# CHAPTER IV
# RESULTS AND DISCUSSION

These experiments involved the search for suitable conditions to convert used lubricating oil with Ni-Mo/Al$_2$O$_3$ and HZSM-5 catalysts to light oil in high yield. The used lubricating oil was selected for this study, because a large quantity of demand in the world where some parts of this would cause the environment problem. The Ni-Mo/Al$_2$O$_3$ and HZSM-5 catalysts were selected because both catalysts were active and gave high activity for hydrocracking as well as for hydrogenation reaction.

## 4.1 Hydrocracking process

The results for all parameters from hydrocracking process of used lubricating oil on Ni-Mo/Al$_2$O$_3$ and HZSM-5 catalysts were studied as a function of processing variables, *i.e.* reaction temperture, hydrogen pressure, reaction time and percentage of catalyst. The oil products were identified by Simulated Distillation Gas Chromatography, following the ASTM D-2887 method. The change in % component of oil product as a function of the above variables allowed for the selection of suitable conditions.

### 4.1.1 Effect of reaction temperature on light oil composition.

The study of the temperature on the hydrocracking process of used lubricating oil with Ni-Mo/Al$_2$O$_3$ and HZSM-5 catalysts was performed by operating at various conditions.
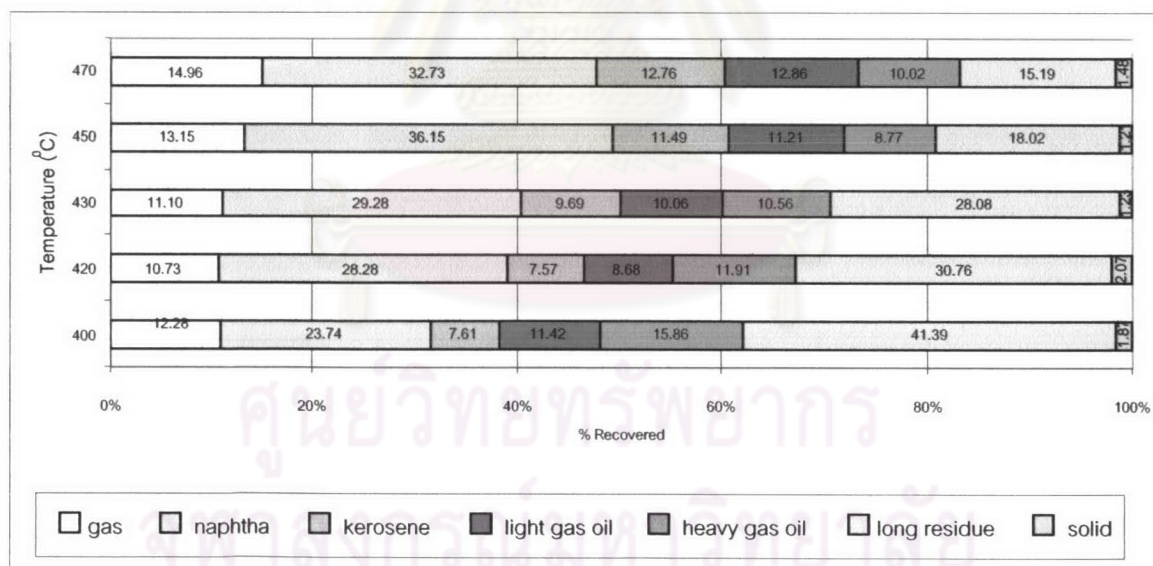
#### 4.1.1.1 Effect of reaction temperature on light oil composition for Ni-Mo/alumina.

The study of the temperature on the hydrocracking process of used lubricating oil with Ni-Mo/Al$_2$O$_3$ catalyst was performed by operating at various reaction temperatures: 400, 420, 430, 450 and 470 $^{0}$C by using 1.0 % Ni-Mo/Al$_2$O$_3$ catalyst under initial hydrogen pressure 100 psi while fixing reaction time at 90 minutes. The compositions of products from

catalytic hydrocracking process as a function of temperature were shown in Table 4.1 and Figure 4.1.

**Table 4.1** Effect of hydrocracking process at various temperatures on product composition at 100 psi of initial hydrogen pressure, 90 minutes of reaction time and 1.0 % Ni-Mo/Al$_2$O$_3$ catalyst.

| Temperature ($^0$C) | Gas product (% Yield) | Oil products (% recovered) | | | | | Solid (%Yield) | Oil Product (% Yield) |
|---|---|---|---|---|---|---|---|---|
| | | Naphtha | Kerosene | Light Gas Oil | Heavy Gas Oil | Long Residue | | |
| 400 | 12.28 | 23.74 | 7.61 | 11.42 | 15.86 | 41.39 | 1.87 | 85.85 |
| 420 | 10.73 | 28.28 | 7.57 | 8.68 | 11.91 | 30.76 | 2.07 | 87.20 |
| 430 | 11.10 | 29.28 | 9.69 | 10.06 | 10.56 | 28.08 | 1.23 | 87.67 |
| 450 | 13.15 | 36.15 | 11.49 | 11.21 | 8.77 | 18.02 | 1.21 | 85.64 |
| 470 | 14.96 | 32.73 | 12.76 | 12.86 | 10.02 | 15.19 | 1.48 | 83.56 |



**Figure 4.1** Effect of hydrocracking temperature range of 400-470 $^0$C on product composition at 100 psi of initial hydrogen pressure, 90 minutes of reaction time and 1.0 % Ni-Mo/Al$_2$O$_3$.

Table 4.1 and Figure 4.1 show the effect of reaction temperature on the hydrocracking process of used lubricating oil with 1.0% Ni-Mo/Al$_2$O$_3$ under initial hydrogen pressure 100 psi and reaction time 90 minutes. When the reaction temperature increased from 400 to 450 $^0$C, the thermal cracking of long chain hydrocarbon from lubricating oil firstly was broken down with high temperature to lower hydrocarbon such as gases (C$_1$-C$_5$), naphtha, kerosene and gas oil. Nevertheless thermal and catalytic cracks were the competitive reactions, but Ni-Mo/Al$_2$O$_3$ was not so active as zeolite. For these reasons the percentage of recovered of naphtha increases largely with an increase reaction temperature from 23.74% to 36.15%. When the temperature reached 470 $^0$C, we noticed the nephtha decreased from 36.15% to 32.73%, because catalytic cracking was dominated by thermal cracking. On the contrary, when increased of temperature, light hydrocarbon could be cracked more, as a result we found the % of gaseous product increased from 13.15% to 14.96%, this confirmed the idea above.

In conclusion, it was found that the optimum reaction temperature was 450 $^0$C because it gave high naphtha 36.15%, kerosene 11.49%, gas oil 19.98% and low residue product 19.23% and gaseous product 13.15%. Although the % oil yield was slighted from 87.67% to 85.64% this temperature was used to study for other variables.

4.1.1.2 Effect of reaction temperature on light oil composition for HZSM-5 catalyst.

The study of the temperature on the hydrocracking process of used lubricating oil with HZSM-5 catalyst was carried out operating at various reaction temperatures: 400, 420, 430, 450 and 470 $^0$C by using 0.5 % HZSM-5 catalyst under initial hydrogen pressure 100 psi and fixing reaction time at 60 minutes. The compositions of products from catalytic hydrocracking process as a function of temperature were shown in Table 4.2 and Figure 4.2.

**Table 4.2** Effect of hydrocracking process at various temperatures on product composition

at 100 psi of initial hydrogen pressure, 60 minutes of reaction time and 0.5 %

HZSM-5 catalyst.

| Temperature ($^{0}$C) | Gas product (% Yield) | Oil products (% recovered) | | | | | Solid (%Yield) | Oil Product (% Yield) |
|---|---|---|---|---|---|---|---|---|
| | | Naphtha | Kerosene | Light Gas Oil | Heavy Gas Oil | Long Residue | | |
| 400 | 6.99 | 6.39 | 4.14 | 6.90 | 18.23 | 53.96 | 3.39 | 89.62 |
| 420 | 10.23 | 21.15 | 8.77 | 10.95 | 12.85 | 30.27 | 5.78 | 83.99 |
| 435 | 14.69 | 32.89 | 9.66 | 9.88 | 8.63 | 22.13 | 2.12 | 83.19 |
| 450 | 12.33 | 34.87 | 11.03 | 11.49 | 8.73 | 19.34 | 2.21 | 85.46 |
| 470 | 17.03 | 26.30 | 6.54 | 7.17 | 7.91 | 33.24 | 1.81 | 81.16 |
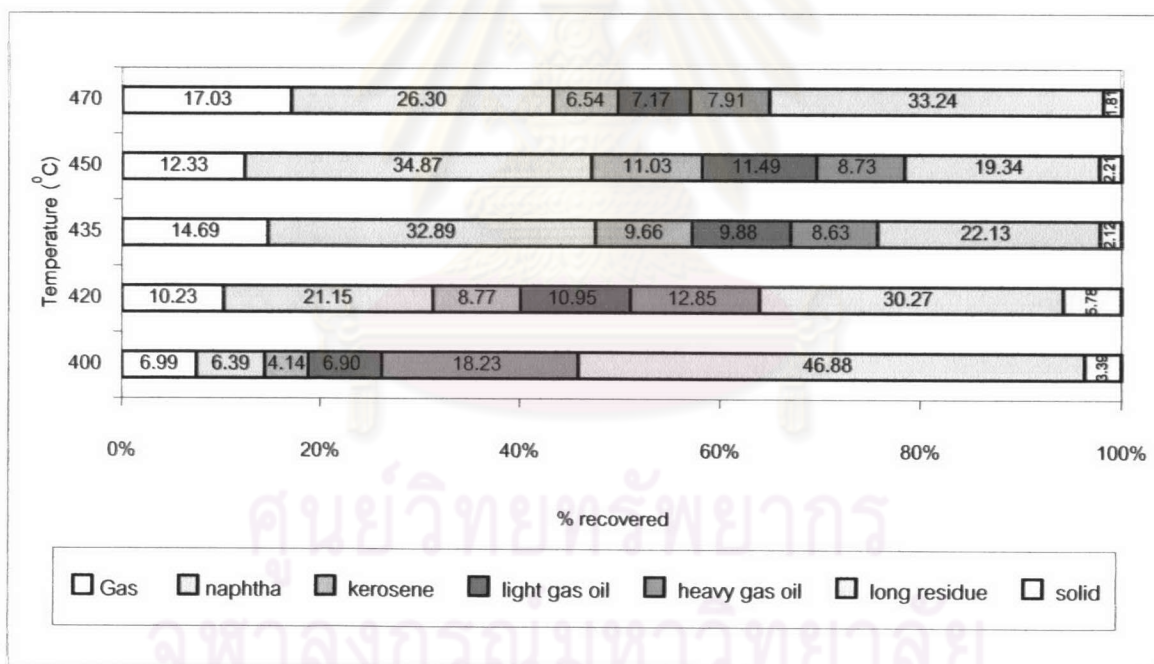


**Figure 4.2** Effect of hydrocracking temperature range of 400-470 $^{0}$C on product composition

at 100 psi of initial hydrogen pressure, 60 minutes of reaction time and 0.5%

HZSM-5 catalyst.

Table 4.2 and Figure 4.2 show the effect of reaction temperature on the hydrocracking process of used lubricating oil with 0.5% HZSM-5 under hydrogen pressure 100 psi and reaction time 60 minutes. When the temperature increased from 400 to 450 $^{o}$C, we found that the percentage of recovered naphtha increased largely with an increase reaction temperature from 6.39% to 34.87%, because the high temperature (450 $^{o}$C) accelerating the thermal cracking which changed kerosene and gas oil. After that kerosene to convert to naphtha and gases (normally $C_1$-$C_4$). We noticed that the percentage of kerosene and gas oil at 450 $^{o}$C was slightly more than 435 $^{o}$C about 1.5% and 2%, respectively. On the contrary we found total solid increased by 0.1% at the surface of catalyst which meaned that coking was also occurred at the same time. When the temperature reached 470 $^{o}$C, we observed the large decreasing of naphtha and kerosene from 34.87% to 26.30% and 11.03% to 6.54%, respectively. It seemed that when higher temperature was used, light hydrocarbon could be cracked more, as a result we found the % of gases increasing about 2%, because thermal cracking was faster than catalytic cracking.

In conclusion in case of temperature, the suitable temperature was 450 $^{o}$C because of high oil yield and low solid. The composition of product was naphtha, kerosene, light gas oil, heavy gas oil, long residue and solid at 34.87%, 11.03%, 11.49%, 8.73%, 19.34% and 2.21% respectively with 85.46% of oil yield.

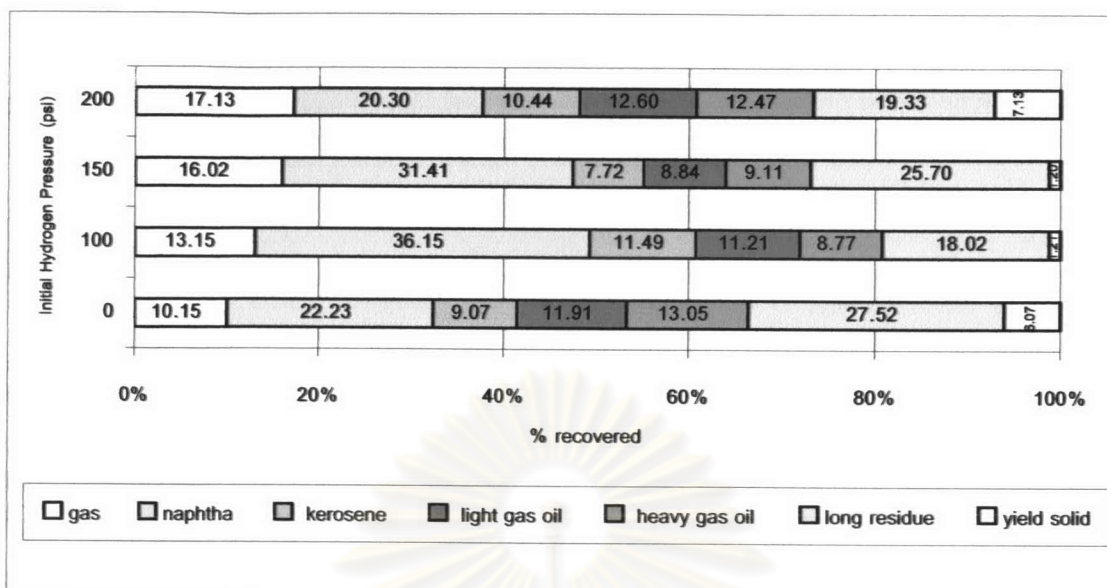4.1.2 Effect of initial hydrogen pressure on light oil composition.

The study of the initial hydrogen pressure on the hydrocracking process of used lubricating oil with Ni-Mo/Al$_2$O$_3$ and HZSM-5 catalysts was performed by operating at various conditions.

4.1.2.1 Effect of initial hydrogen pressure on light oil composition for Ni-Mo/alumina.

The study of the effect of initial hydrogen pressure was performed by various initial hydrogen pressures at 100, 150 and 200 psi by using 1.0 Ni-Mo/Al$_2$O$_3$ catalyst under reaction temperature 450 $^{\circ}$C and fixing reaction time at 90 minutes. The compositions of products from catalytic hydrocracking process as a function of initial hydrogen pressure were shown in Table 4.3, Figure 4.3.

Table 4.3 Effect of initial hydrogen pressure on product composition at 450 $^{\circ}$C of reaction temperature, 90 minutes of reaction time and 1.0 % Ni-Mo/Al$_2$O$_3$ catalyst.

| initial pressure ( psi) | Gas product (% Yield) | Oil products (% recovered) | | | | | Solid (%Yield) | Oil Product (% Yield) |
|---|---|---|---|---|---|---|---|---|
| | | naphtha | kerosene | light gas oil | heavy gas oil | long residue | | |
| blank | 10.15 | 22.23 | 9.07 | 11.91 | 13.05 | 27.52 | 6.07 | 83.78 |
| 100 | 13.15 | 36.15 | 11.49 | 11.21 | 8.77 | 18.02 | 1.21 | 85.64 |
| 150 | 16.02 | 31.41 | 7.72 | 8.84 | 9.11 | 25.70 | 1.20 | 82.78 |
| 200 | 17.13 | 20.30 | 10.44 | 12.60 | 12.47 | 19.33 | 7.13 | 75.14 |

**Figure 4.3** Effect of hydrocracking initial hydrogen pressure range of 0-200 psi on product composition 450 $^{\circ}$C of reaction temperature, 90 minutes of reaction time and 1.0 % Ni-Mo/Al$_2$O$_3$ catalyst.

Table 4.3 and Figure 4.3 show the effect of variation of initial hydrogen pressure from 0-200 psi on the hydrocracking process of used lubricating oil with 1.0% Ni-Mo/Al$_2$O$_3$ catalyst at reaction time 90 minutes and reaction temperature 450 $^{\circ}$C. It noticed that the pressure increased from 0 to 100 psi, the %yield of liquid and naphtha increased from 83.78% to 85.64% and 22.33% to 36.15%, respectively. It was observed obviously that the role of hydrogen to convert of lubricating oil is more important. When hydrogen concentration increased, it would promote the catalytic reaction by increasing more hydrogen free radical. Thus catalytic cracking could be occurred than thermal cracking at 100 psi of initial hydrogen pressure as a result. When the initial hydrogen pressure was increased from 100 to 200 psi, the %yield of liquid and naphtha was decreased from 85.64% to 75.14% and 36.15% to 20.30%, respectively. But the gases and solids were slightly increased from 13.15% to 17.13% and 1.21% to 7.13%, respectively. It seemed that the pressure at 100 psi was the best condition.

In conclusion, the optimum initial hydrogen pressure condition was 100 psi, because this presure gave the highest yield of oil 85.64%, % recovery of naphtha and kerosene was 36.15% and 11.49% respectively.
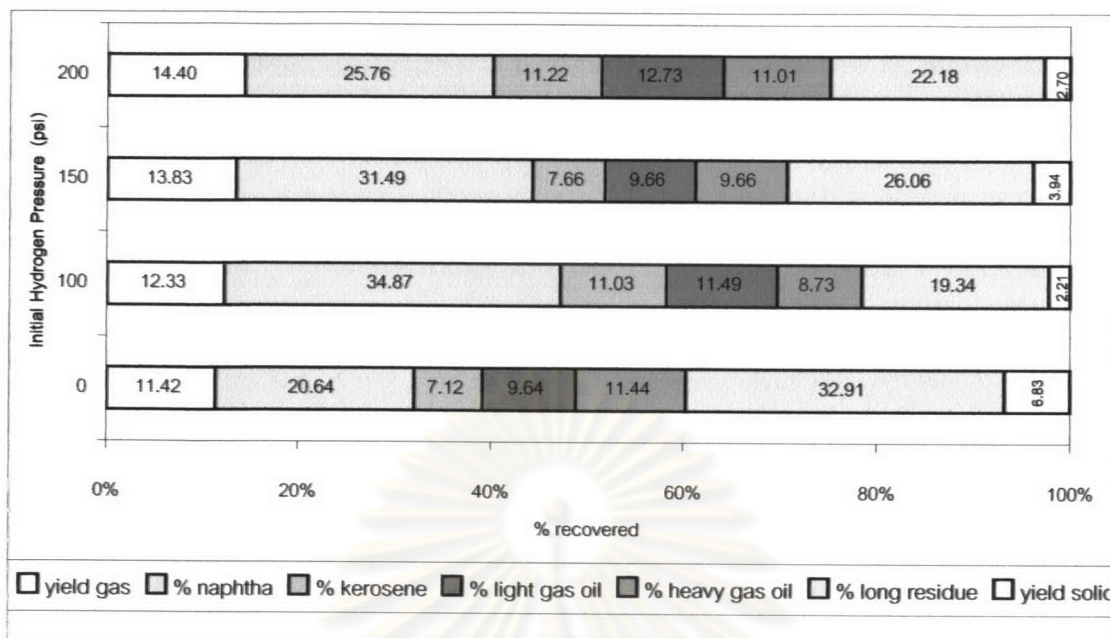
4.1.2.2 Effect of initial hydrogen pressure on light oil composition for HZSM-5 catalyst

The study of the initial hydrogen pressure on the hydrocracking process of used lubricating oil with HZSM-5 catalyst was performed by operating at various initial hydrogen pressures: 100, 150 and 200 psi by using 0.5 % HZSM-5 catalyst at reaction temperature 450 $^{o}$C and fixing reaction time at 60 minutes. The compositions of products from catalytic hydrocracking process as a function of initial hydrogen pressure were shown in Table 4.4 and Figure 4.4.

**Table 4.4** Effect of initial hydrogen pressure on product composition at 450 $^{o}$C of reaction temperature, 60 minutes of reaction time and 0.5 % HZSM-5 catalyst.

| initial pressure ( psi) | Gas product (% Yield) | Oil products (% recovered) | | | | | Solid (%Yield) | Oil Product (% Yield) |
|---|---|---|---|---|---|---|---|---|
| | | naphtha | kerosene | light gas oil | heavy gas oil | long residue | | |
| blank | 11.42 | 20.64 | 7.12 | 9.64 | 11.44 | 32.91 | 6.83 | 81.75 |
| 100 | 12.33 | 34.87 | 11.03 | 11.49 | 8.73 | 19.34 | 2.21 | 85.46 |
| 150 | 13.83 | 31.49 | 7.66 | 9.66 | 9.66 | 26.06 | 1.64 | 84.53 |
| 200 | 14.40 | 25.76 | 11.22 | 12.73 | 11.01 | 22.18 | 2.70 | 82.90 |

**Figure 4.4** Effect of hydrocracking initial hydrogen pressure range of 0- 200 psi on product composition at 450 $^0$C of reaction temperature, 60 minutes of reaction time and 0.5 %HZSM-5 catalyst.

Table 4.4 and Figure 4.4 show the effect of variation of initial hydrogen pressure range from 0-200 psi on percentage of light oil product. The initial hydrogen pressure was responsible to the catalytic cracking step. It was noticed that when the pressure increased, the % yield of light oil, naphtha and kerosene were increased, while long residues decreased. In cases of initial hydrogen pressure 0 to 100 psi the percentage of naphtha more increased from 20.64% to 34.87% when hydrogen pressure increased to 150 psi the percentage of naphtha slightly decreased to 31.49%, when increased initial hydrogen pressure to 200 psi the percent of naphtha more decreased to 25.76%. Normally HZSM-5 gave protons from the structural surface of zeoilte to long chain hydrocarbon for hydrocracking and these hydrogen compensated at the surface by hydrogen feed. These expressed that catalytic cracking take place very well at higher pressure of hydrogen. It seemed pressure 100 psi was the best condition.

In conclusion, initial pressure of hydrogen has an impact on the amount of naphtha, kerosene and gas oil with its suitable value of pressure was 100 psi giving 34.87% of naphtha, 11.03% of kerosene and 20.22% of gas oil.

4.1.3 Effect of reaction time on light oil composition.

The study of the reaction time on the hydrocracking process of used lubricating oil with Ni-Mo/Al$_2$O$_3$ and HZSM-5 catalysts was performed by operating at various conditions.

4.1.3.1 Effect of reaction time on light oil composition for Ni-Mo/alumina.

The study of the effect of reactiom time was performed by various reaction time at 30, 45, 60 and 90 minutes by using 1.0% Ni-Mo/Al$_2$O$_3$ catalyst under initial hydrogen pressure 100 psi and fixing reaction temperature as 450 $^{\circ}$C. The compositions of products from catalytic hydrocracking process as a function of reaction time were shown in Table 4.5 and Figure 4.5.

Table 4.5 Effect of reaction time on product composition at 450 $^{\circ}$C of reaction temperature, 100 psi of initial hydrogen pressure and 1.0 % Ni-Mo/Al$_2$O$_3$.

| Reaction time (minutes) | Gas product (% Yield) | Oil products (% recovered) | | | | | Solid (%Yield) | Oil Product (% Yield) |
|---|---|---|---|---|---|---|---|---|
| | | naphtha | kerosene | light gas oil | heavy gas oil | long residue | | |
| 30 | 18.45 | 27.11 | 10.27 | 9.87 | 9.60 | 20.48 | 4.22 | 77.33 |
| 45 | 12.35 | 22.11 | 7.37 | 9.15 | 8.65 | 33.83 | 6.54 | 81.11 |
| 60 | 12.30 | 28.15 | 7.39 | 8.27 | 7.45 | 32.08 | 4.36 | 83.34 |
| 90 | 13.15 | 36.15 | 11.49 | 11.21 | 8.77 | 18.02 | 1.21 | 85.64 |
| 120 | 14.45 | 33.75 | 9.88 | 8.97 | 9.32 | 20.32 | 3.31 | 82.24 |
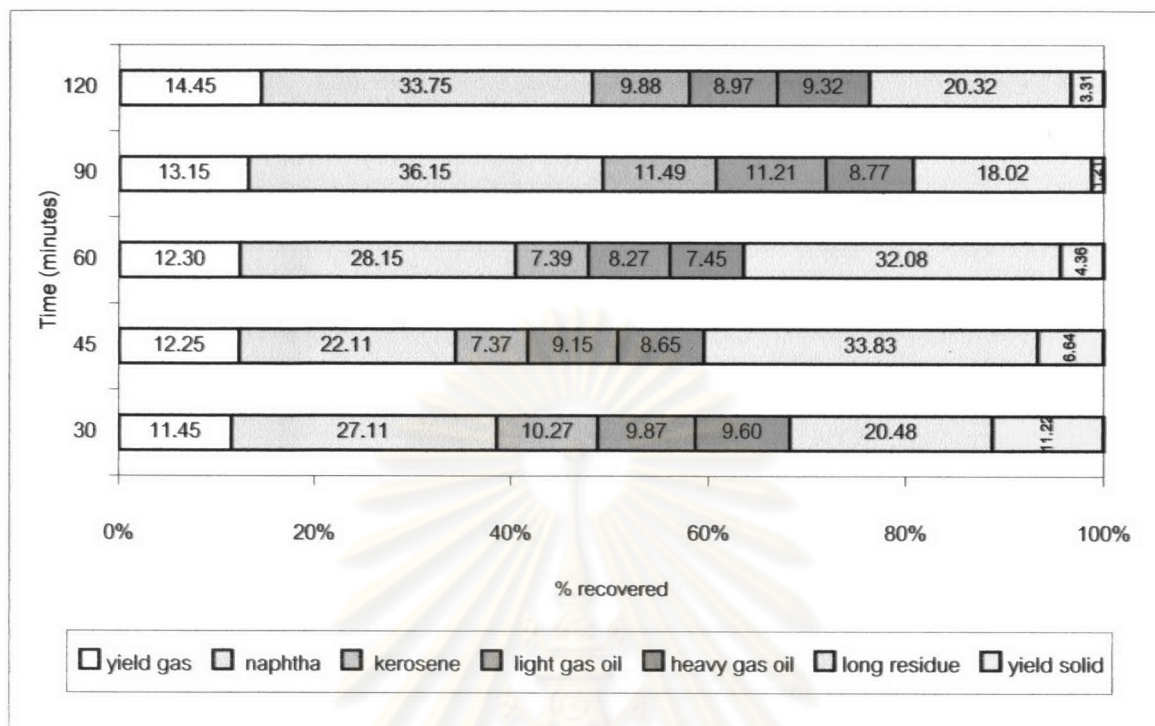
**Figure 4.5** Effect of hydrocracking reaction time range of 30-120 minutes on product
composition at 450 $^0$C of reaction temperature, 100 psi of initial hydrogen
pressure and 1.0 % Ni-Mo/Al$_2$O$_3$.

From Table 4.5 and Figure 4.5, it showed that when the reaction time increased from
30 to 90 minutes, the % yield of light oil and % naphtha increased from 77.33% to 85.64% and
27.11% to 36.15% respectively , whereas other components being the same quantities. But
solides were slightly decreased, it has not responded to hydrocracking process. After
reaction time was more than 90 minutes, we observed the % yield of light oil and % naphtha
decreased from 85.64% to 82.24% and 36.15% to 33.75% respectively, in the contrast we
noticed the gases and solid were increased. The experiments were fixed the temperature and
pressure hydrogen, so the thermal and catalytic crackings were occurred the same
phenomena when the reaction time increased to 90 minutes. We obtained the maximum %

yield, % naphtha and lowest % solide, it means that this condition cause, thermal cracking (changing long chain hydrocarbon to short chain) corresponding to catalytic the moderate chain hydrocarbon. When the reaction time more than 90 minutes the catalytic reaction was neary faster than thermal cracking and long time also caused coking at the surface of catalyst; as result we observed the % naphtha and % yield of light oil product were decreased.

In the same way we observed also that when the longer reaction time, the overall % of short chain hydrocarbon such as kerosene, gas oil and long residue decreased, while % solid increased, it means that this time caused the decreased activity of catalytic cracking, but thermal cracking still working.

In conclusion, the optium of reaction time was 90 minutes, because this time gave the highest % yield of light oil as 85.64% and % naphtha as 36.15% at condition of 450 $^{\circ}$C of reaction temperature, 100 psi of hydrogen pressure and 1% Ni-Mo/Al$_2$O$_3$.

### 4.1.3.2 Effect of reaction time on light oil composition for HZSM-5 catalyst

The study of the reaction time on the hydrocracking process of used lubricating oil with HZSM-5 catalyst was performed by operating at various reaction times at 30, 60 and 90 minutes by using 0.5 % HZSM-5 catalyst at reaction temperature 450 $^{\circ}$C and fixing initial hydrogen pressure at 100 psi. The compositions of products from catalytic hydrocracking process as a function of reaction time were shown in Table 4.6 and Figure 4.6.

**Table 4.6** Effect of reaction time on product composition at 450 $^0$C of reaction

temperature,100 psi of initial hydrogen pressure and 0.5 % HZSM-5 catalyst.

| Reaction time (minutes) | Gas product (% Yield) | Oil products (% recovered) | | | | | Solid (%Yield) | Oil Product (% Yield) |
|---|---|---|---|---|---|---|---|---|
| | | naphtha | kerosene | light gas oil | heavy gas oil | long residue | | |
| 30 | 12.20 | 25.86 | 10.13 | 11.79 | 10.90 | 23.34 | 5.78 | 82.02 |
| 60 | 12.33 | 34.87 | 11.03 | 11.49 | 8.73 | 19.34 | 2.21 | 85.46 |
| 90 | 12.55 | 22.95 | 8.09 | 10.42 | 10.34 | 28.99 | 6.66 | 80.79 |
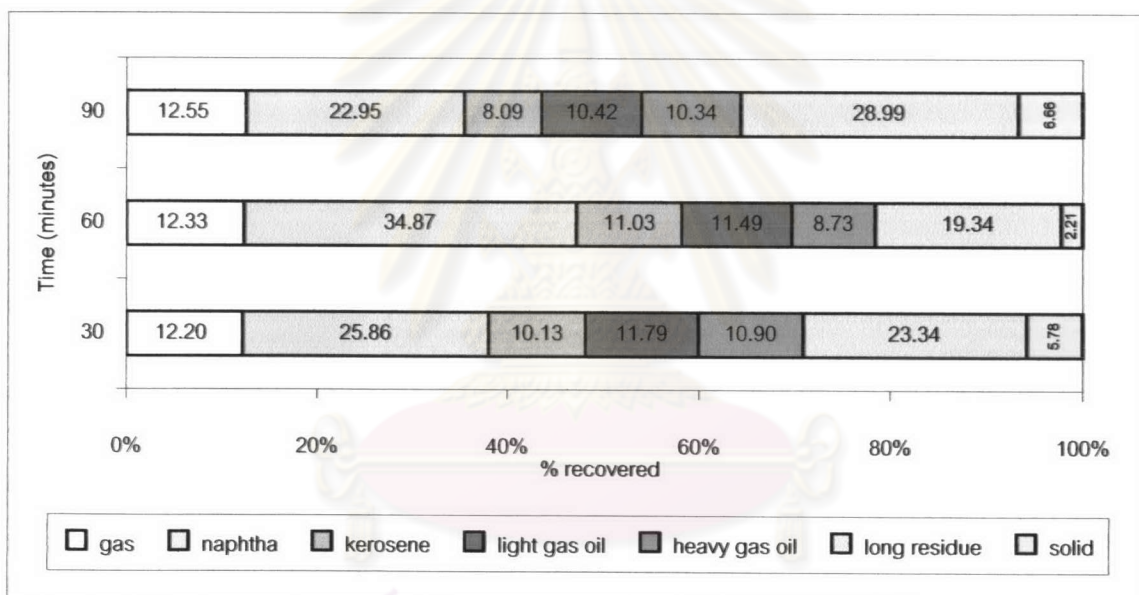


**Figure 4.6** Effect of hydrocracking reaction time range of 30-90 minutes on product

composition at 450 $^0$C of reaction temperature, 100 psi of initial hydrogen

pressure and 0.5 % HZSM-5 catalyst.

From Table 4.6 and Figure 4.6, it showed that when the reaction time increased from 30 to 60 minutes, % yield of light oil and % naphtha increased from 82.02% to 85.46% and 25.86% to 34.87% respectively, whereas other components being the same quantities. After reaction time more 60 minutes, % yield of light oil and % naphtha were decreased from 85.46% to 80.79% and 34.87% to 22.95% respectively, whereas noticed the gases and solid were slightly increased, because thermal cracking was well developed more than catalytic cracking namely, the light oil product increased. The solid was increased with time because the more reaction time, the more coke developed at the surface of catalyst. The coke deposits act as a poison, blocking the pore entrance and deactivating the HZSM-5 catalyst.

In conclusion, the optimum of reaction time was 60 minutes, because this time gave the highest % yield of light oil as 85.46% and % naphtha as 34.87%, but it gave a slighlty residue.

4.1.4 Effect of amount of catalyst on oil composition.

The study of the amount of catalyst on the hydrocracking process of used lubricating oil with Ni-Mo/Al$_2$O$_3$ and HZSM-5 catalysts was performed by operating at various conditions.

4.1.4.1 Effect of amount of catalyst on light oil composition for Ni-Mo/alumina.

The study of the effect of amount of catalyst was performed by various amounts of catalyst at 0.0, 1.0, 3.0 and 5.0 % w/w Ni-Mo/Al$_2$O$_3$ catalyst under initial hydrogen pressure 100 psi at reaction time 90 minutes at fixing reaction temperature at 450 $^0$C. The compositions of products from catalytic hydrocracking process as a function of amount of catalyst were shown in Table 4.7 and Figure 4.7.

**Table 4.7** Effect of amount of Ni-Mo on Alumina on product composition at 450 $^0$C of reaction
temperature, 100 psi of initial hydrogen pressure and 90 minutes of reaction time.

| % of catalyst (Ni-Mo/Al$_2$O$_3$) | Gas product (% Yield) | Oil products (% recovered) | | | | | Solid (%Yield) | Oil Product (% Yield) |
|---|---|---|---|---|---|---|---|---|
| | | naphtha | kerosene | light gas oil | heavy gas oil | long residue | | |
| blank | 14.04 | 27.70 | 12.36 | 12.98 | 10.14 | 18.04 | 4.74 | 81.21 |
| 1.0 | 13.15 | 36.15 | 11.49 | 11.21 | 8.77 | 18.02 | 1.21 | 85.64 |
| 3.0 | 14.18 | 33.45 | 8.51 | 9.98 | 9.11 | 21.94 | 2.83 | 82.99 |
| 5.0 | 5.56 | 30.09 | 12.67 | 12.79 | 9.83 | 15.78 | 13.28 | 81.16 |
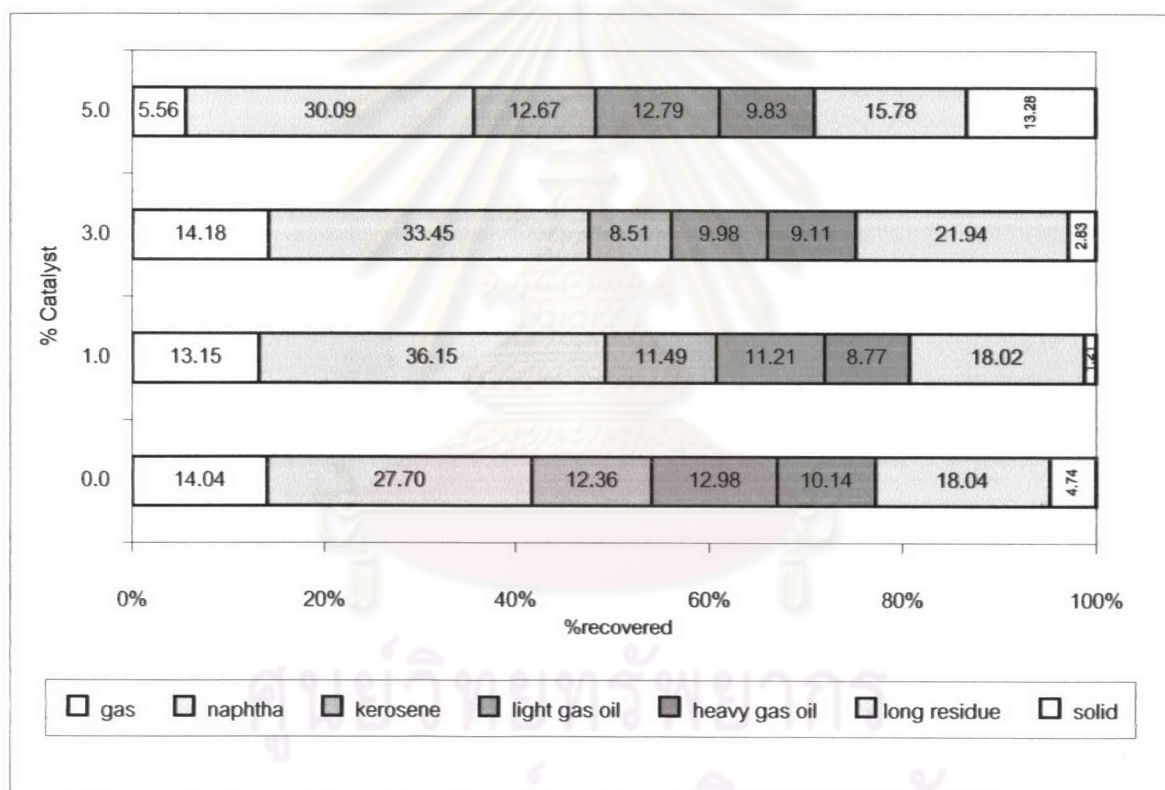


**Figure 4.7** Effect of hydrocracking percent by weight of Ni-Mo on alumina range of 0.0–5.0%
on product composition at 450 $^0$C of reaction temperature, 90 minutes of reaction
time and 100 psi of initial hydrogen pressure.

The product composition changed with percent by weight of catalyst. It showed in Table 4.7 and Figure 4.7, when increased percent by weight of catalyst from 0.0% to 1.0%, yield of liquid and % naphtha were increased from 81.21% to 85.64% and 27.70% to 36.15%, respectively. Because ratio of sample per catalyst was increased, many molecules of sample attacked to catalyst became high product. When the percentage of catalyst was increased from 1.0% to 5.0%, yield of liquid and % naphtha were decreased from 85.64% to 81.16%and 36.15% to 30.09% respectively, whereas solid increases from 1.21% to 13.28%. When using higher percent by weight of catalyst would have higher possibility contaction of catalyst with lubricating oil. As result, it caused rate of coking more than rate of cracking. So we observed the increasing of solid 13.28% at highest mass of catalyst as 5%.

In conclusion the percentage of catalyst is very important for the product selectivity. In this case, 1.0% by weight of Ni-Mo/Al$_2$O$_3$ gave the highest % yield of light oil as 85.64% and % naphtha as 36.15%, but it gave a slighlty solid.

4.1.4.2 Effect of amount of catalyst on light oil composition for HZSM-5 catalyst.

The study of amount of catalyst was performed by various amount of catalyst at 0.0%, 0.1%, 0.3%, 0.5% and 0.6 % w/w HZSM-5 catalyst under initial hydrogen pressure 100 psi at reaction time 60 minutes and fixing reaction temperature as 450 $^{\circ}$C. The compositions of products from catalytic hydrocracking process as a function of amount of catalyst were shown in Table 4.8 and Figure 4.8.

Table 4.8 Effect of amount of HZSM-5 catalyst on product composition at 450 $^0$C of reaction

temperature, 100 psi of initial hydrogen pressure and 60 minutes of reaction time.

| % of catalyst (HZSM-5) | Gas product (% Yield) | Oil products (% recovered) | | | | | Solid (%Yield) | Oil Product (% Yield) |
|---|---|---|---|---|---|---|---|---|
| | | naphtha | kerosene | light gas oil | heavy gas oil | long residue | | |
| blank | 15.84 | 33.75 | 7.33 | 8.08 | 7.99 | 22.81 | 1.37 | 79.96 |
| 0.1 | 12.62 | 33.54 | 10.37 | 10.61 | 8.87 | 21.68 | 2.30 | 85.08 |
| 0.3 | 15.97 | 34.32 | 7.91 | 9.27 | 8.04 | 21.84 | 2.65 | 81.38 |
| 0.5 | 12.33 | 34.87 | 11.03 | 11.49 | 8.73 | 19.34 | 2.21 | 85.46 |
| 0.6 | 20.50 | 22.83 | 5.91 | 6.87 | 6.62 | 20.47 | 16.81 | 62.69 |
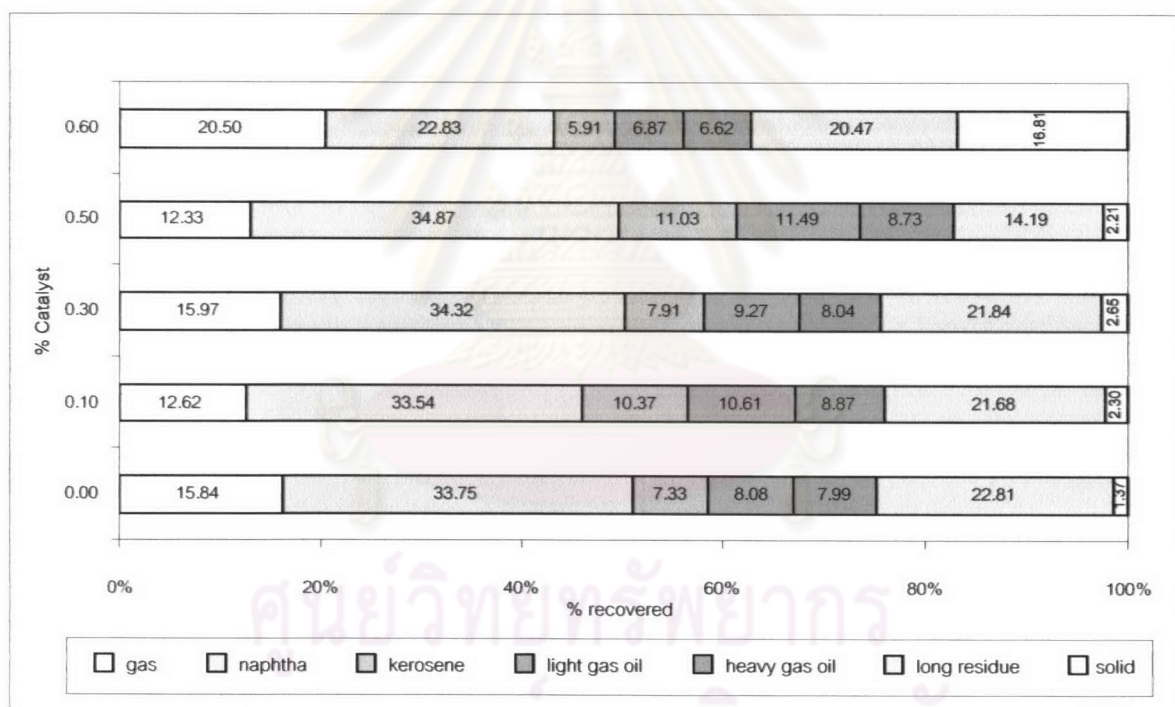


Figure 4.8 Effect of hydrocracking percent by weight of HZSM-5 catalyst range of 0.0–0.6%

on product composition at 450 $^0$C of reaction temperature, 60 minutes of reaction

time and 100 psi of initial hydrogen pressure.

From Table 4.8 and Figure 4.8, it showed that when the percent by weight of HZSM-5 catalyst was increased from 0.0 to 0.5%, the % light oil product and naphtha were increased from 79.96% to 85.46% and 33.75% to 34.87%, respectively until percent by weight of catalyst at 0.6 %, the % naphtha more decreased to 22.83%, but gases and solid were many increased from 12.33% to 20.50% and 2.21% to 16.81%, respectively. It means that when use the higher amount of catalyst was used, the highest possibility contaction of catalyst with lubricating oil was occured, as a result, it caused rate of coking more than cracking.

In conclusion the optimum of percent by weight of HZSM-5 catalyst was 0.5%, it given the highest 85.46% of yield of oil, 34.87% naphtha, 11.03% kerosene, 20.22% gas oil and 2.21% solid.

4.2 Comparison of efficiency of 2 kinds of catalysts

The comparison of efficiency of 2 kinds of Ni-Mo/Al$_2$O$_3$ and HZSM-5 catalysts presented with condition of reaction, fraction of products and product composition were shown in Table 4.9.

**Table 4.9** Comparison efficiency of 2 kinds of catalysts Ni-Mo/Al$_2$O$_3$ and HZSM-5

| Discription | Kinds of catalyst | |
|---|---|---|
| | Ni-Mo/Al$_2$O$_3$ | HZSM-5 |
| Condition | | |
| Reaction Temperature ($^\circ$C) | 450 | 450 |
| Initial Hydrogen Pressure (psi) | 100 | 100 |
| Reaction Time (minutes) | 90 | 60 |
| Percentage of Catalyst (wt% ) | 1.0 | 0.5 |
| Results | | |
| Oil Products (wt%) | 85.64 | 85.46 |
| - naphtha | 36.15 | 34.87 |
| - kerosene | 11.49 | 11.03 |
| - light gas oil | 11.21 | 11.49 |
| - heavy gas oil | 8.77 | 8.73 |
| - long residue | 18.02 | 19.34 |
| Gas Products (wt%) | 13.15 | 12.33 |
| Solid Products (wt%) | 1.21 | 2.21 |

To comparison efficiency of catalyst Ni-Mo/Al$_2$O$_3$ and HZSM-5 using to convert used lubricating oil to light oil by hydrocracking process was found that HZSM-5 shows better efficiency catalyst than Ni-Mo/Al$_2$O$_3$. Because it used less reaction time and percentage of catalyst, while it gave nearly the same yield of light oil and % recovered of naphtha.

4.3 Comparison of this work with other works

The comparison of work with Farouq A.A. *et al.* [38] was presented with fractions of oils, gases and yield of gasoline in terms of wt% in Table 4.10.

**Table 4.10** Comparison of this work with Farouq A.A. *et al.* (2003)

| Discription | This work (2004) | Farouq A.A. *et al.* (2003) |
|---|---|---|
| Raw Material | Used lubricating oil | Palm oil |
| Catalyst | HZSM-5 | HZSM-5 |
| Condition | | |
| Temperature | 450 $^0$C | 450 $^0$C |
| Results | | |
| Oils (wt%) | 85.46 | 90-95 |
| Gases (wt%) | 12.33 | 11-25 |
| Naphtha or Gasoline (wt%) | 34.87 | 38-47 |

Farouq A.A. *et al.* studied performance of composite catalysts in palm oil cracking for the production of liquid fuels. The palm oil cracking was performed under nitrogen gas over the catalyst at atmospheric pressure, reactor temperature of 450 $^0$C and weight hourly space velocity (WHSV) of 2.5 $hr^{-1}$. The reactor was heated to the desired reaction temperature under nitrogen gas flowing at rate of 100 ml $min^{-1}$. The palm oil was fed using a syring pump and oil/catalyst ratio of 7.2. From Table 4.10 Farouq A.A. *et al.* gave 90-95% of oil yield whereas this work gave 85.46% of oil yield. This result can be explained that Farouq's method gave yield of oil products more than this work. Because Farouq's method was used continuous cracking process, but this work was used batch cracking process therefore this work have losed oil products in during process.