

THE MANUFACTURE OF AVIATION GASOLINE IN GERMANY

Report prepared by
U.S. NAVAL TECHNICAL MISSION IN EUROPE

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SUMMARY

This report records information obtained by technical investigators on the quantity, quality, composition, and manufacture of German aviation gasolines during the past war years.

Figures for the quantities of components and finished gasolines produced are presented and analyzed. The qualities and compositions of the different grades are shown and discussed.

The methods and plants used in Germany for synthesizing isoparaffins, for manufacturing base stocks, and for synthesizing aromatics are described. Process and operating data are given for these operations, particularly where the practice is new or different from that used in the United States.

The synthesis of nitration grade toluene is described in an appendix.

July 1945

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NOTE

All documents listed in this Report are contained in T.O.M. reel No. 138, which is available at the Technical Information & Documents Unit, German Division, Board of Trade, 40 Cadogan Square, London, S.W.1.

Applications to inspect should quote the "F.D." number where mentioned.

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1. Introduction.

It was well known that Germany had always depended largely on synthetic operations for her liquid fuel supply. As the air force of that nation grew and developed, and its fuel requirements increased both in quantity and quality, it was correctly concluded that synthetic oil plants had kept pace with the aircraft development and continued to be the main source of fuel supply.

The ever increasing quality of aviation gasoline used by the Allies was paralleled by that of the German supply. The many new processes applied in America for manufacturing high quality gasolines were well understood by the Germans. They obtained information through Allied technical publications, through analysis of gasoline from captured planes, and otherwise. At the same time, German research in great force was supplying new processes, many the same as those being developed by the Allies, to their own operations. Toward the end of the war the quality of fuel being used by the German fighter planes was quite similar to that being used by the Allies

In entering Germany to study their manufacture of aviation gasoline, it was to be expected therefore that many processes and developments would be found that were the same as those in use in America. Also, from examination of the gasoline in captured enemy planes, it was believed that no radically new compounds were being synthesized by the enemy. It could be anticipated, however, that new manufacturing techniques and technology might be found, that new designs in engineering might be seen, or that new or better catalysts might be in use in the various synthetic processes.

In the course of the technical survey being reported herein, most of the plants that manufactured aviation gasoline components were visited. Many industrial and government technical people were interrogated. A great variety and volume of technical and operating documents were obtained and studied.

In the following sections are discussed the overall German position on supply of aviation gasoline, and there are described the plants and processes producing the isoparaffin, base stock, and

aromatic components. Some of the newer research work is described. The manufacture of nitration grade toluene is also reported, because its production was rather closely related to the aviation gasoline systems.

2. Supply and Composition of Aviation Gasolines.

(a) Supply and Sources.

The German aviation gasoline volume came very largely from the synthetic oil plants that hydrogenated coals and coal tars. A very small volume only came from petroleum, while essentially none came from the Fischer-Tropsch plants. Some components in small volume came from various chemical plants.

Parallel to the situation in the United States, great efforts were put forth continually in Germany to increase the supply of aviation gasoline. Much of the new construction was never completed due firstly to Allied bombing and then to termination of the war.

In Table I is given a partial breakdown of the sources and volumes of supply of aviation gasolines and their components.

TABLE I.

Sources and Supply of German Aviation Gasoline. (All figures are barrels per day)

<u>Company and Location</u>	<u>Total Aviation Components</u>	<u>Base Stocks & Aromatics</u>	<u>Synthetic Isoparaffins</u>
I.G. - Leuna	6,900	5,500	1,400
Brabag - Böhlen	4,100	4,100	-----
Brabag - Magdeburg	2,750	2,750	-----
Hibernia - Scholven	5,800	4,400	1,400
Gelsenberg - Gelsenkirchen	8,000	8,000	-----
Pöhlitz A.G. - Pöhlitz	13,900	12,400	1,500
Rheinbraun - Wesseling	2,750	2,750	-----
Ruhröl - Welheim	1,100	1,100	-----
Sudetendeutsche - Brüx	5,500	5,500	-----

TABLE I (Continued)

<u>Company and Location</u>	<u>Total Aviation Components</u>	<u>Base Stocks & Aromatics</u>	<u>Synthetic Isoparaffins</u>
I.G. - Oppau	1,200	1,100	100
I.G. - Heydebek	600	300	300
I.G. - Moosbierbaum	2,000	2,000	---
I.G. - H ^u ls	200	200	---
I.G. - Schopau	200	200	---
Total from above-listed Plants.	55,000	50,300	4,700
Aromatic Oils from Coal Tar	1,100	1,100	---
Grand Total	56,100	51,400	4,700

The volume figures given in Table I represent the highest production level in 1943 before bomb damage interfered greatly with production. (The highest production for an entire month was in 1943, and the average daily volume during that month was 52,200 barrels.) At that time, when the maximum daily production of total aviation gasoline was about 56,000 barrels, there was under construction, or being developed, extensions to increase that figure to nearly 100,000 barrels. (It is interesting to note that at the time the aviation gasoline production reached the figure of 56,000 barrels per day, the total German motor gasoline production was 55,000 barrels per day.)

(b) Composition and Specifications.

There were two grades of aviation gasoline produced in volume in Germany, one the B-4 or blue grade, and the other the C-3 or green grade. Both grades were leaded with the equivalent of 4.35 cubic centimeters tetraethyl lead per gallon. The B-4 grade was simply a fraction of the gasoline product from coal and coal tar hydrogenation. It contained normally 10 to 15 percent volume aromatics, 45 percent volume naphthenes, and the remainder paraffins. The octane number was 89 by a measurement corresponding to the C.F.R.

motor method. The C-3 grade was a mixture of 10 to 15 percent volume of synthetic isoparaffins (alkylates and isooctanes) and 85 percent of an aromatized base stock produced by hydroforming types of operation on coal and coal tar hydrogenation gasolines. The C-3 grade was permitted to contain not more than 45 percent volume aromatics. This aromatic limitation sometimes required that the base stock component include some diluent other than the aromatic fraction, which could then be balanced if necessary by the inclusion of slightly more isoparaffin. (The C-3 grade corresponded roughly to the U. S. grade 130 gasoline, although the octane number of C-3 was specified to be only 95 and its lean mixture performance was somewhat poorer.)

The components of the two grades were therefore simple and few in number. The isoparaffins were produced by standard, well known methods and there was nothing abnormal found in their compositions. The base stocks were fractionated to end points of 300 to 320 degrees fahrenheit. No normal isopentane separation was carried out, and the pentane and butane contents were adjusted simply for vapor pressure control. Small amounts of specially synthesized aromatic compounds were included from time to time, but no regular large scale use of such materials was practiced. No aromatic amines or other special additives were used.

Oxidation inhibitors were not used in the regular blended aviation gasolines. It will be seen that the components were in general of such nature that oxidation inhibition should not have been necessary. Lead deposition from fuels was an operating problem, however, but no inhibitors were used for its prevention. This "lead instability" was believed to be related to aromatic content, and fear of lead deposits was a reason for the limitation of the aromatic contents of the two grades.

The relative volumes of production of the two grades cannot be accurately given, but in the last war years the major volume, perhaps two-thirds of the total, was the C-3 grade. Every effort was being made toward the end of the war to increase isoparaffin production so that C-3 volume could be increased for fighter plane use. The isoparaffin usage in that grade had already been cut to a minimum.

In Table II are given the important RLM (Reichs Luftfahrtministerium) specifications for aviation gasolines supplied to the Air

Ministry. The complete specification sheet is appended. On that RLM sheet are also given specifications for aircraft diesel fuel. (The subject of diesel fuel manufacture in Germany is covered by B.I.O.S. MISCELLANEOUS REPORT NO. 71, entitled "German Diesel Fuels.")

TABLE II.

RLM Specifications for B-4 and C-3 Gasolines.

	<u>Blue Grade</u> <u>B-4</u>	<u>Green Grade</u> <u>C-3</u>
Density at 59°F.	0.710 - 0.760	0.760 - 0.795
Distillation °F., IBP	104 min.	104 min.
10 percent	167 max.	176 max.
50 percent	221 max.	230 max.
90 percent	320 max.	320 max.
E.P.	338 max.	356 max.
Recovery, percent volume	98 min.	98 min.
Reid Vapor Pressure lbs.	7.0 max.	6.3 max.
Aromatic Content, percent volume	25 max.	45 max.
Tetraethyl Lead Content, percent volume	0.115 - 0.120	0.115 - 0.120
Ethylene Dibromide Content, percent volume	0.050 - 0.053	0.050 - 0.053
Melting Point, °F	-76 max.	-76 max.
Leaded Octane Number (Motor Method)	89 min.	95 min.

Note--The mixture response curve for each gasoline shall at least equal that of a standard reference fuel, supplied by the R.L.M., at all air-fuel ratios between 0.75 and 1.3. The following document transmitted to the Bureau of Ships relates to specifications:

- I. Technische Lieferbedingungen für die Flugmotoren-Frontkraftstoffe. (RLM specifications for aviation gasolines).

(c) Engine Testing.

The anti-knock performance of aircraft fuels was evaluated in two different manners: by the octane number, using a test very similar to the C.F.R. Motor Method, and by a mixture response curve. The specifications of B-4 and C-3 fuels include both octane number and the mixture response curves.

Octane number was measured on the one-cylinder "I.G. Prüfmotor". The technical data for this engine are as follows:

Bore	65 mm.
Stroke	100 mm.
Volume	332 cc.
Power Output at 900 rpm.	0.7 kw.
Consumption at 900 rpm.	600 cc. per hour
Compression Ratio	4.0 to 15.0
Inlet valve clearance (cold)	0.20
Inlet valve opens	11° after top center
Inlet valve closes	173° " " "
Outlet valve clearance (cold)	0.25
Outlet valve opens	173° after top center
Outlet valve closes	3° before top center

The values obtained with this I.G. test engine agree quite closely with those obtained on the C.F.R. engine. All values given herein for octane numbers, motor method, were determined on I.G. engines. The test conditions for measurement of aviation fuels were as follows:

Speed	900 rpm.
Cooling Medium	Glycol and Water
Cooling Medium Temperature	300°F.
Inlet Temperature of Fuel-air mixture	300°F.
Ignition	22° before top center
Compression Ratio	Start of "medium heavy" knocking

The mixture-response curves of aircraft fuels were measured on a B.M.W. (Bayerische Motorenwerke) 132-F single cylinder engine. Liquid injection was employed and the following test conditions were used:

Speed	1600 rpm.
Compression Ratio	6.5
Cooling air temperature	77°F.
Cooling air pressure	200 mm H ₂ O
Begin Liquid Injection	26° to 30° after top center
Injection Pressure	60 atmospheres
Inlet air temperature	175° and 265°F.
Ignition	Highest power output at air to fuel ratios of 0.7, 0.9, 1.3 without knock- ing.
Air to Fuel Ratio	0.7 to 1.3
Measurement of knock	Audible

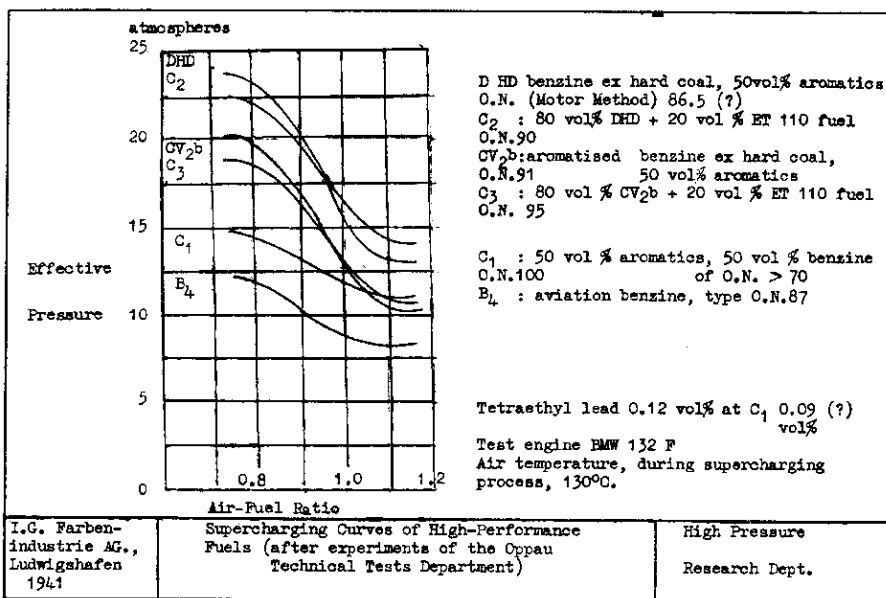
There are attached on the following page two small photographs which give several comparable mixture response values and plots for different components and fuels.

The first is a plot of air-fuel ratio (abscissa) against "useful" pressure in atmospheres. The B-4 and C-3 fuels are shown thereon (MOZ is motor method octane number).

The second is a table with a title meaning "Mixture-Response Power Outputs for Aromatic Fuels" showing relative power outputs of several components at air-fuel ratios of 0.9 and 1.1, and also their motor method and research method octane numbers. The top group is for mixtures of 50 percent volume of 73 octane number (unleaded) coal hydrogenation gasoline, leaded with 4.35 cc. tetraethyl lead per gallon, and 50 percent volume of each of the components listed, also leaded. The lower group is of well known materials for comparison. (Fliegerbenzol is aircraft fuel; Dehydrier means "from dehydrogenation process"; Aromatisierungs means "produced by a process yielding high aromatic contents.")

The composition of C-3, with a high aromatic content, resulted in that gasoline having a good rich mixture (less than 1.0) performance. Its performance, i.e., allowable power output, at lean mixture was not entirely satisfactory, however. If more isoparaffin had been included, the lean mixture performance would have been

* These photographs are unsuitable for reproduction, but versions (in English) are given.



Performance of Aromatic Fuels

due to supercharging

(Performance with ethyl propyl benzol at $\lambda = 0.9$ taken as 100%)

Mixture of 50 vol% benzine from hydrogenation ex hard coal, O.N. 73, plus 0.12 vol % Pb, with	% performance at air excess index of		octane number	
	$\lambda = 0.9$	$\lambda = 1.1$	Motor Method	Research Method
ethyl propyl benzol	100	71	99	110
di-ethyl benzol	95	67	97	107
aviation fuel	81	60	94	104
aromatics from dehydrogenation 150-175°C	80	59	93	103
aromatics from dehydrogenation, 175-200°C	77	55	92	101
iso-octane	60	52	100	101
For comparison: known high-performance fuels:				
Aviation benzine ex hard coal, (0.09 vol % Pb)	44	33	88	91
motor fuel, O.N. 100 containing about 50 vol % isoparaffins (0.09 vol % Pb)	56	49	101	104
aromatised benzine ex hard coal (300 atmospheres pressure) (0.12 vol % Pb)	64	50	90	100
aromatised benzine ex pitch (700 atmospheres pressure) 0.12 vol % Pb)	80	59	93	103
iso-octane pure (0.09 vol % Pb)	72	67	114	115

improved. This was recognized as the outstanding shortcoming in the German aviation fuel quality position. Had raw materials and equipment been available, more isoparaffins would have been included in the C-1 blend. As isoparaffin content increased, the aromatic content could simultaneously have been decreased (by use of base stocks with octane numbers equal to those of the aromatic base stocks) and a gasoline with increased heat content would have resulted. However, because of the relatively greater ease of manufacturing aromatics, they were used in large quantity to help gain a satisfactory lean mixture performance, with the result that rich mixture performance was not limiting.

(d) Safety Aviation Fuels.

A note should be made regarding the development of safety aviation fuels. The Germans were quite aware of the desirability of safety fuels. Tests had been made with 390 to 660 degrees fahrenheit fractions of coal and coal tar hydrogenation products, but no full scale use of such materials was being made.

Some tests had been made to relate flash point and boiling range of a safety fuel to its resistance to ignition by incendiary bullets. It was concluded from this work that for a safety fuel to be effective, the flash point must exceed 200 degrees fahrenheit and should be in the region of 300 degrees fahrenheit.

3. Specifications and Supply of Jet Fuels.

The requirements for jet fuels in Germany were increasing rapidly at the end of the war. The 1944 consumption was 650 barrels per day, and it was planned to increase that figure to 3,250 barrels per day in 1945. While that consumption apparently never was reached, the demands had become appreciable in terms of Germany's available supply of liquid fuels.

Mixtures of gasoline and diesel oil fractions were used as fuel in 1944, but with increasing requirements efforts were being made to use higher boiling fractions only in order to release all gasoline for other critical uses. Tests were in progress using materials from the sump phase and pre-hydrogenation steps in coal hydrogenation.

The tests had shown that only a low aromatic content could be tolerated if clean burning was to be obtained, and it was also concluded that some gasoline was necessary in order to obtain satisfactory ignition.

The status toward the end of the war was that gasoline-rich mixtures were still being used with the higher boiling diluents being any available material such that the blend met the following specifications:

(1) Viscosity maximum 12 centistokes at -31 degrees fahrenheit (or maximum 22 centistokes at -4 degrees fahrenheit). The viscosity specification was to insure flow through the fuel pump and good distribution in the fuel jets.

(2) Pour point maximum -31 degrees fahrenheit. (It was stated in another instance that in practice the maximum pour point was -40 degrees fahrenheit and that no crystal appearance could occur above -13 degrees fahrenheit). In a flight of one to one and one-half hours, such as is experienced with jet fighters, the contents of the fuel tank can reach a temperature as low as -31 degrees fahrenheit. For long distance flights it was believed that the pour point specification would have to be lowered to -56 degrees fahrenheit.

(3) The fuel shall burn without carbon formation. Aromatic oils deposit carbon in the combustion chamber and the turbine. Paraffinic oils are clean burning and therefore desired for jet fuels. It was the opinion in Germany that the chemical character (and hence burning quality) of the fuel was of more importance than such properties as boiling range.

(4) Heating value minimum 18,000 BTU per pound.

(5) Sulfur content maximum 1.0 percent weight.

4. Synthesis of Isoparaffins.

Isoparaffins were synthesized commercially in Germany by two processes; isobutylene polymerization followed by hydrogenation of the polymer, and by alkylation of butylenes and isobutane. Of the two processes, alkylation was much the more important from the stand-

point of volume produced. Both of the above processes have been highly developed in America, and the German applications were not more highly developed than present practice elsewhere. They are described below, however, together with the methods by which their raw materials are produced.

The production of isoparaffins other than those obtained from the two commercial processes was given extensive study. The synthesis of triptane was studied and a process was designed from this work, although triptane itself is not the end product. This development is described below.

The isomerization of normal butane was being carried out commercially to supply isobutane to alkylation. The commercial process used is described in this section together with some new research on the isomerization of normal C₆ and C₇ paraffins.

(a) Isobutylene Polymerization and Polymer Hydrogenation.

This process for isooctane manufacture was employed at Leuna Ludwigshafen-Oppau, and Heydebrek.

Isobutyl alcohol was synthesized directly from CO and H₂ by the "Isobutyl Synthese" (described in B.I.O.S. MISCELLANEOUS REPORT NO. 60 titled "Synthesis of Hydrocarbons and Chemicals from Mixtures of CO and H₂"). The alcohol was dehydrated to isobutylene over precipitated alumina at 630 to 680 degrees fahrenheit and normal pressure. In this temperature interval a 95 percent conversion of alcohol to olefin was obtained, with a small accompanying yield of isobutyraldehyde. A one pass operation was therefore employed. Isobutyraldehyde and water were separated from the isobutylene by simple distillation. The aldehyde was hydrogenated to alcohol and recycled back to dehydration feed.

Isobutylene from the alcohol dehydration was compressed to 20 atmospheres, heated to 300 to 350 degrees fahrenheit and polymerized over a catalyst of 25 percent phosphoric acid on activated carbon. Unpolymerized isobutylene was separated and recycled, and combined dimers and trimers were taken overhead in a second column, leaving only a small amount of high boiling polymers as bottoms. The dimer-trimer mixture was then hydrogenated under 200 atmospheres of

hydrogen pressure at 660 degrees fahrenheit, using a tungsten nickel-sulfide catalyst. A hydrogen recycle of four to one based on fresh hydrogen was employed.

The hydrogenated fraction, known as ET 110 or Di 1000, had the following properties:

Density at 59° F.	0.710
Distillation, ° F, IBP	176
Distillation 10 percent	214
Distillation 50 percent	217
Distillation 90 percent	230
Distillation EP	385
Octane Number (Motor Method)	
Unleaded	98
Octane Number with 4.35 cc.	
Tetraethyl Lead/gallon 115.	

Before the advent of the alkylation process, isobutylene was being produced by isobutane dehydrogenation at Leuna, Pölitz, and Scholven. Polymerization and polymer hydrogenation systems were used to convert this isobutylene to T-52, a product nearly identical to ET 110. The processing of the isobutylene to T-52 differed from the ET 110 system only in that, due to slightly different feed composition, the polymerization catalyst in the T 52 process was 50 percent phosphoric acid on asbestor instead of the 25 percent phosphoric acid on active carbon catalyst in the ET 110 system.

The following document, transmitted to the Bureau of Ships, relates to this process:

II. Herstellung von Di. 1000.
(Flow diagram of the Di 1000
or ET 110 process)

(b) Alkylation.

Although research and development work on alkylation was started in Germany prior to 1940, the commercial production of alkylate did not begin until 1943. Prior to that time, Leuna, Politz, and Scholven had

been producing isobutylene by isobutane dehydrogenation, and those dehydrogenation plants were then shifted to normal butane feed.

In early 1944, these three plants were still the only operating alkylation units, but plants were being constructed in Wesseling, Brux, Bohlen, and Blechhammer. Had these plants all been completed and put into operation, Germany's alkylate output would have risen about 50 percent above her actual attained production.

Normal butane dehydrogenation and isomerization processes were both in use in Germany. Appendix I to this report describes dehydrogenation, and the general subject of isomerization is discussed later.

Only butylene alkylation was practiced in Germany. By the application of the processes of dehydrogenation, isomerization, and alkylation, C_4 components from the large coal and coal tar hydrogenation plants could be totally converted to butylene alkylate. (Some C_4 fraction was still being used as liquefied gas, but nearly all of the large hydrogenation plant C_4 output was to have gone ultimately into alkylates).

No propylene or amylene alkylation was carried out commercially. While these operations had been completely explored in the laboratory, it was not considered worthwhile to dehydrogenate propane, for example, to supply an additional olefin to alkylation and thereby increase the volume of alkylate at a sacrifice in quality. In calculating the optimum position on isoparaffin production, the most stress was placed on lean mixture performance rating. Rich mixture performance was at a lower premium apparently because of the relatively greater availability of aromatics and aromatizing capacity.

The alkylation plants varied in a few respects only from those in common use in America. Refrigeration of the reactor was accomplished by evaporating C_4 from the surface, compressing and liquefying, and returning the liquid to feed. The reactor itself was sometimes a stirred autoclave with no external recycle of reactor hydrocarbon phase being practiced. Only pure isobutane, prepared from reactor product through a series of columns, was then used for recycle to build up the isobutane to olefin ratio.

In other plants, however, a reactor system was used which consisted of a mixing and cooling vessel, where vapor was withdrawn to the refrigerating cycle, a circulating pump, and a time tank. Emulsion was recycled, and a portion of the emulsion was withdrawn to a settling vessel, from which acid was recycled back to the mixing vessel.

The important operating variables and yield figures for a butylene plant employing the last described reactor system are summarized in Table III. Triisobutylene from ET 110 plants was used for alkylation feed when available, and the alkylate yield and quality were about equal to those obtained when using the equivalent amount of isobutylene.

Regeneration of spent sulfuric acid from alkylation was practiced in at least one location (Leuna). In that plant, alkylation acid was diluted to ca. 50 percent concentration, the liberated oil (tar) layer was separated off, and the acid was reconcentrated in a "Pauling Kessel" to 93 or 94 percent acid. It was then fortified with SO_2 to 98 percent concentration.

The following documents, transmitted to the Bureau of Ships, relate to alkylation:

III. Herstellung hochklopfester
isoparaffinischer Treibstoffe durch
Alkylierung aliphatischer Kohlenwasserstoffe.

(I.G. Leuna - Dr. Pohl II report of 6 Jan. 1943)

IV. Alkylierung - Anlage-Leuna

(I.G. Leuna - flow diagram of Alkylation Plant)

V. Alkylierung und Destillation

(I.G. Leuna - report by Dr. Strätz of about
April 1944)

order to obtain a 40 percent conversion per pass (disappearance from the original boiling range) of a 340 to 660 degrees fahrenheit Fischer-Tropsch fraction. Of the converted feed material, 75 percent appeared as C₃, C₄ and C₅ fractions, of which about 90 percent were olefins. Gasoline was only 15 percent of the converted yield.

By employing a recycle, a 75 percent weight ultimate yield of usable materials could be realized.

The process was to be discontinuous, with catalyst regeneration after operating cycles of 20 to 25 minutes. The carbon yield was estimated to be 1.5 percent weight of reactor feed.

In Table VII is given a set of yield and product composition data characteristic of this operation. A copy of a report by Ruhrchemie, which describes quite completely the development of the process and its planned application, was forwarded to the Bureau of Ships:

XXII. Herstellung von Isogasolen
und Flugbenzin aus Syntheseprodukten.

(Ruhrchemie report by Dr.
Kolling in January 1943)

TABLE VII

Yield and Product Composition Data - Ruhrchemie Catalytic Cracking.

Feed to process is Fischer-Tropsch fraction of 340 to 660 degrees fahrenheit boiling range.

Yields of Components,
Percent wt. of Feed

Total Conversion	40 percent wt. of feed
Gasoline (C ₆ to ca. 320° F.)	6-8
C ₅ Fraction	7.6-9.6
C ₄ Fraction	10-12
C ₃ Fraction	8-10
C ₂ Fraction	2-2.8
Methane & Hydrogen	0.4-0.8
Coke	1.2-1.6

TABLE VII. (Continued)

Yield and Product Composition Data - Ruhrchemie Catalytic Cracking.Olefin Contents, percent volume

C ₅ Fraction	85-90
C ₄ "	90-95
C ₃ "	90-95
C ₂ "	60-65

Iso-Contents, percent volume

C ₅ Paraffins	60-65
C ₅ Olefins	45-50
C ₄ Paraffins	60-65
C ₄ Olefins	38-43

*6. Conclusions.

(a) The maximum rate of production of total aviation gasolines achieved by Germany during the war was roughly 50,000 barrels per day, of which essentially the entire volume came from coal and coal tar hydrogenation plants. Of this total volume of liquid, about 10 percent was synthetic isoparaffins, 40 percent was high aromatic content base stocks produced by processing of hydrogenation plant gasolines, and the remaining 50 percent was almost entirely hydrogenation plant gasolines of aviation gasoline endpoint and volatility.

(b) Two grades of aviation gasoline were produced, one with a motor method octane number of 91, and the other of 95. The former, labeled B-4 (blue) contained about 10 percent volume aromatics, while the latter, known as C-3 (green), contained about 40 percent volume aromatics and would thus allow much higher power output under rich mixture conditions. Both grades contained 4.35 cc. tetra-ethyl lead per gallon (American). The 50 percent distilled specifications were 221 and 230 degrees fahrenheit, for B-4 and C-3, respectively.

(c) The B-4 grade was produced directly by the addition of tetra-ethyl lead to the entire liquid product from the large coal and coal tar hydrogenation plants. The volatility was adjusted to about 7 pounds Reid vapor pressure by stabilizing and no further refining or blending

was done.

(d) The C-3 grade was a leaded blend of about 15 percent volume of synthetic isoparaffins and 85 percent volume of a base stock containing 45 to 50 percent volume aromatics, produced by further processing of a hydrogenated gasoline almost identical to unleaded B-4. The C-3 grade represented at least two-thirds of the combined volume of the two grades.

(e) Small amounts of synthetic aromatic compounds such as diethyl benzene, were used as components, but with unimportant exceptions, no additives or components other than those mentioned above were included in the commercial blends. No inhibitors of any kind were normally used

(f) Had raw materials and manufacturing facilities been available, more isoparaffins would have been produced to improve the lean mixture performance of both grades and, ultimately, to allow a decrease in the aromatic content of the C-3 grade. The rich mixture performance of the gasolines was satisfactory for the engines being built and used.

(g) Synthetic isoparaffins were manufactured primarily by the alkylation of butylenes and isobutane. Some isobutylene polymerization and polymer hydrogenation was being carried out. No propylene or amylene alkylation was being done. No triptane synthesis had been developed, and no isoparaffin syntheses other than those mentioned above were being used.

(h) Isobutylene for polymerization was made by dehydrogenation of isobutyl alcohol which was synthesized directly from carbon monoxide and hydrogen. Normal butylene for alkylation was produced by catalytic dehydrogenation of normal butane produced by the coal and tar hydrogenation plants. Isobutane for alkylation came in part directly from the hydrogenation plants and in part by catalytic isomerization of some of the normal butane.

(i) To produce the bulk of high aromatic content base stock used in C-3, a process known as DHD was employed. This process produced aromatics both by dehydrogenation of naphthenes and by cyclization of paraffins. Hydroforming was used at one refinery to produce base stock, of quality eligible for use in C-3 grade, from Austrian and Roumanian crude oil fractions.

(j) No catalytic cracking units existed in the German area, but the process had been studied and two plants installations were being planned. It is generally agreed that catalytic cracking of the type employed today in America will not find wide application in the synthetic oil industry. It was of interest to Germany only as a wartime means of producing aviation gasoline. The units being planned were similar in general design to a FCC unit and were to use a synthetic silica-alumina catalyst.

(k) Some new processes developed in Germany during the war years but which were not in commercial operation included:

(1) A specific and efficient catalytic process for dealkylating aromatics;

(2) A catalytic cracking process for normal paraffins boiling in the kerosene range, producing primarily C₃, C₄ and C₅ olefins;

(3) A catalytic process for producing an ultimate weight yield of 70 to 78 percent of toluene from normal heptane, and

(4) A process for producing high quality gasoline isoparaffins by combining propane and isobutane via chlorination.

(1) Jet fuels were being produced in Germany at a rate of ca. 1,000 barrels per day in 1944. The fuel was a mixture of gasoline and diesel oil fractions. The specifications for jet fuel were lenient; no unusual quality was demanded and no unusual specifications were forthcoming.

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