

**CHAPTER VI**  
**EFFECTS OF IRON SUPPORTED ON ZEOLITES ON STRUCTURES OF**  
**HYDROCARBON COMPOUNDS AND PETROCHEMICALS IN**  
**WASTE TIRE-DERIVED OILS**

**6.1 Abstract**

Waste tire, a hydrocarbon-based material, exhibits potential to be used for petrochemical production. Valuable chemicals such as benzene, toluene, xylenes, and styrene for instances have been observed in pyrolytic oils. Furthermore, sulfur compounds causing the low quality of oil and the environmental pollutant are also absolutely found. Iron catalysts appear to be economically feasible in catalytic fields. Especially, iron can be used to substitute the noble metal promoters in the pyrolysis of waste tire due to its good activities on hydrogenation and ring opening reactions. This study therefore investigates the effects of iron supported on zeolites (HMOR, HBeta, HZSM-5, and KL) on structures of hydrocarbon compounds and petrochemicals in waste tire-derived oils. Fe-promoted zeolites were prepared by incipient wetness impregnation technique with the fixed amount of Fe at 5 wt.%. The products and catalysts were characterized by using GC, SIMDIST-GC, GC×GC-TOF/MS, elemental analyzer, XRD, and SAA. The results showed that the introduction of 5%Fe on zeolites can enhance the cracking ability of products. Namely, the gas yield increased, at the expense of liquid yield. In addition, light hydrocarbon gases increased in accordance with the reduction of heavier gases. Moreover, the light fractions in oil also increased with using iron-loaded zeolites. Moreover, olefins and naphthenes tended to decrease, but mono-aromatics increased with using all 5%Fe-loaded zeolites. Consequently, the reduction of di- and poly-aromatics was observed for all Fe-promoted catalysts, except 5%Fe/HBeta. Using 5%Fe-loaded zeolites, except 5%Fe/HBeta resulted in the increasing yields of petrochemicals such as benzene, toluene, ethylbenzene, xylenes, and styrene, for examples, in oil. Furthermore, 5%Fe-loaded catalysts resulted in the reduction of sulfur in oil. Dibenzothiophenes and benzothiazoles were the sulfur compounds in oil

that decreased with the presence of 5%Fe, except 5%Fe/HZSM-5, whereas benzothiophenes tended to decrease.

## 6.2 Introduction

Tire is difficult to degrade, and it has a long life; thus, resulting in a large amount of waste tire discarded. Over a half of waste tires go to land fill, resulting in losing a large amount of valuable landfill space. Moreover, the combustion of waste tire releases environmental pollutants. However, tires are hydrocarbon materials which exhibit potential to be used as a source for petrochemical production through waste tire pyrolysis that is an alternative technique to handle waste tire problems. Several researchers reported that products from waste tire pyrolysis can be used as fuels and feedstock for petrochemical production. Aromatics, especially benzene, toluene, xylenes, and ethylbenzene, are important compounds in the production of petrochemicals and plastics. Moreover, styrene and cumene are also widely used in chemical industry. It has been reported that pyrolytic oils can be used as diesel fuel after upgrading such as removing sulfur or blending with commercial fuels (Laresgoiti *et al.*, 2004; Islam *et al.*, 2008; Fernández *et al.*, 2012). In addition, the oil which has high sulfur is not permitted to use in vehicle due to the environmental regulations. The source of sulfur in pyrolytic oil is from vulcanization agents and accelerators such as benzothiazole, 2-mercaptobenzothiazole in vulcanization process during tire production (Li *et al.*, 2010; Llompart *et al.*, 2013). In order to reduce sulfur in oil, sulfur removal technology have been developed. García-Cruz *et al.* (2008) reported that small sulfur compounds are easier to be desulfurized than larger sulfur compounds. The activity of sulfur species towards hydrodesulfurization was ranked as thiophenes > benzothiophenes > dibenzothiophenes > 4,6-dimethyldibenzothiophene.

Several researchers used catalysts to improve the quality of pyrolytic oil, especially zeolites. Dũng *et al.* (2009) used HMOR zeolite in waste tire pyrolysis. The results showed that introduction of HMOR led to the increasing amounts of gasoline and kerosene and the decreasing amounts of heavy vacuum gas oil due to the good cracking performance of catalyst. They mentioned that HMOR favored to

produce gasoline, which was selective to pore size. The pyrolysis of waste tire with using HBeta and KL zeolites were studied by Saeng-arayakul (2013). The results showed that using HBeta produced higher gas yield than using KL. Moreover, HBeta zeolite reduced the concentration of heavy liquid fractions (long residues and heavy gas oil) more greatly than KL zeolite. The results demonstrated that long-chain hydrocarbons were more easily cracked by HBeta. Furthermore, both HBeta and KL can reduce the sulfur in oil. Olazar *et al.* (2008) studied the effect of using HZSM-5 catalyst on waste tire pyrolysis. The gas product increased with using HZSM-5 due to cracking of heavy fractions. Additionally, light olefins which consisted of ethene and propene increased with the use of catalyst. Poly-aromatics in oil products increased with using catalyst. It was suggested that cyclization, aromatization and condensation reactions occurred inside the pore to form aromatics.

Iron catalysts are environment-friendly ones with low toxicity, the usage of iron catalysts are mainly in Fischer-Tropsch synthesis, and appear to be economically feasible in catalytic fields (Abbasi-Atibeh and Yozgatligil, 2014). Pour *et al.* (2008) studied Fischer-Tropsch synthesis catalyzed by pure Fe and Fe supported on ZSM-5. They indicated that the Fe/ZSM-5 catalyst gave a longer chain of hydrocarbons than the pure Fe catalyst because ZSM-5 promoted oligomerization activity, cracking activity, and shape selectivity, followed by aromatization that led to the reduction of light products. Moreover, ZSM-5 improved the quality of gasoline by increasing C<sub>5</sub>-C<sub>11</sub> hydrocarbons. Namely, Fe/ZSM-5 enhanced secondary chain growth. Fe catalysts were investigated for selective catalytic reduction (SCR) by He *et al.* (2009). Using Fe catalyst supported on HBeta zeolite in order to reduce nitrogen oxide (NO) from the diesel engine. They found that iron loading at 2.5 wt.% gave the high conversion of NO about 97 %. Additionally, they compared the activity of Fe/HBeta with Fe/ZSM-5. The result showed that Fe/HBeta gave higher activity of SCR than Fe/ZSM-5 due to higher surface area.

Recently, an iron catalyst has been used in waste tire pyrolysis as a substitute for a noble metal catalyst (Ru). The result showed that the increasing amount of Fe loading on HBeta and HMOR zeolites tended to enhance the cracking ability of liquid to gas products. For liquid products, it was reported that presence of Fe catalyst led to sharp increase in saturated hydrocarbons in accordance with

reduction of poly- and polar-aromatic hydrocarbons. It was attributed to Fe site that had an important role on promotion of hydrogenation and hydrodesulfurization reactions of poly- and polar aromatic hydrocarbons. Moreover, heavy fractions such as heavy gas oil and long residue increased with increasing Fe loading because the secondary reactions, which consist of oligomerization, aromatization and H-transfer, were enhanced on Fe. As observed above, the Fe catalyst had as high activity as the noble metal, Ru, which is costly (Saeae, 2012).

Currently, no study has been made on the effect of iron-loaded zeolites on the structure and distribution of hydrocarbons in waste tire pyrolysis. The aim of the present study was to investigate effects of iron promotion on zeolites on structures of hydrocarbon compounds and petrochemicals in tire-derived oils. A series of Fe supported zeolites was prepared by incipient wetness impregnation technique loading and the amount of Fe was fixed at 5wt.% for all cases.

## 6.3 Experimental

### 6.3.1 Catalyst Preparation

HMOR (Si/Al = 13.5), HBeta (Si/Al = 9.5), KL (Si/Al = 3), and HZSM-5 (Si/Al = 15) were purchased from Tosoh Company in Singapore and Zeolyst International. First, all zeolites were calcined to remove impurity. HMOR, HZSM-5, and KL were calcined at 500 °C for 3 h with the heating rate of 10 °C/min. HBeta was calcined at 600 °C for 5 h with 2 °C/min. Then, each zeolite was loaded with metal, iron(III) chloride hydrate hexahydrate ( $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ ), using incipient wetness impregnation technique to obtain 5 wt.% metal-supported catalyst. After that, the catalysts were dried at 100 °C for 3 h followed by calcination at the same conditions. Next, catalyst powders were pelletized, ground, and sieved to 400-425  $\mu\text{m}$  of particle size. Finally, they were reduced for 2 h with  $\text{H}_2$  to convert the metal oxide to a metal element.

### 6.3.2 Catalyst Characterization

Temperature-programmed reduction (TPR) was used to identify the reducibility of the impregnated catalysts and the metal-support interaction. The temperature was ramped from 30 °C to 850 °C with a heating rate of 10 °C/min.

X-ray Diffraction (XRD) was used to verify the structure and existence of metal of the catalysts. The detector scanned the peak position from the sample as a function of  $2\theta$  by starting at the  $5^\circ$  to  $100^\circ$  ( $2\theta$ ) range and a scan speed of  $5^\circ(2\theta)/\text{min}$ . XRD patterns were matched to the standards to identify crystalline phases by smartlab guidance program. The amount of coke on spent catalysts was analyzed by using a Thermogravimetric/Differential Thermal Analysis (TG/DTA). The surface area and pore volume of catalysts were analyzed by using a surface area analyzer (Sorptomatic 1990). Moreover, an elemental analyzer was used to determine sulfur content on spent catalyst.

### 6.3.3 Pyrolysis of Waste Tire

Waste tire was loaded into the lower zone of reactor, operated at  $500^\circ\text{C}$ , and catalyst was loaded to the catalytic zone, operated at  $350^\circ\text{C}$ . The heating rate was controlled at  $10^\circ\text{C}/\text{min}$  and then kept for 2 h at the atmospheric pressure. The flow rate of  $\text{N}_2$  was controlled at  $30\text{ ml}/\text{min}$ , which was continuously flown to purge the oxygen out of the pyrolysis system. The obtained product was next passed through condensers in order to collect the liquid product, and subsequently the gas product was kept in a gas sampling bag. The solid and liquid products were weighed to determine the distribution of pyrolysis products.

### 6.3.4 Product Analysis

Pyrolysis gas was analyzed by using a Gas Chromatography (GC), Agilent Technologies 6890. A carrier gas was helium and detector was FID type. For liquid product, it was dissolved in *n*-pentane to precipitate asphaltene for overnight. Then, asphaltene was filtrated out from maltene in a vacuum system using a polyamide membrane, which has  $0.45\ \mu\text{m}$  of pore size. The true boiling point curves of maltenes were obtained by using a Simulated Distillation Gas Chromatography (SIMDIST-GC). Then, they were cut into 5 petroleum fractions; that are, full range naphtha ( $< 200^\circ\text{C}$ ), kerosene ( $200\text{-}250^\circ\text{C}$ ), light gas oil ( $250\text{-}300^\circ\text{C}$ ), heavy gas oil ( $300\text{-}370^\circ\text{C}$ ), and long residue ( $> 370^\circ\text{C}$ ). In addition, the compositions of maltenes were identified by using a two-dimensional Gas Chromatography with Time of Flight Mass Spectroscopy (GC $\times$ GC-TOF/MS). Sulfur content in oils and char were determined by using an elemental analyzer.

## 6.4 Results and Discussion

### 6.4.1 Catalyst Characterization

The TPR profiles of Fe-loaded catalysts are shown in Figure 6.1. It is found that 5%Fe on HMOR, HBeta, HZSM-5, and KL has the reduction peak at 558 °C, 551 °C, 505 °C, and 619 °C, respectively. Therefore, the interaction between Fe and supports can be ranked in the following order: Fe/KL > Fe/HMOR > Fe/HBeta > Fe/HZSM-5. Figure 6.2 shows the XRD patterns of Fe-loaded catalysts. It exhibits that the introduction of 5% of Fe on zeolites results in the presence of the metallic Fe peaks at  $2\theta$  of 44 °, 65 °, and 82 ° in the XRD patterns.

### 6.4.2 Pyrolysis Yield

The distribution of pyrolysis products, which consist of char, oil, gas, and coke, is illustrated in Figure 6.3. The results show that products mostly consist of oil and char. Using pure zeolites (KL, HBeta, HMOR, and HZSM-5), except HBeta, gives a reduction of the oil yields in accordance with the increment of gas and coke as compared to the non-catalyst case. The zeolites gives a lower gas yield than using the-non catalyst case

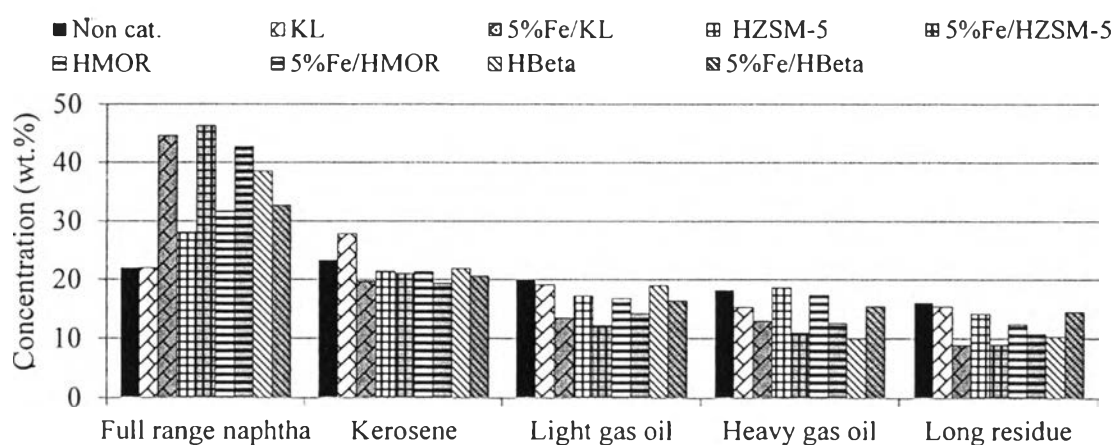
The introduction of 5 wt.% Fe on zeolites (KL, HBeta, HMOR, and HZSM-5) strongly influences the pyrolysis products. Fe-loaded catalysts further decrease the oil yield in accordance with increment of the yield of gas as compared with using pure zeolites. Coke decreases with 5%Fe supported on KL, HBeta, and HMOR, but increases with using 5%Fe/HZSM-5. Moreover, the amount of char is not significantly different for all cases. In addition, gas compositions obtained from using zeolites (HMOR, KL, HBeta, and HZSM-5) and 5%Fe-loaded zeolites are illustrated Figure 6.4.

### 6.4.3 Petroleum Fractions

The petroleum fractions, which are classified into full range naphtha, kerosene, light gas oil, heavy gas oil, and long residue, are revealed in Figure 6.5. The results show that the amount of full range naphtha increases with using pure zeolites. Moreover, using Fe-loaded catalysts, except 5%Fe/HBeta gives a higher amount of full range naphtha than using pure zeolites. Namely, using 5%Fe/HBeta decreases the amount of full range naphtha, kerosene, and light gas oil as compared

to using HBeta. Moreover, heavy gas oil and long residue increase with using 5%Fe/HBeta.

It can be concluded that Fe enhances the ability of cracking heavy fractions (kerosene, light gas oil, heavy gas oil, and long residue), which are converted to full range naphtha. For 5%Fe/HBeta, it can be explained that the increments of heavy gas oil and long residue are possibly caused the promotion of secondary reactions, which are oligomerization and aromatization of olefins to form heavy fractions, by Fe (Pour *et al.*, 2008; Saeaeah, 2012).



**Figure 6.5** Petroleum fractions in maltenes obtained from using pure zeolites (KL, HZSM-5, HMOR, and HBeta) and 5%Fe-promoted catalysts.

#### 6.4.4 Petrochemicals in Oil

Components in gasoline ( $C_5$ - $C_9$ ), which are classified into paraffins, olefins, naphthenes, and aromatics, are exhibited in Figure 6.6. The results show that using Fe-loaded catalysts result in the change of species in gasoline, and it is found that aromatics are the most abundant species in gasoline. It can be concluded that the oils obtained from Fe-loaded catalysts are not suitable for use as a fuel due to the high aromatics content.

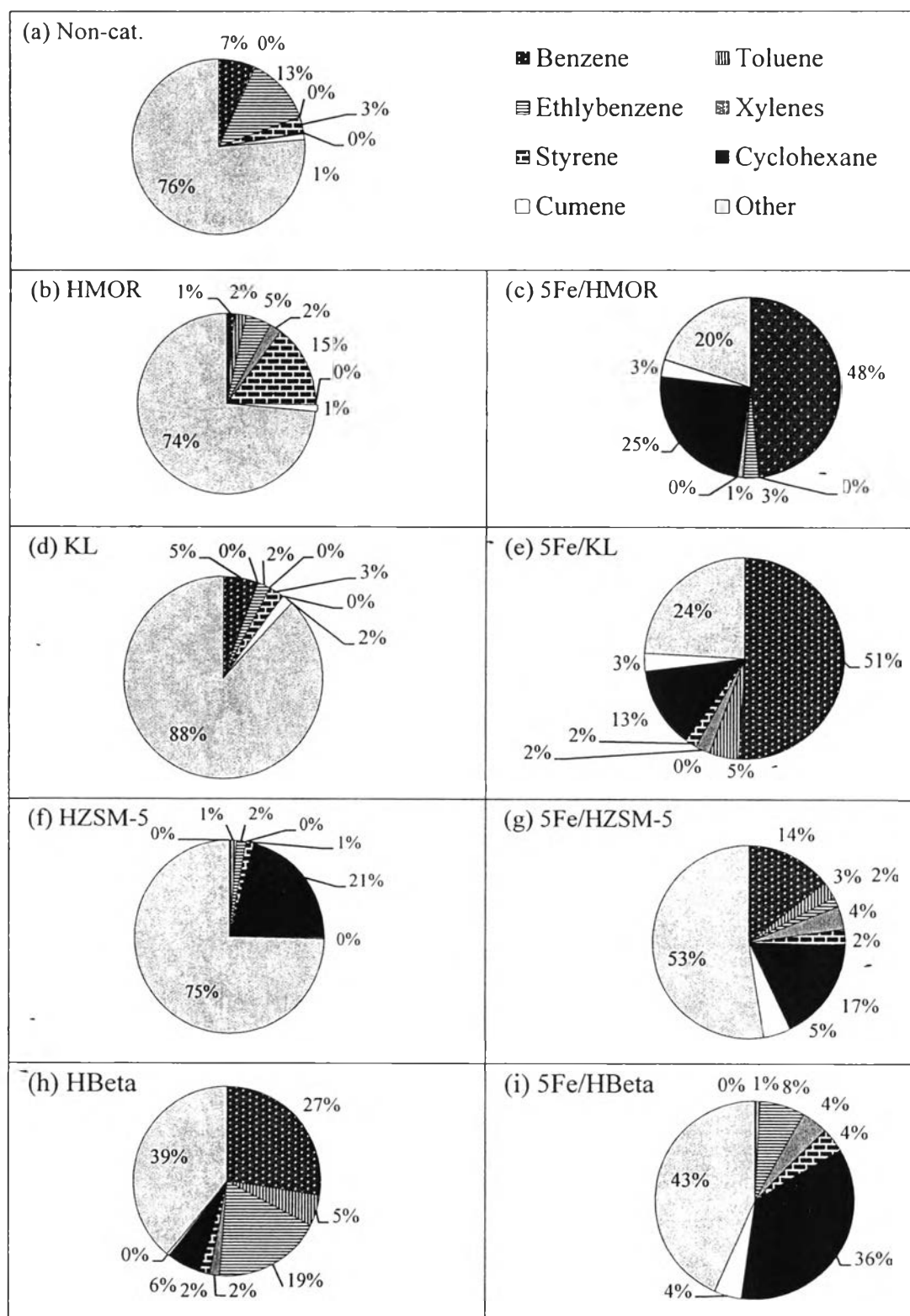
Moreover, the oils have a potential as a feedstock for petrochemicals production since the petrochemicals, which are benzene, toluene, ethylbenzene,

xylenes, styrene, cyclohexane, and cumene, increase with using Fe-loaded catalysts as shown in Figure 6.7. The results exhibit that using Fe-loaded catalysts result in the increasing petrochemicals production, as compared to using those pure zeolites, especially 5%Fe/HMOR and 5%Fe/KL. Using 5%Fe/HMOR sharply increases benzene and cyclohexane as compared to using HMOR. Using 5%Fe/KL results in the increases of benzene, cyclohexane, and toluene as compared to using KL. Moreover, 5%Fe/HZSM-5 produces more amount of benzene than HZSM-5, and using 5%Fe/HBeta increases the amount of cyclohexane in accordance with the reduction of benzene. It can be suggested that Fe supported on HMOR and KL, which have 1D pore channel, sharply increases the petrochemicals, whereas Fe supported on HZSM-5 results in a little increase of petrochemicals, and Fe supported on HBeta decreases the production of these components. It can be explained that Fe supported on HBeta that has a large 3D pore channel, allows molecules to go inside the pore with long residence time to form heavy compounds via oligomerization (secondary reaction), which can be enhanced by Fe as mentioned in Figure 6.5. In case of using Fe/HZSM-5, which has 3D channel and medium pore size, allows the molecules to go inside the pore with a longer contact time than 1D channel, but the medium pore of HZSM-5 may inhibit the formation of large molecules.

It can be concluded that loading 5%Fe on KL, HMOR, and HZSM-5 cause the oils gives more value products than using those pure zeolites. In addition, the introduction of 5%Fe on KL and HMOR (1D pore channel) enhances the production of valuable hydrocarbons more effectively than using HZSM-5 and HBeta (3D pore channel).

Table 6.1 exhibits the yield of petrochemicals in oil (wt.%) obtained from waste tire pyrolysis using pure zeolites (KL, HZSM-5, HMOR, and HBeta) and Fe-promoted catalysts. From the results, it can be concluded that 5%Fe/HMOR is the best catalyst to produce benzene (14.0 wt.%) and cyclohexane (7.17 wt.%), and HBeta can be used to produce ethylbenzene (3.31 wt.%). On other hand, a small amount of other petrochemicals, that are styrene, toluene, cumene, and xylenes, are found in oils.

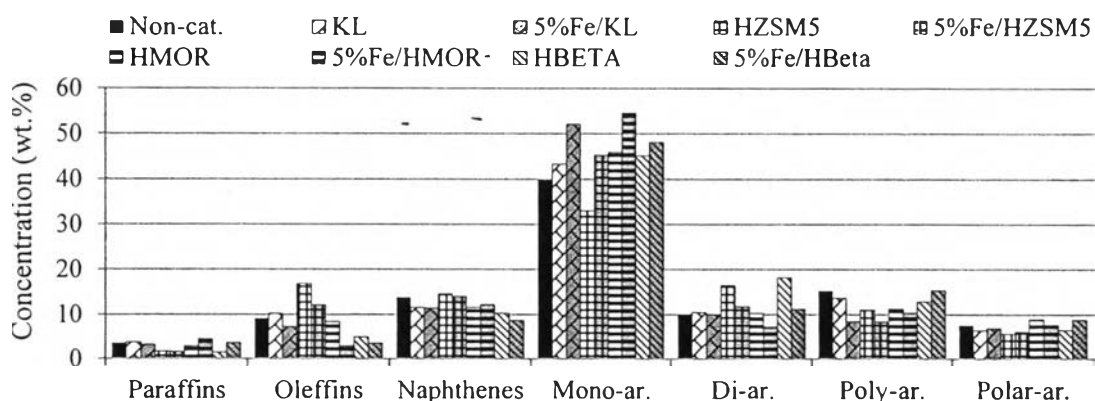




**Figure 6.7** Petrochemicals (wt.% in gasoline) obtained from (a) the non-catalyst case, (b) HMOR, (c) 5%Fe/HMOR, (d) KL, (e) 5%Fe/KL, (f) HZSM-5, (g) 5%Fe/HZSM-5, (h) HBeta, and (i) 5%Fe/HBeta.

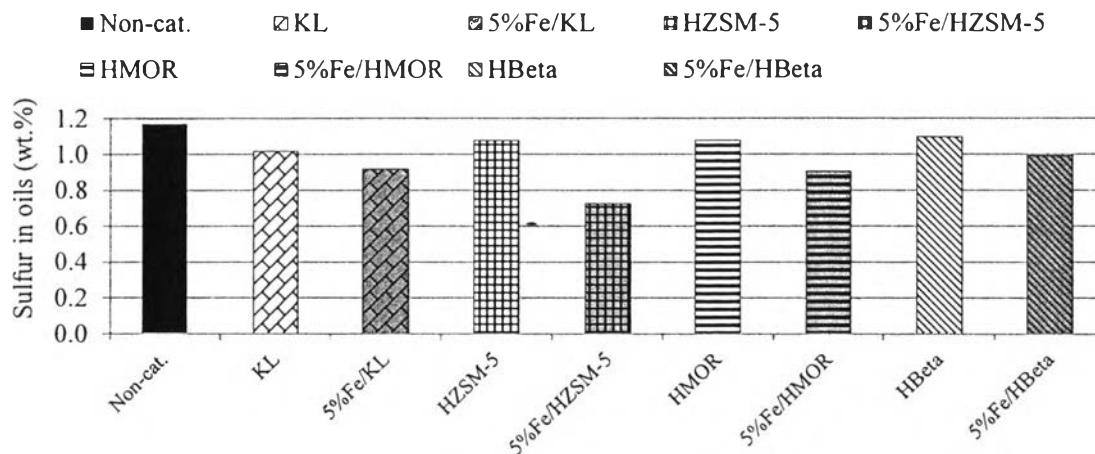
#### 6.4.5 Liquid Components

The chemical components in maltenes are shown in Figure 6.8. It reveals that the concentration of paraffins does not change significantly with using catalysts. Moreover, the concentration of olefins and naphthenes tends to decrease with using Fe-loaded catalysts. It can be explained that olefins and naphthenes may convert to aromatics via Diel-Alders reaction (Kyong-Hwan and Dae-Hyun, 2007; Meng-*et al.*, 2013). Moreover, mono-aromatics increase significantly with using Fe-loaded catalysts as compared to using those pure zeolites. The use of 5%Fe supported on KL, HMOR, and HZSM-5 gives a lower amount of di- and poly-aromatic hydrocarbons than the use of those pure zeolites, but using 5%Fe/HBeta gives a higher amount of poly-aromatic hydrocarbons than pure HBeta. It can be suggested that di- and poly-aromatics convert to mono-aromatics via hydrogenation and ring opening reaction enhanced by Fe (Li and Hung, 2003; Saeach, 2012). Moreover, the introduction of Fe results in the reduction of some mono-aromatic species (see in Tables 6.2-6.5). It can be suggested that these mono-aromatics might be converted to other hydrocarbon compounds or petrochemicals by hydrogenation and ring opening enhanced by Fe. Additionally, polar-aromatic hydrocarbons, which are S, O, and N-containing aromatics, slightly increase with loading Fe on KL, HZSM-5, and HMOR zeolites, but decrease with using Fe supported on HBeta.



**Figure 6.8** Concentration of chemical components in maltenes obtained from using pure zeolites (KL, HZSM-5, HMOR, and HBeta) and 5%Fe-promoted catalysts.

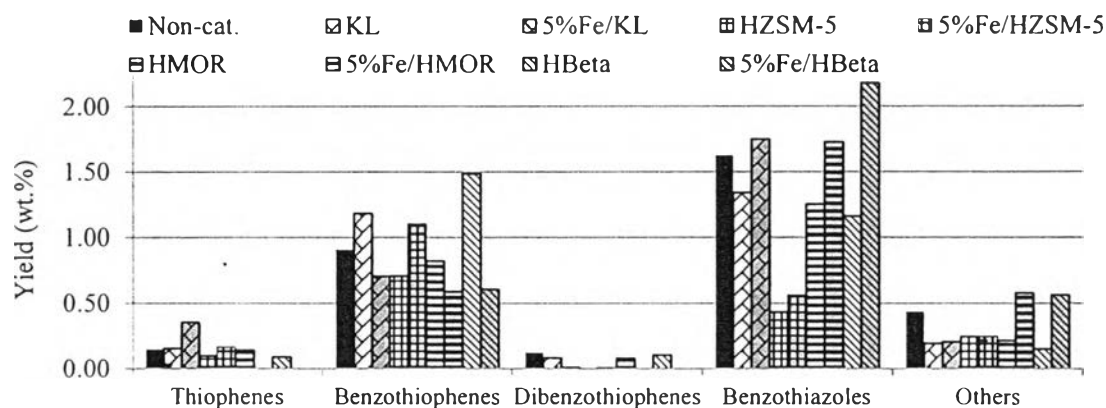
#### 6.4.6 Desulfurization Activity



**Figure 6.9** Sulfur content in oils obtained from using pure zeolites (KL, HZSM-5, HMOR, and HBeta) and 5%Fe-promoted catalysts.

The sulfur content in pyrolytic oils as exhibited in Figure 6.9 is determined by using an elemental analyzer. It can be seen that all catalysts result in the reduction of sulfur in oils as compared to the non-catalytic pyrolysis (1.17 wt.%). In addition, the use of pure zeolites can reduce sulfur in oil significantly. Using Fe-loaded catalysts further reduce sulfur in oils. The lowest sulfur in oils is obtained from using 5%Fe/HZSM-5 (0.73 wt.%), followed by 5%Fe/HMOR (0.91 wt.%), 5%Fe/KL (0.92 wt.%), and then 5%Fe/HBeta (0.99 wt.%). It can be concluded that Fe enhances sulfur removal activity.

Figure 6.10 reveals the yield of sulfur species in maltenes, which are classified into two groups: (1) sulfur-containing compounds, which consist of thiophenes (Ts), benzothiophenes (BTs), and dibenzothiophenes (DBTs), and (2) heteroatom-containing sulfur compounds, which consist of benzothiazoles (N-containing sulfur compound) and others (N or/and O-containing sulfur compound). Nitrogen and oxygen are found in oils because nitrogen- and oxygen-containing compounds are used as vulcanization accelerators in rubber production, especially benzothiazoles, which are commonly used in vulcanization process (Li *et al.*, 2010; Avagyan *et al.*, 2013; Llompert *et al.*, 2013).



**Figure 6.10** Yield of sulfur species in maltenes obtained from using pure zeolites (KL, HZSM-5, HMOR, and HBeta) and 5%Fe-promoted catalysts.

The results show that using Fe-loaded catalysts tends to decrease sulfur-containing compounds (BTs and DBTs), except 5%Fe/HZMS-5 that increases the amount of BTs as compared to HZSM-5. From the results, it can be suggested that Fe enhances the C-S bond breaking activity, resulting in the reduction of BTs and DBTs, whereas Fe supported on HZSM-5 causes the lowest surface area and pore volume; thus, resulting in the decreasing activity in reduction of BTs and DBTs. Moreover, using Fe-loaded catalysts increases the heteroatom-containing sulfur compounds for all cases. It can be suggested that the introduction of Fe on zeolites may reduce the active sites of zeolite, so it results in the reduction of cracking activity.

## 6.5 Conclusions

The use of Fe supported on KL, HMOR, HZSM-5, and HBeta catalysts increased light gases. All Fe-promoted catalysts increased the light fraction (full range naphtha) at the expense of the heavier fractions in oil because Fe enhanced the cracking activity of zeolites. Especially, the petrochemicals in oil were highly increased with using Fe-loaded catalysts, except 5%Fe/HBeta. It can be ranked as 5%Fe/HMOR > 5%Fe/KL > 5%Fe/HZSM-5 > 5%Fe/HBeta. 5%Fe/HMOR appeared

to be the best catalyst to produce benzene and cyclohexane. 5%Fe/KL was the best catalyst for toluene production, whereas 5%Fe/HZSM-5 can be used to produce xylenes and cumene. Moreover, sulfur content in oils reduced with using Fe-loaded catalysts, and the lowest sulfur in oil was obtained from using 5%Fe/HZSM-5.

## 6.6 Acknowledgements

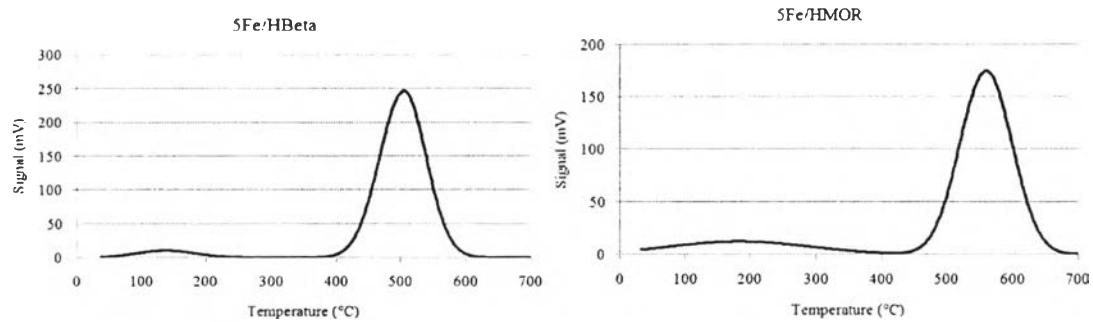
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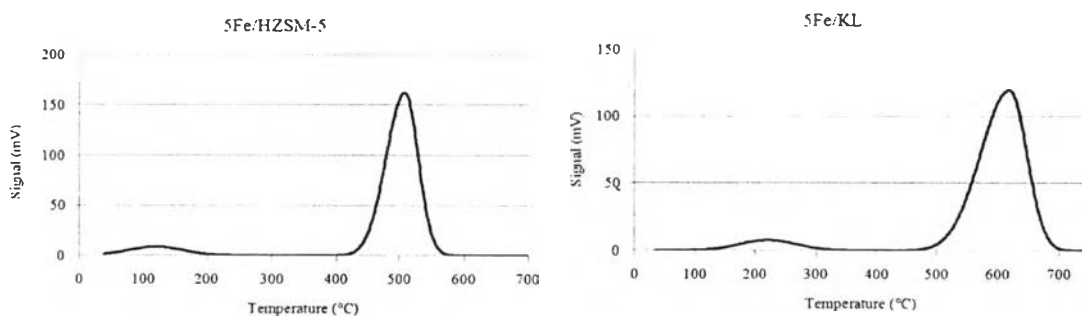
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(a) 5%Fe/HBeta

(b) 5%Fe/HMOR

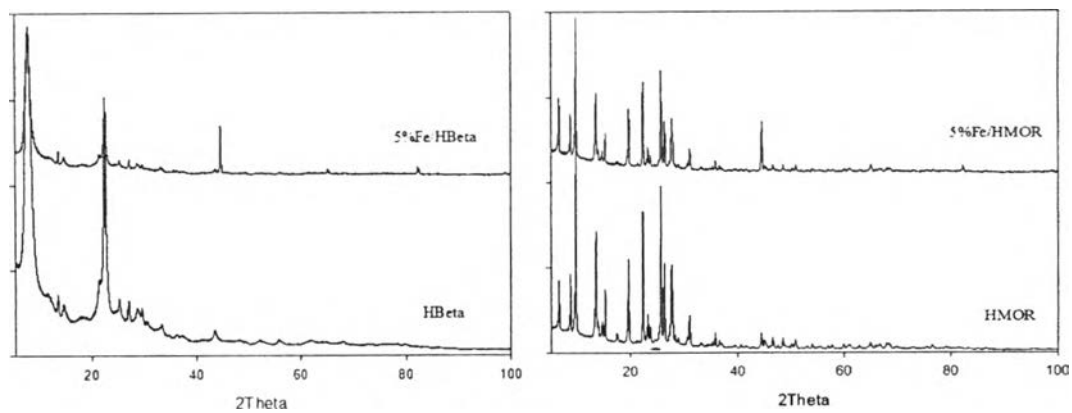


(c) 5%Fe/HZSM-5

(d) 5%Fe/KL

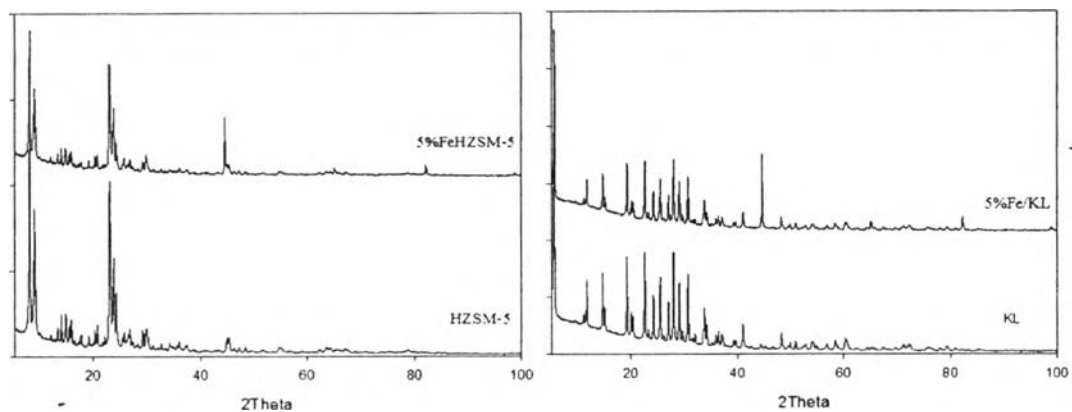
**Figure 6.1** H<sub>2</sub>-TPR profiles: (a) 5%Fe/HBeta, (b) 5%Fe/HMOR, (c) 5%Fe/HZSM-5, and (d) 5%Fe/KL.





(a) 5%Fe/HBeta

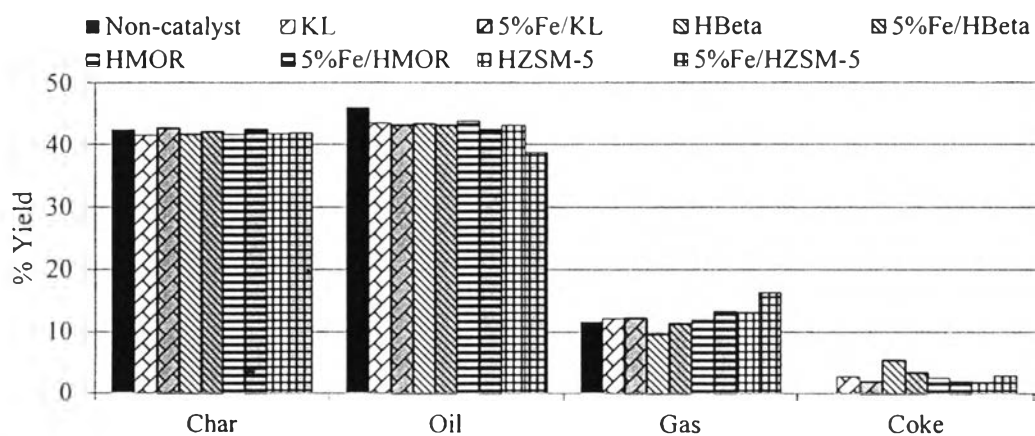
(b) 5%Fe/HMOR



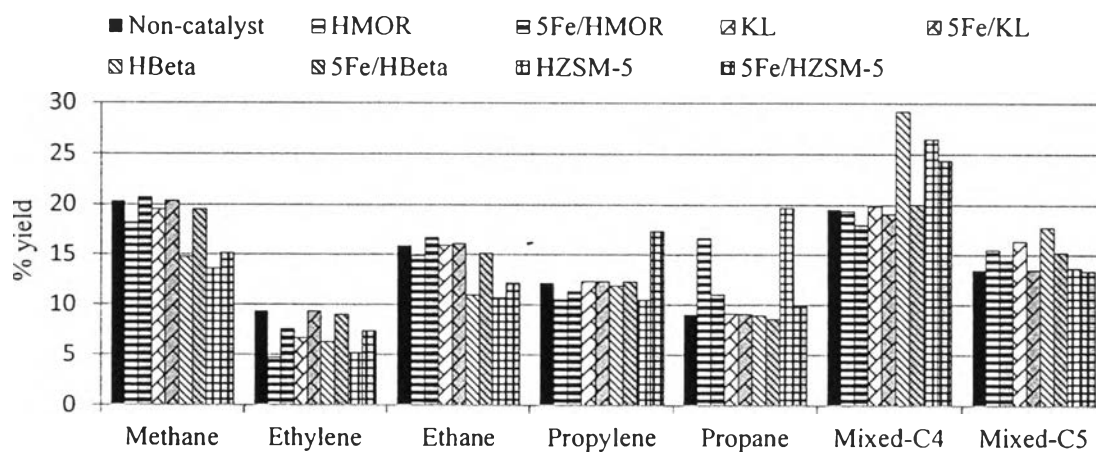
(c) 5%Fe/HZSM-5

(d) 5%Fe/KL

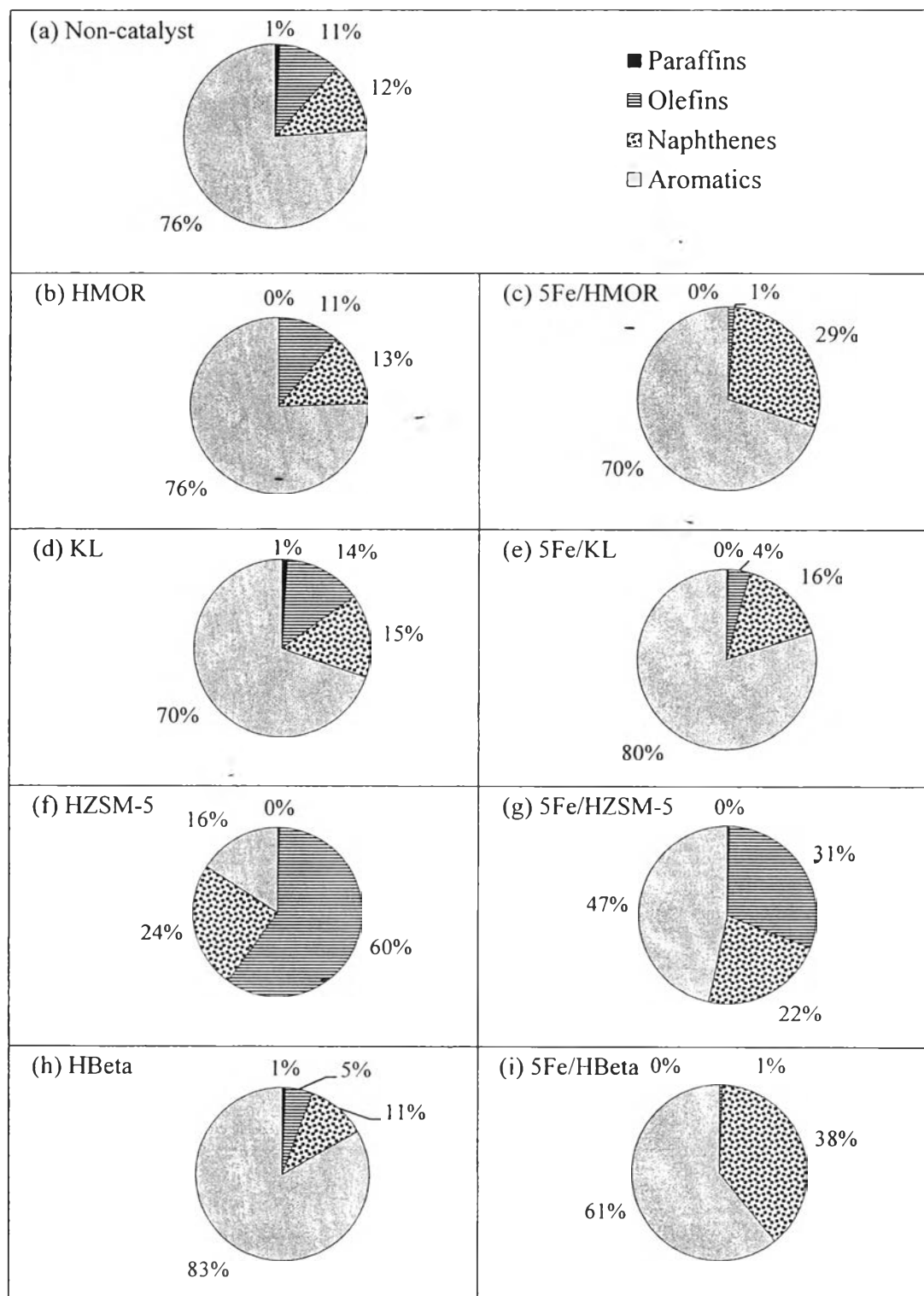
**Figure 6.2** XRD pattern of (a) 5%Fe/HBeta, (b) 5%Fe/HMOR, (c) 5%Fe/HZSM-5, and (d) 5%Fe/KL.



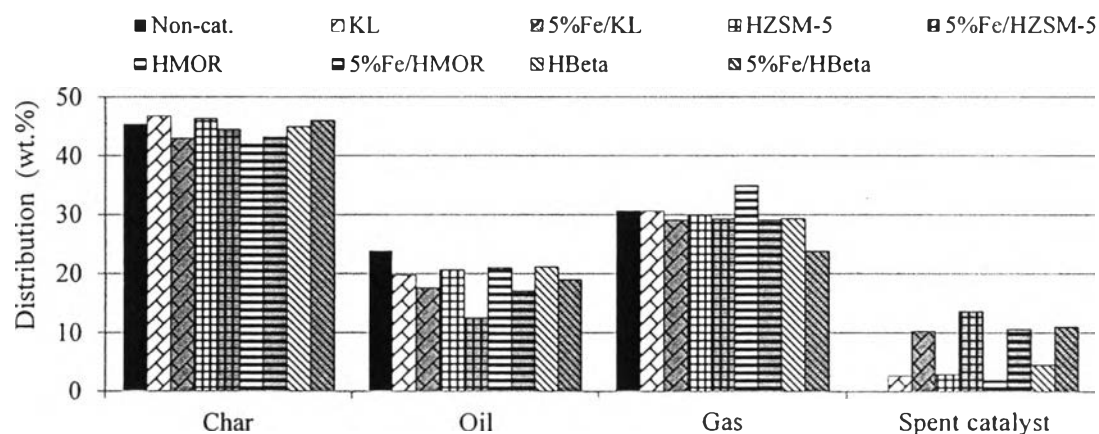
**Figure 6.3** Yield of pyrolysis products obtained from using pure zeolites (KL, HBeta, HMOR, and HZSM-5) and 5%Fe-promoted catalysts.



**Figure 6.4** Gas compositions obtained from using pure zeolites (KL, HZSM-5, HMOR, and HBeta) and 5%Fe-promoted catalysts.



**Figure 6.6** Components in gasoline (wt.%): (a) the non-catalyst case, (b) HMOR, (c) 5%Fe/HMOR, (d) KL, (e) 5%Fe/KL, (f) HZSM-5, (g) 5%Fe/HZSM-5, (h) HBeta, and (i) 5%Fe/HBeta.



**Figure 6.11** Overall distribution of sulfur in pyrolysis products obtained from using, pure zeolites (KL, HZSM-5, HMOR, and HBeta) and 5%Fe-promoted catalysts.

**Table 6.1** Petrochemicals (wt.% in oil) obtained from zeolites (HMOR, HBeta, HZSM-5, and KL) and Fe-loaded zeolites

	HM	5Fe/HM	HB	5Fe/HB	HZ	5Fe/HZ	KL	5Fe/KL
<b>Benzene</b>	0.124	14.0	4.81	-	-	3.41	0.265	12.7
<b>Toluene</b>	0.184	0.0532	0.917	0.095	0.196	0.652	0.00497	1.18
<b>Ethylbenzene</b>	0.408	0.833	3.31	0.867	0.258	0.403	0.102	-
<b>m-Xylene</b>	0.185	-	-	-	0.0981	0.835	-	0.392
<b>o-Xylene</b>	-	-	0.161	0.234	-	0.0105	-	-
<b>p-Xylene</b>	-	0.284	0.129	0.253	0.030	0.0441	-	0.210
<b>Styrene</b>	1.31	-	0.320	0.464	0.207	0.602	0.125	0.464
<b>Cyclohexane</b>	-	7.17	1.05	4.12	3.46	4.11	-	3.28
<b>Cumene</b>	0.105	0.882	0.0771	0.507	0.0348	1.09	0.0827	0.682
<b>Total</b>	<b>2.32</b>	<b>23.3</b>	<b>10.8</b>	<b>6.54</b>	<b>4.28</b>	<b>11.2</b>	<b>0.580</b>	<b>18.9</b>

**Table 6.2** Decreases in mono-aromatic species found in oils obtained from using HMOR and 5%Fe/HMOR

Name	Area (%)	
	HMOR	5Fe/HMOR
Styrene	1.115	-
1-Cyclopenten-1-yl-benzene	0.876	-
2,3-Dimethyl-1H-indene	0.791	0.176
3-Phenyl-2-pentene	0.761	-
Cyclohex-3-en-1-yl-benzene	0.716	0.034
(1-Methylenepent-2-enyl)-benzene	0.714	0.359
Hexylbenzene	0.516	-

**Table 6.3** Decreases in mono-aromatic species found in oils obtained from using HZSM-5 and 5%Co/HZSM-5

Name	Area (%)	
	HZSM-5	5Fe/HZSM-5
(1-Methylpenta-2,4-dienyl)benzene	1.37	1.01
Cyclohex-3-en-1-yl-benzene	0.789	0.183
1,2,3,4-Tetrahydro-6-propyl-naphthalene	0.783	0.523
1,2,3-Trimethylindene	0.677	0.628
2-Methyl-1,2-dihydronaphthalene	0.587	0.108
1,1a,6,6a-Tetrahydrocycloprop[a]indene	0.377	0.046

**Table 6.4** Decreases in mono-aromatic species found in oils obtained from using KL and 5%Fe/KL

Name	Area (%)	
	KL	5Fe/KL
1,2,3-Trimethylindene	1.19	0.760
3-Phenyl-2-pentene	1.11	0.679
(1-Methylpenta-1,3-dienyl)benzene	1.04	0.408
7-Butylbicyclo[4.2.0]octa-1,3,5-triene	0.845	0.757
(1-Methylpenta-2,4-dienyl)benzene	0.676	-
Cyclopentylbenzene	0.619	0.641
Hexylbenzene	0.694	0.641

**Table 6.5** Decreases in mono-aromatic species found in oils obtained from using HBeta and 5%Fe/HBeta

Name	Area (%)	
	HBeta	5Fe/HBeta
Benzene	4.44	-
Ethylbenzene	3.01	0.811
(1-ethyl-1-propenyl)-benzene	0.804	0.754
1,2,3,4-Tetrahydro-1,4-ethanonaphthalene	0.761	-
Toluene	0.758	0.088
1-Cyclopenten-1-yl-benzene	0.637	-
1-Propynyl-benzene	0.582	0.151