Conversion of Light Naphtha to Aromatic Hydrocarbons (Part 4)  
Kinetic Study of Hexane Conversion Catalyzed by Platinum Supported on Zeolite L

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The reaction scheme of the aromatization of C₆ hydrocarbons catalyzed by platinum supported on zeolite L (Pt/KL) was investigated using n-hexane, methylcyclopentane and 3-methylpentane as reactants. The aromatization proceeded through a similar scheme to that using conventional non-acidic reforming catalysts. Skeletal isomerization of hexanes proceeded via methylcyclopentane and benzene was formed through the closure of the 1,6-carbon ring from n-hexane.

Based on the experimental results, a kinetic model and rate equations for the reactions of C₆ hydrocarbons over Pt/KL were proposed. The kinetic constants for the n-hexane reactions at 470, 500, and 530°C were determined using experimental data. Activation energies for closure of the 1,6-carbon ring and 1,5-carbon ring from n-hexane were 180.2 and 111.2 kJ/mol, respectively. Using these kinetic parameters, the product distribution for the reaction of C₆ hydrocarbons over Pt/KL could be successfully predicted at various reaction temperatures and pressures.

1. Introduction

Conversion of light naphtha to aromatic hydrocarbons has attracted much attention, since light naphtha is abundant in petroleum fractions and aromatics such as benzene, toluene, and xylenes are important raw materials in the petrochemical industry¹¹).

The aromatization process of light naphtha using ZSM-5 combined with Pt, Zn, or Ga has been extensively studied²³-⁴). ZSM-5 combined with gallium or zinc has a high catalytic activity for the aromatization of light naphtha and LPG. Transformation of hydrocarbons over zeolites containing metals involves very complex reactions and is important from both the industrial and scientific points of view. In the present series of studies, the kinetic studies were conducted on the transformation of light naphtha over Zn- and Ga-ZSM-5 to establish a reaction model, and determine the kinetic parameters for the reactions⁵⁻⁷).

Benzene can be produced from C₆ hydrocarbons using platinum supported on zeolite-L (Pt/KL) with a significantly higher selectivity compared to conventional reforming catalysts. The conventional reforming catalyst (e.g., Pt-Re/Al₂O₃-Cl) increases the yield of aromatic hydrocarbons and accordingly the octane number of C₆ or higher hydrocarbons. However, the catalyst has relatively poor activity and selectivity to produce aromatics from C₆-C₇ paraffins⁸). Platinum supported on non-acidic zeolite L (Pt/KL) is an effective catalyst for the aromatization of n-hexane⁹⁻¹¹), and has been the focus of research on the aromatization of n-hexane because of its high activity and selectivity for aromatics¹²⁻¹⁸).

The improved selectivity of Pt/KL is basically related to the geometry of the zeolite¹⁹⁻²²) and also related to the basicity of the zeolite²³⁻²⁶). Pt/KL have been extensively characterized to account for the high aromatic yield²⁷⁻³３). The high activity and the selectivity of Pt/KL can be ascribed to its unique channels, non-acidity, and the appropriate interaction of platinum particles with zeolite.

Aromatization of hydrocarbons over platinum catalysts have been studied extensively to investigate the mechanism of the reaction, including skeletal isomerization of paraffins and formation of aromatics. An investigation of the roles of metals and acidic sites of the bifunctional catalysts used three different types of catalysts: the first containing only an acidic function, the second only a dehydrogenation function, and the third containing both functions⁴⁰). Isomerization-dehydroisomerization of methylcyclopentane to cyclohexane and benzene generally occurred only over the
catalysts with both functions. The mechanism of the isomerization of 2-, 3-methylpentane, and methycyclopentane over Pt-Al₂O₃ depends on the size of the Pt particles. Skeletal isomerization of C₆ alkanes proceeds via methycyclopentane. The hydrogenolysis of methycyclopentane on supported platinum catalysts is widely known to be structure-sensitive. The reaction scheme of the aromatization over bifunctional catalysts may involve the formation of a 5- or 6-membered ring compound as an intermediate prior to aromatic formation. However, direct 1,6-carbon ring closure with dehydrogenation of C₆ and C₇ alkanes over platinum supported on non-acidic alumina has also been proposed, and more than 80% of aromatics may be formed by direct six-carbon ring formation. Experiments on platinum films detected cyclohexane and benzene in the primary products from 2- or 3-methylpentane in small quantities, but in substantial amounts from n-hexane. Therefore, C₆ rings could be formed by prior isomerization of isohexane giving a linear chain or by cyclization to the C₅ ring, followed by ring enlargement. The general consensus is that the reaction of n-hexane on non-acidic platinum catalysts, as illustrated in Fig. 1, involves 1,6-carbon ring closure of n-hexane to form benzene and 1,5-carbon ring closure to form methycyclopentane, and skeletal isomerization of hexanes proceeds through methycyclopentane. The objectives of this study are to examine the reaction scheme for aromatization of C₆ hydrocarbons over Pt/KL catalyst using n-hexane, methycyclopentane, and 3-methylpentane, to propose a reaction model for the aromatization of n-hexane, and to establish the kinetic model and rate equations, and to determine the kinetic parameters.

2. Experimental

KL zeolite was obtained from Tosoh Co. (TSZ-500). Platinum was supported on the zeolite by the impregnation method, using an aqueous solution of Pt(NH₃)₄Cl₂. The content of platinum metal in the catalysts was 1.0 wt%. The catalysts were dried in air at 80°C for 3 h, and then calcined in air at 300°C for 1 h. The catalysts were pressed, crushed, and sieved in the range of 16-32 mesh.

The reactions were carried out using 0.5 to 1.5 g of catalyst which was diluted to 15 fold with non-acidic silica (16-32 mesh) to prevent excessive decreases in the temperature of the catalyst bed due to the endothermic heat of reaction. Both catalyst and silica were charged into a stainless steel tubular reactor (8 mm I.D.) with an internal thermocouple. The reactor was placed into a fluidized sand bath heater. Prior to the reaction, the catalyst was reduced in-situ under flowing hydrogen at a GHSV (gas hourly space velocity) of 10,000 h⁻¹ under atmospheric pressure for 24 h at 540°C. After the reducing operation, the temperature was decreased to the reaction temperature and C₆ hydrocarbons and hydrogen were introduced into the reactor. The effect of the space velocity on the conversion of C₆ hydrocarbons and product selectivity was investigated by changing the mass of the catalyst and/or by changing the flow rate of the C₆ hydrocarbon-hydrogen feed mixture. The reaction was carried out, unless otherwise indicated, at 500°C under 0.59 MPa, with a hydrogen/C₆ hydrocarbon molar ratio (H₂/HC ratio) of 5.

Conversion, selectivity, and yield of each product are defined as follows: Conversion (wt%) = [1 - (C₆ weight in product/C₆ weight fed to reactor)] × 100; Selectivity (wt%) = [(hydrocarbon weight in products)/(C₆ weight fed to reactor − C₆ weight in products)] × 100; Yield (wt%) = (product weight in product/C₆ weight fed to reactor) × 100.

3. Results and Discussion

3.1. Reaction of C₆ Hydrocarbons

The reaction model for the aromatization of C₆ hydrocarbons over Pt/KL catalyst was investigated by reacting n-hexane and the probable intermediates in aromatization, methycyclopentane and 3-methylpentane.

3.1.1. Reaction of n-Hexane

The reaction of n-hexane was carried out to investigate the change in product yield over Pt/KL with con-
tact time (1/GHSV). Figure 2 shows the change in product distribution with contact time ranging from 7.7 × 10⁻⁶ to 7.7 × 10⁻⁴ h, where temperature, pressure, and H₂/HC ratio were 500°C, 0.59 MPa, and 5 mol/mol, respectively. The yields of benzene, C₁-C₄, and C₅ increased with longer contact time. The yield of C₁-C₄ increased significantly at a high contact time. However, the yield of C₅ decreased above a contact time of 4 × 10⁻⁴ h. The dependence of these yields on contact time suggests that benzene could be a final product from n-hexane and that C₅ could be hydrocracked to give lighter hydrocarbons.

The dependence of the yields of 2-methylpentane (2MP), 3-methylpentane (3MP), and methylcyclopentane (MCP) on contact time differed significantly, compared to those of benzene, C₁-C₄, and C₅. The yields of 2MP and 3MP increased with longer contact time and were greatest at a contact time of 1 × 10⁻⁴ h, when the conversion of n-hexane was 82%. A further increase in contact time led to a decrease in the yield of these components. A similar trend in yield was obtained for MCP. These trends in yields indicate that successive reactions had occurred. In the early stage of the reaction of n-hexane, below a contact time of 2 × 10⁻³ (25% n-hexane conversion), the yield of MCP was higher than that of 2MP or 3MP. This suggests that MCP is an intermediate for the formation of 2MP and 3MP from n-hexane.

3.1.3. Analysis of Reaction Data
Evaluation of the reaction scheme must discriminate primary and non-primary products. Conventional analyses have plotted the concentration of each product against contact time. A positive initial slope indicates a primary product and a zero slope indicates a non-primary product. Reaction of n-hexane over platinum supported on alumina was studied using this method⁴⁸). However, the extrapolation of concentration to zero contact time might fail to provide a clear indication of primary or non-primary products¹²). Therefore, we used the alternative method¹²),⁴⁹) as briefly described below.

Primary products are determined by plotting selectivities for components as a function of conversion of reactant and by extrapolating to zero conversion. When a zero intercept is obtained, the product is non-primary, and when a non-zero intercept is obtained, the product is primary. Furthermore, secondary products can be determined by plotting (selectivity for component)/(conversion of reactant) as a function of conversion of reactant. Primary products diverge at zero conversion, whereas secondary products have finite

Conversion of n-hexane (■). Yield of benzene (●), C₁-C₄ (○), C₅ (△), MCP (■), 2MP (◇), and 3MP (○).

Fig. 2 Changes in Product Yields and Conversion with Contact Time in the Reaction of n-Hexane over Pt/KL

Conversion of MCP (■). Yield of benzene (●), C₁-C₄ (○), C₅ (△), n-hexane (□), 2MP (◇), and 3MP (○).

Fig. 3 Changes in Product Yields and Conversion with Contact Time in the Reaction of MCP over Pt/KL
intercepts and higher-order products have zero intercepts.

The data shown in Figs. 2 and 3 were analyzed to investigate the reaction scheme for \( n \)-hexane using this method. Figure 4 (a), 4 (b) and Fig. 5 (a), 5 (b) show the reactions of \( n \)-hexane and MCP, respectively. Figure 4 (a) indicates that benzene and MCP are predominantly primary products with non-zero intercepts in the \( n \)-hexane reaction. Isohexanes (2MP and 3MP) and cracked products (C1-C4 and C5) have smaller intercepts. Figure 4 (b) shows that isohexanes (2MP and 3MP), C1-C4 and C5 products have finite intercepts, whereas benzene and MCP diverge at lower conversions of \( n \)-hexane, indicating that benzene and MCP are primary products from \( n \)-hexane. Moreover, the yield of MCP showed a maximum in Fig. 2, apparently indicating that MCP is converted to secondary products, such as 2MP and 3MP.

Figure 5 (a), 5 (b) show the plots of selectivity and selectivity/conversion as a function of MCP conversion. Figure 5 (a) demonstrates that benzene and isohexane (2MP and 3MP) are the predominant products with non-zero intercepts. Figure 5 (b) shows that 2MP and 3MP have infinite intercepts, and benzene has a finite intercept, indicating that 2MP and 3MP are primary products and benzene is a secondary product from MCP. Furthermore, the yields of 2MP and 3MP showed maximum values in Fig. 3. The decreases in

the yields of 2MP and 3MP seem to correspond to an increase in the yield of benzene. Therefore, 2MP and 3MP may react to form benzene. A similar trend of the reaction profile is also seen in the case of \( n \)-hexane reaction in Fig. 2.

Figure 6 (a), 6 (b) show the plots of component selectivity and selectivity/conversion as a function of 3MP conversion. MCP has a non-zero intercept in Fig. 6 (a) and an infinite intercept in Fig. 6 (b), indicating that MCP is a primary product from 3MP. Benzene, \( n \)-hexane, and 2MP have non-zero intercepts in Fig. 6 (a), but these components may be secondary or higher-order products, considering the selectivity/conversion profiles shown in Fig. 6 (b).

Based on these experimental results, several features of \( C_6 \) hydrocarbon reactions over Pt/KL can be summarized as follows:

Firstly, benzene is formed from \( n \)-hexane by 1,6-carbon ring closure and may be a final product.

Secondly, ring opening of MCP occurs to give 2MP, 3MP, and \( n \)-hexane.

Thirdly, MCP can be independently formed from \( n \)-hexane or isohexane by 1,5-carbon ring closure, as indicated by the experimental results shown in Fig. 4 (a), 4 (b) and Fig. 6 (a), 6 (b). MCP was the primary product in the conversion of \( n \)-hexane and 3MP at a low contact time. Therefore, ring opening of MCP and ring closure of \( n \)-hexane or isohexane to form MCP...
are reversible, and isohexane can back react to form benzene. In other words, isohexane is not a final product, but rather an intermediate to benzene. This scheme is in agreement with the results of the n-hexane and MCP reactions shown in Figs. 2 and 3, in which the yield of benzene increased with a decrease in the yield of isohexane at a high conversion of n-hexane or MCP.

3.2. Kinetic Analysis

3.2.1. General Reaction Model for C6 Hydrocarbon Reaction

Based on the reaction scheme for C6 hydrocarbons, we propose a general reaction model for the aromatization of C6 hydrocarbons over Pt/KL catalysts as illustrated in Fig. 7. The characteristics of the model are summarized as follows.

(1) To simplify the model, several components are grouped according to the results of the yield profiles shown in Figs. 2 and 3, that is, with the dependence of selectivity on contact time, hydrocracked gases of C1-C4 (HG); n- and isopentane (PE); methylcyclopentane (MCP); 2- and 3-methylpentane (IHE); n-hexane (HE); benzene (BZ); and hydrogen (H2).

(2) n-Hexane and isohexane undergo hydrocracking to form C1-C4 or pentane and C1-C4.

(3) Pentane produced by hydrocracking of n-hexane or isohexane is hydrocracked to form C1-C4.

(4) Skeletal isomerization between n-hexane and isohexane occurs via methylcyclopentane.

3.2.2. Rate Equations

The rate equation for each basic reaction illustrated in Fig. 7 is given as follows.

(i) Benzene formation from n-hexane

\[ \text{n-C}_6 \rightarrow \text{BZ} + 4\text{H}_2 \]

The rate equation for benzene formation from n-hexane by 1,6-carbon ring closure is given below, assuming a first order reaction with respect to partial pressure of n-hexane:

\[ r_1 = \frac{k_1}{K_{p1}} P_{\text{HE}} \left( K_{p1} - \frac{P_{\text{BZ}} \cdot P_{\text{H}_2}^4}{P_{\text{HE}}} \right) \]  \hspace{1cm} (1)

The reverse reaction is represented using the equilibrium constant, assuming a first order and fourth order reaction with respect to the partial pressure of benzene and hydrogen, respectively.

(ii) MCP formation from n-hexane

\[ \text{n-C}_6 \rightarrow \text{MCP} + \text{H}_2 \]

The rate equation for MCP formation from n-hexane by 1,5-carbon ring closure is given below, assuming a first order reaction with respect to the partial pressure of n-hexane:

\[ r_2 = \frac{k_2}{K_{p2}} P_{\text{HE}} \left( K_{p2} - \frac{P_{\text{MCP}} \cdot P_{\text{H}_2}}{P_{\text{HE}}} \right) \]  \hspace{1cm} (2)

The reverse reaction (ring opening) is represented using the equilibrium constant, assuming a first order reaction with respect to the partial pressure of MCP and hydrogen.

(iii) MCP formation from isohexane

\[ \text{i-C}_6 \rightarrow \text{MCP} + \text{H}_2 \]

The rate equation for MCP formation from isohexane by 1,5-carbon ring closure and the reverse reaction are similar to those for n-C6 \( \rightarrow \) MCP + H2:

\[ r_3 = \frac{k_3}{K_{p3}} P_{\text{HE}} \left( K_{p3} - \frac{P_{\text{MCP}} \cdot P_{\text{H}_2}}{P_{\text{HE}}} \right) \]  \hspace{1cm} (3)

(iv) Hydrocracking of n-hexane and isohexane

\[ \text{n-C}_6 + \text{a} \text{H}_2 \rightarrow \text{b} \text{HG} \]

\[ \text{n-C}_6 + \text{c} \text{H}_2 \rightarrow \text{d} \text{HG} + \text{C}_5 \]

\[ \text{i-C}_6 + \text{a} \text{H}_2 \rightarrow \text{b} \text{HG} \]

\[ \text{i-C}_6 + \text{c} \text{H}_2 \rightarrow \text{d} \text{HG} + \text{C}_5 \]

The rate equations for hydrocracking of n-hexane
and isohexane to give light hydrocarbons (HG) or HG and pentane are given below, assuming a first order reaction with respect to the partial pressure of n-hexane or isohexane and hydrogen:

\[-r_4 = k_4 P_{HE} \cdot P_{H_2} \] (4)
\[-r_5 = k_5 P_{HE} \cdot P_{H_2} \] (5)
\[-r_6 = k_6 P_{IHE} \cdot P_{H_2} \] (6)
\[-r_7 = k_7 P_{IHE} \cdot P_{H_2} \] (7)

(v) Hydrocracking of pentane

\[C_5 + H_2 \rightarrow \text{HG} \]

As well as the hydrocracking of n-hexane or isohexane, the rate equation for hydrocracking of pentane to give light hydrocarbons (HG) is given below:

\[-r_8 = k_8 P_{P} \cdot P_{H_2} \] (8)

The rate of formation or consumption of each component can be derived from Eqs. (1) to (8) as follows:

\[r_{HG} = -b\, r_4 - d\, r_5 - b\, r_6 - d\, r_7 - f\, r_8 \] (9)
\[r_{PE} = -r_5 - r_7 + r_8 \] (10)
\[r_{IHE} = r_3 + r_6 + r_7 \] (11)
\[r_{HE} = r_1 + r_2 + r_4 + r_5 \] (12)
\[r_{MCP} = -r_2 - r_3 \] (13)
\[r_{BZ} = -r_1 \] (14)
\[r_{H_2} = -4\, r_1 - r_2 - r_3 + a\, r_4 + c\, r_5 + a\, r_6 + c\, r_7 + e\, r_8 \] (15)

Stoichiometric coefficients of reactions for the hydrocracking of n-hexane and isohexane were experimentally obtained in terms of carbon number and hydrogen number of hydrocracked C1-C4 (HG; C2.21H6.42): a = 1.72, b = 2.72, c = 0.45, d = 0.45, e = 1.27, and f = 2.27.

3.2.3. Determination of Rate Constants

Equilibrium constants, Kp1, Kp2, and Kp3, shown in the above rate equations, were calculated from thermodynamic data. The rate equations include eight unknown parameters, k1-k8. These parameters were estimated by treating the kinetic data of n-hexane reactions at 470, 500, and 530°C, separately. The rate constants were calculated using a nonlinear regression program based on Marquard’s algorithm. As shown in Fig. 8, the rate constants evaluated at different temperatures were used to determine the activation energy and frequency factor, using the Arrhenius relationship

\[k_i = k_{0i} \exp(-E_{Ai}/RT)\]

A least-squares fitting program was used to obtain the slope and the intercept for lnk_i versus 1/T values. From the slope and intercept, the activation energy and frequency factor were calculated and presented in Table 1, together with the rate constants at 470, 500, and 530°C.

Activation energies for 1,6-carbon ring closure of n-hexane (k1) and 1,5-carbon ring closure (k2) were 180.2 and 111.2 kJ/mol, respectively. The ratio of 1,6- to 1,5-carbon ring closure (k1/k2) was 1.17 at 470°C and increased with higher temperature. Figure 8 also shows that the rate of 1,6-carbon ring closure (k1) dominates at high temperatures, whereas the rate of 1,5-carbon ring closure exceeds that of 1,6-carbon ring closure below about 460°C. A high ratio of 1,6- to 1,5-carbon ring closure of n-hexane over Pt/KL led to a decrease in

![Fig. 8 Arrenhius Plot of the Rate Constant for Each Elementary Reaction over Pt/KL](image)

Table 1 Rate Constants, Activation Energy, and Frequency Factor for C6 Hydrocarbon Reactions

<table>
<thead>
<tr>
<th>ki</th>
<th>Rate constant [kg-mol^{-1}·m^{-3}·h^{-1}·MPa^{-1}]</th>
<th>Frequency factor [kg-mol^{-1}·m^{-3}·h^{-1}·MPa^{-1}]</th>
<th>Activation energy [kJ·mol^{-1}]</th>
</tr>
</thead>
<tbody>
<tr>
<td>k1</td>
<td>240.9</td>
<td>1210 × 10^3</td>
<td>180.2</td>
</tr>
<tr>
<td>k2</td>
<td>206.3</td>
<td>1277 × 10^6</td>
<td>111.2</td>
</tr>
<tr>
<td>k3</td>
<td>1899.3</td>
<td>3372 × 10^4</td>
<td>160.5</td>
</tr>
<tr>
<td>k4</td>
<td>29.2</td>
<td>1302 × 10^4</td>
<td>194.4</td>
</tr>
<tr>
<td>k5</td>
<td>20.5</td>
<td>1688 × 10^4</td>
<td>198.1</td>
</tr>
<tr>
<td>k6</td>
<td>40.0</td>
<td>1326 × 10^4</td>
<td>177.7</td>
</tr>
<tr>
<td>k7</td>
<td>27.3</td>
<td>1027 × 10^4</td>
<td>193.1</td>
</tr>
<tr>
<td>k8</td>
<td>11.7</td>
<td>2463 × 10^9</td>
<td>260.8</td>
</tr>
</tbody>
</table>

a) For k1, k5, k6, k7, and k8: kg-mol·m^{-3}·h^{-1}·MPa^{-3}.
C1-C5 yield and thus an increase in benzene yield\(^{47}\). Our results also indicate that the formation of benzene by 1,6-carbon ring closure of n-hexane is promoted by higher reaction temperatures because of the higher activation energy of 1,6-carbon ring closure \((k_1)\), compared to that of 1,5-carbon ring closure \((k_2)\). However, that the rates of hydrocracking of n-hexane and isohexane also increased with higher temperature, leading to a decrease in the yield of benzene. Therefore, an optimum operating temperature is possible for the aromatization of n-hexane over Pt/KL.

3.2.4. Simulation of Product Distribution

Figures 9 (a), 9 (b), 9 (c) compare the experimental results and predicted values of product distribution for the reaction of n-hexane over Pt/KL at 470, 500, and 530°C. Good correlations are observed between experimental and predicted values, indicating that the proposed model of the reaction network and kinetics over Pt/KL fit well for the reaction of n-hexane. The reaction model and rate constants were also evaluated in terms of the conversion of a mixture of C6 hydrocarbons as a starting feedstock at 500°C, 0.40 MPa, and H2/HC of 5 mol/mol. The mixture of C6 hydrocarbons consisted of 57.8 wt% of n-hexane, 26.2 wt% of isohexane, and 16.0 wt% of methylcyclopentane. Figure 10 compares the experimental and predicted values of product distribution, showing good agreement in the product distribution even for different reactants and different reaction pressures.

4. Conclusions

A reaction model of C6 hydrocarbon aromatization over Pt/KL catalyst was established based on the investigation of reactions using n-hexane, methylcyclopentane, and 3-methylpentane as reactants. The reactions proceeded through a scheme similar to that over conventional non-acidic platinum catalyst. Rate equations for the conversion of C6 hydrocarbons over Pt/KL were developed and kinetic constants for each elementary reaction were determined based on the kinetic data. The product distribution could be successfully predicted using the kinetic model and the determined kinetic parameters.

The reaction model to predict the product distribution can be used for investigating the optimum operat-
Composition of the reactant: n-hexane, 57.8; isohexane, 26.2; methylcyclopentane, 16.0 wt%.

Pressure: 0.40 MPa, H2/HC: 5 mol/mol, and temperature: 500°C. n-Hexane (●), benzene (○), C1-Ci (△), MCP (■), isohexane (□), and H2 (●).

Fig. 10 Comparison of Experimental Results and Predicted Values for the Reaction of C6 Hydrocarbons Mixture over Pt/KL

References

要 旨

軽質ナフサからの芳香族製造（第 4 報）
白金担持 L 型ゼオライト上でのヘキサン転化反応速度

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Pv/KL 触媒上でのヘキサンの芳香化反応スキャンについて，芳香族中の間体と考えられる各種炭水素の反応速度を
行い検討した。その結果，Pv/KL 触媒上でのヘキサンの反応は
白金の一元的な触媒作用により進行することが明らかとなっ
た。反応速度結果に基づき，Pv/KL 触媒上での一般化反応モデ
ルを提案し，速度式の決定を行った。決定した反応速度式を用
いて，異なる反応物，反応条件（温度，圧力）下で良好に生成
物分布をシミュレーションすることができた。

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Keywords

Light naphtha, Aromatization, Kinetics, Zeolite L, Reforming

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