

CHAPTER IV

RESULTS AND DISCUSSION

Characterization of NGL and Products

All GC chromatograms were obtained by using a CBP-1 capillary column. The compositions of NGL and its products were identified by P.I.A.N.O. autosystem GC with its library search program, while the percentages of compositions of NGL and its products were determined directly from the normalized areas of the GC peaks. GC chromatogram of NGL was shown in Figure 4.1, and its percentages of compositions and relative retention times were presented in Table 4.1. These data indicated that there were many types of hydrocarbons in NGL, i.e., straight-chain paraffins, branched-chain paraffins, cycloparaffins, aromatics, and very few of olefins (about 1% of 1-heptene), nevertheless, the C₅ and C₆ hydrocarbons were the major compositions of NGL. Some chromatograms of NGL's products from the significant reaction conditions were presented in Appendix A, and the compositions of them were similar to NGL's. However some products from some reaction conditions were especially different because of occurring of some isomers of paraffins and some higher carbon atom of aromatics that were not existing in NGL, such as occurring of 2-methyl-2-butene in C₅-isomers, and another branched isomers in C₇ and C₈ paraffins. These increased isomers of each product were summed to the other isomers in the same product, which having the same number of carbon atom, to be calculated percentage of total conversion summingly in each carbon atom related to NGL. All the results of percentages of total conversion were presented in Appendix C, which be calculated from the cumulative data of percentages of compositions of products in Appendix B related to NGL.

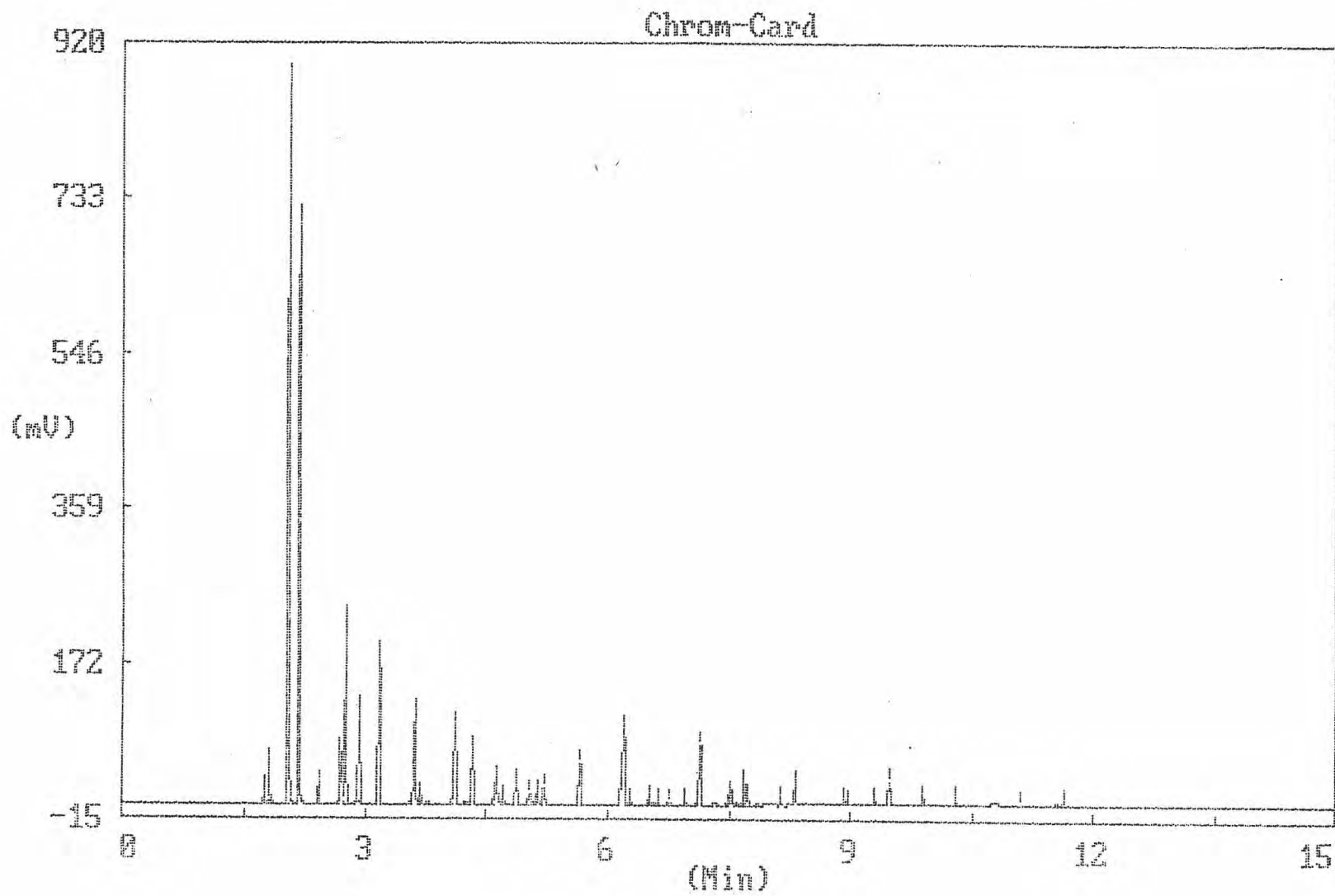


Figure 4.1 GC Chromatogram of NGL

Table 4.1 Identification of NGL's compositions

| Peak No. | Retention time (min) | Area | %Area (%Composition) | Name |
|----------|-------------------------|---------|-------------------------|---|
| 1 | 1.75 | 160367 | 0.3714 | 2-Methylpropane (Isobutane) |
| 2 | 1.81 | 460770 | 1.0671 | <i>n</i> -Butane |
| 3 | 2.04 | 9264802 | 21.4561 | 2-Methylbutane (Isopentane) |
| 4 | 2.18 | 7994195 | 18.5135 | <i>n</i> -Pentane |
| 5 | 2.42 | 265577 | 0.6150 | 2,2-Dimethylbutane |
| 6 | 2.68 | 1471164 | 3.4070 | 2,3-Dimethylbutane |
| 7 | 2.75 | 3201647 | 7.4146 | 2-Methylpentane |
| 8 | 2.92 | 1599463 | 3.7041 | 3-Methylpentane |
| 9 | 3.17 | 2987114 | 6.9178 | <i>n</i> -Hexane |
| 10 | 3.61 | 2069670 | 4.7931 | Methylcyclopentane |
| 11 | 3.68 | 135077 | 0.3128 | 2,4-Dimethylpentane |
| 12 | 4.11 | 2059716 | 4.7700 | Benzene |
| 13 | 4.32 | 1390364 | 3.2199 | Cyclohexane |
| 14 | 4.61 | 806103 | 1.8668 | 2-Methylhexane |
| 15 | 4.69 | 132246 | 0.3063 | 2,3-Dimethylpentane |
| 16 | 4.86 | 546731 | 1.2662 | 3-Methylhexane |
| 17 | 5.03 | 291341 | 0.6747 | 1 <i>t</i> ,3-Dimethylcyclopentane |
| 18 | 5.12 | 261474 | 0.6055 | 3-Ethylpentane |
| 19 | 5.20 | 437066 | 1.0122 | 1-Heptene |
| 20 | 5.66 | 1072321 | 2.4834 | <i>n</i> -Heptane |
| 21 | 6.19 | 2323681 | 5.3813 | Methylcyclohexane |
| 22 | 6.27 | 76117 | 0.1763 | 2,2-Dimethylhexane |
| 23 | 6.50 | 102502 | 0.2374 | Ethylcyclopentane |
| 24 | 6.63 | 34708 | 0.0804 | 2,4-Dimethylhexane |
| 25 | 6.75 | 57206 | 0.1325 | 1 <i>c</i> ,2 <i>t</i> ,4-Trimethylcyclopentane |
| 26 | 6.95 | 46664 | 0.1081 | 1 <i>t</i> ,2 <i>c</i> ,3-Trimethylcyclopentane |
| 27 | 7.14 | 1527521 | 3.5375 | Toluene |
| 28 | 7.50 | 227521 | 0.5269 | 2-Methylheptane |
| 29 | 7.53 | 50945 | 0.1180 | 3-Methylheptane |

Table 4.1 Identification of NGL's compositions (continued)

| Peak No. | Retention time (min) | Area | %Area (%Composition) | Name |
|----------|-------------------------|----------|-------------------------|----------------------------|
| 30 | 7.68 | 419101 | 0.9706 | 3-Ethylhexane |
| 31 | 7.73 | 116620 | 0.2701 | 1t,4-Dimethylcyclohexane |
| 32 | 8.13 | 85729 | 0.1985 | 1t,2-Dimethylcyclohexane |
| 33 | 8.31 | 399226 | 0.9246 | <i>n</i> -Octane |
| 34 | 8.93 | 104004 | 0.2409 | 2,4-Dimethylheptane |
| 35 | 8.96 | 38243 | 0.0886 | Ethylbenzene |
| 36 | 9.30 | 69506 | 0.1610 | <i>o</i> -Xylene |
| 37 | 9.48 | 617058 | 1.4290 | <i>m</i> -Xylene |
| 38 | 9.90 | 112155 | 0.2597 | <i>p</i> -Xylene |
| 39 | 10.29 | 103213 | 0.2390 | 1,1-Methylethylcyclohexane |
| 40 | 11.10 | 20635 | 0.0478 | 1-Methyl-3-ethylbenzene |
| 41 | 11.64 | 40821 | 0.0945 | <i>t</i> -Butylbenzene |
| | Totals | 43180368 | 100.00 | |

Studies of Various Effects on Isomerization Reactions

The results of percentages of total conversion from Table C1-C6 in Appendix C were indicated that there were four significant reactions of NGL occurred over the bifunctional catalysts (Pt/Al₂O₃ or Pt-F/Al₂O₃), these were skeletal isomerization, aromatization (or dehydrocyclization), dehydrogenation of cycloparaffins, and hydrocracking [5]. The percentages of total conversion of these reactions were calculated from different precursor composition, they were:

- In skeletal isomerization, the percentages of total conversion were calculated from decreasing of *n*-paraffins and *n*-olefins (C₆₊) in conversion to

branched-chain paraffins (C_{6+}), as the calculation methods shown in Appendix C.

- In aromatization, they were calculated from decreasing of total paraffins and olefins (C_{6+} , straight-chain and branched-chain) in conversion to aromatics (C_{6+}), as the calculation methods shown in Appendix C.

- In dehydrogenation of cycloparaffins, they were calculated from decreasing of total cycloparaffins (C_{6+}) in conversion to aromatics (C_{6+}), as the calculation methods shown in Appendix C.

- And in hydrocracking, they were calculated from decreasing of total paraffins and olefins (C_{5+} , straight-chain and branched-chain) in conversion to C_1 - C_4 hydrocarbons, as the calculation methods shown in Appendix C.

C_4 and its lower hydrocarbons were not mentioned in skeletal isomerization, because they were partially occurred in the hydrocracking reactions of the higher atom hydrocarbons. And they were not mentioned in dehydrogenation and aromatization, since they were not the precursors or products of these reactions.

C_5 hydrocarbons were not mentioned in skeletal isomerization, because they also were not the precursors or products of dehydrogenation and aromatization, so that they could not be cumulatively compared in the percentages of conversion among these three reactions.

All studies of effects on isomerization of NGL in this research were performed by curves, which plotted reaction temperatures as X-axis versus to percentages of total conversion (in these significant reactions) as Y-axis.

1. Study of Temperature Effect

The study of temperature effect on isomerization of NGL was performed by operating at various reaction temperatures (270, 320, 370, 400, 420, and 450°C) over the 0.3% Pt-0.5% F/Al₂O₃ catalyst under 60 psi hydrogen pressure.

When the results in the variation of temperatures from Table C1 in Appendix C were plotted, they gave the curves as shown in Figure 4.2.

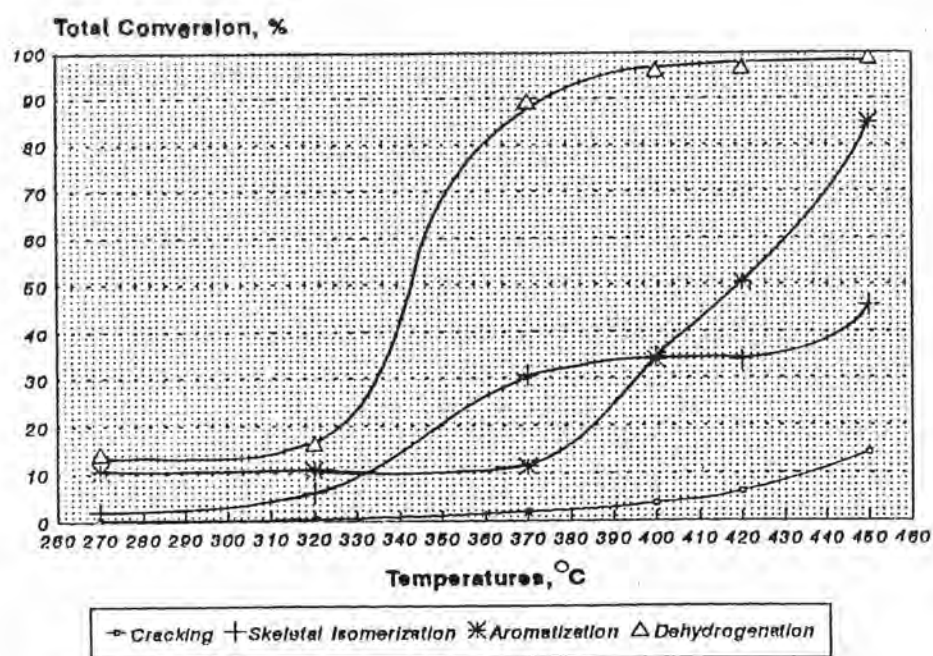


Figure 4.2 Comparison of temperatures effect on the significant reactions of NGL under 60 psi H₂ over 0.3%Pt-0.5%F on Alumina.

These curves in Figure 4.2 indicated that the optimum reaction temperatures for isomerization of NGL were in the range of 370°C to 450°C, because all the reactions occurred below 370°C were not significant or interesting as their curves shown a very low level of percentages of total conversion.

Furthermore, the curves in Figure 4.2 could be considered in accordance with some of standard thermodynamic data in Figure 4.3 and Table 4.2 below.

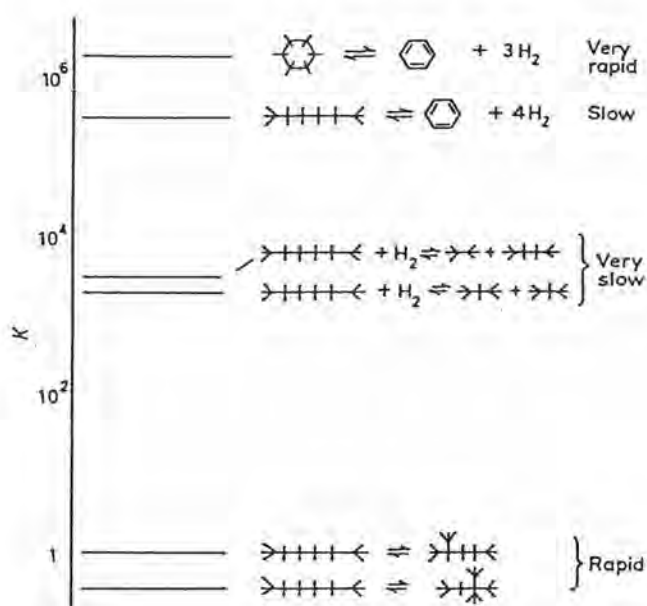


Figure 4.3 Values of standard equilibrium constants at 800 K for various structural conversions of n -hexane and cyclohexane, with commentary on the rates of the forward reactions over a bifunctional catalyst on the right. [37]

Table 4.2 Heat of Formation for Typical Reactions

| Reaction | ΔH_f , kcal/mole |
|--|-----------------------------|
| Cyclohexane \rightarrow Benzene + 3H ₂ (Dehydrogenation) | 52.8 |
| Methylcyclopentane \rightarrow Benzene + 3H ₂ (Dehydrogenation) | 49.0 |
| <i>n</i> -Hexane \rightarrow Benzene + 4H ₂ (Aromatization) | 63.6 |
| <i>n</i> -Hexane \rightarrow 2-Methylpentane (Skeletal Isomerization) | -1.4 |
| <i>n</i> -Hexane \rightarrow 3-Methylpentane (Skeletal Isomerization) | -1.1 |
| <i>n</i> -Hexane \rightarrow <i>n</i> -Butane + Ethane (Hydrocracking) | -11.9 |

Source : represented from the data of references number [38,39].

The thermodynamic data as shown in Figure 4.3 and Table 4.2 in accordance with the data of this research shown in Figure 4.2 similarly indicated that the aromatization reactions of paraffins and the dehydrogenation reactions of cycloparaffins to yield aromatics which were seen to be strongly endothermic, so increasing reaction temperatures, the extents of conversion to aromatics were increased easily.

The equilibria in the skeletal isomerization reactions were much less temperature sensitivity than in the dehydrogenation and aromatization reactions, since the heats of formation in skeletal isomerization reactions were relatively small and the equilibrium constants of them were lower than those (be lower approximately 10⁶-fold of dehydrogenation and 10⁵-fold of aromatization). The heat of formation data of the skeletal isomerization reactions were shown that the reactions were seen to be so slightly exothermic that increasing temperature gave no marked effect on increasing the extent of conversion to branched-chain paraffins. These were according with the data obtained in this research that the slopes of skeletal isomerization graph-curve were only slightly shifted up on relation to increasing the reaction temperature.

The hydrocracking reactions were explained by the equilibrium constant of their reaction equilibrium in Figure 4.3 that they have the feasibility to occur much enough, but on the fact that they were occurred in very slow rate and their heats of formation were very exothermal being the reasons why the hydrocracking reactions gave the lowest conversion in comparison of these four significant reactions.

The temperature effects on the significant reactions had already been explained in accordance with the thermodynamic data above. However, the comparison study in these reactions could be presented summarily in Table 4.3.

Table 4.3 Influence of Temperature on the Reactions

| Reaction | Thermal effect of reaction | Influence of increase in temperature |
|-----------------------------------|----------------------------|--------------------------------------|
| Skeletal Isomerization | Slightly Exothermal | Slowly Increase |
| Aromatization | Endothermal | Rapidly Increase |
| Dehydrogenation of cycloparaffins | Very Endothermal | Very Rapidly Increase |
| Hydrocracking | Very Exothermal | Very Slowly Increase |

2. Study of Hydrogen Pressure Effect

The study of hydrogen pressure effect was performed by varying hydrogen pressures under 40, 60, and 80 psi at 370-450°C (the optimum range of temperatures from the study of temperature effect).

The results from Table C5 in Appendix C were plotted to give the curves as shown in Figure 4.4-4.7 for example of the reactions occurred over 0.6% Pt/Al₂O₃ catalyst.

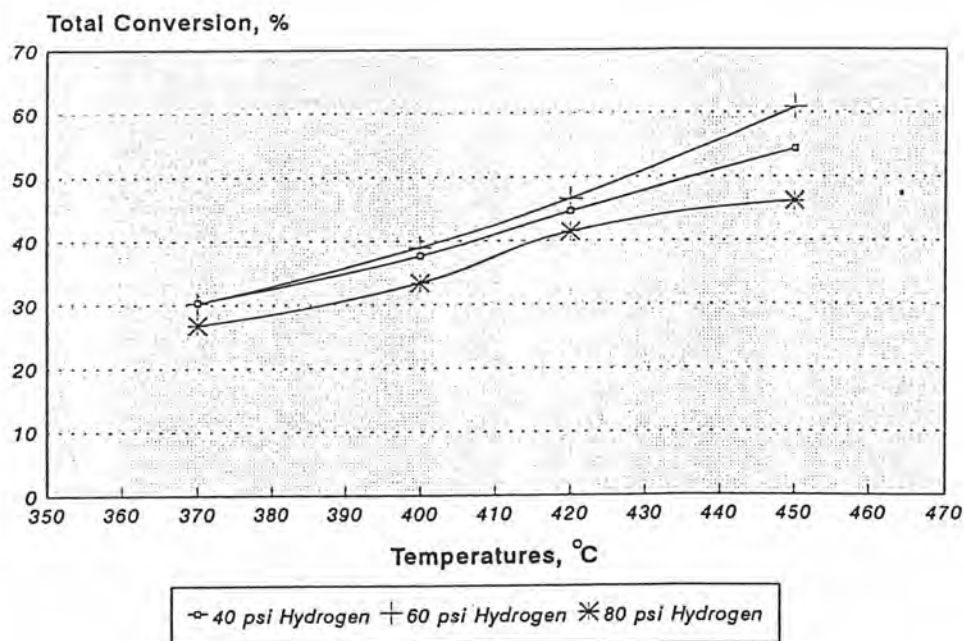


Figure 4.4 Comparison in Skeletal Isomerization Reactions of NGL under different H₂ pressures, over 0.6% Pt/Al₂O₃ catalyst.

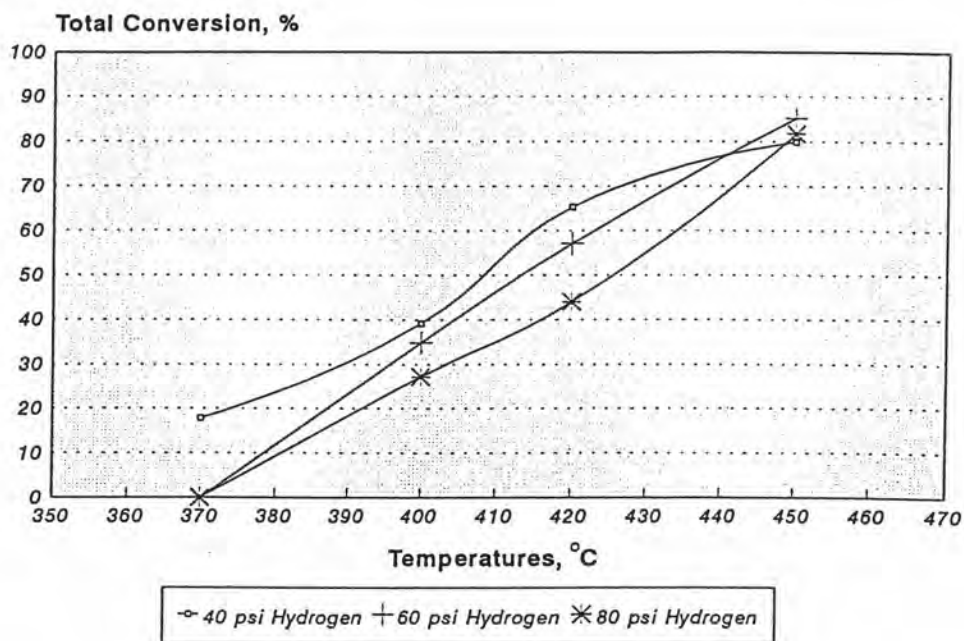


Figure 4.5 Comparison in Aromatization Reactions of NGL under different H₂ pressures, over 0.6% Pt/Al₂O₃ catalyst.

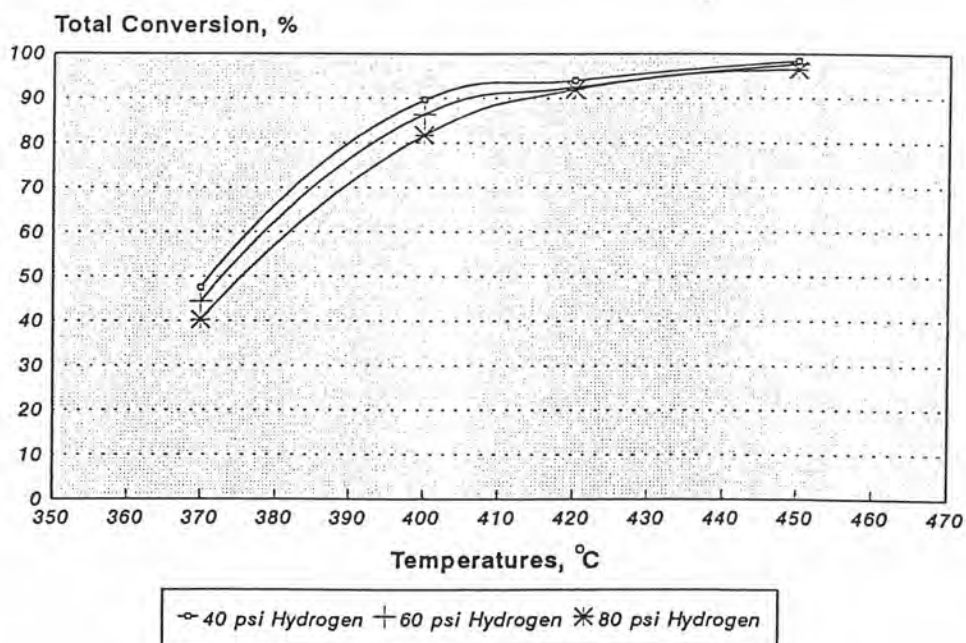


Figure 4.6 Comparison in Dehydrogenation Reactions of NGL under different H₂ pressures, over 0.6% Pt/Al₂O₃ catalyst.

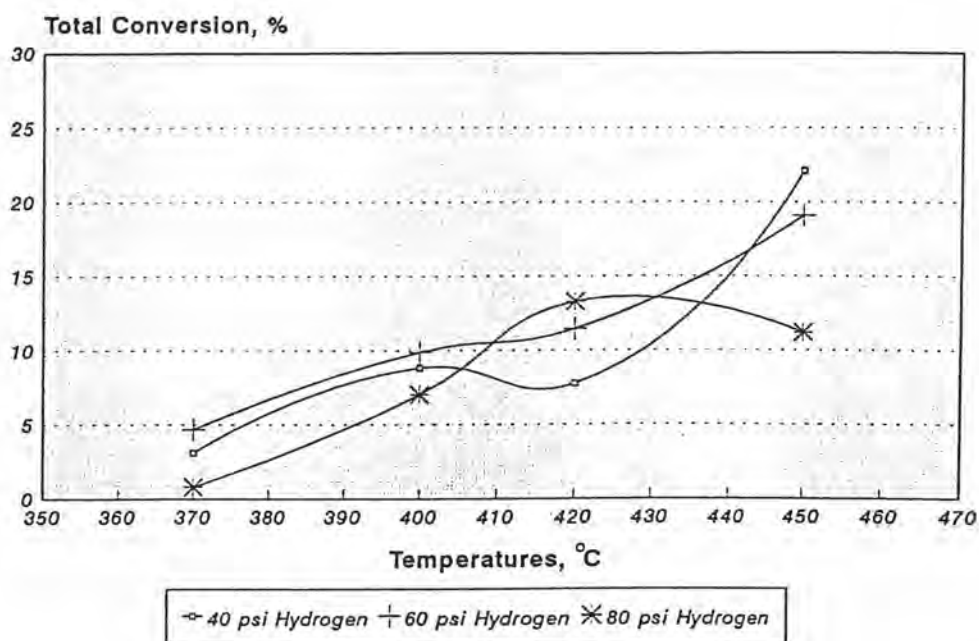
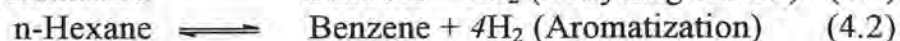
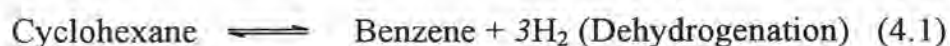


Figure 4.7 Comparison in Hydrocracking Reactions of NGL under different H₂ pressures, over 0.6% Pt/Al₂O₃ catalyst.

These curves indicated that the variation of hydrogen pressures gave no significant difference. However, when the 60 psi hydrogen pressure was used, the percentages of total conversion in skeletal isomerization reactions were higher than using of 40 psi and 80 psi hydrogen pressure at the same temperature, respectively.

This result demonstrated that the 40 psi hydrogen pressure used in the skeletal isomerization reactions was not sufficient for activating the Pt-surface to be occurred the dehydrogenation-hydrogenation reaction during skeletal isomerization reaction pathways [30]. Otherwise, the catalyst surface might be covered with the coke simply in using of the low 40 psi hydrogen pressure [3], therefore these reactions could not be occurred absolutely. Under 80 psi hydrogen pressure, the skeletal isomerization reactions were also not occurred absolutely, since the flow of hydrogen was too high for the reactant to maintain in the tubing reactor to undergo the reactions.

The hydrogen pressure effects on the dehydrogenation reactions of cycloparaffins and the aromatization reactions were indicated that using of higher hydrogen pressure was resulted in the lower percentages of total conversion to aromatics. These results were performed in accordance with the Le Chatelier's principle (1888) about equilibrium of chemical reaction. The Le Chatelier's principle stated that *"If a system at equilibrium is disturbed by some change, the system will shift so as to partially counteract the effect of the change."* [40]. For example, according to equation 4.1 and 4.2, increasing the hydrogen content would be obtained more left shift of equilibrium, then it could not be obtained benzene so much.



When strong hydrogen flows (40-80 psi H₂) were used in these reaction operations, they caused the reactant (NGL) not to be cracked throughly and perfectly on the catalyst surfaces. Therefore the feasibility of occurring hydrocracking reactions was very low and unsteady under any hydrogen pressure.

3. Studies of Catalyst Concentration Effects

Since the optimum reaction temperatures in isomerization of NGL were in the range of 370-450°C and the optimum hydrogen pressure was 60 psi H₂. The studies of catalyst concentration effects were then performed under these optimum hydrogen pressure and temperatures.

3.1 Study of Hydrogenation-Dehydrogenation Center Effect

The study of hydrogenation-dehydrogenation center effect was performed by varying percentages of platinum (0.3%, 0.6%, and 0.9% Pt) on 0.5% F/Al₂O₃ catalysts under a constant hydrogen pressure, 60 psi (the optimum hydrogen pressure), and at 370-450°C (the optimum range of reaction temperatures).

The results from Table C1, C3, and C4 in Appendix C were plotted to give the curves as shown in Figure 4.8-4.11 for comparisons of the hydrogenation-dehydrogenation center effect on the four significant reactions.

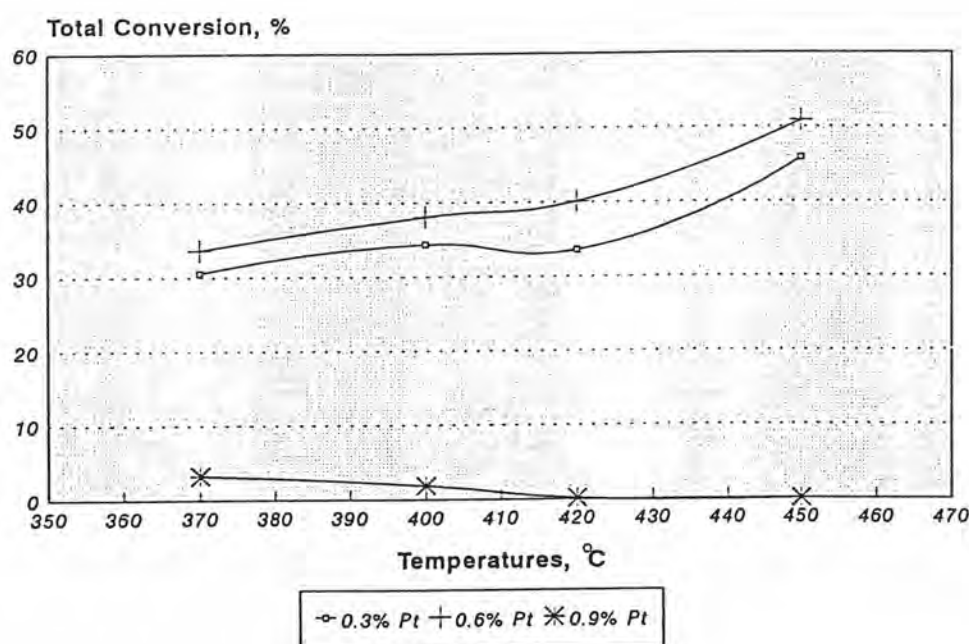


Figure 4.8 Comparison of Hydro-dehydrogenation Center Effect in Skeletal Isomerization Reactions of NGL under 60 psi H₂. (varying in different concentration of Pt on 0.5% F/Al₂O₃)

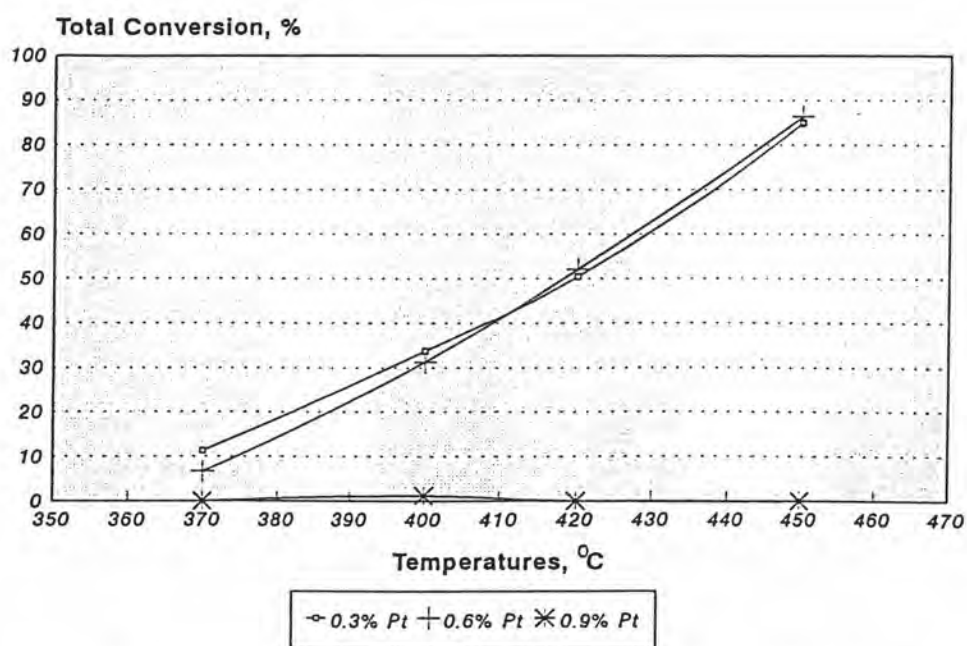


Figure 4.9 Comparison of Hydro-dehydrogenation Center Effect in Aromatization Reactions of NGL under 60 psi H₂. (varying in different concentration of Pt on 0.5% F/Al₂O₃)

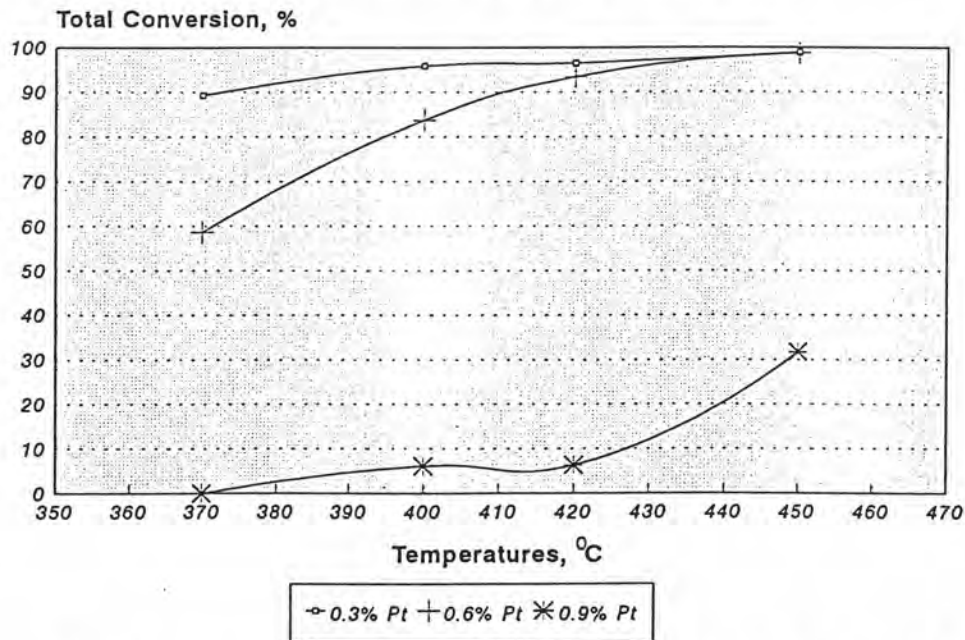


Figure 4.10 Comparison of Hydro-dehydrogenation Center Effect in Dehydrogenation Reactions of NGL under 60 psi H₂. (varying in different concentration of Pt on 0.5% F/Al₂O₃)

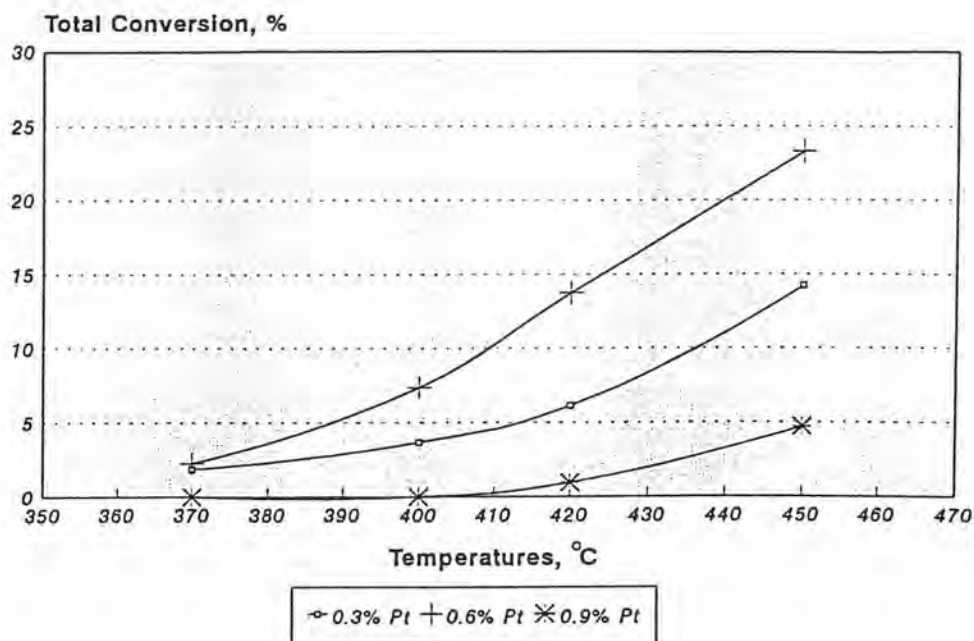


Figure 4.11 Comparison of Hydro-dehydrogenation Center Effect in Hydrocracking Reactions of NGL under 60 psi H₂. (varying in different concentration of Pt on 0.5% F/Al₂O₃)

These curves indicated that the suitable catalyst for isomerization of NGL was the 0.6% Pt-0.5% F/Al₂O₃ catalyst when compared with the 0.3% Pt-0.5% F/Al₂O₃ catalyst and the 0.9% Pt-0.5% F/Al₂O₃ catalyst.

When the percentage of platinum was higher than 0.6%, the products of all reactions were lower. This result indicated that the catalyst could not be used the percentage of platinum higher than 0.6%. It's probably the reactions proceeded via reversible process; when the platinum concentration was too high, the reverse reaction rate was higher than the forward reaction rate to result the lower conversion products.

3.2 Study of Acidic Center Effect

The acidic center effect of catalysts was studied by varying percentages of fluoride (0%, 0.5%, and 1.0% F) on 0.6% Pt/Al₂O₃ catalysts under the constant hydrogen pressure, 60 psi (the optimum hydrogen pressure), and at 370-450°C (the optimum range of temperatures).

The results from Table C3, C5, and C6 in Appendix C were plotted to give the curves as shown in Figure 4.12-4.15 for comparison of the acidic center effect on the four significant reactions.

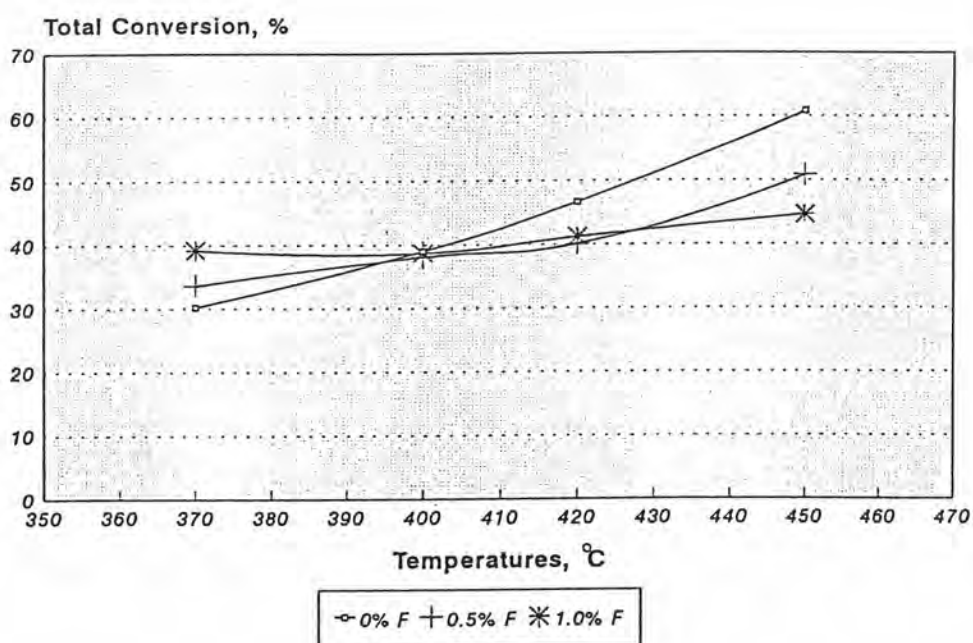


Figure 4.12 Comparison of Acidic Center Effect in Skeletal Isomerization Reactions of NGL under 60 psi H₂. (varying in different concentration of F on 0.6% Pt/Al₂O₃)

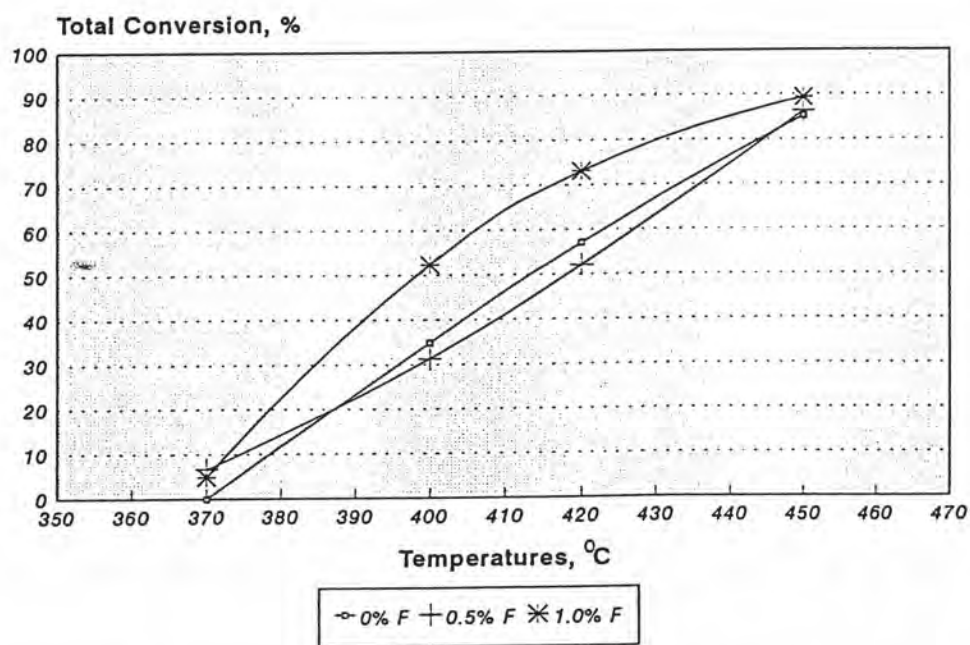


Figure 4.13 Comparison of Acidic Center Effect in Aromatization Reactions of NGL under 60 psi H₂. (varying in different concentration of F on 0.6% Pt/Al₂O₃)

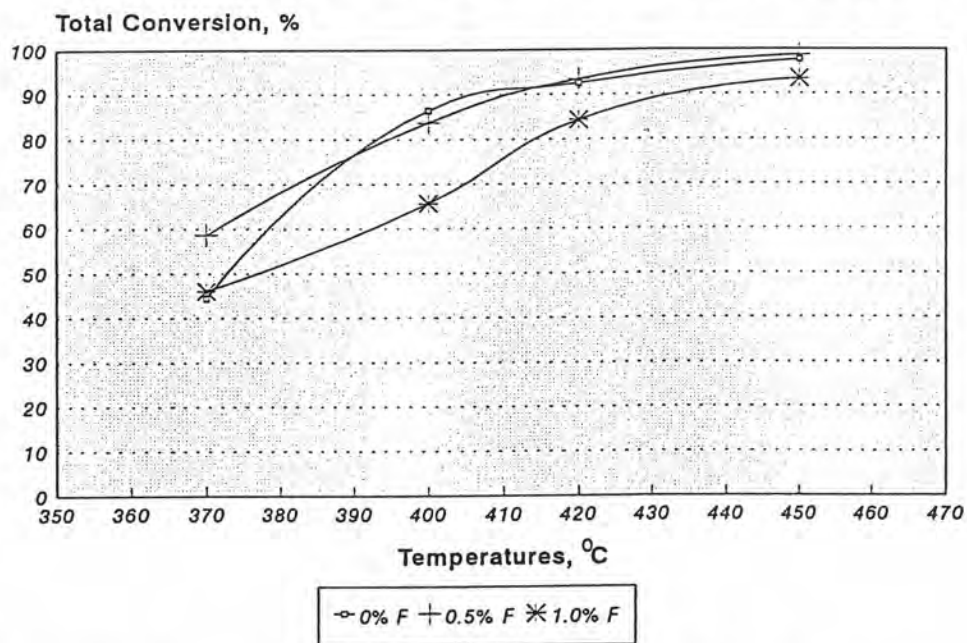


Figure 4.14 Comparison of Acidic Center Effect in Dehydrogenation Reactions of NGL under 60 psi H₂. (varying in different concentration of F on 0.6% Pt/Al₂O₃)

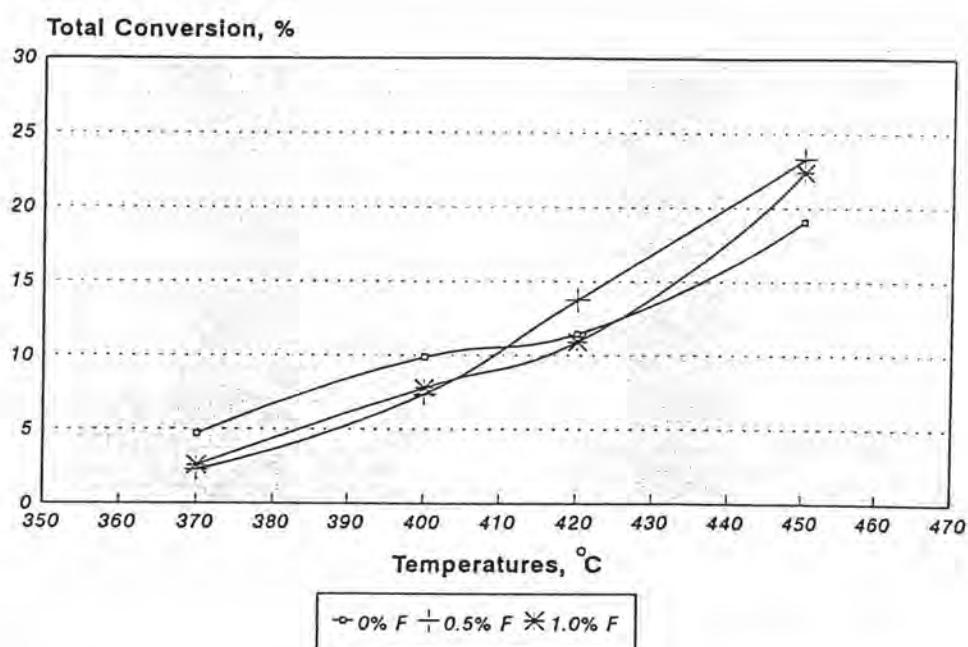


Figure 4.15 Comparison of Acidic Center Effect in Hydrocracking Reactions of NGL under 60 psi H₂. (varying in different concentration of F on 0.6% Pt/Al₂O₃)

The curves shown in Figure 4.12-4.15 indicated that varying in fluoride concentrations were obtained no significant difference occurred on the four significant reactions.

Nevertheless, the curves in Figure 4.12 for the skeletal isomerization reactions showed that at the lower reaction temperature (370°C), 1.0% F on 0.6% Pt/Al₂O₃ was more active than 0.5% F and 0% F, respectively, but at the higher temperatures the activities of these catalysts were opposite. Thus at 450°C, the 0.6% Pt-0% F/Al₂O₃ catalyst was the most active catalyst.

Therefore, the most suitable catalyst for isomerization of NGL at 370 °C was the 0.6% Pt-1.0% F/Al₂O₃ catalyst when compared with the 0.6% Pt-0.5% F/Al₂O₃ and 0.6% Pt-0% F/Al₂O₃ catalysts.

Studies of Some Physical Properties

1. Selection of the Optimum Condition

The optimum condition for isomerization of NGL was selected to study of the antiknock property of product comparatively to NGL. It was considered from the studies of the effects mentioned in this research, i.e., the temperature effect, the hydrogen pressure effect, and the catalyst concentration effects.

Since the products from the dehydrogenation reactions of cycloparaffins and the aromatization reactions were aromatic hydrocarbons that be limited in their permissible maximum concentration on blended-gasoline, the optimum condition should be selected from the appropriate reaction condition that gave as least of aromatic hydrocarbons as possible. Includingly, the hydrocracking reactions were the side reactions for isomerization of NGL, so these reactions should be also occurred in the lowest conversion level.

From the results of comparisons of temperature effect and hydrogen pressure effect shown in Figure 4.2 and Figure 4.4-4.7, respectively, were found that the reaction operated at 370°C was obtained the lowest conversion level in the reactions of aromatization, dehydrogenation of cycloparaffins, and hydrocracking, and the skeletal isomerization reactions were occurred in the highest conversion level when the reactions were performed under 60 psi hydrogen pressure. Furthermore, the results of comparisons of the catalyst concentration effect were found that the highest conversion level in skeletal isomerization was obtained by using of the 0.6% Pt-1.0% F/Al₂O₃ catalyst.

In summary, the optimum condition, for study of antiknock property of its product in comparison to NGL, was the reaction operation at 370°C under 60 psi hydrogen pressure over the 0.6% Pt-1.0% F/Al₂O₃ catalyst.

2. Results of Antiknock Property and the Other Physical Properties

The results of antiknock property were presented in Table 4.4 by the Research Octane Number (RON) of NGL and its product from the optimum condition. Moreover, the blended gasoline from the extraordinary studies in blending NGL or isomerate (product of NGL) with reformat and MTBE were also presented their RON, percentages of total aromatics and percentages of benzene in comparison with the gasoline specification of Petroleum Authority of Thailand (PTT) in Table 4.4.

Table 4.4 Data of Some Physical Properties

| | S.G. 60/60 °F | RON | %Total aromatics | %Benzene |
|---|---------------------|-------------|---------------------|------------|
| NGL | 0.7067 | 74.8 | - | - |
| ISOMERATE (PRODUCT) | 0.7302 | 83.7 | - | - |
| REFORMATE | 0.7863 | 97.9 | - | - |
| MTBE | 0.5565 | 115.5 | - | - |
| NGL(6%)+REFORMATE(84%)+MTBE(10%) | 0.7585 | 98.3 | 50.50 | 2.36 |
| ISOMERATE(6%)+REFORMATE(84%)+MTBE(10%) | 0.7600 | 98.8 | 51.88 | 2.54 |
| NGL(15%)+REFORMATE(75%)+MTBE(10%) | 0.7514 | 96.2 | 45.26 | 2.39 |
| ISOMERATE(15%)+REFORMATE(75%)+MTBE(10%) | 0.7549 | 97.5 | 47.82 | 2.93 |
| SPECIFICATION OF ULP (SUPER 97) | report | 97.0 min | 50 max | 3.5 max |

From the data presented in Table 4.4, the isomerate (or the product from the optimum condition) had higher RON than NGL, thus, blending with the isomerate into reformat and MTBE to be blended gasoline was also obtained the higher RON in comparison with NGL blending.

However, blending with the isomerate in the proportion of 15% isomerate was obtained 97.5 in value of RON, 47.82% of total aromatics and 2.93% of benzene, which these results were in the range of ULP (Super 97) specification. Comparatively, blending with NGL in the same proportion could not be obtained RON in the range of this gasoline specification.

These results indicated that the isomerate was better than NGL in the antiknock property and in the use of blending into gasoline base (reformat+MTBE) to produce blended gasoline.

Further Studies of Activities of Used Catalysts and Reproducibility

1. Activities of Used Catalysts

The study of activities of used catalysts were performed by using of the 0.3% Pt-0.5% F/Al₂O₃ catalyst, under the constant hydrogen pressure, 60 psi (the optimum hydrogen pressure), and at 370-450°C (the optimum range of temperature).

The results from Table C1, and C2 in Appendix C were plotted to give the curves as shown in Figure 4.16-4.19 below.

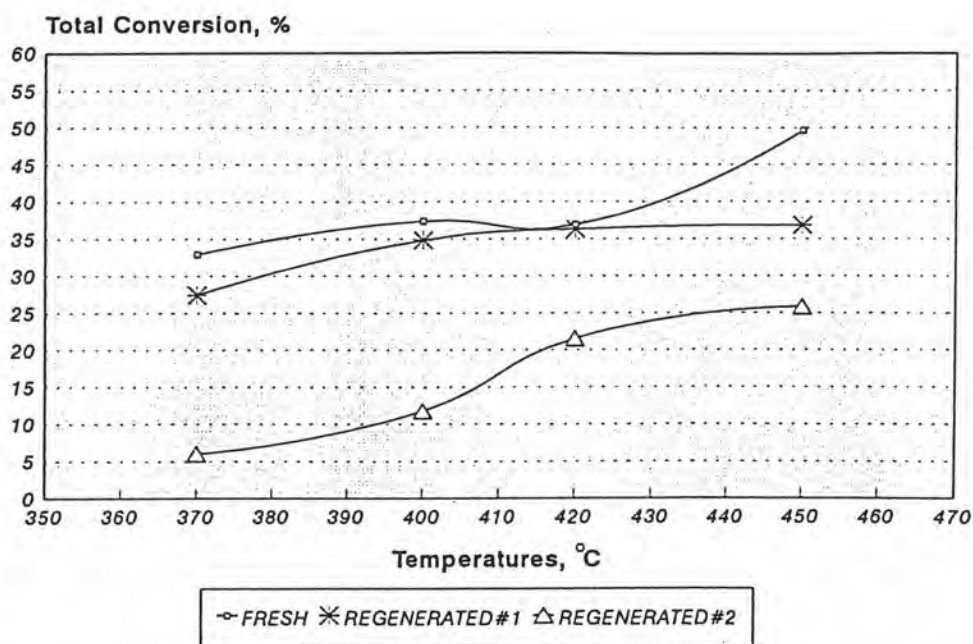


Figure 4.16 Comparison of Activities of Used Catalysts in Skeletal Isomerization Reactions of NGL under 60 psi H₂ by 0.3% Pt-0.5% F/Al₂O₃ catalysts.

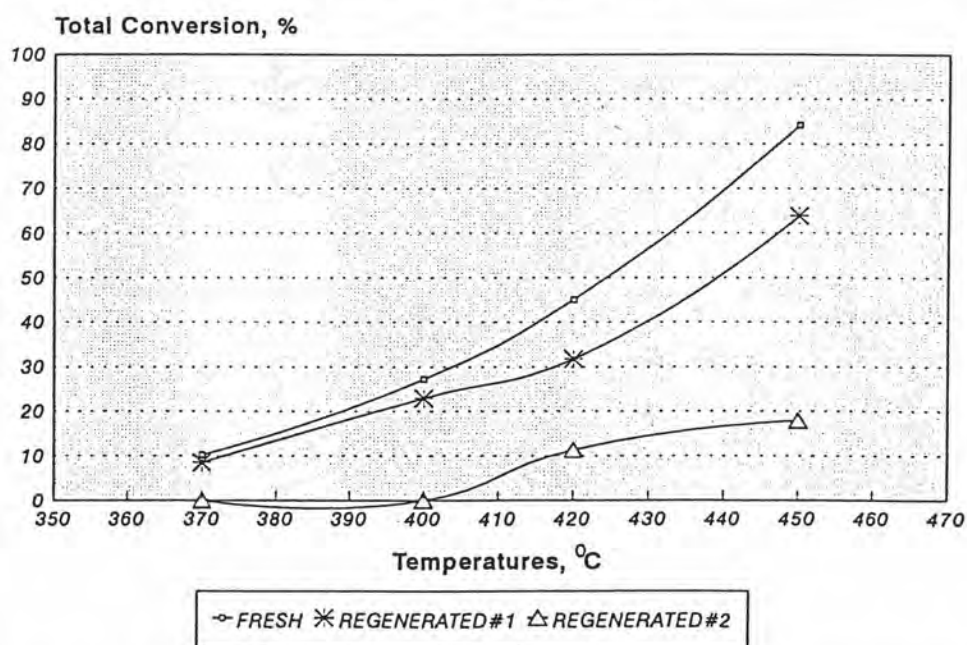


Figure 4.17 Comparison of Activities of Used Catalysts in Aromatization Reactions of NGL under 60 psi H₂ by 0.3% Pt-0.5% F/Al₂O₃ catalysts.

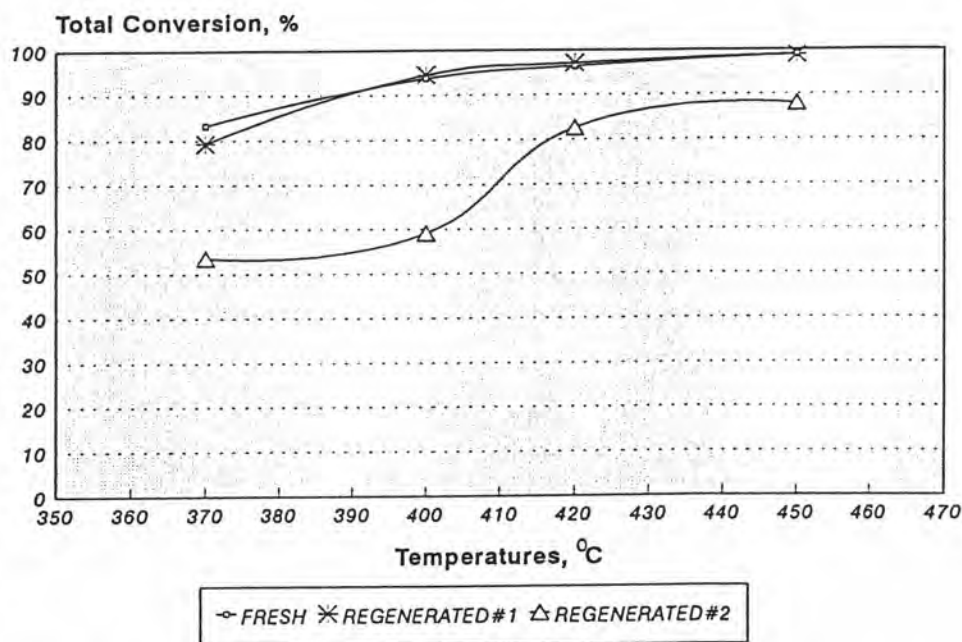


Figure 4.18 Comparison of Activities of Used Catalysts in Dehydrogenation Reactions of NGL under 60 psi H₂ by 0.3% Pt-0.5% F/Al₂O₃ catalysts.

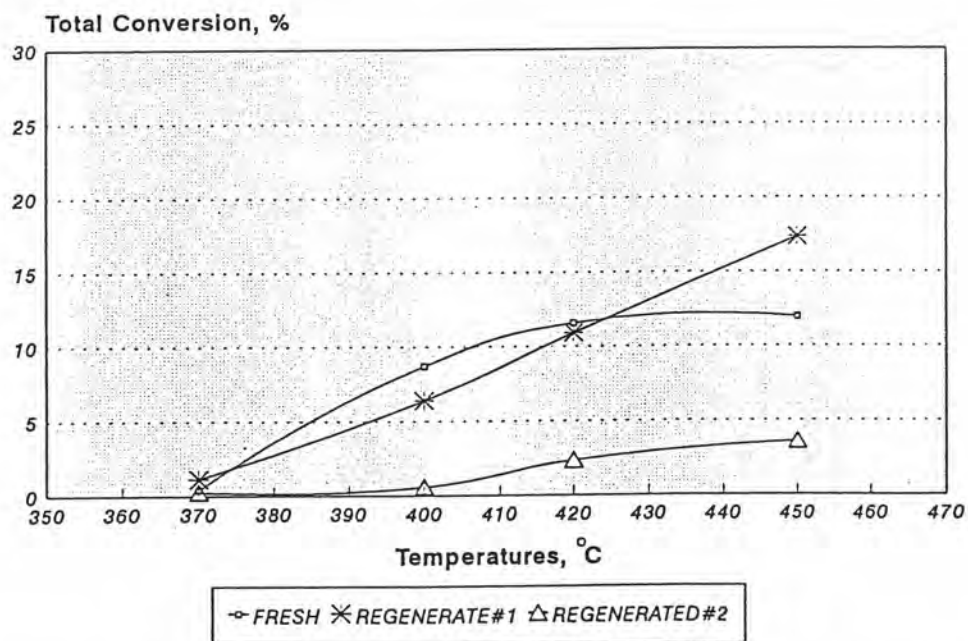


Figure 4.19 Comparison of Activities of Used Catalysts in Hydrocracking Reactions of NGL under 60 psi H₂ by 0.3% Pt-0.5% F/Al₂O₃ catalysts.

The curves shown in Figure 4.16-4.19 indicated that using of fresh catalyst was obtained the highest conversion level when the reactions were performed. Although the catalyst was regenerated once, its activity was not significant different from the activity of the fresh catalyst.

Nevertheless, the activity of the second time regenerated catalyst was obviously lower than the activities of the fresh catalyst and the first time regenerated catalyst.

2. Reproducibility

The study of reproducibility of reactions was also performed by using the 0.3% Pt-0.5% F/Al₂O₃ catalyst, under the constant hydrogen pressure, 60 psi (the optimum hydrogen pressure), and at 370-450°C (the optimum range of temperature).

The results from Table C1, and C2 in Appendix C were plotted to give the curves as shown in Figure 4.20-4.23 below.

These curves shown in Figure 4.20-4.23 demonstrated that there was reproducibility of reactions performed on the same type of catalysts, since there was no significant difference in conversion of all reactions.

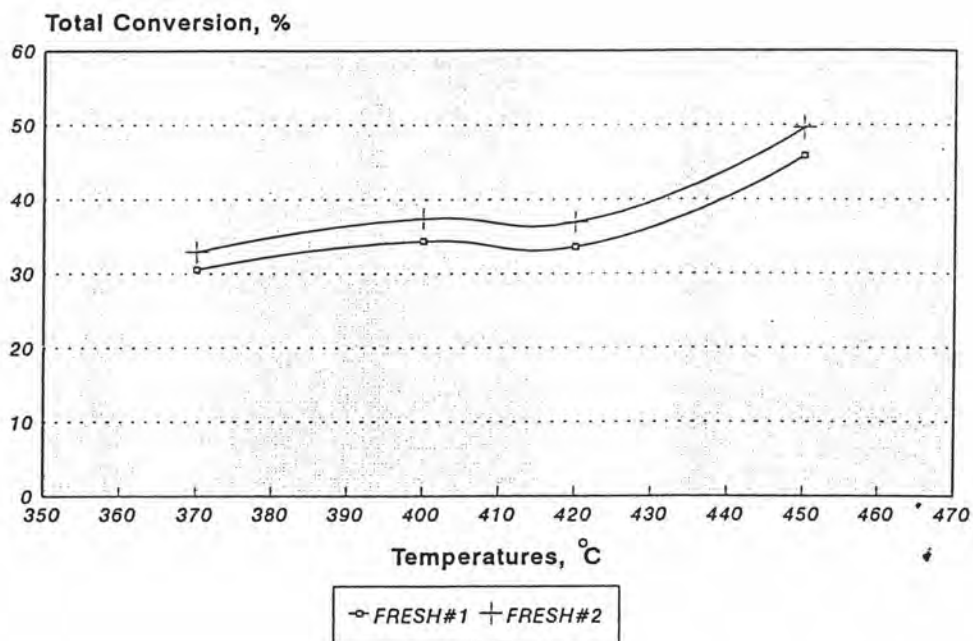


Figure 4.20 Reproducibility Study in Skeletal Isomerization Reactions of NGL under 60 psi H₂ by 0.3% Pt-0.5% F/Al₂O₃ fresh catalysts.

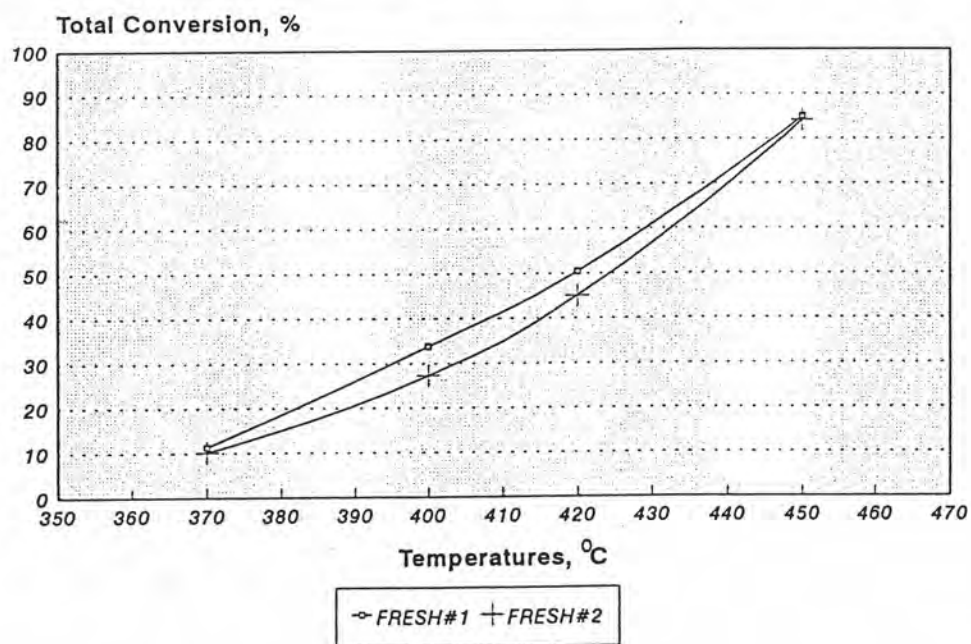


Figure 4.21 Reproducibility Study in Aromatization Reactions of NGL under 60 psi H₂ by 0.3% Pt-0.5% F/Al₂O₃ fresh catalysts.

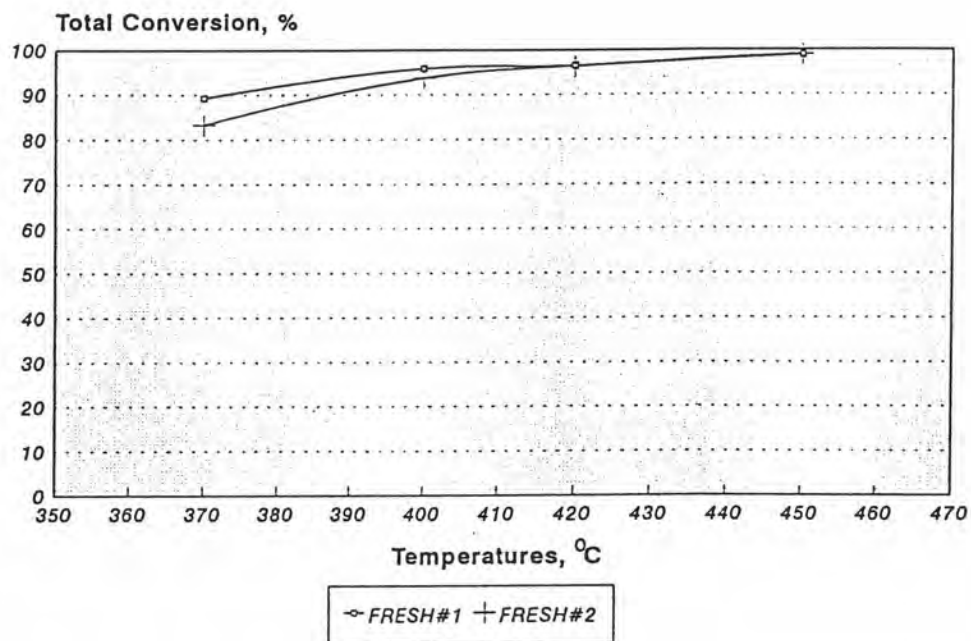


Figure 4.22 Reproducibility Study in Dehydrogenation Reactions of NGL under 60 psi H_2 by 0.3% Pt-0.5% F/ Al_2O_3 fresh catalysts.

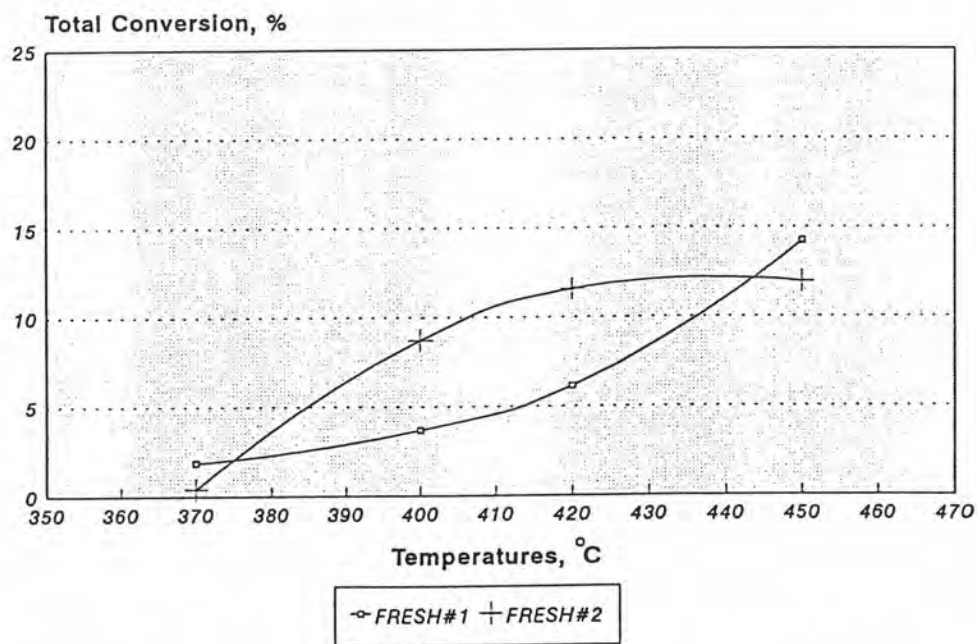


Figure 4.23 Reproducibility in Hydrocracking Reactions of NGL under 60 psi H_2 by 0.3% Pt-0.5% F/ Al_2O_3 fresh catalysts.