kerosene.

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