Adsorption and Phase Equilibria for Hydrogen Storage System Based on Dehydrogenation Reaction of Naphthenes, and Its Process Design

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A hydrogen storage medium, using a dehydrogenation reaction of naphthene in a membrane reactor, is proposed for fuel cell systems. In this system, the permeation rate of hydrogen is not high so that the residual hydrogen, not passing through the membrane, must be recovered. A gas-liquid separator and an adsorption column were evaluated. For the design of the separator, the hydrogen solubility has been already reported for aromatic hydrocarbon, naphthenes, and equimolar mixtures. In this study, adsorption on activated carbon was measured in hydrogen flow saturated with pure benzene, cyclohexane, methycyclohexane, and toluene, and the equimolar mixtures, benzene + cyclohexane and methycyclohexane + toluene. The measurement was carried out by a new apparatus specially designed for this study, based on a flow type method, and equipped with gas chromatograph with both FID and TCD. In the measurement, the breakthrough curve and the specific mass adsorbed were measured at 347 kPa and 303.15 K. The adsorption mechanism was also discussed based on the breakthrough curves for the pure adsorbates and mixtures. Finally, the required mass of adsorbate, activated carbon, was estimated for the system by assuming the reaction rate and the hydrogen permeation ratio in the membrane reactor.

Keywords
Adsorption, Hydrogen storage, Activated carbon, Hydrogen solubility, Equation of state, Breakthrough curve

1. Introduction

Hydrogen is an extremely important potential clean energy source for the fuel cell vehicle (FCV). Some national projects have been promoted since the 1990s in Japan, and various new technologies have been proposed for hydrogen storage.

Figure 1 shows a method of chemical hydrogen storage based on the dehydrogenation reactions of naphthene1). The theoretical mass content of hydrogen is 7.19 mass% for cyclohexane, and 6.16 mass% for methycyclohexane, respectively, using these reactions. A bench scale hydrogen supply system3),4) has been already demonstrated by Chiyoda Corp. in Japan, whereas we have proposed a hydrogen supply system based on a palladium membrane reactor.

Figure 2 shows the flow diagram of our proposed system1),2),(7)~(10). Naphthene is passed from a fuel tank to a membrane reactor, and catalytically converted to hydrogen and aromatic hydrocarbon. The aromatic hydrocarbon is returned to the fuel tank. The thermophysical properties necessary for the process design are also illustrated. A synthetic type apparatus has been reported, and hydrogen solubility was measured for two pure aromatics, benzene and toluene, and two pure naphthenes, cyclohexane and methycyclohexane, and two binary mixtures, benzene + cyclohexane, and methycyclohexane + toluene, at 303.15 K. The parameters of the Peng-Robinson (PR) equation of state11),(12) were optimized to evaluate the vapor-liquid equilibrium in the gas separator1),(10),(11). The solid-liquid equilibria were also measured for benzene + cyclohexane, and
methylcyclohexane + toluene using an apparatus based on a direct temperature measuring method. The present study investigated adsorption to design an adsorption column for the purification of hydrogen from the gas separator using a specially designed apparatus based on a flow type method. In particular, the gas chromatograph was equipped with hydrogen-flame ionization detector (FID) and thermal conductivity detector (TCD) to measure the adsorption in the hydrogen flow saturated with the vapor of the two mixtures, benzene + cyclohexane, and methylcyclohexane + toluene. The breakthrough curve and the specific mass adsorbed were measured at 347 kPa and 303.15 K. The adsorption mechanism was investigated using the breakthrough curves for pure adsorbate and the mixtures. Finally, the required mass of the adsorbent, activated carbon, was estimated for design of the fuel cell system by assuming the reaction rate and the hydrogen permeation ratio in the membrane reactor.

2. Experimental Section

2.1. Materials

Hydrogen (P-grade one, purity no less than 99.99 %) was purchased from Takachiho Chem. Ind. Co., Ltd., Tokyo, Japan. Benzene (99.5 %), cyclohexane (99.5 %), methylcyclohexane (98.0 %), and toluene (99.5 %), were special reagent grades from Wako Pure Chem. Ind., Ltd., Osaka, Japan. All chemicals were used without further purification. The adsorbent was charcoal, activated, broken parched from Wako Pure Chem. Ind., Ltd., Tokyo, Japan. The stated particle diameter was 0.2 to 1.0 mm, and was classified with 18/36 mesh before use. The physical properties of adsorbents were estimated by measuring the isotherm of liquefied nitrogen at 77 K. The automatic analyzer, Belsorp 18plus, Bel Japan Inc., Osaka, Japan, showed the BET specific surface area was 676 m²/g, the total pore volume 0.309 cm³, and the mean pore diameter 1.82 nm.

2.2. Equipment and Procedure

Figure 3 shows a schematic diagram of the experimental apparatus. The apparatus was based on a flow method, and consisted mainly of gas preparation, adsorption column, and analysis functions. Hydrogen flow supplied from the cylinder was saturated with the vapor pressure of adsorbate in the gas preparation part. The saturation cell was a glass tube, HPG-96, Taiatsu Techno Corp., Tokyo, Japan with inner volume of 96 cm³, and maximum safe pressure up to 2 MPa. The saturation cell included a stirrer tip driven by a water proof magnetic stirrer MS-101, Asone Corp., Tokyo, Japan. After loading the cell with about 30 cm³ of the adsorbate solution, the cell was connected with a 4way valve and placed in a low temperature bath, TRL-N11 L, Thomas Kagaku Co., Ltd., Tokyo, Japan. The bath was equipped with a 300-W heater and built-up chiller unit to maintain the temperature at 298.15 ± 0.05 K. The hydrogen flow was passed through a spherical glass filter, G3, Kinoshita Rika Kogyo Co., Tokyo, Japan, and bubbled into the solution. The diameter of the hydrogen bubbles was estimated as 20 to 30 μm. Therefore, the hydrogen was saturated to the vapor pressure of adsorbate, and sent to the adsorption column.

The adsorption column consisted of a glass column,
6010-21102, GL Science Inc., Tokyo, Japan, with internal diameter of 10 mm and length of 150 mm, and safe pressure up to 3.9 MPa. After loading about 3 g of the adsorbent, activated carbon, the column was connected with the 4-way valve, and set in a constant temperature bath, TRL101FEZ, Thomas Kagaku Co., Ltd., Tokyo, Japan and the temperature was maintained at 303.15 ± 0.01 K. The inlet and outlet pressures of the column were measured by PG-100KU and PG-10KU, Kyowa Electronic Instruments Co., Ltd., Tokyo, Japan. The capacity and resolution were 10 MPa and 0.001 MPa for the PG-100KU, and 1 MPa and 1 kPa for the PG-10KU, respectively. After passing though the adsorption column, the hydrogen flow was controlled and separated into two flow lines using two mass flow controllers, SEC-E440, HORIBA Ltd., Tokyo, Japan. One flow line was directly connected with the FID of a gas chromatograph, GC-4000 DSTF-20B, GL Science Inc., Tokyo, Japan, and the other with the column of the gas chromatograph, or the cold trap with volume of about 50 cm³ and wet flow meter. The column was connected the TCD in the gas chromatograph. The flow rate for the FID was set to 39 cm³/min by the mass controller. In the other line, the flow rate was set to 100 cm³/min. The pressure was adjusted to 347.0 ± 5.0 kPa using the gauge pressure with a capacity of 1 MPa. The actual flow rate, indicated values 39 ± 100 cm³/min, was estimated to be \( F = 1.565 \times 10^{-6} \) mol/s measured by a wet flow meter, W-NK-0.5A, Shinagawa Co., Ltd., Tokyo, Japan, with resolution of 0.001 L. After controlling the flow rate, the flow line was changed between the cold trap or the column with the 4-way valve.

The mass in the cold trap was measured with an electronic balance, BX-3200H, Shimadzu Corp., Kyoto, Japan, with maximum capacity of 3.2 kg and resolution of 0.01 g. The gas chromatograph was a GC-4000 DSTF-20B, GL Science Inc., Tokyo, Japan, with FID and TCD. The capillary type column, just connected with TCD, had internal diameter of 0.53 mm and length of 2500 mm, Pora plot on Plot fused silica, GL Science Inc., Tokyo, Japan. The flow rate of the carrier gas was 30 cm³/min He, and the column temperature 423 K. The automatic 6-way valve was used to introduce the sample gas at 4-s intervals.

The two water baths were enclosed in an air chamber. To avoid condensation of adsorbate in the hydrogen flow, the temperature was maintained at 313 K with heaters. The temperature of the baths was measured with a thermistor thermometer SXA-33, Technoseven Co., Yokohama, Japan, with resolution of 0.01 K and precision of 0.03 K.

3. Result and Discussion

3.1. Adsorption of Pure Benzene

This experiment was carried out using the FID, and the cold trap with wet flow meter. Figure 4 shows a typical signal from the FID for the hydrogen flow, saturated with benzene, passing through the adsorption column at 303.15 K. The procedure of the adsorption experiments is described below:

Initially, the two 4-way valves allowed the hydrogen flow to pass through the valves. To start the measurement, the hydrogen flow was connected with the saturation cell, seen at 80 s in Fig. 4. The signal rapidly
increased, and reached a constant value, indicating saturation of the hydrogen flow with benzene vapor. The hydrogen flow was changed to the adsorption column with the other valve at 600 s in Fig. 4. The signal rapidly decreased, indicating adsorption was started. The signal increased again around 2500 s, showing adsorption was completed. These procedures obtained the breakthrough curve for the pure adsorbate.

After adsorption was completed, the column was removed from the bath. The mass increase was measured by the balance. The mass increase indicates the total mass adsorbed, which was also estimated by numerical integration of the breakthrough curve. The total mass adsorbed corresponded to the hatched area in Fig. 4. This estimation required the total mole flow rate, \( F \), and the mole fraction of benzene in the hydrogen flow, \( y_2 \). The mole flow rate of hydrogen was obtained from the indicated total volume in the wet test meter. The total mole flow rate was assumed to be the same as that of hydrogen because of the low vapor pressure of benzene. The mole fraction of benzene, \( y_2 \), was evaluated by the trapped mass in the cold trap. In our previous study, hydrogen solubility in benzene was reported at 303.15 K. The temperature of the saturation cell was slightly lower, but the mole fraction of benzene in hydrogen flow was also estimated from the equation of state.

Figure 5 shows the mole fraction of benzene from the trapped mass, and that estimated from the Peng-Robinson (PR) equation of state\(^{11,12} \). The PR eq. and its mixing rule are given by:

\[
P = \frac{RT}{v-B} - \frac{a}{v^2 + 2Bv - B^2}
\]

\[
a = \sum_{i,j} (1 - k_{ij})(a_ia_j)^{0.5} x_i x_j
\]

where \( a_i \) is the attraction parameter of component \( i \), \( b_i \) the excluded volume parameter, \( v \) the molar volume, and \( x_i \) mole fraction. The binary parameters, \( k_{ij} \) and \( I_{ij} \), have been already optimized from the experimental data for the mole fraction of the liquid phase\(^{7} \). The calculation method has been described elsewhere\(^{7,9} \). The experimental measurement of mole fraction in vapor phase agreed well with that of the calculation as shown in Fig. 5. Therefore, in this study, the mole fraction of pure adsorbate in the hydrogen flow was estimated from the trapped mass.

Table 1 compares the adsorbed mass with the value
from the numerical integration of the breakthrough curve for benzene. The two values perfectly matched, so the former was employed as the experimental data.

The adsorption isotherm of benzene on activated carbon has been reported at the same temperature\(^{13}\).

**Figure 6** compares the experimental data with the literature. The specific area of adsorbate was 826 m\(^2\)/g in the literature, higher than that of the experiment. However, the experimental data was of similar order. The experimental methods were different, but the trend was almost the same.

### 3.2. Adsorption of Other Adsorbates

Similarly, **Fig. 7** shows the breakthrough curves for the four adsorbates, benzene, cyclohexane, methylcyclohexane, and toluene.

**Table 2** lists the specific masses adsorbed. Interesting behavior was seen in the experimental data for the specific masses. In our previous study, the hydrogen solubility was measured for the four adsorbates at the same temperature\(^{7,8}\).

**Figure 8** shows the summary of the previous hydrogen solubility data\(^7\). The hydrogen solubility was highest for methylcyclohexane and lowest for benzene. Hydrogen solubility generally increased with higher temperature. Therefore, hydrogen solubility depended on the number of microscopic voids and the thermal motion of the adsorbate molecules. Methylcyclohexane and cyclohexane have two molecular forms, the chair and boat structures, whereas benzene and toluene have just one molecular form. In addition, the methyl groups of methylcyclohexane and toluene have bulky molecular structures\(^7\). Consequently, the order of hydrogen solubility is as follows:

\[
C_7H_{14} > C_6H_{12} > C_7H_8 > C_6H_6
\]

The specific mass adsorbed followed a similar order for the four adsorbates. The specific mass adsorbed was highest for benzene and lowest for methylcyclohexane. Generally the specific mass adsorbed decreased with higher temperature. Therefore, the microscopic flatness of the molecule, and the voids among the molecules were important factors for the specific mass adsorbed. In other words, molecules

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**Table 1** Comparison of Mass Adsorbed on Activated Carbon in Hydrogen Flow Saturated with Benzene at 347 kPa and 303.15 K

| Method | Increased mass in column | Estimated from numerical integration |
|--------|--------------------------|------------------------------------|
| Mass adsorbed [g] | 0.6265 | 0.6236 |

**Table 2** Comparison of Specific Mass Adsorbed on Activated Carbon in Hydrogen Flow Saturated with Vapor of Pure Substance at 347 kPa and 303.15 K

| Specific amount adsorbed q [mol/kg] | Benzene | Cyclohexane | Methylcyclohexane | Toluene |
|------------------------------------|---------|-------------|-------------------|--------|
|                                    | 3.489   | 1.959       | 1.585             | 2.453  |

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with microscopic flatness and no bulky side groups had high adsorption ability. Therefore, the order of specific mass adsorbed should be as follows:

C7H14 < C6H12 < C7H8 < C6H6

This order was perfectly the inverse to that for hydrogen solubility.

3.3. Adsorption of Two Vapor Mixture, Benzene + Cyclohexane, and Methylcyclohexane + Toluene

These experiments were carried out using the FID, and the gas chromatograph equipped with the TCD. In the measurement, an equimolar mixture of benzene + cyclohexane, or methylcyclohexane + toluene, was loaded in the saturation cell. The breakthrough curves were obtained for the hydrogen flow saturated with the bubble point vapor of the mixtures. Prior to the measurements, the molar ratios were estimated of benzene : cyclohexane and methylcyclohexane : toluene in the hydrogen flow. In our previous study\textsuperscript{7)}, the vapor liquid equilibria were calculated for hydrogen + benzene + cyclohexane, and hydrogen + methylcyclohexane + toluene using the PR eq. at 303.15 K. Assuming that the binary parameters, \( k_{ij} \) and \( l_{ij} \), at the temperature of the saturator, 298.15 K, would have the same values at 303.15 K, the ratio in the hydrogen flow was estimated for the liquid phase saturated with the equimolar mixture of benzene + cyclohexane, or methylcyclohexane + toluene at 298.15 K.

Figure 9 shows the estimated composition and ratio of benzene : cyclohexane in the vapor phase at 303.15 K. The calculation method was basically the same as that used in Fig. 5. According to the calculation based on the PR eq., the molar fractions of benzene and cyclohexane in the hydrogen flow at 347 kPa were estimated to be \( y_2 = 0.0219 \) and \( y_3 = 0.0220 \), respectively. In this case, the ratio of benzene in the vapor was estimated to be \( y_2/(y_2 + y_3) = 0.4989 \). Similarly, the mole fractions of methylcyclohexane and toluene were estimated to be \( y_2 = 0.0106 \), and \( y_3 = 0.0062 \), respectively. Therefore, the ratio of methylcyclohexane was estimated to be \( y_2/(y_2 + y_3) = 0.6396 \).

Figure 10 compares the breakthrough curves for the two systems using the FID data. Findings for the hydrogen flow, saturated with pure adsorbate, are also shown. The two step breakthrough was observed for the two systems. In the case of benzene + cyclohexane, the first breakthrough occurred at the same time as that for pure cyclohexane. The second breakthrough was slightly later than that for pure benzene. Similar findings was also obtained for the system of methylcyclohexane + toluene. To investigate the breakthrough curve in detail, composition analysis was carried out using the gas chromatograph with the TCD.

Benzene, cyclohexane, methylcyclohexane, and toluene show different sensitivities in the FID and TCD.
Therefore, the sensitivity was checked for benzene and toluene.

Figure 11 compares the FID and TCD signals. The TCD signal was normalized with the FID signal. Using this relationship, the breakthrough curve for benzene + cyclohexane was separated into those for the pure adsorbates.

Figure 12 shows the breakthrough curves obtained for benzene, cyclohexane, and benzene + cyclohexane. The combined TCD signal of benzene + cyclohexane is also illustrated. The combined TCD signal agreed well with that for the FID signal of benzene + cyclohexane. From the final height of the TCD signal, the mole fractions of benzene and cyclohexane were estimated to be $y_2 = 0.0185$, and $y_3 = 0.0201$, respectively. Therefore, the ratio of benzene in the vapor was $y_2/(y_2 + y_3) = 0.4792$. This value was close to the estimated $y_2/(y_2 + y_3) = 0.4989$.

Figure 13 shows the mechanism of adsorption for hydrogen flow saturated with an equimolar mixture of benzene + cyclohexane. So-called competitive adsorption was thought to occur. At first, cyclohexane was adsorbed on the activated carbon because of the high diffusivity. However, the specific mass of benzene adsorbed was much larger than that of cyclohexane. Benzene has lower diffusivity than cyclohexane, so the exchange of adsorbate from cyclohexane to benzene occurred on the activated carbon.

3.4. Estimation of Activated Carbon Required

Using the experimental data of adsorption and hydrogen solubility, the required mass of activated carbon was estimated in the process shown in Fig. 2. The estimation was carried out for cyclohexane or methylcyclohexane as a fuel. The assumptions were as follows:

(1) The inner volume of the fuel reservoir was 55 L. The reservoir was filled with cyclohexane or methyl-
cyclohexane at 298.15 K.
(2) Conversion in the membrane reactor was assumed to be \( x \% \), and just \( \varepsilon \% \) of hydrogen was passed through the membrane.
(3) The residuals were sent to the decanter, and separated into two phases, vapor and liquid, at 347 kPa and 303 K.

(4) The vapor was sent to the adsorption column packed with the adsorbent, activated carbon at 303 K. The required mass of activated carbon was estimated from the breakthrough curve shown in Fig. 7.

**Table 3** lists the estimates of hydrogen, naphthene, and aromatic in the system, and the mass of absorbent required to obtain pure hydrogen.

**Figure 14** shows the corresponding part in the system of Fig. 2. The density of fuels, cyclohexane, and methylcyclohexane were obtained from the literature\(^{14}\).

In the membrane reactor, values of \( x = 50 \% \) and \( \varepsilon = 50 \% \) were assumed. In the separator, the vapor-liquid equilibrium was evaluated by the PR eq. for the liquid composition of the experiment. Then, the mole ratio of the vapor phase to the feed, \( D/F \), was approximated. The hydrogen obtained from the adsorption column was greater with methylcyclohexane than with cyclohexane. In addition, the required mass of adsorbent was also less for methylcyclohexane than for cyclohexane. Consequently, methylcyclohexane was the optimum hydrogen storage medium.

### 4. Conclusion

The breakthrough curve, and the specific mass adsorbed on the activated carbon were measured in hydrogen flow saturated with four pure substances, benzene, cyclohexane, methylcyclohexane, and toluene,
and the equimolar mixtures, benzene + cyclohexane and methylcyclohexane + toluene, at 347 kPa and 303.15 K. The microscopic flatness of the molecule, and the voids among the molecules were important factors for the specific mass adsorbed. In other words, molecules with microscopic flatness and no bulky side groups had large adsorption ability. The order of specific mass adsorbed was as follows: 

\[
C_7H_{14} > C_6H_{12} > C_7H_8 > C_6H_6
\]

This order was perfectly the inverse of that for the hydrogen solubility in our previous study. In addition, so-called competitive adsorption was thought to occur for benzene + cyclohexane.

In this study, the required mass of the activated carbon was estimated in the proposed fuel cell system using the experimental data of adsorption and hydrogen solubility. Comparing cyclohexane and methylcyclohexane as a hydrogen storage medium, cyclohexane has larger mass content of hydrogen than methylcyclohexane. However, considering the specific mass adsorbed, and the breakthrough period in the membrane reactor condition of the reaction rate, \( x = 50 \% \), and the permeation \( \epsilon = 50 \% \), methylcyclohexane seems to be preferable material as the hydrogen storage medium. Further improvement in the membrane reactor is a key to success in the fuel cell system.

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### References

1) Itoh, N., Xu, W. C., Hara, S., Sakaki, K., *Catal. Today*, 56, 307

J. Jpn. Petrol. Inst., Vol. 59, No. 3, 2016
Fig. 14 Process Flow Diagram and the Estimated Conditions

2) Kariya, N., Fukuoka, A., Ichikawa, M., Appl. Catal., 233, 91 (2002).
3) Okada, Y., Yasui, M., Kagaku Kogaku, 77, 46 (2013).
4) Okada, Y., Sasaki, E., Watanabe, E., Hyodo, S., Nishijima, H., Int. J. Hydrogen Energy, 34, 1348 (2006).
5) Gratz, J., Drolet, B., Kluyskens, D., Sandmann, F., Ullmann, O., Int. J. Hydrogen Energy, 19, 169 (1994).
6) Gratz, J., Baselt, J. B., Ullmann, O., Wendt, H., Int. J. Hydrogen Energy, 19, 169 (1994).
7) Tsuji, T., Shinya, Y., Hiaki, T., Itoh, N., Fluid Phase Equilibria, 238-229, 499 (2005).
8) Tsuji, T., Sue, K., Hiaki, T., Itoh, N., Fluid Phase Equilibria, 257, 183 (2007).
9) Tsuji, T., Hiaki, T., Itoh, N., Fluid Phase Equilibria, 261, 375 (2007).
10) Itoh, N., Watanabe, S., Kawasoe, K., Sato, T., Tsuji, T., Desalination, 234, 261 (2008).
11) Peng, D. Y., Robinson, D. B., Ind. Eng. Chem. Fundam., 15 (1976).
12) Stryjek, R., Vera, J. H., Can. J. Chem. Eng., 64, 323 (1986).
13) Yun, J., Choi, D., J. Chem. Eng. Data, 42, 894 (1997).
14) Reddick, J. A., Bunger, W. B., Sakano, T. K., “Organic Solvents Physical Properties and Methods of Purification 4th Ed.,” John Willy & Sons, New York (1986).
要旨
ナフタレン脱水素反応を用いた水素貯蔵システムにおける吸着と相平衡およびプロセス設計

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ナフタレンの脱水素反応を利用した燃料電池用の水素貯蔵システムを提案した。このシステムでは脱水素反応器にパラジウム系のメンプレンリアクターを使用するが、水素透過量があまり大きくないので未透過の水素も回収する必要がある。既報では水素および未反応物を冷却して気液分離し、気相についてはさらに吸着カラムを用いる方法を考えて、ナフタレン、芳香族およびその等物質量混合物の水素溶解度を報告した。本報ではナフタレン、芳香族、およびその等物質量混合物の蒸気で飽和させた水素気流に対する活性炭への吸着実験を行った。装置は本研究のために新たに構築した流連法に基づくものであり。TCDおよびFIDのいずれも搭載したガスクロマトグラフが組み込まれている。この装置を用いてベンゼン、シクロヘキサン、メチルシクロヘキサン、トルエン、およびベンゼン+シクロヘキサン、メチルシクロヘキサン+トルエンの破断曲線、非吸着量を気相圧力347 kPa、温度303.15 Kにおいて測定した。最後に、メンプレンリアクターのナフタレン反応率と水素の透過率を仮定し、水素溶解度および吸着データから水素精製に必要な活性炭質量を見積もった。

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