CHAPTER VII

EFFECTS OF COBALT SUPPORTED ON ZEOLITES ON STRUCTURES OF HYDROCARBON COMPOUNDS AND PETROCHEMICALS IN TIRE-DERIVED OILS

7.1 Abstract

Pyrolysis of waste tire is a effective way to recover valuable compounds. In order to increase the value of pyrolysis products, metal-loaded catalysts are used. Cobalt is used in many catalytic reactions; moreover, it exhibited a good activity in waste tire pyrolysis to increase light fractions, and reduce the sulfur in oil. This study investigates the impact of Co supported on zeolites (KL, HBeta, HZSM-5, and HMOR) on structures of tire-derived products. Co-promoted catalysts were prepared by incipient wetness impregnation technique, and the amount of Co was fixed at 5wt.%. The pyrolytic products and catalysts were characterized by using GC, SIMDIST-GC, GC×GC-TOF/MS, elemental analyzer, XRD, and SAA. The results showed that using Co suported on zeolites increased the light fraction at the expense of heavier fractions in oils due to Co that enhanced the cracking ability. The valuable hydrocarbons in oils such as benzene, cyclohexane, and toluene significantly increased with the presence of Co. Moreover, using Co-loaded catalysts resulted in the reduction of sulfur contents in oils, and sulfur species in oils were changed significantly.

7.2 Introduction

Tires have long-life and complication to recycle result in a large amount of waste tire. Pyrolysis process is a technical way to recover valuable products from waste tire. The products of waste tire pyrolysis consist of carbonaceous materials, and a mixture of hydrocarbons, which can be separated into gas and oil. These fractions can be used as valuable fuels and chemical feedstock (Laresgoiti *et al.*, 2004; Islam *et al.*, 2008). Light aromatics, BTEX, are of the great importance because they are used in a wide range of materials. Benzene is a raw material for the production of dye, ethylbenzene, and resin. Toluene is used in phenol, benzoic acid, and pesticide production. Xylenes are used in plastics industry. In contrast, poly-aromatic hydrocarbons (PAH) have serious drawbacks; for instance, they are identified as carcinogenic and mutagenic compounds. Similarly, polar-aromatic hydrocarbons, which are the heteroatom (S, O, and N)-containing aromatics, also caused the health hazard and pollution (Cunliffe and Williams, 1998a; Cunliffe and Williams, 1998b; Llompart *et al.*, 2013). In addition, new environmental regulations of many countries impose a reduction of sulfur emission from fuel combustion. Thus, the technique to improve the quality of oils has been developed via sulfur removal. There are many techniques to remove sulfur compounds such as hydrodesulfurization and adsorption.

Zeolites have been paid the important role in the field of adsorptive desulfurization of transportation fuels, owing to the channel structure, high surface area, and pore volume that allow thiophene molecules with a smaller diameter than benzothiophene and dibenzothiophene molecules to go inside the pore. Pore structure plays an important role in adsorptive desulfurization, whereas the large pore of a zeolite is beneficial to great desulfurization desulfurization (García-Cruz *et al.*, 2008; Tian *et al.*, 2012).

Recently, it was reported the use of Co, instead of Rh, in the pyrolysis of waste tire. The results showed that using Co supported on KL increased light olefins and cooking gas production. In addition, Co-loaded catalysts gave a high production of mono-aromatics and a low concentration of multi-ring aromatics. These results were attributed to Co that provided good performance in hydrogenation and ring opening reactions, leading to the conversion of multi-ring aromatics to mono-aromatics. It was suggested that 5%Co/KL produced a higher amount of mono-aromatics than using Rh/KL (Pinket, 2011). Similarly, waste tire pyrolysis using 5wt.%Co supported on various supports, namely HY, HMOR, HBeta, HZSM-5, and SAPO-34 were investigated. The results showed that the introduction of 5%Co on zeolites resulted in an increasing gas yield and decreasing liquid yield as compared to the non-catalytic pyrolysis due to Co that enhanced the ability in breaking heavy products to lighter products. Mono-aromatic hydrocarbons increased with using zeolites, and further increased with using Co-loaded catalysts (Saparakpunya, 2012).

Piyawongpinyo (2013) studied Co-modified on HBeta zeolite. The results exhibited that using 5%Co/HBeta gave the highest yield of cooking gas among all non-catalytic and catalytic cases. In addition, 5%Co/HBeta increase full range naphtha in accordance with decrease in heavier fractions. On the other hand, 5%Co/HBeta catalyst showed a good hydrodesulfurization ability since the sulfur content in oil was decreased.

Since, no researcher has studies the effect of Co on the structure and distribution of hydrocarbons in oils, the aim of this study was to investigate effects of cobalt supported on zeolites on structure of hydrocarbon compounds and petrochemicals in tire-derived oils. A series of Co supported zeolites was prepared by incipient wetness impregnation technique loading, and the amount of Co was fixed at 5wt.% for all cases.

7.3 Experimental

7.3.1 Catalyst Preparation

All zeolites (HMOR, HBeta, KL, and HZSM-5) were obtained from Tosoh Company in Singapore and Zeolyst International. In order to remove impurity from zeolite, HMOR and HZSM-5 zeolites 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, and KL was calcined at 500 °C for 3 h at 10 °C/min. Then, Co was loaded on the zeolite using incipient wetness impregnation technique. Cobalt (II) nitrate hexahydrate ($Co(NO_3)_2 \cdot 6H_2O$) solution was dropped on a zeolite, and the amount of Co was fixed at 5 wt.%. After that, the catalysts were dried at 100 °C for 3 h in an oven, and then calcined again at the same conditions. Finally, they were reduced at 600 °C for 2 h with H_2 to convert the metal oxide to metal.

7.3.2 Catalyst Characterization

X-ray Diffraction (XRD) technique was used to verify the metallic form of the catalysts. X-ray diffraction patterns were taken by using a Bruker X-ray diffractometer system (D8 Advance) equipped with a 2.2 kW Cu anode in a long fine focus ceramic X-ray tube for generating a CuKα radiation (1.5405 Å). The detector scanned the peak position from the samples as a function of 2θ by starting at the

5 ° to 100 °(2θ) range and a scan speed of 5 °(2θ)/min. H_2-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 to 850 °C with a heating rate of 10 °C/min. Surface area (BET) was determined by using Sorptomatic equipment. In addition, TG/DTA was used to determine coke deposited on spent catalysts.

7.3.3 Pyrolysis of Waste Tire

There are 2 zones of the pyrolysis reactor, which are catalytic zone (the upper zone) and pyrolytic zone (the lower zone). Firstly, 30 g of the waste tire with sizes in the range of 20-40 mesh was loaded into the lower zone, and 7.5 g of pellet catalyst was loaded to the catalytic zone. Then, the pyrolysis was heated with the rate of 10 °C/min from the room temperature to 500 °C, and then kept for 120 min at the atmospheric pressure. The temperature of pyrolytic zone was controlled at 350 °C. The flow rate of N_2 was controlled at 30 ml/min, continuously flown to purge the oxygen out of the system prior to pyrolysis and subsequently for carrying the pyrolysis products to condensers and a gas sampling bag. These condensers were placed into an ice bath in order to collect the liquid product. A gas sampling bag collected the incondensable products. The liquid product was dissolve in *n*-pentane to separate asphaltene by using a polyamide membrane (pore size = 0.45μm). Then, true boiling point curve and petroleum fractions were determined by using a Simulated Distillation Gas Chromatography (SIMDIST-GC) conformed with ASTM D-2887. Finally, the composition of a maltene was analyzed by using a comprehensive two-dimensional Gas Chromatography with Time of Flight Mass Spectrometer (GC×GC-TOF/MS). The gas products were analyzed for compositions by using a Gas Chromatography (GC-FID). In addition, an elemental analyzer was used to determine the sulfur content in solid products and spent catalysts.

7.4 Results and Discussion

7.4.1 Catalyst Characterization

The XRD patterns of Co-loaded catalysts are shown in Figure 7.1. It exhibits that the introduction of 5 wt.% of cobalt should result in the presence of new peaks that belong to metallic Co in the XRD patterns of all catalysts; however, the low amount of cobalt only gives the low intensity of Co peaks at 2θ of 44 °, 51 °, and 55 °.

TPR profiles of Co-loaded catalysts are shown in Figure 7.2. The results indicate that reduction peak exhibits at 429 °C, 535 °C, 485 °C, and 458 °C for 5%Co/HMOR, 5%Co/KL, 5%Co/HZSM-5, and 5%Co/HBeta, respectively.

7.4.2 Pyrolysis Yield

The distribution of pyrolysis products is shown in Figure 7.3. The results show that using zeolites, which are KL, HMOR, and HZSM-5, except HBeta, results in the reduction of oil in accordance with the increment of gas and coke as compared to the non-catalytic pyrolysis. Moreover, the char yield is not significantly different. The introduction of cobalt strongly affects the yield of pyrolysis products. Using 5%Co supported on KL, HBeta, HMOR, and HZSM-5 zeolites further decreases the oil yield in accordance with the increment of gas and char, except 5%Co/HMOR. In addition, Figure 7.4 illustrates gas compositions obtained from using pure zeolites (HBeta, HMOR, HZSM-5, and KL) and 5%Co supported on those zeolites. It can be seen that using 5%Co-loaded zeolites results in the increment of methane, ethylene, ethane, and propylene, with the decreases of propane, mixed-C_4, and mixed-C_5 as compared to using those pure zeolites. It can be suggested that light hydrocarbon gases increase with the presence of Co. It indicates that the presence of Co enhances the cracking ability, which converts the heavy hydrocarbon gases to lighter hydrocarbon gases.

7.4.3 Petroleum Fractions

Figure 7.5 illustrates the petroleum fractions in maltenes; that are, full range naphtha (< 200 °C), kerosene (200-250 °C), light gas oil (250-300 °C), heavy gas oil (300-370 °C), and long residue (> 370 °C). The results exhibit that full range naphtha increases with using pure zeolites (KL, HZSM-5, HMOR, and HBeta). Furthermore, using all Co-loaded zeolites, except 5%Co/HBeta results in further increment of full range naphtha. It can be seen that Co highly influences on the petroleum fractions; namely, using Co-loaded catalysts cause the increment of light fraction (full range naphtha) in consequence with the reduction of the heavier fractions. In addition, kerosene tends to decrease with the use of Co supported on

KL, HMOR, and HBeta zeolites as compared to using those pure zeolites, but it slightly increases with 5%Co/HZSM-5. Using Co-loaded catalysts give a less amount of light gas oil than using pure zeolites for all cases. Heavy gas oil and long residue decrease with using 5%Co supported on KL, HZSM-5, and HMOR as compared to those pure zeolites, but they increase with using 5%Co/HBeta. According to the results, it can be suggested that the increment of full range naphtha caused by cracking ability, which is enhanced by Co that converts kerosene, light gas oil, heavy gas oil, and long residue to full range naphtha.

Using 5%Co supported on HBeta, which has a large pore size and 3D pore channel, gives a higher amount of heavy gas oil and long residue than using HBeta. It can be explained that introduction of Co on HBeta might promote the secondary reaction of Co, such as oligomerization, to form heavy fractions such as heavy gas oil (Teiseh *et al.*, 2012).

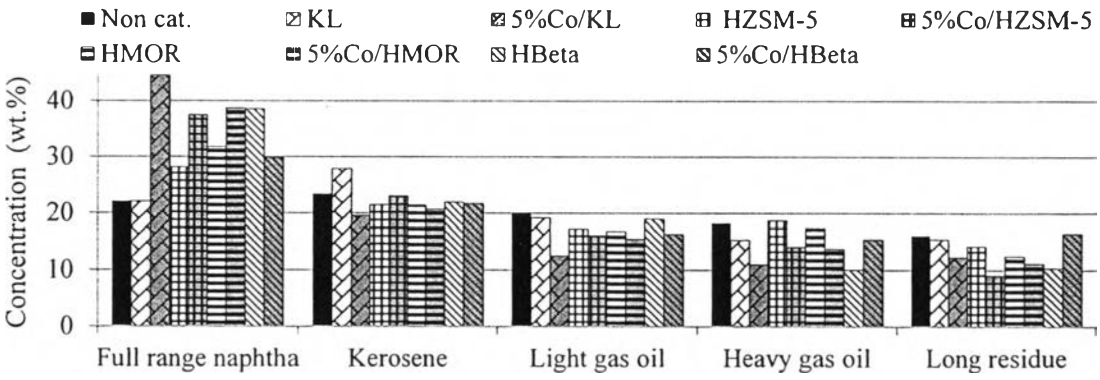

Figure 7.5 Petroleum fractions in maltenes obtained from using pure zeolites (KL, HZSM-5, HMOR, and HBeta) and 5%Co-promoted catalysts

The components in gasoline classified into paraffins, olefins, naphthenes, and aromatics, are illustrated in Figure 7.6. The results exhibit that aromatics are the most abundant species with using 5%Co supported on KL, HZSM-5, and HBeta, whereas a high amount olefins are produced with using 5%Co/HMOR.

7.4.4 Petrochemicals in Oils

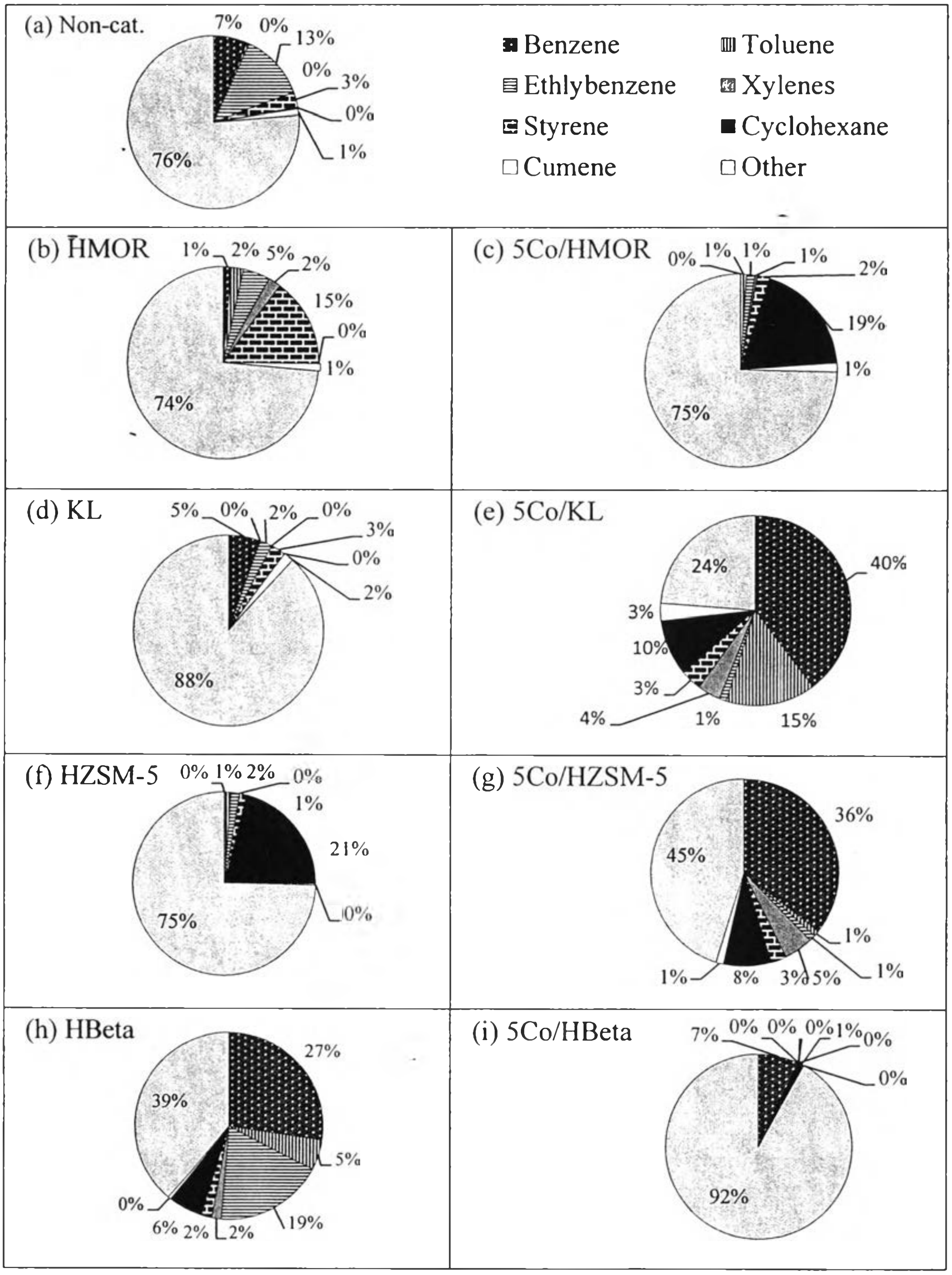

Figure 7.7 Petrochemicals (wt.% in gasoline) obtained from (a) the non-catalyst case, (b) HMOR, (c) 5%Co/HMOR, (d) KL, (e) 5%Co/KL, (f) HZSM-5, (g) 5%Co/HZSM-5, (h) HBeta, and (i) 5%Co/HBeta.

A high content of aromatics and olefins in oil can cause a high amount of smoke and gum formation in motor, respectively. Thus, pyrolytic oils are not suitable to use in fuel application. However, it can be used as a feedstock for petrochemical production since the valuable hydrocarbons, which are benzene, toluene, ethylbenzene, xylenes, styrene, cyclohexane, and cumene, are found as shown in Figure 7.7. The results show that the introduction of Co enhances petrochemical production, except 5%Co/HBeta. Using 5%Co/HMOR highly increases the production of cyclohexane as compared to using HMOR. 5%Co/KL can produce a higher amount of benzene, toluene, and cyclohexane than using KL. 5%Co/HZSM-5 increases the production of benzene and xylenes, whereas using 5%Co/HBeta decreases the production of all petrochemicals. It may be due to 5%Co/HBeta can enhance the production of heavy compounds as mentioned before in Figure 7.5; thus, resulting in the decrease of petrochemicals. Moreover, it can be concluded that the oils obtained from using 5%Co on KL, HMOR, and HZSM-5 have more value than using those pure zeolites.

The yields of petrochemicals in oils obtained from using pure zeolites (HMOR, HBeta, HZSM-5, and KL) and 5%Co supported on zeolites are shown in Table 7.2. From the results, it can be suggested that 5%Co/KL is the best catalyst to produce benzene (9.99 wt.%), toluene (3.79 wt.%), *m*-xylene (0.994 wt.%), and cumene (0.717 wt.%). 5%Co/HZSM-5 can be used to produce cyclohexane (3.78 wt.%). The highest amount of styrene (1.31 wt.%) and ethylbenzene (0.408 wt.%) are produced by using HMOR.

It can be seen that loading Co on KL and HMOR, which have a large pore size and 1D pore channel, results in the sharp increment of petrochemical production. Loading Co on HZSM-5 and HBeta, which have 3D pore channel, changes petrochemical production differently. Namely, using 5%Co/HBeta results in a sharp decrease of petrochemical production as compared with using HBeta, whereas using 5%Co/HZSM-5 produces a higher amount of petrochemicals about 1.5 times higher than using HZSM-5. It can be concluded that 1D pore channel possibly enhances the activity of Co on producing petrochemicals more effectively than 3D pore channel. HBeta, which has 3D pore channel and large pore size, possibly allows the molecules to go inside with longer contact time than 1D channel;

thus, resulting in the production of heavy compound via secondary reaction such as oligomerization, enhanced by Co (Teiseh et al., 2012). In addition, using Co/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 size of HZSM-5 may inhibit the formation of heavy compounds as compared with the large pore size of HBeta.

7.4.5 Liquid Components

The components in maltenes, which consist of paraffins, olefins, naphthenes, mono-aromatic, di-aromatic, poly-aromatic, and polar-aromatic hydrocarbons are shown in Figure 7.8. The results show that maltenes contain a small amount of paraffins (> 4 wt.%). Using 5%Co supported on KL and HZSM-5 results in the reduction of olefins and naphthenes as compared to using pure KL and HZSM-5, whereas total aromatics are increased. Moreover, it is found that using 5%Co/KL and 5%Co/HZSM-5 produce a higher amount of mono-aromatics than using pure KL and HZSM-5 in accordance with the decreases of di- and poly-aromatics. It indicates that Co causes the reduction of di- and poly-aromatics, which convert to mono-aromatics, via saturation aromatic ring and open the hydrocarbon ring by hydrogenation (Pedrosa *et al.*, 2006; Saparakpunya, 2012).

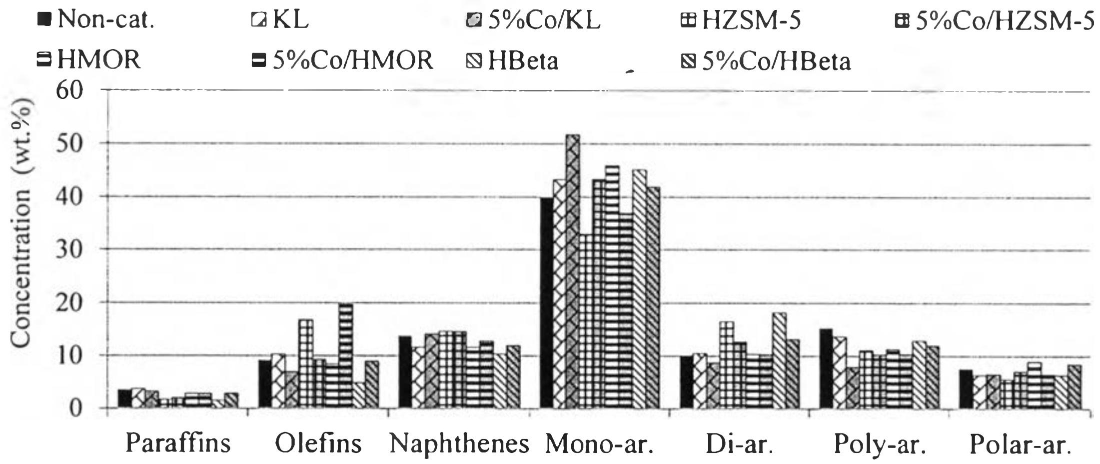

Figure 7.8 Concentration of chemical components in maltenes obtained from using pure zeolites (KL, HZSM-5, HMOR, and HBeta) and 5%Co-promoted catalysts.

In addition, the use of 5%Co-promoted HMOR and HBeta gives a higher amount of olefins and naphthenes than using HMOR and HBeta zeolites. The results show that mono-, di-, and poly-aromatics decrease with using 5%Co/HMOR and 5%Co/HBeta. It can be explained that the presence of Co can enhance hydrogenation and ring opening activity, which further convert mono-aromatics to olefins and naphthenes. Polar-aromatics, which are the heteroatom (S, O, and N)-containing aromatics, slightly increase with the use of 5%Co-promoted catalysts, except 5%Co/HMOR.

Moreover, the species of mono-aromatics are changed differently, and the reduction of some mono-aromatic species with using Co-loaded catalysts are shown in Tables 7.3-7.6. For instance, using 5%Co/HMOR decreases the amount of styrene and 1-cyclopenten-1-yl-benzene as compared to using pure HMOR. Using 5%Co/KL decreases the amount of (1-methylpenta-1,3-dienyl)-benzene and 3-phenyl-2-pentene. In addition, 5%Co/HZSM-5 produces a less amount of 2-methyl-1,2-dihydronaphthalene and 1,1,5-trimethyl-indan. It indicates that these mono-aromatics species might be converted to petrochemicals by hydrogenation and ring opening enhanced by Co. This is well consistent with the increment of petrochemicals, which are cyclohexane with using 5%Co/HMOR, benzene, toluene and cyclohexane with using 5%Co/KL, and benzene and xylenes with using 5%Co/HZSM-5, as mentioned before in Table 7.2.

7.4.6 Desulfurization Activity

Sulfur distribution in pyrolysis products is shown in Figure 7.9. The results show that sulfur mostly distributed in char with no significant difference for all cases. Using 5%Co supported on zeolites shifts the sulfur in oil and char to the spent catalyst. In addition, the use of 5%Co supported on KL, HBeta and HZSM-5 results in the insignificant difference of sulfur distribution in gas, whereas using 5%Co/HMOR slightly decreases sulfur distribution in gas. Moreover, the sulfur content in oils are shown in Figure 7.10. The results show that 5%Co supported on all zeolites exhibits the reduction of sulfur contents in oils as compared to using those pure zeolites. It can be suggested that Co has ability to break C-S bond. In addition, the lowest sulfur content in oils obtained from 5%Co/KL (0.850 wt.%).

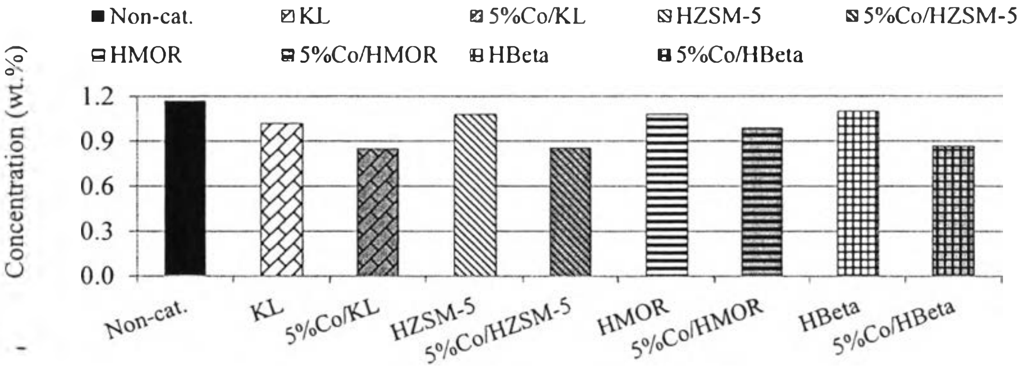

Figure 7.10 Sulfur contents in oils obtained from using pure zeolites (KL, HZSM-5, HMOR, and HBeta) and 5%Co-promoted catalysts.

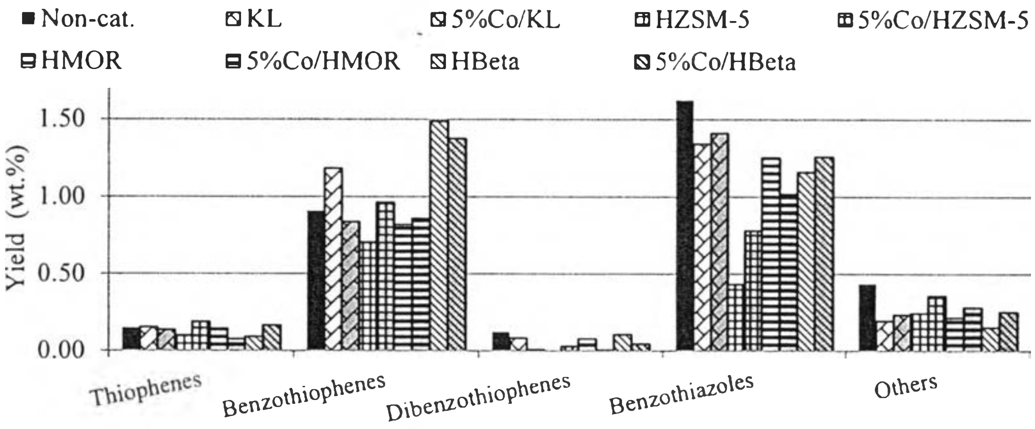

Figure 7.11 Yield of sulfur species in maltenes obtained from using pure zeolites (KL, HZSM-5, HMOR, and HBeta) and 5%Co-promoed catalysts.

Figure 7.11 illustrated the yield of sulfur species in oils, 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). The presence of benzothiazoles in oil can be explained that these compounds is used in tire production as a vulcanization accelerator (Li *et al.*, 2010; Avagyan *et al.*, 2013; Llompart *et al.*, 2013). It can be seen that that using Co-loaded catalysts tends to decrease sulfur-containing compounds (BTs and DBTs), except 5%Co/HZMS-5. Using 5%Co/HZSM-5 increases the amount BTs as compared to using HZSM-5. From the results, it can be suggested that Co enhances the C-S bond breaking activity, resulting in the reduction of BTs and DBTs, whereas Co loading on HZSM-5 causes the lowest surface area and pore volume; thus, it might result in the decreasing activity in reducing of BTs and DBTs. Moreover, using Co-loaded catalysts tends to increase the heteroatom-containing sulfur compounds. It can be suggested that the introduction of Co may reduce the active sites of zeolite, resulting in the reduction of cracking activity.

7.5 Conclusions

The use of Co supported on KL, HMOR, HZSM-5 and HBeta catalysts enhanced the cracking ability of heavy products to lighter products. The petrochemicals in oils sharply increased with using Co-loaded catalysts, except 5%Co/HBeta. The best catalyst for production of valuable petrochemicals was 5%Co/KL, followed by 5%Co/HZSM-5, 5%Co/HMOR-5, and 5%Co/HBeta, accordingly. In addition, 5%Co/KL can produce the highest amount of benzene, toluene, and *p*-xylene. 5%Co/HZSM-5 exhibited the potential for *o*-xylene and *p*-xylene production. 5%Co/HMOR showed an activity for production cyclohexane. Moreover, sulfur in oils were reduced with using Co-loaded catalysts, and the lowest sulfur in oil was obtained from 5%Co/KL.

7.6 Acknowledgements

The authors would like to gratefully thank the Petroleum and Petrochemical College, Chulalongkorn University, Thailand (PPC), and Thailand Research Fund (TRF)

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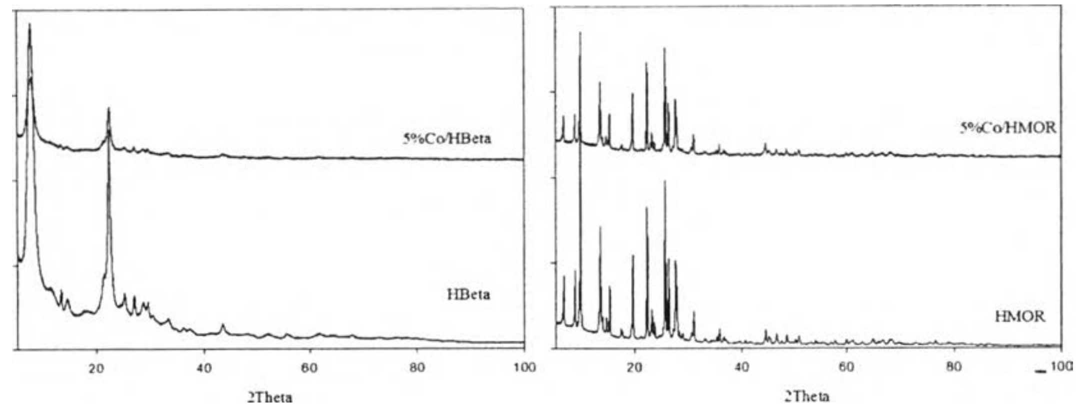
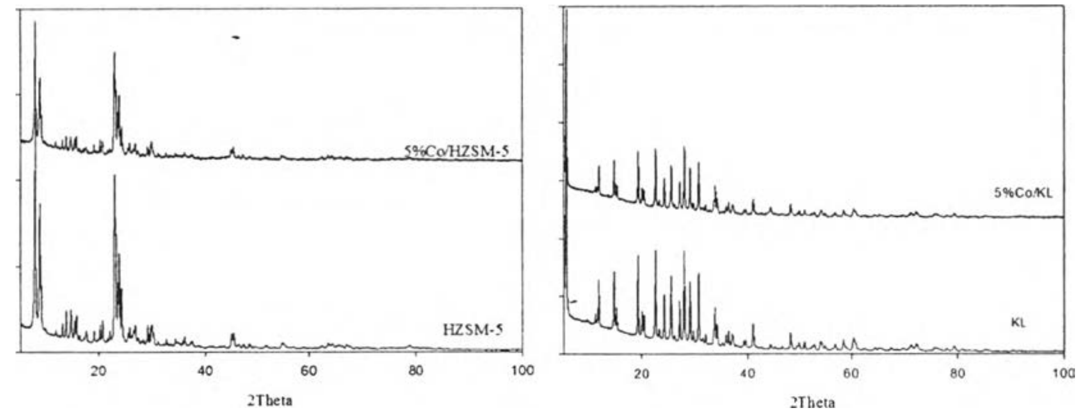


(a) 5%Co/HBeta

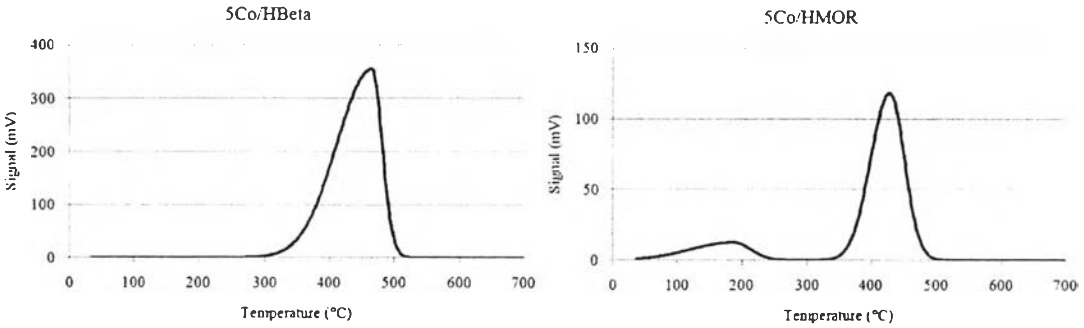
(b) 5%Co/HMOR



(c) 5%Co/HZSM-5

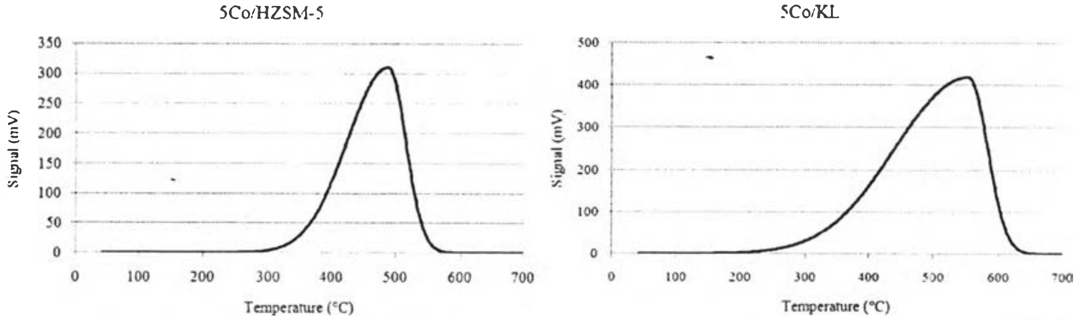
(d) 5%Co/KL

Figure 7.1 XRD pattern of (a) 5%Co/HBeta, (b) 5%Co/HMOR, (c) 5%Co/HZSM-5, and (d) 5%Co/KL.



(a) 5%Co/HBeta

(b) 5%Co/HMOR



(c) 5%Co/HZSM-5

(d) 5%Co/KL

Figure 7.2 H_2-TPR profiles: (a) 5%Co/HBeta, (b) 5%Co/HMOR, (c) 5%Co/HZSM-5, and (d) 5%Co/KL.

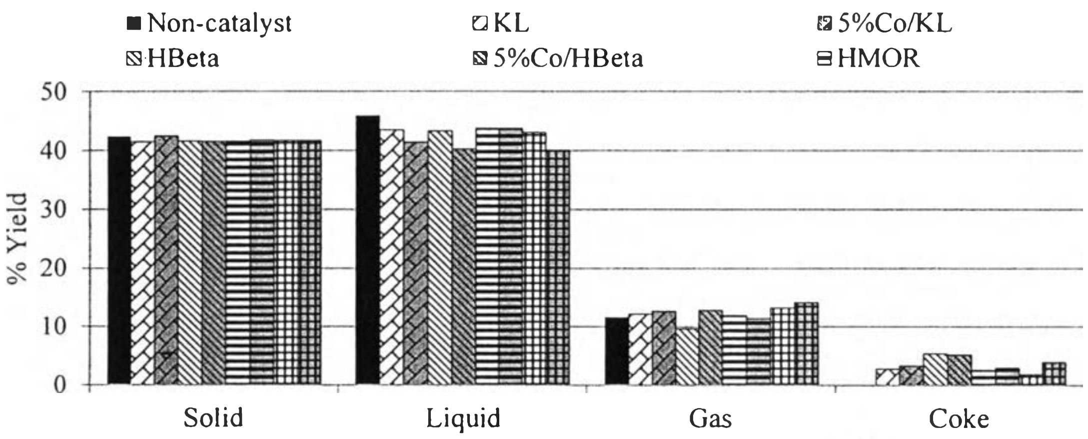


Figure 7.3 Yield of pyrolysis products obtained from using pure zeolites (KL, HBeta, HMOR, and HZSM-5) and 5%Co-promoted catalysts.

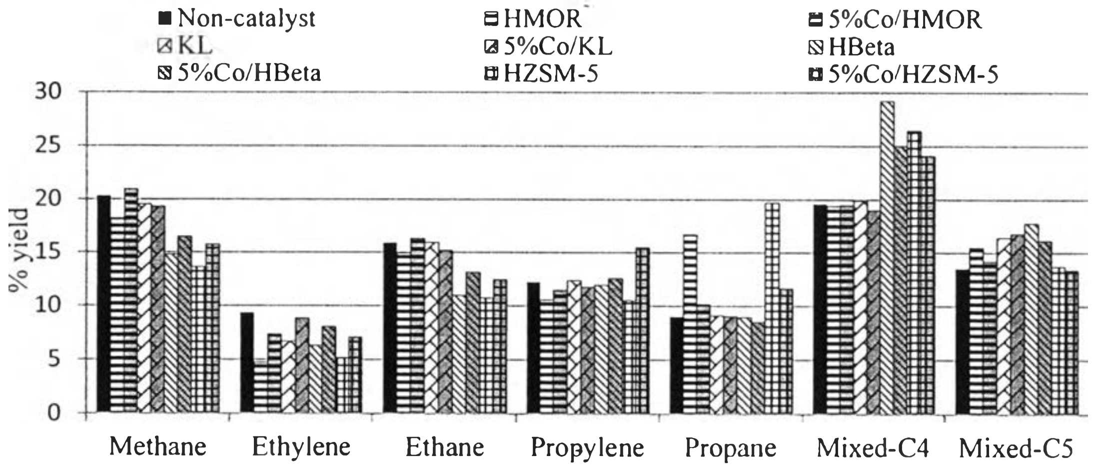


Figure 7.4 Gas compositions obtained from using pure zeolites (KL, HZSM-5, HMOR, and HBeta) and Co-promoted catalysts.

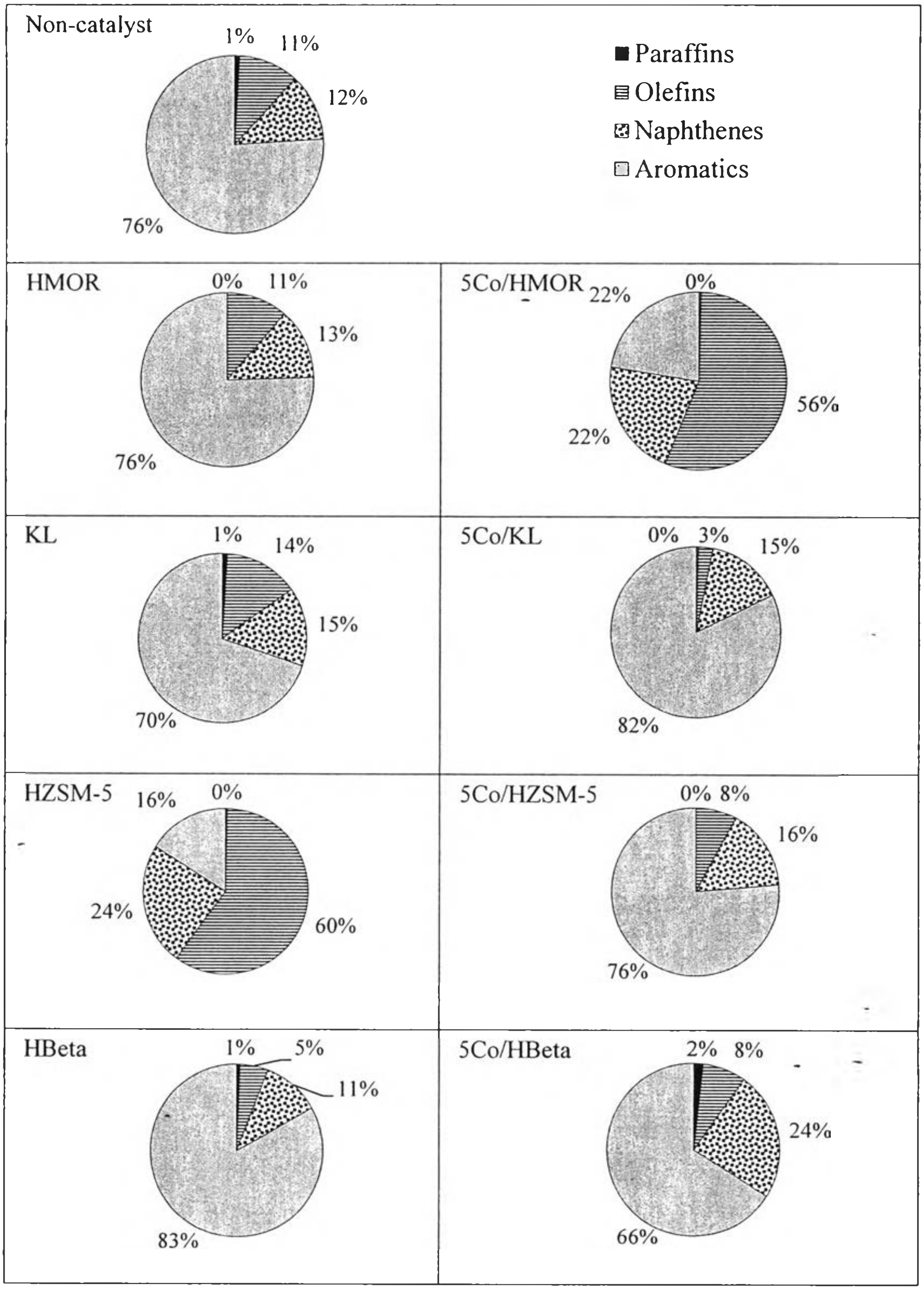


Figure 7.6 Components in gasoline (wt.%): (a) the non-catalyst case, (b) HMOR, (c) 5%Co/HMOR, (d) KL, (e) 5%Co/KL, (f) HZSM-5, (g) 5%Co/HZSM-5, (h) HBeta, and (i) 5%Co/HBeta.

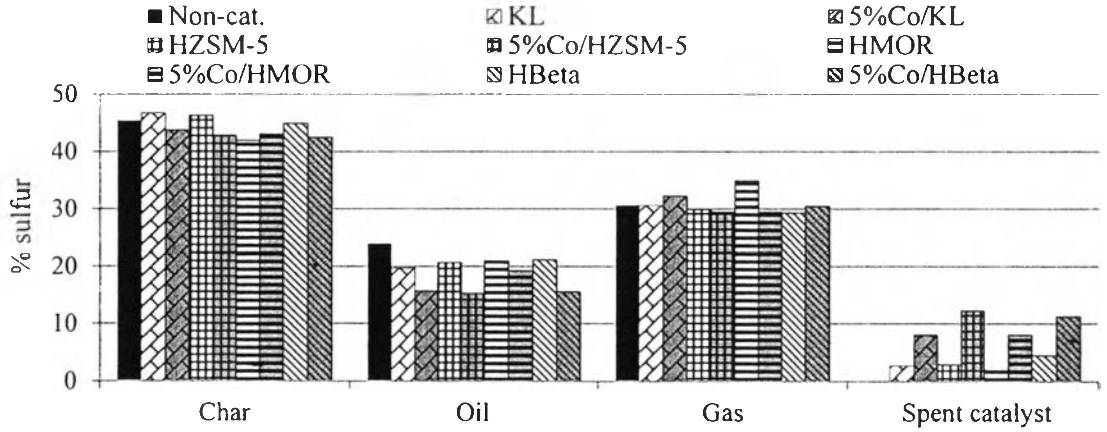


Figure 7.9 Overall distribution of sulfur in pyrolysis products obtained from using pure zeolites (KL, HZSM-5, HMOR, and HBeta) and 5%Co-promoted catalysts.

Table 7.1 Amount of gasoline (wt.%) in oils

	% gasoline in oil
Non-cat.	6.87
HBeta	17.6
HMOR	9.17
KL	5.03
HZSM-5	16.5
5Co/HBeta	4.14
5Co/HMOR	19.8
5Co/KL	25.1
5Co/HZSM-5	11.8

Table 7.2 Valuable hydrocarbon compounds (wt.% in oils) obtained from zeolites (HMOR, HBeta, HZSM-5, and KL) and Co-loaded zeolites

	HM	**5Co/HM**	**HB**	**5Co/HB**	**HZ**	**5Co/HZ**	**KL**	**5Co/KL**
Benzene	0.124	-	4.81	0.284	-	4.21	0.265	9.99
Toluene	0.184	0.197	0.917	0.005	0.196	0.108	0.00497	3.79
Ethylbenzene	0.408	0.280	3.31	0.004	0.258	0.132	0.102	0.311
***m*-Xylene**	0.185	-	-	-	0.098	-	-	0.994
***o*-Xylene**	-	-	0.161	-	-	0.123	-	-
***p*-Xylene**	-	0.0831	0.129	-	0.0304	0.451	-	-
Styrene	1.31	0.396	0.320	-	0.207	0.313	0.125	0.891
Cyclohexane	-	3.78	1.05	0.0394	3.46	0.972	-	2.43
Cumene	0.105	0.280	0.077	-	0.0348	0.144	0.0827	0.717
Total	**2.32**	**5.01**	**10.8**	**0.332**	**4.28**	**6.45**	**0.580**	**19.1**

Table 7.3 Decreases in mono-aromatic species found in oils obtained from using HMOR and 5%Co/HMOR

Name	**Area (%)**	
	HMOR	**5Co/HMOR**
2,3-dimethyl-1H-Indene	1.27	0.972
(1-Methylpenta-1,3-dienyl)-benzene	1.21	0.174
Cyclohexcyl-benzene	1.15	0.655
Styrene	1.11	0.351
1-Cyclopenten-1-yl-benzene	0.876	-
3-Phenyl-2-pentene	0.761	0.615
(1-Methylenepent-2-enyl)-benzene	0.714	0.358
6-Ethyltetralin	0.524	0.189

Table 7.4 Decreases in mono-aromatic species found in oils obtained from using HZSM-5 and 5%Co/HZSM-5

Name	**Area (%)**	
	HZSM-5	**5Co/HZSM-5**
1,2,3,4-Tetrahydro-6-propyl-naphthalene	0.783	0.378
1,2,3-Trimethylindene	0.677	0.158
Cyclopentyl-benzene	0.590	0.415
2-Methyl-1,2-dihydronaphthalene	0.587	0.049
1,1,5-Trimethylindan	0.400	0.288
1,1a,6,6a-Tetrahydrocycloprop[a]indene	0.377	-

Table 7.5 Decreases in mono-aromatic species found in oils obtained from using KL and 5%Co/KL

Name	**Area (%)**	
	KL	**5Co/KL**
6-Phenyl-2-hexene	1.98	1.29
1,2,3-Trimethylindene	1.19	0.596
3-Phenyl-2-pentene	1.11	0.547
(1-Methylpenta-1,3-dienyl)-benzene	1.04	0.165
Benzene, 3-cyclohexen-1-yl-	0.805	0.810
Hexylbenzene	0.694	0.626
Cyclopentylbenzene	0.619	0.575
Cyclohexylbenzen	0.578	0.402

Table 7.6 Decreases in mono-aromatic species found in oils obtained from using HBeta and 5%Co/HBeta

Name	Area (%)	
	HBeta	**5Co/HBeta**
Benzene	4.44	0.242
Ethylbenzene	3.01	0.003
7-Butyl-Bicyclo-[4.2.0]octa-1,3,5-triene	0.823	1.00
(1-ethyl-1-propenyl)-benzene	0.804	0.829
1,2,3,4-Tetrahydro-1,4-ethanonaphthalene	0.761	-
Toluene	0.758	0.005
1-Cyclopenten-1-yl-benzene	0.637	0.856