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Removal of Basic Compounds and Dealkylation of Alkyl Polycyclic Aromatic Hydrocarbons in Vacuum Gas Oil

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We propose a novel method to upgrade heavy oil. This method utilizes dealkylation of alkyl polycyclic aromatic hydrocarbons on a silica monolayer solid acid catalyst to produce alkanes with preserved alkyl chain length and aromatic hydrocarbons without alkyl groups, resulting in maximization of the yields of value-added products, alkanes suitable for diesel fuel and alkylbenzenes suitable for gasoline and chemical feedstocks. Basic compounds in vacuum gas oil were found to inhibit the reaction, but were removed by treatment with solid acids such as strongly acidic cation exchange resin and amorphous silica-alumina. Drying of the silica-alumina significantly enhanced the removal rate. The silica-alumina was repeatedly usable by calcination in an oxygen flow. After the treatments for the removal of basic compounds, dealkylation of alkyl polycyclic aromatic hydrocarbons proceeded at 673 K. However, rapid catalyst deactivation was observed. Higher reaction temperature of 723 K suppressed deactivation of the catalyst and maintained the high selectivity. Even in the optimized conditions, slow deactivation of the catalyst was observed, but the catalyst was regenerated by calcination at 773 K in oxygen, and the catalytic performance was repeatedly demonstrated.

Keywords
Dealkylation, Alkyl polycyclic aromatic hydrocarbon, Regeneration, Catalyst deactivation, Vacuum gas oil, Basic compound

1. Introduction

The C6-C10 hydrocarbons are some of the most valuable products of the atmospheric distillation of crude oil in the petroleum industry1) and have important uses as gasoline and chemical feedstocks. These fractions are processed by catalytic reforming reaction to enrich the content of monocyclic aromatic hydrocarbons, mainly BTX (benzene, toluene and xylenes)2). The C10-C20 fractions are also valuable as diesel fuels, but need to be enriched with linear alkanes for high cetane values3). Vacuum gas oil (VGO) is a product of vacuum distillation of the 10-35 % of heavy residue oil remaining after atmospheric distillation4), and is upgraded by fluid catalytic cracking (FCC) and hydrocracking5) to form C6-C10 hydrocarbons. However, both FCC and hydrocrackng are substantially non-selective and also form less valuable < C6 alkanes.

Hydrocracking deeply hydrogenates aromatic rings into cycloalkanes resulting in decreased content of monocyclic aromatics and the consumption of large amounts of hydrogen. In recent years, use of direct combustion of fuel oil (heavy oil) has decreased, but the content of heavy components is higher in the newly available supplies of heavy crude oil with the development of drilling technology. Such crude oil includes large components of hydrocarbons with high molecular weight and heteroatoms (nitrogen, sulfur and metals). These conditions have increased the requirement for deep upgrading of heavy oils, but with the disadvantages of high yield of < C6 fraction, large hydrogen consumption or low yield of monocyclic aromatic hydrocarbons.

We previously reported that dealkylation of alkyl polycyclic aromatic hydrocarbons occurs over a silica monolayer solid acid catalyst to yield long-chain alkanes with preserved chain length and polycyclic aromatic hydrocarbons without side chains, as shown in Scheme 16). Hydrogen was introduced for the hydro-

\[ \text{C6-C10} + \text{H}_2 \rightarrow \text{alkanes} + \text{polycyclic aromatic hydrocarbons} \]

Scheme 1 Dealkylation of Hexadecylphthalene

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genation of alkene into alkanes over a solid acid\(^{6-8}\). The silica monolayer catalyst has comparatively large mesopore size (10-30 nm) or, more exactly, non-porous nature, which are the important features for the high activity for the desired reaction, resulting in the high selectivity, because the dealkylation requires the formation of carbenium cations with high steric hindrance\(^{8}\). This dealkylation process minimizes the formation of unnecessary light alkanes and maximizes the yield of alkane fractions usable for gasoline and diesel fuel. On the other hand, monocyclic aromatics are directly used for chemical feedstock, and even the polycyclic aromatics can be converted into tetralin derivatives through partial hydrogenation on catalysts such as zeolite-supported molybdenum compound\(^{9-12}\), followed by the ring-opening reaction to form monocyclic aromatic hydrocarbons based on known techniques\(^{9,12-15}\). Therefore, this dealkylation process will allow the petroleum refinery to maximize the yield of valuable fractions (long chain alkanes and monocyclic aromatic hydrocarbons) with lower hydrogen consumption, compared to the FCC process which produces gasoline and cracked gas oil, and hydrocracking which consumes large quantities of hydrogen. Moreover, the proposed process under a hydrogen atmosphere will restrain side reactions such as the polycondensation reaction, compared with the FCC process.

Application of this method to a practical sample of VGO included some problems. The reaction was prohibited by basic nitrogen compounds which poisoned the acid sites\(^{16-19}\). In the first stage of the study, we demonstrated that removal of basic substances from the reactant oil resulted in high reactivity for the subsequent dealkylation\(^{19}\). However, we employed a strongly acidic cation exchange resin as the solid acid. To reduce the cost for this step, repeated use of the solid acid is necessary, so a more stable and inexpensive solid acid like amorphous silica-alumina should be applied. In addition, catalyst deactivation was observed even after removal of basic substances.

The present research is intended to find principles and overcome the problems with the solid acid treatment of VGO. Our present method uses amorphous silica-alumina to remove the basic compounds from VGO to prevent catalyst deactivation, and regenerates the amorphous silica-alumina by calcination in an oxygen flow; the reason for catalyst deactivation and the reaction conditions to minimize the deactivation in the dealkylation; and a method for regeneration of the silica monolayer catalyst by calcination in oxygen.

2. Experimental

2.1 Preparation of Silica Monolayer Solid Acid Catalyst

The catalyst was prepared by chemical vapor deposition of silica on alumina, JRC-ALO-6 (Reference Catalyst, Catalyst Society of Japan), as reported in our previous study\(^{12}\). After degassing the alumina in a glass vacuum vessel at 673 K, tetramethoxysilane [Si (OCH\(_3\))\(_4\)] vapor as a precursor of silica was introduced at 593 K, and the resultant increase in weight was monitored using a quartz spring balance. After the weight of the solid reached the required value (16.5 wt%) corresponding to full coverage of the silica monolayer, the sample was calcined in oxygen at 673 K. The surface density of Si atoms was calculated based on the weight gain and BET surface area measured after the final oxidation as 11 nm\(^{-2}\). Physicochemical properties of this material have been described previously\(^{18}\).

2.2 Removal of Basic Compounds in VGO

This study investigated VGO obtained from the vacuum distillation of a middle-east origin crude (final boiling point at 1008 K analyzed by Distillation Gas Chromatography System, specific gravity 0.915 g mL\(^{-1}\), C: 85.11 wt\%, H: 12.35 wt\%, S: 2.35 wt\%, N: 0.06 wt\%), which was mixed with benzene and hexadecynaphthalene (HDN). The composition of VGO, benzene and hexadecynaphthalene was 0.47 : 0.47 : 0.053 in weight ratio, respectively. Here benzene was added to increase the fluidity to allow mixing of the resultant VGO solution (VGO-sol) with adsorbent for the removal of basic compounds and to allow pump feeding for the reaction tests. HDN was added as an index reactant, and the reactivity was assessed by the conversion of this compound in this study. The VGO contained too many types of alkylpolycyclic aromatic hydrocarbons to simply evaluate the rate of the dealkylation reaction.

For the removal of basic compounds, a strongly acidic cation exchange resin (Amberlyst-15DRY, purchased from Organo Corp., Japan) or amorphous silica-alumina (JRC-SAL-2, supplied by Reference Catalyst Division, Catalysis Society of Japan) was added to the VGO-sol. The result mixture was stirred at room temperature for 1 h, and then the Amberlyst-15DRY was filtered, or JRC-SAL-2 was centrifuged. The acid amount of JRC-SAL-2 was measured by an ammonia IRMS-TPD method (IRMS-TPD analyzer, MicrotracBEL Corp.) as described elsewhere\(^{20}\). Physical properties of these materials were analyzed by nitrogen adsorption at 77 K (BEL-Sorp Max, MicrotracBEL Corp.) after pretreatment at 373 K (Amberlyst-15DRY) or 573 K (JRC-SAL-2). The surface area was calculated by the BET (Brunauer-Emmett-Teller) equation\(^{21}\), and the pore diameter distribution was analyzed from the desorption branch using a BJH (Barrett-Joyner-Halenda) method\(^{22}\).

The amount of base in the VGO-sol was measured by neutralization titration with the perchloric acid method (JIS K 2501\(^{23}\)) using an automatic neutralization titrator (916Ti-Touch, Metrohm AG). Perchloric acid (0.1 mol L\(^{-1}\), acetic acid solution) was added dropwise
until the neutralization point to a mixed solution of 80 mL of chlorobenzene, 40 mL of acetic acid and 20 g of the VGO-sol. The control experiment without VGO-sol was also carried out. The base amount in the VGO-sol was calculated from the value after the subtraction of the amount in a control experiment from the amount of dropped acid until the neutralization point.

After removal of the basic compounds, JRC-SAL-2 was regenerated by calcination. The sample was packed in a glass tube and calcined in a flow of oxygen at 773 K for 2 h.

2.3 Dealkylation of Hexadecylnaphthalene in VGO and Regeneration of the Catalyst after Reaction

Dealkylation was carried out using the VGO-sol after removal of the basic compounds. The catalyst (0.21 g) was packed in a stainless steel fixed bed flow reactor (i.d. 4 mm) and pretreated in a flow of hydrogen (0.12 mol h⁻¹) under atmospheric pressure at 773 K for 1 h. Then, the VGO-sol was fed at 1.2 g h⁻¹ with a hydrogen flow (0.12 mol h⁻¹) at 673-773 K. The total pressure in the reactor was maintained at 1.0 MPa using a back-pressure valve connected to the outlet. The outlet material was trapped in a glass tube chilled with an ice bath (273 K). The products were analyzed using a 2D-GC (Agilent 7890) with two capillary columns (0.25 μm thickness DB-5 MS in length 30 m and i.d. 0.250 mm, and 0.15 μm thickness DB-17HT in length 5 m and i.d. 0.250 mm). An internal standard method was adopted using tetraethylene glycol dimethyl ether as the standard substance.

The structure, composition and characteristics of residues adsorbed on the silica monolayer catalyst after dealkylation were investigated with elemental analysis, infrared (IR) spectroscopy and thermogravimetry differential thermal analysis (TG-DTA). For IR measurement, a self-supporting disc (1 cm diameter) was molded from a mixture of the catalyst and potassium bromide (1 : 30 in weight ratio) and analyzed with an IR analyzer (JASCO, FT/IR-4200 attached to MicrotracBEL Corp., IRMS-TPD analyzer). After removal of adsorbed water on the catalyst under vacuum at 473 K for 1 h, the IR spectrum was recorded under vacuum at 293 K. TG-DTA (Thermo Plus II EVOSeries, Rigaku Corp.) was carried out in a flow of air (160 mL min⁻¹) at 10 K⁻¹.

3. Results and Discussion

3.1 Removal of Basic Compounds in VGO Solution

The removal of basic compounds in VGO-sol was achieved with solid acids, i.e., strongly acidic cation exchange resin (Amberlyst-15DRY) and amorphous silica–alumina (JRC-SAL-2). Figure 1 shows the amount of basic substances remaining after removal treatment with 10 wt% of solid acid added to the VGO-sol. The original VGO-sol contained about 6 μmol g⁻¹ of basic substances. Amberlyst-15DRY removed 75% of the basic substances in VGO-sol at the first treatment, and the basic substances did not remain after the second treatment (Fig. 1 (a)). The amount of acid sites on Amberlyst-15DRY (4.0 g) used for one treatment was 24.92 mmol, whereas 0.24 mmol of base was contained in the VGO-sol employed (40.0 g). This incomplete removal of basic compounds despite using excess acid indicates that the rate of ion exchange process is slow due to mass transfer limitations to approach equilibrium. As shown below, diffusion of liquid molecules in the macro- and mesopores of the adsorbents seems to limit the total adsorption removal efficiency.

JRC-SAL-2 removed 65% of basic substances at the first treatment (Fig. 1 (b)), so amorphous silica–alumina was less effective than the ion exchange resin. However, it should be considered that the Amberlyst-15DRY was a pre-dried sample. In contrast, silica–alumina must adsorb water in air before the removal treatment, and the adsorbed water may inhibit the diffusion of components of VGO-sol with hydrophobicity in the mesopores of silica–alumina, so reducing access of basic compounds to the acid sites. To examine the effect of drying on removal efficiency, JRC-SAL-2 was dried at 353 K overnight. The dried JRC-SAL-2 removed all basic substances at the first treatment (Fig. 1 (c)). As shown in Table 1, JRC-SAL-2 had fewer acid sites than Amberlyst-15DRY, whereas JRC-SAL-2 had larger surface area than Amberlyst-15DRY. Basic compounds in VGO-sol could probably access to the exposed acid sites on the surface of JRC-SAL-2, whereas Amberlyst-15DRY includes the acid sites in complexly intertwined polymers, so most sites do not contact the basic com-
Regeneration and recycling of the acidic adsorbent are probably necessary for industrial processes involving the removal of basic compounds. The present study investigated combustion of adsorbed compounds on JRC-SAL-2. JRC-SAL-2 used for the adsorption of basic compounds in VGO-sol was calcined at 773 K in O2 for 4 h. The recovered amorphous silica-alumina was mixed with VGO-sol and again showed complete removal of the basic compounds. Therefore, JRC-SAL-2 can be regenerated to remove basic compounds from VGO. Here the basic compounds were combusted for the regeneration. However, hydrocarbon components including the basic groups were also lost by this step, which may be a disadvantage compared to conventional hydrodenitrogenation which removes only nitrogen but not hydrocarbon moieties if the selectivity is 100%. Separation and efficient use of the adsorbed basic compounds will be a subject of future study.

**3.2. Influence of Coexisting Substances in VGO on Reactivity in Dealkylation**

HDI conversion in the dealkylation was enhanced by solid acid treatment, but the reactivity decreased with time on stream, indicating deactivation of the catalyst. The deactivation in the flow of VGO-sol was less after treatment with JRC-SAL-2 than that with Amberlyst-15DRY. Deactivation was probably not due to structural change of the silica monolayer catalyst, which is known to be stable even at high temperatures of 973-1173 K. Therefore, poisoning of the active sites and/or pore plugging by various materials presumably caused the deactivation.

VGO contains hydrocarbons with bulky polycyclic aromatic ring derivatives, containing sulfur and nitrogen. Some of these coexisting substances may cause deactivation of the silica monolayer catalyst. However, basic compounds should not be the cause of deactivation at this stage, because all basic materials were considered to be removed by the solid acid treatment of VGO-sol prior to the reaction. We tested the effects of addition of various compounds other than typically basic ones in VGO-sol on the reactivity.

**Figure 2** shows the time courses of conversion in dealkylation of hexadecylphthalene (HDN) at 673 K in flow of (a) Only HDN, (b) VGO Solution without Removal of Basic Compounds, or (c) VGO Solution Treated with (c) Amberlyst-15DRY or (d) JRC-SAL-2.

### Table 1 Acidic and Physical Properties of Amberlyst-15DRY and JRC-SAL-2

|                | Number of acid sites [mmol g⁻¹] | Surface area [m² g⁻¹] |
|----------------|-------------------------------|-----------------------|
| Amberlyst-15DRY| 6.23a)                        | 39                    |
| JRC-SAL-2      | 0.45b)                        | 560                   |

| a) Amount of sulfo groups as strong Brønsted acid sites. |
| b) Sum of Brønsted and Lewis acid sites. |

Figure 2 **Time Courses of Conversion in Dealkylation of Hexadecylphthalene (HDN) at 673 K in Flow of (a) Only HDN, (b) VGO Solution without Removal of Basic Compounds, or (c) VGO Solution Treated with (c) Amberlyst-15DRY or (d) JRC-SAL-2.**

J. Jpn. Petrol. Inst., Vol. 61, No. 5, 2018
derivatives should remain. Addition of carbazole (0.07 wt%) and indole (0.24 wt%) caused no or only slight decrease of the reactivity. Indole was possibly slightly converted into 2-phenylethylamine through hydrogenation of the pyrrole ring and cleavage of the bond between nitrogen and carbon on the aromatic ring, and then 2-phenylethylamine as the basic product slightly prohibited the dealkylation of hexadecyl-naphthalene. However, the deactivation rate was obviously lower than that in the dealkylation in VGO at 673 K (Fig. 2), so indole was not the main cause of the deactivation.

### 3.3. Influence of Reaction Temperature on Reactivity in Dealkylation in VGO

In order to find the factors controlling the deactivation behaviors, we examined the influence of reaction temperature on the dealkylation as shown in Fig. 4(A). In contrast to the deactivation observed at 673 K, the deactivation was slow at 723 K in the VGO-sol treated with Amberlyst-15DRY or JRC-SAL-2. More stable conversion was observed at 773 K. Figure 4(B) indicates the time course of the yield of hexadecane, which was the desired product from the dealkylation of hexadecyl-naphthalene, at 673-773 K. HDN conversion and hexadecane yield showed different behaviors. Hexadecane was formed through dealkylation, but yield...
decreased due to the cracking. The yield at 673 K was higher due to less cracking, and then decreased with time on stream after 3 h, according to the decrease in conversion stated above and reflecting the deactivation. In contrast, the yield at 723 K increased with time on stream and plateaued at relatively high value for VGO-sol treated with Amberlyst-15DRY or JRC-SAL-2.

Increasing the temperature up to 773 K decreased the yield of hexadecane, presumably due to subsequent cracking of hexadecane. Therefore, the highest yield of hexadecane was obtained at 723 K.

3.4. Analysis of Residues Adsorbed on the Silica Monolayer Catalyst after the Dealkylation in VGO

The chemical and physical properties of residues adsorbed on the silica monolayer catalyst after dealkylation at 673 K and 773 K (cat-673 and cat-773 as shown below) were analyzed, because the adsorbates on cat-673 could be the cause of deactivation. Both catalysts were grey after the reaction. Table 2 displays the results of elemental analysis. VGO-sol contains about 90% carbon, followed by hydrogen, sulfur and little nitrogen. The amounts of nitrogen, sulfur, carbon and hydrogen detected on cat-673 were larger than those on cat-773. As mentioned above, sulfur-containing compounds (e.g. dibenzothiophene) and non-basic nitrogen compounds (e.g. carbazole and indole) did not severely deactivate the silica monolayer catalyst. The molar ratio of hydrogen to carbon on cat-673 and cat-773 was found to be 1.64 and 0.97, respectively. The hydrogen to carbon molar ratio should be higher than 1, typically 2, in aliphatic oligomers or polymers, but should be less than 1 in aromatic compounds. The value on cat-673 indicates that the content of aliphatic compounds was larger than that of aromatic compounds in this sample, whereas cat-773 had mainly aromatic compounds and a small amount of aliphatic compounds. Figure 5 shows the IR spectra of cat-673 and cat-773. On cat-673, a pair of absorption bands at 2850 cm⁻¹ and 2923 cm⁻¹, and a band at 1460 cm⁻¹, assignable to C-H stretching and bending vibrations, respectively, were observed. Negligible C-H vibration was observed on cat-773. Therefore, the adsorbate on cat-673 was mainly aliphatic compounds, whereas that on cat-773 was mainly polymerized aromatic hydrocarbons. The aliphatic compounds were probably formed from heavy alkanes originally contained in VGO or formed by dealkylation. Then cat-673 and cat-773 were analyzed by TG-DTA in a flow of air (Fig. 6). Weight loss peaks in the range of 500-700 K and 700-900 K in TG were found on cat-673, and both are assignable to combustion of adsorbed materials, because of the associated exothermic peaks in DTA. On cat-773, only weight loss and exothermic peak in the range of 700-900 K was observed. Considering the results of IR and elemental analyses, the peaks in the lower and higher temperature regions indicate the combustion of aliphatic compounds and polymerized aromatic hydrocarbons, respectively. As catalyst deactivation was significant at 673 K but not at 773 K, the substances on cat-673 poisoning the active sites were probably aliphatic hydrocarbons with higher molecular weight, and the reaction at high temperature readily decomposed such compounds and suppressed the deactivation of silica monolayer catalyst for the dealkylation of alkyl polycyclic aromatic hydrocarbons.

3.5. Regeneration of the Catalyst

As described above, catalytic dealkylation in VGO at 723 K kept high reactivity and achieved higher yield of hexadecane, but the reactivity slightly decreased due to adsorption of hydrocarbons. To regenerate the catalyst, the substances deposited on the catalyst was calcined at 773 K in oxygen in the reactor after the reaction. Figure 7 shows time courses of conversion of hexadecylnaphthalene at 723 K. The regeneration at

| N  | S  | C   | H   | H/C |
|----|----|-----|-----|-----|
| VGO-sol | <0.05 | 1.15 | 89.70 | 8.30 | 1.11 |
| cat-673 | 0.05 | 0.41 | 22.22 | 3.04 | 1.64 |
| cat-773 | <0.05 | <0.05 | 9.18 | 0.74 | 0.97 |

Fig. 5 IR Spectra of the Catalysts after Dealkylation in VGO at (a) 673 K and (b) 773 K
773 K and reaction at 723 K were repeated three times. After regeneration of the catalyst, the conversion recovered, and dependence of reactivity on time on stream was repeatedly observed. Therefore, regeneration of the catalyst after the dealkylation was possible.

4. Conclusion

We have developed a novel method of upgrading heavy oil (VGO) through dealkylation of alkyl polycyclic aromatic hydrocarbons. Before the dealkylation in VGO, the basic nitrogen-containing aromatic hydrocarbons were removed with Amberlyst-15DRY or JRC-SAL-2. The used JRC-SAL-2 after the removal of basic compounds can be regenerated by calcination at 773 K in oxygen flow. Dealkylation of alkyl polycyclic aromatic hydrocarbons in VGO without basic compounds proceeded at 673 K, but the HDN conversion drastically decreased. VGO contains various substances, but coexisting aromatic hydrocarbons with a large number of aromatic rings, and sulfur-containing and non-basic nitrogen-containing aromatic hydrocarbons hardly affected the dealkylation. Higher reaction temperature kept higher catalytic activity. However, excessively high temperature caused cracking of alkanes, so the reaction condition at 723 K exhibited higher yield of long-chain alkanes without cracking. Characterization of catalysts after dealkylation at different temperatures revealed that poisoning substances on the catalyst were mainly aliphatic compounds, presumably bulky alkanes in VGO or polymerized alkanes after reaction. The deactivated catalyst could be regenerated by calcination at 773 K in oxygen flow.

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References

1) Meyers, R. A., “Handbook of Petroleum Refining Processes,” fourth edition, McGraw Hill Professional, New York (2016).
2) American Society of Testing Materials, “Knocking Characteristics of Pure Hydrocarbons,” ASTM Special Technical Publication No. 225, ASTM, Philadelphia (1958).
3) Kakizaki, R., Suzuki, M., Li, T., Ogawa, H., Murase, M., Trans. Soc. Automotive Eng. Jpn., 40, 1503 (2009).
減圧軽油中の塩基性物質の除去とアルキル多環芳香族の脱アルキル化反応

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我々が提案する新たな重油のアップグレーディング法では、シリカモノレイヤー固体酸触媒によるアルキル多環芳香族の脱アルキル化を利用し、飽和を保ったアルカンとアルキル鎖を含む芳香族が生成可能である。この方法はディーゼル燃料に適したアルカン、ガソリン化成品原料に適したアルキルペンゼンの収率を最大化できる。実油の減圧軽油を用いた反応では反応の進行が塩基性物質によって阻害されるが、塩基性物質は溶液に強酸性カチオン交換樹脂やアモルファスシリカアルミナを投入して混合することで吸着除去できる。特に、乾媒したアモルファスシリカアルミナは吸着速度が大きく、使用後に酸素中で焼成することで再生可能である。除去後の減圧軽油中のアルキル多環芳香族の脱アルキル化反応温度723 Kで高い目的物選択率を維持できる。また、触媒は緩やかな劣化を示すが、酸素中773 Kで焼成することで再生可能である。