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CATALYTIC CRACKING OF PURE HYDROCARBONS.

Laboratory experiments were carried out in which a series of pure hydrocarbons were subjected to catalytic cracking. The operating conditions were chosen in such a way that they corresponded to conditions under which the most favorable cracking results have been obtained before. All cracking experiments should be carried out under these optimal conditions. In this way a direct comparison of the results is possible and predictions can be made for the cracking behavior of oils whose composition is approximately known. It was attempted to obtain detailed analyses of the reaction products and thereby obtain information on the secondary and side reactions like dehydrogenation, cyclization, alkylation and polymerization, which accompany the main cracking reaction.

Only those hydrocarbons were investigated which fall in the range of heavy gas oils and can occur in petroleum oils or synthetic oils.

Preparation of Starting Materials.

The hydrocarbons were distilled over a 5-foot packed column at atmospheric pressure. Substances which boil at about 410°F. were distilled over Widmer columns or over 1-foot packed columns under vacuum.

n-Decane.

From a Kogasin fraction in the boiling range of n-decane a 1°C. fraction was distilled out which had the following physical constants: d_{20} 0.732; aniline point 171°F. (77.5°C.); boiling point 343 - 345°F. (173 - 174°C.); n_D^{20} 1.4130.

n-Heptadecane.

The hydrocarbon was obtained by fractionation of technical cetane. Aniline point 210°F. (99°C.); boiling point 572 - 590°F. (300 - 310°C.); n_D^{20} 1.4370.

iso-Dodecane.

A branched hydrocarbon with 12 carbon atoms was obtained by fractionation of the higher boiling residue obtained during the manufacture of iso-octane by polymerization of butylene. d_{20} 0.758; aniline point 180°F. (82.3°C.); boiling point 367 - 383°F. (186 - 195°C.); n_D^{20} 1.4257.

n-Decene.

The olefin was obtained from a Synol alcohol in the C₁₀ region which was converted into the olefin by dehydration over alumina at 570°F.

Subsequent distillation yielded a hydrocarbon which is not entirely uniform with respect to the position of the double bond. It had the following data: d_{20}^0 0.745; bromine number 115; boiling point 331 - 347°F. (166 - 175°C.) (the main portion boils at 336 - 342°F. (169 - 172°C.)); n_D^{20} 1.4260.

n-Cetene.

The hydrocarbon was prepared analogous to n-decene from cetylalcohol. d_{20}^0 0.784; bromine number 70.0; boiling point 536 - 538°F. (280 - 281°C.); n_D^{20} 1.4445.

Xylene.

The post-toluene cut from the synthetic manufacture of toluene was used as raw material from which a xylene fraction boiling at 277 - 293°F. (136 - 145°C.) was obtained by distillation. According to the boiling range the material is probably a mixture of the three isomeric xylenes.

Durene.

The commercial product was used - melting point 174°F. (79°C.); boiling point 381°F. (194°C.).

sec. Amylbenzene.

The hydrocarbon was obtained from the residue boiling above 329°F. (165°C.) obtained in the alkylation of benzene with isobutyl oil. d_{20}^0 0.865; boiling point 376 - 379°F. (191 - 193°C.); n_D^{20} 1.4910.

Diphenyl.

The commercial product was used - melting point 158°F. (70°C.); boiling point 489°F. (254°C.).

Diphenylmethane.

The manufacture of the starting material was carried out by the Friedel-Crafts synthesis from benzylchloride and benzene in the presence of aluminum chloride (the molar ratio of benzylchloride to anhydrous aluminum chloride was 3 : 1). The benzene was used in excess and served, at the same time, as solvent; the reaction temperature was between +5 and +10°C. The yield of diphenylmethane was about 70% of the theory. Melting point 79°F. (26°C.); boiling point 500 - 504°F. (260 - 262°C.).

α -Methylnaphthalene.

The commercial product contains, besides the isomeric β -compounds, impurities consisting of sulfur, oxygen and nitrogen compounds. By extraction with dilute caustic and sulfuric acid, followed by distillation over sodium, the product could be considerably purified. d_{20}^0 1.004; boiling point 464 - 469°F. (240 - 243°C.).

Tetralin.

After distillation the commercial tetralin had the following physical constants: d_{20} 0.973; boiling point 401 - 405°F. (205 - 207°C.); n_D^{20} 1.5438.

Isoamylcyclohexane.

The previously-mentioned sec. amylbenzene was hydrogenated using a nickel-tungsten sulfide catalyst (3076) at a hydrogen pressure of about 3,000 pounds and a temperature of 570°F. After distillation the product, which was free from aromatics, had the following physical constants: d_{20} 0.817; boiling point 383 - 388°F. (195 - 198°C.); n_D^{20} 1.4500.

Dicyclohexyl.

The preparation was carried out by hydrogenation of diphenyl using catalyst 58/2 (tungsten-nickel sulfide) at a pressure of about 3,000 psi and 572°F. Benzene and cyclohexane were used as solvents. The hydrocarbon was purified by distillation and treated with concentrated sulfuric acid under cooling with ice. In order to remove the small amount of aromatics it was, subsequently, rerun. d_{20} 0.885; aniline point 97°F. (46.3°C.); boiling point 451 - 457°F. (233 - 236°C.); n_D^{20} 1.4800.

Dicyclohexylmethane.

Diphenylmethane was used as starting material. The hydrogenation and purification was the same as for dicyclohexyl. d_{20} 0.876; aniline point 151°F. (66.6°C.); boiling point 482 - 487°F. (250 - 253°C.); n_D^{20} 1.4763.

Decalin.

The commercial product was used. d_{20} 0.880; boiling point 365 - 374°F. (185 - 190°C.).

ANALYTICAL PROCEDURE.

1. Investigation of the Gaseous Cracking Products.

The condensable hydrocarbons were separated from the non-condensable constituents of the cracking gas by means of liquid nitrogen. The uncondensable gas, which consists of hydrogen, methane, ethane and inert gas, was analyzed according to the Drehschmidt method. The determination of ethylene was carried out by bromine absorption.

The condensed portion of the cracking gas and the gaseous hydrocarbons obtained during stabilization of the liquid product were combined and separated into the C_2 , C_3 , $n-C_4$ and $iso-C_4$ fractions using a Leuna column. The olefin content of the fraction was determined by bromine absorption. The ratio of n -butylene to iso -butylene cannot be determined in this way. The distillation residue, which consists mainly of pentanes, was blended with the gasoline fraction.

2. Identification of the Hydrocarbons Boiling in the Gasoline Boiling Range.

After stabilization of the liquid product the gasoline was finished by rerunning over a 5-foot column. The gasoline was fractionated in a Jentzen spiral tube column (length of the tube 40 feet, height of the column 5 feet). The charge was 300 - 400 cc., the take-off per hour was 3.4 cc. with a reflux of 1 drop per second. The choice of the cut point was controlled by the mixture of hydrocarbons to be analyzed. On the average, up to 365 F. (185 C.), 50 fractions were taken off. Since the olefins and aromatics were not separated before the distillation, the fractions usually contained olefins and the higher boiling ones also aromatics. The cracking experiment with decalin was an exception in this respect because the aromatics and olefins were extracted by SO₂ prior to distillation. In the cracking experiments with naphthenes the evaluation of the fractions boiling above 158°F. (70°C.) was difficult because the presence of compounds of all four hydrocarbon classes had to be assumed. The determination of the degree of branching is, in that case, usually not possible.

3. Determination of Olefins.

Since, in most cases, the presence of olefins had to be assumed, the bromine number by the Winkler method was determined for each fraction and the percentage of olefins was calculated from the molecular weight in known manner.

4. Identification of a Mixture Consisting of Two Components.

The determination of the degree of purity of the fraction was based on the determination of the boiling point and the refractive index. If the latter shows a slight deviation from the refractive index of the pure compound expected, the presence of a second component must be assumed. From the known refractive indices of the two components which are suspected in the blend, the percentage of the two components can be calculated by means of the mixture rule. It is assumed for this purpose that the refractive indices are additive. This assumption is only strictly valid for mixtures of paraffins and naphthenes.

5. Identification of a Mixture Containing Three Components.

If two other components are expected besides the olefin, the olefin content is first calculated from the bromine number and the refractive index of the mixture is determined. The refractive index of the olefin-free mixture is calculated using the known value for the olefin and from this the percentage of the component is calculated according to the mixture rule. The components of the olefin-free mixture are calculated from the boiling curve under consideration of the calculated refractive index. In case that the mixture contains aromatics they are removed by means of 98% sulfuric acid and the refractive index of the remaining hydrocarbon mixture is determined. The refractive index of the aromatics can be

determined from the known value for the mixture before sulfuric acid treatment.

6. Identification of a Mixture of Four and More Components.

In the mixtures boiling above 212°F. a determination of the degree of branching is usually impossible, especially when representatives of all four classes of hydrocarbons are present. This possibility, however, need only be considered for the case when cracked gasoline from naphthenic hydrocarbons is analyzed. When cracking olefins, paraffins or aromatics, no naphthenes are formed in sizable quantities. If a mixture of various hydrocarbons must be analyzed, the following method is used:

After calculating the olefin content from the bromine number and determining the aromatics by means of ultraviolet absorption, the refractive index of the mixture free from olefins and aromatics is calculated by applying the mixture rule twice. In case of doubt, part of the fraction is extracted with 98% sulfuric acid and the refractive index of the raffinate is determined experimentally.

In some cases where only very small intermediate fractions were obtained, only the bromine number and refractive index were used for analysis. Since, however, these fractions did not make up more than about 0.5% of the total product and since the values obtained were calculated on the charge, the error should be slight.

7. Analysis of the Cracked Products Boiling above the Gasoline Boiling Range.

The same procedure as with the lighter-boiling hydrocarbons is followed but, in this case, only separation according to hydrocarbon groups can be obtained in most cases. Fractionation of higher-boiling materials was carried out in packed columns under vacuum. With very high boiling fractions it was sometimes possible to separate them into liquid and solid components. Aromatic hydrocarbons were sometimes separated in the form of their picric acid compounds.

8. Determination of Coke.

The carbon deposited on the catalyst is burned to carbon dioxide and water during regeneration with air. The complete oxidation to CO_2 is effected by passing the gas mixture over heated copper oxide. The CO_2 content is obtained from the consumption of barium hydroxide solution of known concentration. The small hydrogen content of the carbon deposit was not determined.

9. Cracking Experiments.

a. Apparatus and Reaction Conditions.

The experiments were carried out in an electrically-heated

reactor with a capacity of 1.7 liters of catalyst (104 cubic inches). The charge stock was pumped by means of a gear pump from a graduated storage tank through a preheater coil into the reactor. The liquid cracking products were cooled to 32°F. and collected in a round flask. The gaseous portion was collected in a gas holder; it was separated by fractional condensation into dry gas (hydrogen, methane and a small amount of ethane) and condensable gas. After each cracking period, regeneration was preceded by a purge period of 60 minutes; nitrogen was used as purge gas. The purge gas flowed through 2 receivers kept at low temperature and a tower packed with activated charcoal in order to remove entrained hydrocarbons. The regeneration of the catalyst was carried out by gradual addition of air to the inert gas; the temperature was not permitted to exceed 968°F.

The cracking temperature was 788°F., the space velocity 0.6 volumes of feed per volume of catalyst per hour, and the length of the cracking period was 60 minutes. Cracking catalyst #3248 was used.

b. n-Decane.

The hydrocarbon shows only a slight tendency to crack under normal cracking conditions. In spite of shortening the length of the cracking period to 30 minutes, the total conversion amounts to only 26% of the feed. Half of the cracking product is gaseous. The predominant formation of isobutane is remarkable and also the high degree of isomerization of the cracking product. Besides the cracking reaction proper and the formation of olefins amounting to 3.5% of the charge, a small amount of aromatization also takes place. The amount of aromatics formed increases in the order benzene, toluene, xylene. No significant quantities of naphthenes could be detected. Besides the formation of hydrocarbons with a number of carbon atoms smaller than that of decane, paraffins with longer chains are also formed due to alkylation and polymerization reactions. The amount of carbon deposited on the catalyst is moderate because of the low degree of cracking.

c. n-Heptadecane.

This hydrocarbon is cracked about twice as much as n-decane. The experimental result indicates clearly

that the thermal stability decreases for paraffins with increasing chain length. The decrease in thermal stability is equivalent to an increase of the free energy.

Only the hydrocarbons boiling below the starting material are considered as cracking products. The higher-boiling products which are formed from ~~primary-cracking-products-are-not-taken-into-con-~~sideration. The amount of gaseous hydrocarbons formed is somewhat smaller than for decane because the increased chain length favors the formation of liquid cracking products. Because of the higher degree of cracking the amount of olefins and aromatics formed is also increased. The branched hydrocarbons predominate in the cracked product analogous to the results obtained with decane. About 80% of the total paraffins are branched. Naphthenic hydrocarbons are not formed in any considerable quantity. More carbon is deposited on the catalyst than in the case of decane due to the higher degree of cracking.

d. Isododecane.

The hydrocarbon shows only a slightly lower degree of cracking than heptadecane and is much more easily cracked than n-decane. The relatively high tendency to cracking of isododecane can probably be explained by the high degree of branching. The butane fraction which forms 17.3% of the feed stock predominates in the cracking product. This is explained by the structure of the starting material.

e. Decene.

Under the same cracking conditions this hydrocarbon is thermally considerably less stable than n-decane. Its tendency to cracking exceeds by far that of the paraffin of equal chain length. The yield of lower-boiling-cracking products is about 80% which means that the hydrocarbon is about 3 times as easily cracked as the corresponding paraffin. This is in agreement with data of Francis and Egloff. If it is considered that no significant quantities of the decene charge are recovered, the degree of cracking becomes even greater since it must be assumed that the higher-boiling components are formed from primarily formed small molecules. The preferred formation of C₄, C₅, and C₆ hydrocarbons indicates that the

principal location of attack is in the center of the chain. The high olefin content of the cracked product and the quite considerable formation of higher-boiling polymerization products is remarkable. The predominant formation of branched-chain hydrocarbons indicates again the strong isomerizing effect of the catalyst. The formation of aromatics and coke is greater than with decane.

f. Cetene.

Cetene exceeds heptadecene by far in its ease of cracking and is somewhat easier cracked than decene. It is practically completely converted and the reaction products and the product distribution is not significantly different from decene.

g. Isoamylbenzene.

In accordance with expectations the main effect of cracking is splitting off of the paraffinic side chain. The main cracking products are, accordingly, benzene (31.5% of the charge) and pentene (21.7%, including pentene). Isobutane predominates among the gaseous products. The amount of toluene, xylene and ethyl benzene formed is considerably smaller than the amount of benzene. About 90% remain unreacted or are isomerized. The yield of higher-boiling products, mainly alkylated naphthalenes, amounts to about 12%. The formation of alkyl-substituted naphthalene might take place under ring closure; tetrahydronaphthalene is formed first and subsequently dehydrogenated. The small amount of paraffin in the $C_6 - C_9$ region indicates that a slight amount of polymerization of low-molecular weight cracked products to paraffins takes place in addition to the cracking reaction.

h. α -Methylnaphthalene.

Methylnaphthalene forms only a very small amount of lower-boiling cracking products; the bulk remains unchanged or is isomerized to the β -compound. The formation of 15% higher-boiling aromatics is remarkable; they consist partly of dimethylnaphthalene and $\beta\beta'$ -dinaphthyl. Probably, α -methylnaphthalene isomerizes to the thermally more stable β -compound and is then subjected to demethylation. The 2 naphthalene nuclei than unite, whereas the methyl groups which are split off exert an alkylating effect. It is to be assumed that the extent of carbon formation which is considerable for the degree of cracking obtained is due to

polymerization and condensation reaction of the naphthalene nuclei. The boiling range of the high-boiling residue points in this direction because it has an end point above 752°F. (400°C.).

i. Diphenyl.

This hydrocarbon is not cracked under the experimental conditions chosen.

j. Diphenylmethane.

Diphenylmethane is considerably less thermally stable than diphenyl and is almost completely cracked. Cracking takes place mainly at the methylene bridge. From the large amount of benzene formed it could be concluded that, predominantly, splitting of the 2 phenyl groups takes place with the methylene group furnishing the hydrogen necessary for the formation of benzene resulting in its dehydrogenation to carbon. The considerable formation of carbon (11% of the charge) makes this course of reaction rather probable. The rather appreciable amount of toluene (20% of the charge) formed indicates that in addition to the cracking reaction mentioned, the molecule decomposes to benzene and toluene. Alkylation and polymerization represent the side reactions. This is indicated by the formation of alkylated benzene and naphthalene derivatives. The formation of small amounts of anthracene could be explained by condensation of 2 benzyl groups to 9 - 10-dihydroanthracene which is subsequently dehydrogenated.

k. Durene.

Durene is mainly disproportionated to trimethylbenzene and penta- or hexamethylbenzene. About 50% of the charge remains unchanged or is isomerized. Coke formation amounts to 3% and gaseous hydrocarbons are formed only in traces.

l. Xylene.

The disproportionation observed with durene also takes place with xylene. Toluene and trimethylbenzene are predominantly formed. The amount of benzene, including gaseous cracking products, amounts to about 3% of the charge. The slight formation of higher-boiling aromatics could be explained by the assumption that part of the primarily-formed trimethylbenzene is again disproportionated. It is also not impossible that methyl

groups are split off which alkylate the benzene and thereby contribute to the formation of higher-boiling aromatics. Traces of olefins and paraffins which are formed in the course of the reaction must also be mentioned.

m. Tetralin.

Tetralin ranges between α -methyl-naphthalene and decalin with respect to its cracking properties. The hydrogenated ring is the main point of attack. The cracking process proper is exceeded by the dehydrogenation reaction by which at least 27% of the charge stock are converted to naphthalene. The equilibrium of the system naphthalene-tetrahydronaphthalene lies probably on the side of the naphthalene under the reaction conditions chosen. The cracking reaction appears to proceed largely so that short-chain cleavage products are removed from the hydrogenated ring system; this assumption is confirmed by the large amount of monocyclic aromatics which are formed with benzene predominating. The rather considerable quantities of higher-alkylated benzenes indicate that the hydroaromatic ring is split only at one point. Naphthenic hydrocarbons are also found among the cracking products, besides a very small amount of olefins (about 0.5% of the charge); the naphthenes found are predominantly methylcyclopentanes amounting to 1.4% of the charge. The paraffins are mainly concentrated in the gaseous product.

n. Isoamylcyclohexane.

This naphthene is more easily cracked than the corresponding paraffin. Only 17% of the charge product remains unchanged and about 65% are cracked to lower-boiling hydrocarbons, whereas the remainder is converted to higher-boiling hydrocarbons. The considerable formation of butane and pentane indicates that the cracking reaction preferentially attacks the side chain. The naphthenic 6-membered ring is mainly isomerized to methyl and dimethylcyclopentane or dehydrogenated. The amounts of paraffins and olefins with 6 and 4 carbon atoms indicate that rupture of the ring takes place, although the quantitative importance of this reaction is slight. Whereas, with aromatic hydrocarbons of the same structure mainly splitting off of the entire paraffinic side chain takes place with conservation of the aromatic ring, with isoamylcyclohexane pentane formation is favored as compared to butane formation. The quaternary carbon in the side chain of the isoamylbenzene

represents the preferred point of attack for the cracking reaction. The slight formation of coke and olefins should be noted.

c. Dicyclohexyl.

This hydrocarbon is much more easily cracked than the corresponding aromatic hydrocarbon of the same structure. The starting material is practically completely converted. The attack takes place principally at the linkage of the two rings and ring-splitting occurs simultaneously to a rather considerable extent. The gaseous hydrocarbons and the monocyclic naphthenes formed can be taken as a proof for the course of the reaction. Analogous to isomethylcyclohexane, the 6-ring naphthenes are strongly isomerized to the corresponding 5-membered rings. With respect to gas formation, it can be stated that it is smaller than with the naphthene having a side chain. When compared with cetane which shows about the same amount of cracking, the gas formation of the olefin is about twice as high as that of dicyclohexyl. The product distribution, with respect to gasoline formation, is especially favorable in the case of the bicyclic naphthene. The considerable amount of aromatization is also worth mentioning and finds its explanation in the structure of the starting material.

p. Dicyclohexylmethane.

This hydrocarbon is only slightly differentiated from dicyclohexyl with respect to cracking tendency and product distribution. The methylene bridge affects the general direction of cracking only slightly. Only the greater extent of dimethylcyclopentane formation caused by the carbon atom linking to the 2 rings should be mentioned. It must be assumed that methylcyclohexane forms the primary product which is immediately isomerized. The formation of aromatics is somewhat higher than for dicyclohexylmethane, due to the purely naphthenic character of dicyclohexyl.

q. Decalin.

The results of the cracking test confirmed the previously-found ease of cracking of naphthenes. The compound is thermally somewhat more stable than the previously-investigated bicyclic naphthenes because 24% of the charge product are recovered unchanged after cracking. The reason for the greater stability is to be sought in the different kind of ring linkage. Cracking consists mainly in cleavage of the ring system and formation of isobutane. The unreacted naphthenic

6-membered ring is simultaneously isomerized or dehydrogenated. A slight amount of dehydrogenation of decalin to naphthalene was also observed.

Discussion of Experimental Results.

The investigations have shown that the degree of cracking and the cracking products formed are dependent, to a large extent, on the structure of the charge stock. The olefins are least stable thermally and therefore, are the easiest compounds to crack, whereas the aromatics have a relatively good thermal stability. In the case of decene and cetene, no significant amounts of unconverted charge stock were recovered. The olefinic hydrocarbons are practically completely converted and form predominantly lower-boiling cracking products.

The paraffins are somewhat more difficult to crack than the olefins and their thermal stability decreases with increasing chain lengths. The branched paraffins are more easily cracked than the straight-chain paraffins with the same number of carbons.

The naphthenic hydrocarbons are easily cracked. The bicyclic naphthenes are cracked most completely, whereas the monocyclic 6-membered rings are isomerized to the corresponding 5-membered rings. Simultaneously, cleavage of the rings takes place. The extent of cleavage in the naphthene series is dependent on the kind of ring linkage; e. g., dicyclohexyl is practically completely cracked, whereas decalin reacts only to about 75%.

The aromatic hydrocarbons are, on the average, not easily cracked. Compounds with methyl groups are easily polymerized and the primary split off methyl groups have an alkylating effect. Very often considerable disproportionation takes place, e. g., from durene (1, 2, 4, 5-tetramethylbenzene) mainly tri- and pentamethylbenzene is formed. Gas formation is only insignificant in cracking of methyl-substituted aromatics but the percentage of higher-boiling polymerization products is quite considerable. If the aromatic character of a hydrocarbon is changed by the introduction of a paraffinic side chain, the compound loses its thermal stability and is more easily cracked; e. g., isocamylbenzene was found to be very easily cracked since the linkage of the side chain to the aromatic nucleus is only very loose. In tetralin also the tendency to cracking is much more pronounced than in α -methylnaphthalene. The difference in the ease of cracking is especially noticeable when diphenyl and diphenylmethane are compared. Diphenyl is thermally extremely stable, whereas the introduction of the methylene bridge results in practically complete cracking. With respect to product distribution, it can be stated that the olefinic hydrocarbons show high gas formation. The easily cracked naphthenic compounds, however, show only slight gas formation which can be explained by the resistance of the rings towards direct cracking; consequently, the formation of short-chain cracking products is not favored.

When the aromatic content of the cracked gasoline is considered, it is found that the naphthenic hydrocarbons form about twice as much aromatics of gasoline boiling range than the paraffins and the olefins. The olefins form aromatics by means of a cyclization reaction which is not so favorable with respect to its free energy as dehydrogenation of naphthenes which, under the experimental conditions chosen, proceeds practically to completion. The easily cracked aromatic hydrocarbons, e. g., isomylbenzene, also yield gasoline which is rich in aromatics; this is due to the thermal stability of the benzene ring.

The olefin content of the cracked gasoline is also strongly dependent on the nature of the hydrocarbon charge. It decreases according to the following series: aromatics, naphthenes, paraffins, olefins. The aromatics give the lowest olefin content of the cracked gasoline, provided that the charge stock does not contain paraffinic side chains of any length. The olefin content of the cracked gasoline is especially high when pure olefins are cracked. Naphthenes are found in the cracked gasoline only if the hydrocarbon charge already has naphthenic character. No significant new formation of naphthenes is observed.

Carbon deposition on the catalyst increases with increasing depth of cracking. Olefins give a somewhat higher carbon deposit, whereas the naphthenes deposit only a comparatively small amount of carbon on the catalyst. The carbon formation in the case of aromatic hydrocarbons depends strongly on the structure of these hydrocarbons; e. g., diphenylmethane gives about 10% carbon, calculated on the charge, whereas isomylbenzene and xylene form only about 2%. Since the aromatics are easily polymerized, especially in the case of bicyclic compounds, condensed ring compounds with high boiling points are formed which remain in the liquid phase at the cracking temperature and are adsorbed on the catalyst. These compounds are then determined as "carbon" in the regeneration of the catalyst.

The high percentage of branched hydrocarbons in the cracked product indicates the strong isomerizing effect of the catalyst. Especially, the large formation of isobutane should be noted. The percentage of isobutane in the total butane formed amounted to about 80% in the experiments reported here.

Rossini (J. A. C. S. 62, 2250, (1940)) calculates that at 427°C. (801°F.) only 38% isobutane are present when equilibrium is reached. Assuming the correctness of Rossini's values, the large deviation from the theoretical equilibrium could be explained by assuming that isomerization precedes cracking so that, mainly, isobutane is split off. The ratio of isopentane to total pentane amounts to about 0.9. The theoretical value, according to Rossini, is 0.7. The fact that 2-methylpentane is formed in preference to the other hexanes is in agreement with the work of Rossini and other American authors. 2,2-Dimethylbutane is only rarely found in large concentration in cracked gasoline. According to equilibrium calculations the percentage in the total hexane fraction would be 24%. In catalytically-cracked gasoline the straight-chain compounds are predominant.

TABLE 1

n-Decane
Cracking products, % by wt. of charge

| Boiling range °F. (°C.) | % by Wt. | Hydrocarbon | Olefins | Aromatics | Paraffins | |
|----------------------------|---|--|--|---|-----------|-----|
| | 0.1 | Hydrogen | - | - | 0.1 | |
| Gaseous | 0.1 | Methane | - | - | 0.1 | |
| | 0.3 | Ethane & Ethylene | 0.1 | - | 0.2 | |
| | 15.2% by Wt. | 4.3 | 3.3 Propane 1.0 Propylene | 1.0 | - | 3.3 |
| 8.4 | | 2.3 n-Butane 5.3 iso-Butane 0.8 Butylenes | 0.8 | - | 7.6 | |
| | 5.3 | 0.5 n-Pentane 4.2 iso-Pentane 0.6 Pentenes | 0.6 | - | 4.7 | |
| | | Gasoline E.P. 343°(173°) | 0.4 n-Hexane (traces methyl cyclopentane) | | | |
| 4.0 | | | 1.8 2-Methylpentane 0.9 3-Methylpentane 0.1 Dimethylbutane 0.7 Hexenes (mainly methyl pentene) | 0.7 | 0.1 | 3.2 |
| | 0.1 Benzene | | | | | |
| | 1.2 | | 0.6 Heptanes <0.1 Heptenes 0.5 Toluene | <0.1 | 0.5 | 0.6 |
| | | | 1.0 | 0.1 Octanes + about 10% Octenes 0.9 Xylene, ethylbenzene | | 0.9 |
| 0.6 | 0.2 Nonanes 0.1 Nonenes 0.3 Alkylated benzenes < 343°F (173°C) | | | 0.1 | 0.3 | 0.2 |
| | 0.9 Methylnonane | | | | | |
| | 1.0 | <0.1 Decene | <0.1 | - | 0.9 | |
| 343-345° (173-174°) | 67.5 | n-Decane | - | - | 67.5 | |
| 345-536° (174-280°) | 3.9 | predominantly paraffins | - | 1.4 | 2.5 | |
| > 536°(280°) | 0.8 | Aromatics & paraffins | | 0.3 | 0.3 | |
| | 1.7 | Coke | | | | |
| Total | | | 3.5 | 3.5 | 91.3 | |

TABLE 2

n-Heptadecane
Cracking products, % by wt. of charge

| Boiling range °F. (°C.) | % by Wt. | Hydrocarbon | Olefins | Aromatics | Paraffins |
|--|----------|---|---------|-----------|-----------|
| | < 0.1 | Hydrogen | - | - | 0.1 |
| Gaseous | 0.3 | Methane | - | - | 0.3 |
| | 0.5 | Ethane & 20% Ethylene | 0.1 | - | 0.4 |
| 20.5% by Wt. | 5.4 | 2.9 Propane 2.5 Propylene | 2.5 | - | 2.9 |
| | 14.2 | 1.9 n-Butane 8.9 iso-Butane 3.4 Butylenes | 3.4 | - | 10.8 |
| Gasoline E.P. 385° (185°) 26.2% by Wt. | 10.3 | 1.4 n-Pentane 5.5 iso-Pentane 3.4 Pentenes | 3.4 | - | 6.9 |
| | 6.5 | 1.4 n-Hexane (little methyl cyclopentane) 2.6 2-Methylpentane 0.8 3-Methylpentane 0.2 Dimethylbutane 1.5 Hexenes | 1.5 | | 5.0 |
| | 3.3 | 0.2 n-Heptane 1.4 Monomethylhexanes 0.5 iso-Heptane 0.9 Heptenes (mainly methyl- hexenes) | 0.9 | 0.3 | 2.1 |
| | 2.6 | 0.3 Toluene (little benzene) 1.1 Octanes (mainly branched) 0.4 Octenes (" ") 1.1 Xylenes, little ethyl benzene | 0.4 | 1.1 | 1.1 |
| | 2.6 | 0.5 Nonanes (mainly branched) 0.2 Nonenes (" ") 1.9 Trimethylbenzenes, propyl benzenes, ethyl toluenes | 0.2 | 1.9 | 0.5 |
| | 0.9 | 0.5 Paraffins 0.4 Olefins | 0.4 | - | 0.5 |
| 365-572° (185-300°) | 9.7 | mainly paraffins | 0.4 | 2.6 | 6.7 |
| 572-590° (300-310°) | 33.0 | Heptadecane | | | 33.0 |
| > 590° (310°) | 4.2 | Polymers | | | |
| | 6.4 | Coke | | | |
| Total | | | 13.2 | 6.9 | 70.3 |

TABLE 3

iso-Dodecane
Cracked-products, % by Wt. of charge

| Boiling range °F. (°C.) | % by Wt. | Hydrocarbon | Olefins | Aromatics | Paraffins |
|-----------------------------|----------|--|-------------|------------|-------------|
| | < 0.1 | Hydrogen | - | - | < 0.1 |
| Gaseous | < 0.1 | Methane | - | - | < 0.1 |
| 22.6% by wt. | 0.5 | Ethane & traces ethylene | - | - | 0.5 |
| | 4.6 | 2.0 Propane | | | |
| | | 2.6 Propylene | 2.6 | | 2.0 |
| | | 0.9 n-Butane | | | |
| | 17.3 | 12.2 iso-Butane | 4.2 | - | 13.1 |
| | | 4.2 Butylenes | | | |
| | | 0.4 n-Pentane | | | |
| | 6.9 | 5.1 iso-Pentane | 1.4 | - | 5.5 |
| | | 1.4 Pentenes | | | |
| Gasoline E.P. 365°(185°) | | 0.1 n-Hexane | | | |
| | | 2.3 2-Methylpentane | | | |
| | 4.6 | 1.1 3-Methylpentane | 1.0 | Traces | 3.5 |
| | | 1.0 Hexenes | | | |
| | | Traces benzene | | | |
| 26.1% by wt. | | 1.3 Methylhexane (ab. 10% di- methylpentane) | | | |
| | 2.7 | 0.6 Heptenes (mainly branched) | 0.6 | 0.8 | 1.3 |
| | | 0.8 Toluene | | | |
| | | 1.5 Octanes (mainly branched) | | | |
| | 3.0 | 0.4 Octenes (" ") | 0.4 | 1.1 | 1.5 |
| | | 1.1 Xylenes, little ethyl benzene | | | |
| | | 0.6 Nonanes/decanes (mainly branched) | | | |
| | 2.3 | 0.1 Nonenes/decenies (mainly branched) | 0.1 | 1.6 | 0.6 |
| | | 1.6 Trimethylbenzenes, ethyl toluenes, little propyl benzene | | | |
| 342-365° (172-186°) | 6.7 | Mainly paraffins | 0.1 | 1.6 | 5.0 |
| 365-385° (185-196°) | 38.5 | iso-Dodecane | - | - | 38.5 |
| 385-446° (198-230°) | 6.8 | Mainly paraffins | < 0.1 | 1.5 | 4.2 |
| 448-628° (230-330°) | 2.4 | Aromatics & paraffins | < 0.1 | 1.2 | 1.1 |
| | 4.6 | Coke | | | |
| Total | | | 10.6 | 7.8 | 77.0 |

TABLE 4

n-Decene
Cracked products, % by wt. of charge

| Boiling Range OF. (°C.) | % by Wt. | Hydrocarbons | Olefins | Aromatics | Paraffins |
|------------------------------|----------|--|---------|-----------|-----------|
| | 0.1 | Hydrogen | - | - | 0.1 |
| Gaseous | 0.3 | Methane | - | - | 0.3 |
| | 0.6 | Ethane & Ethylene | 0.1 | - | 0.3 |
| 28.1% by Wt. | 2.1 | Propane | | | |
| | 6.5 | 4.4 Propylene | 4.4 | - | 2.1 |
| | 1.6 | n-Butane | | | |
| | 20.6 | 9.1 iso-Butane | 9.9 | - | 10.7 |
| | | 9.9 Butylenes | | | |
| Gasoline E.P. 331° (166°) | 19.2 | 1.3 n-Pentane | | | |
| | | 9.0 iso-Pentane | 8.9 | - | 10.3 |
| | | 8.9 Pentenes | | | |
| | | 1.1 n-Hexane (traces methyl cyclopentane) | | | |
| | | 4.0 2-Methylpentane | | | |
| | | 2.1 3-Methylpentane | | | |
| | 15.4 | 1.2 Dimethylbutane | 6.8 | 0.2 | 8.4 |
| | | 6.8 Hexenes | | | |
| | | 0.2 Benzene | | | |
| 48.1% by Wt. | | 0.1 n-Heptane | | | |
| | | 2.0 iso-Heptane (about 70% (monomethylhexane) | | | |
| | 4.4 | 1.9 Heptenes (mainly mono- methylhexenes) | 1.9 | 0.4 | 2.1 |
| | | 0.4 Toluene | | | |
| | | 0.8 Octanes (mainly branched) | | | |
| | 2.6 | 0.5 Octenes (" ") | 0.5 | 1.3 | 0.8 |
| | | 1.3 Xylenes (about 5% ethyl- benzene) | | | |
| | | 4.1 Nonanes/decenes | | | |
| | 6.5 | 1.4 Nonenes/decenes | 1.4 | 1.0 | 4.1 |
| | | 1.0 Propylbenzenes, ethyl- toluenes, trimethyl- benzenes | | | |
| 331-347° (166-175°) | 3.1 | Mainly paraffins | 0.1 | 0.8 | 2.2 |
| 347-392° (175-200°) | 9.5 | Paraffins Alkylated benzenes | 0.3 | 3.4 | 5.8 |
| 392-526° (200-330°) | 5.9 | Mainly aromatics | 0.1 | 3.6 | 2.2 |
| | 5.3 | Coke | | | |
| Total | | | 34.4 | 10.7 | 49.6 |

TABLE 6

N-Cetene

| Boiling Range of. (°C.) | % by Wt. | Hydrocarbon | Olefins | Aromatics | Paraffins |
|----------------------------|---|---|---------|-----------|-----------|
| Gaseous | < 0.1 | Hydrogen | - | - | < 0.1 |
| | 0.7 | Methane | - | - | 0.7 |
| | 0.7 | Ethane | - | - | - |
| 28.0% by Wt. | 1.1 | 0.4 Ethylene | 0.4 | - | 0.7 |
| | 6.9 | 1.7 Propane | - | - | - |
| | | 5.2 Propylene | 5.2 | - | 1.7 |
| | 19.2 | 2.5 n-Butane | - | - | - |
| | | 5.9 iso-Butane | 10.8 | - | 3.4 |
| Gasoline E.P.365°(185°) | 15.4 | 10.8 Butylenes | - | - | - |
| | | 1.3 n-Pentane | - | - | - |
| | 7.2 | 7.2 iso-Pentane | 6.9 | - | 6.5 |
| | 12.1 | 6.9 Pentanes | - | - | - |
| | | 1.1 n-Hexane (traces methyl- cyclopentane) | - | - | - |
| 4.2 2-Methylpentane | | - | - | - | |
| 51.4% by Wt. | 7.2 | 2.0 3-Methylpentane | 4.4 | - | 7.7 |
| | | 0.4 Dimethylbutane | - | - | - |
| | 7.2 | 4.4 Hexenes | - | - | - |
| | | 1.2 n-Heptane | - | - | - |
| | 7.2 | 3.1 2(3)-Methylhexanes | - | - | - |
| | | 3.3 Heptenes (mainly mono- methylhexane) | 2.3 | 0.6 | 4.3 |
| | 6.5 | 0.6 Toluene | - | - | - |
| | | 2.7 Octanes (mainly branched) | - | - | - |
| | | 1.2 Octenes (" ") | 1.2 | 2.6 | 2.7 |
| | | 2.6 Xylenes, little ethylbenzene | - | - | - |
| 5.4 | 2.3 Nonanes (mainly branched) | - | - | - | |
| | 0.6 Nonenes (" ") | 0.6 | 2.5 | 2.3 | |
| 2.5 | 2.5 Propylbenzenes, trimethyl- benzenes, ethylbenzenes | - | - | - | |
| | 2.3 Decanes (mainly branched) | - | - | - | |
| 2.5 | 0.2 Decene | 0.2 | - | 2.3 | |
| 329-365° (165-185°) | 2.3 | Aromatics, paraffins | 0.1 | 1.7 | 0.5 |
| 365-518° (185-270°) | 9.5 | " " | 0.2 | 4.0 | 5.3 |
| 518-550° (270-288°) | 4.9 | Mainly paraffins | - | 0.9 | 4.0 |
| >550°(288°) | 1.8 | Paraffins & aromatics | 0.2 | 0.9 | 0.7 |
| | 4.4 | Coke | | | |
| Total | | | 32.5 | 13.2 | 49.9 |

TABLE 6

iso-Amylbenzene
Cracking products, % by wt. of charge

| Boiling Range °F. (°C.) | % by Wt. | Hydrocarbons | Olefins | Aromatics | Paraffins | | |
|----------------------------|--------------|---------------------------------------|--|----------------------------|-----------|------|--|
| | 0.1 | Hydrogen | - | - | 0.1 | | |
| Gaseous | 0.3 | Methane | - | - | 0.3 | | |
| 7.6% by wt. | 0.4 | Ethane + little ethylene | <0.1 | - | 0.3 | | |
| | 1.2 | Propane | | | | | |
| | 1.8 | 0.6 Propylene | 0.6 | - | 1.2 | | |
| | 5.0 | 1.0 | n-Butane | | | | |
| | | 3.3 | iso-Butane | 0.7 | - | 4.3 | |
| Gasoline E.P.376°(191°) | 0.7 | Butylenes | | | | | |
| | 21.7 | 3.7 | n-Pentane | | | | |
| | | 12.7 | iso-Pentane | 5.3 | - | 16.4 | |
| | 32.9 | 5.3 | Pentenes | | | | |
| | | 0.6 | 2(3)-Methylpentanes | | | | |
| | 31.5 | 0.4 | Dimethylbutanes | | | | |
| | | 0.1 | n-Hexane | 0.3 | 31.5 | 1.1 | |
| | 69.9% by wt. | 0.3 | Hexenes | | | | |
| | | 3.4 | 0.8 | Heptanes (mainly branched) | | | |
| | | | 0.2 | Heptenes (" ") | | | |
| 4.0 | | 2.4 | Toluene | 0.2 | 2.4 | 0.8 | |
| | | 0.6 | Octanes (mainly branched) | | | | |
| 7.9 | | 3.4 | Xylenes + ethyl benzene | - | 3.4 | 0.6 | |
| | | 0.3 | Traces of Octenes | | | | |
| 7.6 | | 0.3 | Nonanes + decanes | | | | |
| | | 7.6 | Alkylated benzines boiling 293-376°F. (145-191°C.) | - | 7.6 | 0.3 | |
| | | | Traces of Olefins | | | | |
| 376-392° (191-200°) | 8.3 | iso-Amylbenzene | - | 8.3 | - | | |
| 392-464° (200-240°) | 4.6 | Mainly aromatics | - | 4.6 | - | | |
| 464-500° (240-260°) | 2.5 | About 80% β -methyl-naphthalene | - | 2.5 | | | |
| 500-680° (260-360°) | 3.6 | Partly alkylated naphthalenes | - | 3.6 | | | |
| > 680°(360°) | 1.3 | Aromatics (condensed rings) | | 1.3 | | | |
| | 2.2 | Coke | | | | | |
| Total | 100.0 | | 7.2 | 66.2 | 25.4 | | |

TABLE 7

o-Methylnaphthalene
Cracking products, % by wt. of charge

| H ₂ C ₁ -C ₆ | < 464°F (240°C) | Methylnaphthalene | Higher Polymers* | Coke |
|--|-----------------|-------------------|---------------------|------|
| 0.6 | 3.3 | 76.4 | 15.0 | 4.7 |

* The fraction contains dimethylnaphthalene and β - β' -dinaphthyl.

TABLE 8

Diphenylmethane
Cracking products, % by wt. of charge

| < 176°F (80°C) C ₁ -C ₆ | Benzene | Toluene | Xylenes, Ethyl- benzenes | 284-392°F (140-200°C) mainly aromatics | 392-482°F (200-250°C) β -methyl- naphthalene | Diphenyl- methane | > 518°F (270°C) anthra- cene | Coke |
|--|---------|---------|--------------------------------|---|---|----------------------|---------------------------------------|------|
| 1.6 | 51.0 | 19.7 | 3.7 | 4.8 | 5.1 | 2.2 | 1.3 | 10.6 |

TABLE 9

Durene
Cracking products, % by wt. of charge

| H ₂ C ₁ -C ₄ | Toluene+ Xylenes (mainly Xylenes) | Trimethyl- benzenes about 90% pseudocumene | Durene + iso-durene | Prehnitene | Pentamethyl- benzene | Hexamethyl- benzene | Coke |
|--|--|---|------------------------|------------|-------------------------|------------------------|------|
| About 0.1 | 3.0 | 21.8 | 50.2 | 3.6 | 12.8 | 5.5 | 3.1 |

TABLE 10

Xylene
Cracking products, % by wt. of charge

| H ₂ | | | | | > 347°F (175°C) | |
|--------------------------------|---------|---------|--------|------------------|--------------------|------|
| C ₁ -C ₅ | Benzene | Toluene | Xylene | Trimethylbenzene | | Coke |
| 1.8 | 1.3 | 8.6 | 69.5 | 14.3 | 2.6 | 2.1 |

TABLE 11

Tetralin

| Boiling Range °F (°C) | % by Wt. | Hydrocarbon | Naphthenes | Olefins | Aromatics | Paraffins |
|--------------------------|----------|---|------------|-----------|-----------|-----------|
| | < 0.1 | Hydrogen | - | - | - | 0.1 |
| Gaseous | 0.5 | Methane & Ethane | - | - | - | 0.5 |
| | | 0.9 Propane | | | | |
| | 1.0 | 0.1 Propylene | - | 0.1 | - | 0.9 |
| 4.5% by wt. | | 1.1 n-Butane | | | | |
| | 2.9 | 1.6 iso-Butane | - | 0.3 | - | 2.6 |
| | | 0.3 Butylenes | | | | |
| | | 0.4 Pentanes (mainly branched) | | | | |
| Gasoline | 0.6 | 0.1 Pentenes | 0.1 | 0.1 | - | 0.4 |
| E.P.358°(180°) | | 0.1 Cyclopentane | | | | |
| | | 0.4 Methylpentanes Dimethylbutanes + traces hexenes | | | | |
| | 8.2 | 1.4 Methylcyclopentane | 1.8 | Traces | 6.0 | 0.4 |
| | | 0.4 Cyclohexane | | | | |
| | | 6.0 Benzene | | | | |
| | | 0.3 Heptanes, very little heptenes | | | | |
| | 2.6 | 0.4 Dimethylcyclopropane, little methyl- cyclohexane | 0.4 | Traces | 1.9 | 0.3 |
| 19.4% by wt. | | 1.9 Toluene | | | | |
| | | 0.2 Octanes & traces octenes | | | | |
| | | 0.3 alkylated 5- and 6-ring naphthenes (boiling 212-291°F, 100-144°C) | 0.3 | Traces | 2.7 | 0.2 |
| | 3.2 | 2.7 Ethylbenzenes, Xylenes | | | | |
| | | 0.2 Naphthenes (291-320°F, 144-160°C), traces olefins & paraffins | 0.2 | Traces | 0.4 | Traces |
| | 0.6 | 0.4 Aromatics (291-320°F, 144-160°C) | | | | |
| | | Aromatics & naphthenes, traces paraffins + olefins | 0.7 | Traces | 1.5 | Traces |
| 320-358° (160-180°) | 2.2 | | | | | |
| 358-374° (180-190°) | 17.9 | Alkylated benzenes (diethyl benzenes, dimethyl benzenes) | - | - | 17.9 | - |
| 374-392° (190-200°) | 1.6 | Probably tetra- methylbenzene | - | - | 1.6 | - |
| 392-410° (200-210°) | 18.3 | Mainly tetralin (con- taminated with naphthalene | - | - | 18.3 | - |
| | 26.7 | Naphthalene | - | - | 26.7 | - |
| > 410°(210°) | | Naphthalene, naphthalene homologs, higher boil- ing aromatics | - | - | 12.3 | - |
| | 1.3 | Coke | | | | |
| Total | 100.0 | | 3.5 | about 0.5 | 89.3 | 5.4 |

TABLE 12

iso-Amylcyclohexane

| Boiling Range °F (°C) | % by Wt. | Hydrocarbon | Naphthenes | Olefins | Aromatics | Paraffins |
|-----------------------------|----------|--|------------|---------|-----------|-----------|
| | <0.1 | Hydrogen | - | - | - | 0.1 |
| Gaseous | 0.2 | Methane | - | - | - | 0.2 |
| | | 0.2 Ethane | | | | |
| 17.8% by wt. | 0.5 | 0.3 Ethylene | | 0.3 | | 0.2 |
| | | 2.6 Propane | | | | |
| | 3.6 | 1.0 Propylene | - | 1.0 | - | 2.6 |
| | | 1.4 n-Butane | | | | |
| Gasoline E.P. 385°(195°) | 13.4 | 11.2 iso-Butane | - | 0.8 | - | 12.6 |
| | | 0.8 Butylenes | | | | |
| | | 1.1 n-Pentane | | | | |
| | 9.8 | 8.0 iso-Pentane | - | 0.7 | - | 9.1 |
| | | 0.7 Pentenes | | | | |
| | | <0.1 n-Hexane | | | | |
| 35.6% by wt. | | 1.6 2-Methylpentane | | | | |
| | | 0.6 3-Methylpentane | | | | |
| | | 0.5 Dimethylbutanes | | | | |
| | 8.0 | 0.4 Hexenes (mainly branched) | 4.3 | 0.4 | 0.5 | 2.8 |
| | | 4.0 Methylcyclopentane | | | | |
| | | 0.3 Cyclohexane | | | | |
| | | 0.5 Benzene | | | | |
| | | 0.8 Heptanes | | | | |
| | | 0.5 Heptenes | | | | |
| | 11.5 | 5.8 Dimethylcyclopentanes | 8.8 | 0.6 | 1.4 | 0.8 |
| | | 3.0 Mixture of dimethyl- cyclopentane, methylcyclohexane, ethylcyclopentane | | | | |
| | | 1.4 Toluene | | | | |
| 338-363° (170-195°) | | 0.6 Octanes | | | | |
| | | 0.7 Octenes | | | | |
| | 6.7 | 1.7 Alkylated 5- and 6-ring naphthenes (230-284°F, 110-140°C) | 1.7 | 0.7 | 3.7 | 0.6 |
| | | 3.7 Xylenes (m+p), ethyl- benzene | | | | |
| | | 0.1 Nonenes | | | | |
| 368-388° (195-198°) | 2.6 | 0.2 Trimethylcyclohexanes | 0.2 | 0.1 | 2.3 | - |
| | | 2.3 Propylbenzenes, ethyltoluenes, trimethylbenzenes | | | | |
| | | 0.1 Olefins | | | | |
| 388-428° (198-220°) | 8.0 | 5.5 Naphthenes | 5.5 | 0.1 | 2.4 | - |
| | | 2.4 Aromatics | | | | |
| 428-572° (220-300°) | 17.3 | iso-Amylcyclohexane | 17.3 | - | - | - |
| 572-612° (300-330°) | 11.8 | mainly naphthenes | 9.2 | - | 2.6 | - |
| 612-652° (330-350°) | 3.3 | mainly aromatics (alkylated naphthalenes) | 0.7 | - | 2.6 | - |
| 652-692° (350-370°) | 1.1 | Aromatics | - | - | 1.1 | - |
| | 2.1 | Coke | | | | |
| Total | 100.0 | | 47.7 | 4.6 | 16.6 | 29.0 |

Dicyclohexyl
Cracked products, % by wt. of charge

| Boiling range °F (°C) | % by Wt. | Hydrocarbon | Naphthenes | Olefins | Aromatics | Paraffins |
|-------------------------------------|-------------------------------------|--|-------------|------------|-------------|-------------|
| | 0.1 | Hydrogen | - | - | - | 0.1 |
| Gaseous | 0.2 | Methane | - | - | - | 0.2 |
| | 0.5 | Ethane, traces ethylene | - | <0.1 | - | 0.4 |
| | 2.7 | Propane | - | - | - | - |
| 14.8% by wt. | 3.4 | 0.7 Propylene | - | 0.7 | - | 2.7 |
| | 1.9 | n-Butane | - | - | - | - |
| | 10.4 | 8.0 iso-Butane | - | 0.6 | - | 9.9 |
| Gasoline | 0.5 | Butylenes | - | - | - | - |
| | 0.3 | n-Pentane | - | - | - | - |
| | 5.3 | iso-Pentane | - | - | - | - |
| | 6.7 | 0.1 Pentenes | 1.0 | 0.1 | - | 5.6 |
| | 1.0 | Cyclopentane | - | - | - | - |
| | 0.7 | n-Hexane | - | - | - | - |
| E.P. 365° (185°) 57.7% by wt. | 2.2 | Methylpentanes (mainly 2-methyl) | - | - | - | - |
| | 0.7 | Dimethylbutanes | - | - | - | - |
| | 16.9 | 0.2 Hexenes | 12.1 | 0.2 | 1.0 | 3.6 |
| | 11.4 | Methylcyclopentane | - | - | - | - |
| | 0.7 | Cyclohexane | - | - | - | - |
| | 1.0 | Benzene | - | - | - | - |
| | 0.8 | Heptanes | - | - | - | - |
| | 0.4 | Heptenes | - | - | - | - |
| | 5.1 | Dimethylcyclopentanes | - | - | - | - |
| | 10.9 | 2.5 Mixture of 1,2-di- methylcyclopentane + ethylcyclopentane + methylcyclohexane | 7.6 | 0.4 | 2.1 | 0.8 |
| 2.1 | Toluene | - | - | - | - | |
| 12.9 | 0.7 | Octanes | - | - | - | - |
| | 0.3 | Octenes | - | - | - | - |
| | 5.3 | Alkylated 5- and 6-ring naphthenes (230-284°F, 110-140°C) | 5.3 | 0.3 | 6.6 | 0.7 |
| | 6.6 | Xylenes, mainly m+p, ethylbenzene | - | - | - | - |
| 10.3 | 0.4 | Olefins + paraffins (1:1) | - | - | - | - |
| | 1.3 | naphthenes (284-329°F, 140-165°C) | - | - | - | - |
| | 0.4 | naphthenes (329-365°F, 165-185°C) | 1.7 | 0.2 | 8.2 | 0.2 |
| | 6.6 | Aromatics (293-338°F, 145-170°C) mainly ethyltoluenes | - | - | - | - |
| 1.6 | Aromatics (338-365°F, 170-185°C) | - | - | - | - | |
| 365-445° (185-230°) | 10.4 | Mainly aromatics | 2.2 | 0.2 | 8.0 | - |
| 445-464° (230-240°) | 6.4 | Aromatics & Naphthenes | 3.2 | - | 3.2 | - |
| 464-500° (240-260°) | 3.0 | Mainly aromatics | 0.7 | - | 2.3 | - |
| 500-626° (260-330°) | 6.1 | " " | 1.3 | 0.2 | 4.6 | - |
| > 626°(330°) | 1.0 | Aromatics | - | - | 1.0 | - |
| | 0.8 | Coke | - | - | - | - |
| Total | 100.0 | | 35.1 | 2.9 | 37.0 | 24.2 |

Table 14

Dicyclohexylmethane
Cracked Products, % by wt. of charge

| Boiling Range OF. (°C) | % by wt. | Hydrocarbons | Naphthenes | Olefins | Aromatics | Paraffins |
|---|--|-------------------------|------------|---------|-----------|-----------|
| gaseous 14.0% by wt. | 0.1 | Hydrogen | - | - | - | 0.1 |
| | 0.1 | Methane | - | - | - | 0.1 |
| | 0.9 | 0.3 Ethane | - | 0.6 | - | 0.3 |
| | | 0.6 Ethylene | | | | |
| | 3.7 | 2.9 Propane | | 0.8 | - | 2.9 |
| | | 0.8 Propylene | | | | |
| 9.2 | 1.7 n-Butene | | - | 0.6 | - | 8.6 |
| | 6.9 iso-Butene | | | | | |
| | 0.6 Butylenes | | | | | |
| Gasoline E.P. 365°(185°) 60.6% by wt. | 6.2 | 5.1 iso-Pentane, traces | 0.8 | 0.3 | - | 5.1 |
| | | n-pentane | | | | |
| | | 0.3 Pentenes | | | | |
| | | 0.6 Cyclopentane | | | | |
| | 16.0 | 0.2 n-Hexane | 11.9 | 0.1 | 0.2 | 3.8 |
| | | 2.2 2-Methylpentane | | | | |
| | | 0.6 3-Methylpentane | | | | |
| | | 0.8 Dimethylbutane | | | | |
| | | 0.1 Hexenes | | | | |
| | | 11.1 Methylcyclopentane | | | | |
| 16.9 | 0.8 Cyclohexane | 14.1 | 0.3 | 1.4 | 1.1 | |
| | 0.2 Benzene | | | | | |
| | 1.1 Heptanes (mainly 1 branching) | | | | | |
| | 0.3 Heptenes (mainly branched) | | | | | |
| | 7.9 Dimethylcyclopentane Mixture of 1,2-dimethyl- cyclopentane + ethylcyclo- pentane + methylcyclo- hexane | | | | | |
| 1.4 Toluene | | | | | | |
| 10.1 | 0.2 Octanes (mainly branched) | 5.3 | 0.3 | 4.3 | 0.2 | |
| | 0.3 Octenes (" ") alkylated 5- and 6-ring naphthenes | | | | | |
| | 5.3 (mainly trimethylcyclo- pentane + dimethylcyclo- hexane) | | | | | |
| | 0.8 Ethylbenzene | | | | | |
| 3.5 Xylenes (about 80% m+p) | | | | | | |
| 11.4 | 0.1 Paraffins | 5.4 | 0.1 | 5.9 | Traces | |
| | 2.2 Naphthenes (284-338°F. (140-170°C.)) Mixture of propylbenzene, ethyltoluene, trimethyl- benzene | | | | | |
| | 4.7 | | | | | |
| | 3.2 Naphthenes (338-365°F. 170-185°C.)) | | | | | |
| 1.2 Aromatics | | | | | | |

Table 14

| | % by wt. | Hydrocarbons | Naphthenes | Olefins | Aromatics | Paraffins |
|--------------------|--------------|--|-------------|------------|-------------|-------------|
| 365-455°(185-235°) | 9.8 | Mixture of aromatics, paraffins and naphthenes | 1.7 | Traces | 3.1 | 5.0 |
| 455-482°(235-250°) | 7.4 | Naphthenes + Aromatics | 4.8 | - | 2.6 | - |
| 482-527°(250-275°) | 2.2 | Mainly aromatics | 0.4 | - | 1.8 | - |
| > 527°(275°) | 4.0 | Aromatics | - | - | 4.0 | - |
| | 2.0 | Coke | | | | |
| Total | 100.0 | | 44.4 | 3.1 | 23.3 | 27.2 |

Table 15

Decalin

Cracking Products, % by wt. of charge

| Boiling Range OF. (°C) | % by wt. | Hydrocarbon | Paraffins Olefins | Aromatics | Naphthenes |
|-----------------------------|----------|--|----------------------|-----------|------------|
| gaseous | 1.0 | Hydrogen, methane, ethane, ethylene | 1.0 | - | - |
| 16.5% by wt. | 2.5 | Propane, propylene | 2.5 | - | - |
| | 13.0 | 2.0 n-Butane + butylenes 11.0 iso-Butane + butylenes | 13.0 | - | - |
| Gasoline E.P. 365°(185°) | 6.1 | Pentane + Pentenes | 6.1 | - | - |
| 40.7% by wt. | 11.7 | 2.2 Hexanes (mainly 2-methylpentane) 8.4 Methylcyclopentane 0.6 Cyclohexane 0.5 Benzene | 2.2 | 0.5 | 9.0 |
| | 6.9 | 0.4 Heptanes 2.7 Dimethylcyclopentane Mixture of dimethylcyclo- 1.2 pentane + methylcyclohexane + ethylcyclopentane 2.6 Toluene | 0.4 | 2.6 | 3.9 |
| | 10.3 | 4.9 Naphthenes (230-320°F.(110-160°C)) 3.0 Xylenes (about 90% m+p), little ethylbenzene 2.4 Aromatics (293-329°F.(145-165°C)) | - | 5.4 | 4.9 |
| | 0.6 | Olefins (C ₆ - C ₁₀) | 0.6 | - | - |
| 329-365°(165-185°) | 5.1 | mainly naphthene | - | 1.9 | 3.2 |
| 365-374°(185-190°) | 24.3 | Decalin | - | - | 24.3 |
| 374-446°(190-230°) | 13.3 | Aromatics | - | 13.3 | - |
| | 1.3 | Naphthalene | - | 1.3 | - |
| > 446°(230°) | 2.5 | Aromatics | - | 2.5 | - |
| | 1.4 | Coke | - | - | - |
| Total | 100.0 | | 25.8 | 27.5 | 45.3 |