

**Early Efforts to Upgrade Fischer-Tropsch Reaction Products into Fuels, Lubricants,
and Useful Materials**

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Historical Development of the Fischer-Tropsch Synthesis/Process – III

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Introduction

There is a significant amount of information available on early efforts to convert carbonaceous deposits into useful products by the Fischer-Tropsch process. Most of the discussions in the literature center on the F-T process itself, and less has been written on the upgrading of F-T hydrocarbons into fuels, lubricants and other useful chemicals. This paper addresses some of the processes used to produce fuels, lubricants and chemicals from F-T reactors, covering the war years and shortly thereafter. Documents acquired from Germany after the war as well as available patent literature have been reviewed for this discussion. Due to the large volume of material available, only selected topics are discussed here.

The primary focus of the German synthetic fuels industry was production of high octane gasoline for the Luftwaffe followed by gasoline for vehicles and diesel for heavy equipment and ships. Jet fuel was also produced later in the war years. The Luftwaffe insisted on high aromatic content aviation gasoline for the increased energy density and high octane rating under rich conditions. This precluded the use of FT products directly, but indirect methods were used to make high octane gasoline fuels. However, F-T products represented about 9% of the total German production capacity during the war.¹

Many other products were produced from Fischer-Tropsch reactors under both low and high pressure conditions. Alcohols, aldehydes, ketones, aromatics, and olefins were obtained from the reactors. F-T waxes were further processed into soap and edible fats as well. Interestingly, as demand for high octane aircraft fuel increased (or supply decreased due to war damage), significant amounts of this chemical production was redirected to fuels.

After the war, oil companies feared decreasing crude oil supplies would threaten their business. Seeking alternative crude sources they looked at F-T processes and methods to upgrade F-T products into fuels and lubricants. Discovery of large deposits of crude oil in the Middle East obviated this need for F-T technology for many years.

German Fischer-Tropsch Plants

Two types of cobalt F-T plants were operated in Germany, low and medium pressure. Some plants operated only low pressure reactors, some only medium pressure and some both.² Table 1 lists the locations and processes used and Table 1a lists typical yields for each process. Direct products from these plants were light hydrocarbons (Gasol), gasoline, diesel oil, and wax (Gatsch). Conversions varied from plant to plant and from process to process. Both Cobalt and Iron catalysts were used. Due to the demand for cobalt for steel manufacture, significant effort was put into converting plants to iron catalysts.

LP gasol (C₃-C₄) contained 50-55% olefins, and MP gasol contained 25-30% olefins; the majority of the butane was linear. These gaseous products were either converted to gasoline by condensation reactions or bottled for use directly as fuel.

Table 1.
Distribution of Low Pressure and Medium Pressure F-T plants in Germany²

Name of Plant	LP Operation T/Year	Mp Operation T/Year	Total T/Year
Ruhrchemie	18,088	44,545	62,633
Viktor	37,699		37,699
Rheinpreussen	67,212		67,212
Krupp*	48,330	11,857	60,187
Hoesch		46,044	46,044
Brabag	164,606		164,605
Essener	79,974		79,974
Schaffgotsch		26,374	26,374
Wintershall	11,468		11,468
TOTAL:	427,377	128,820	556,197
%	76.8%	23.2%	100.00%

* In this plant the first stage operated at low pressure; second stage at medium pressure.

Table 1a
Typical Yields from LP and MP F-T Processes

Product	LP F-T, wt%	MP F-T wt% (% Olefins)
Gasol (C ₃ -C ₄)	10	10 (40)
Gasoline(Benzin)	52.2	25 (24)
Diesel (Kogasin)	26.5	30 (9)
Soft Paraffin Wax	7.6	20
Hard Paraffin Wax	3.7	15

Gasolines obtained from LP and MP F-T processes had the following properties:

For 150° C EP gasolines	<u>LP</u>	<u>MP</u>
Olefin content	33%	19%
Octane No. (Res.)	57	38
200° C EP gasolines		
Octane No. (Res.)	43	25

Diesel fuel obtained directly from F-T processes were called “Kogasin” and distilled between 150 and 325°C. Due to the high olefin content, this cut was often used for further synthesis. Production of diesel fuel involved blending with coal-derived liquids of low cetane value. The 90-100 cetane F-T products nicely upgraded 20-25 cetane coal oils to 40-45 cetane fuel oil.

The F-T process was considered to be about 20% more expensive to operate than direct coal hydrogenation. However, the products were unique and highly useful in chemical synthesis besides their value in upgrading the diesel fraction obtained from coal processing.³

Gasoline Synthesis from F-T Feedstocks

Most gasoline was obtained from hydrogenation of coal, coal tars and the like. This yielded high octane aromatics as the primary product. Specifications for gasolines are shown in Table 2. There still existed a need for high octane paraffinic blend components to reduce deposit formation and improve ignitability. Primary F-T reactor

Table 2
Selected Specifications for German Gasoline (Otto) Engine Fuels⁴

Specification	Gasoline w/TEL	Gasoline w/ Aromatics + TEL	Gasoline w/Aromatics
Density	0.720-0.780	0.740-0.780	0.753-0.780
Octane (Motor)	72	72	72
95% Point	200 °C	200°C	200°C
Cloud Point	-20°C	-20°C	20°C
Heat Value, cal/liter	7500	7650	7700
TEL, vol. %	0.04	0.04	0

products have poor octane due to their linear nature. Octane values for the fraction boiling below 200°C were generally below 40.⁵ Cobalt-based F-T processes usually produced 10% isobutene with isomer content increasing to 20% in the C₈ fraction, with the C₁₆ fraction being all mono-methyl branched compounds. Iron-based processes produced somewhat higher isomer content, up to 20% in the C₈ fraction. Efforts to upgrade the octane by isomerization and other chemical means were attempted, but the best approach was conversion of F-T products to butene, especially isobutene, followed by alkylation to iso-octanes and the like.

Hot Clay Refining of the naphtha fraction at Ruhrchemie could increase octane ratings up to 20 numbers, and produced 81.5 octane fuel.⁶

Butane was dehydrogenated to butene or isomerized to isobutene for use in alkylate production. The butane was thermally cracked over $\text{CrO}_3\text{-K}_2\text{O}$ -Alumina catalyst and the isobutene was produced by $\text{AlCl}_3\text{-HCl}$ isomerization of butane. The Leuna plant produced 888 bbl/day (324,000 bbl/yr) of alkylate using this process although the capacity of the plant was over 445,000 bbl/year. The alkylate - with a boiling range of 185°F to 392°F - had an Octane rating of 93-94.⁷

Due to the great need for high octane blending components, work was progressing on the development of processes to produce isoparaffins directly in the F-T reactor. The Kaiser Wilhelm Institute Für Kohlenforschung developed catalysts⁸ based on Thorium that produced up to 90% isobutene in 45% yield when conventional cobalt and iron catalysts produced less than 10% isoparaffins in low yield. This improvement would greatly simplify the production of alkylate gasoline fractions such as 2,2,4-trimethylpentane (iso-octane), which has 100 octane rating.⁹ In addition, the gasoline produced by the "Isosynthesis" process was also of high octane value. Different pressure and temperature conditions were studied and the gasoline fractions all had octane values between 78 and 85.¹⁰ This process was not commercialized. Yield of the following compounds was observed:

C_4H_{10}	90% isobutene	60-70% yield
C_5H_{12}	96-98% isopentane	20-30% yield
$\text{C}_6, \text{C}_7, \text{C}_8$		Small amounts

This is a marked difference from the normal F-T product distribution with Fe and Co catalysts.^{11,12,13}

Isobutene was mainly used to make high octane blending components. Isobutene could be oligomerized to the dimers and trimers, which were then hydrotreated. Catalysts such as phosphoric acid or aluminum trichloride were used. Alkylation was also practiced.¹⁴ A mixture of butanes, n-butane (6:1 ratio), and some propane were treated with H_2SO_4 . Alkylate of 93-94 octane was produced.

Other methods of isobutene production were also used. Normal butane was isomerized over AlCl_3 and thermally cracked to isobutene at one plant.¹⁴

Aviation Gasoline was produced by blending 80% hydrogenated coal oils with 20% alkylate and 4.5 cc TEL/gallon.¹⁵

Similar to the above process for making iso-octane was the "Higher Alcohol Synthesis Process" which is not technically a F-T reaction although it does produce oxygenated products higher than C_4 . The catalyst is similar to that used to produce methanol.¹⁶

Diesel Fuel Synthesis from F-T Feedstocks

Little mention of diesel fuel production was made in many of the reports on the German F-T synthetic fuels processes. This is probably due to the heavy emphasis on gasoline fuel production and on other chemical processes. Specifications for diesel fuel are shown in Table 3.⁴

The bulk of the F-T diesel fuel was used to upgrade the fuel oil fraction obtained from hydrogenation of coal, shale oil and tar oils. These fuels had a cetane value in the 20's to 30's and were not directly suitable as diesel fuel. Blending was conducted by the Forschung Wirtschaftliche (WIFO) and the blends were generally secret.¹⁸ Only when special processing was needed did F-T plants get involved in fuel blending.

Table 3
German Diesel Fuel Specifications¹⁷

Specification	Wehrmacht Diesel Kraftstoff	Sonder Diesel Kraftstoff	Luftwaffe K1	Kriegsmarine-treigoel Mineral oil
Density @ 15°C	0.810-0.865	0.810-0.865	0.810-0.865	0.88 Max
Pour Point, °C Max.	-30	-30	-45	
Cloud Point, °C	-10	-10		
Flash Point, °C	55	21	50	55
Sulfur, wt%	1.0	1.0	1.0	1.0
Cetane, min	45	45	50	None

F-T diesel fuel on its own was not an appropriate fuel for the then-current German Diesel-cycle engines. Compared to conventionally derived diesel fuel of 47 cetane and 0.856 density, F-T diesel fuel showed increased fuel consumption of 5% and increased exhaust gas temperature of 25%.¹⁹

An example of diesel fuel produced by the F-T process by Ruhrchemie in 1938 and 1943 is shown in Table 4 below. This fuel was blended with diesel fuel fractions (b.p. 180-300°C) obtained from coke-oven tar, brown-coal tar, or low-temperature tar oils. "This oil gives a very clean exhaust and only a small proportion of carbon monoxide and was found preferable, on this account, to natural oils for use in underground motors."²⁰

Table 4
Properties of Diesel Oil Produced by Rhurchemie

Property	1938 Production	1943 Production
Sp. Gr. @ 20°C	0.762	0.745
Flash Point, P-M, °C	75	>57
Setting Point, (PP?), °C	-9	-38
IBP, °C	200	165
95% Point, °C	300	255
Cetane	85	>70
Carbon/Hydrogen/Oxygen	84.8/15.2/0	

Base Oils from Olefin Polymerization

Synthetic base oils accounted for only about 10% of total lubricant oil production in Germany, but these oils found their way into about 45% of the aircraft engine oils due to the higher performance of the base fluid.²¹

Four different methods were evaluated by the Germans to produce base oils from F-T products during the war years: (1) alkylation of aromatics via chlorination and reaction with $AlCl_3$ and aromatics, (2) chlorination followed by direct polymerization, (3) polymerization of the recovered olefinic fraction, and (4) chlorination, dehydrochlorination, and polymerization of paraffinic wax fractions.²² Base oils were also made by polymerization of ethylene followed by thermal cracking.^{23,24}

A fifth method was to directly alkylate mineral base fluids with F-T olefins over $AlCl_3$. This method (called mischpolymerisation, or mixed-polymerization) apparently provided higher overall yield of high quality lubricant than simply solvent refining crude oil lubricant feeds to the desired properties.²⁵ Other methods of synthetic base oil manufacture involved polymerization of ethylene with $AlCl_3$. The ethylene may or may not have been derived from F-T processes, depending on plant location.

An additional method has also been studied. Fischer-Tropsch waxes can be cracked to olefins suitable for polymerization into base oils for aircraft lubrication. Best results were obtained from linear wax free of methyl branching which was cracked into terminal olefins. Low Pressure F-T processes produce good feedstock for this process, but higher pressure processes produced more branched products which yielded inferior lubricants.²⁶

At Stettin-Pölitz, F-T and Coal tar wax was cracked in the vapor phase to 95-97% alpha olefins at 842-896°F and low pressure in 40% yield. Residence time in the cracking coils was about 0.1 seconds. Polymerization over $AlCl_3$ yielded 49-52% of lubricating grade base oil, diesel fuel, gasoline (27-30%), and a heavy fraction isolated from the catalyst remains that was used for steam cylinder lubricant. Properties of the recovered oils are show in Table 4.³²

Table 4
Properties of Lubricating Oils Produced from Cracked Wax at Stettin-Pölitz

Property	SS-1103	SS-1106	Steam Cylinder Oil
SUS@ 210°F	105	200-205	220
Viscosity Index	115-124	108-112	115-116
Pour Point, °C	-30	-11	-20

A diesel fuel was also produced which had a cetane value of 72 and a pour point of 0°C. Up to 290 bbl/day of base oil were produced in 50% yield based on wax feed by this process at Stettin-Pölitz.

Table 5 gives representative properties of base oils produced by polymerization of various octene feeds.²⁷

Table 5
Properties of Synthetic Base Oils Produced from Various Octenes

Octene Feed	Mol. Wt	Viscosity SUS@210°F	V.I.	Yield, wt%
n-1-octene	800	98	100	80
2-methyl-1-heptene	350	32	20	20
n-4-octene	200	28	-10	5-10
6-methyl-1-heptene	1500-1700	290	100	85-90

The Rheinpreussen plant developed their own version of synthetic base oil reasoning that Pennsylvania base oils were excellent with regards to oxidation stability although containing some aromatics.²⁸ Therefore a synthetic oil containing some aromatics might have superior stability compared to pure paraffinic base oils (assuming no anti-oxidant is added to the oil). They alkylated naphthalene with a chlorinated paraffin having an average carbon number of 16. The product had a VI of 105 and a -7°C pour point. The oil was sold to the German Navy and was highly regarded for its service in diesel engines.²⁹

Other F-T processes and Products

The olefins produced in the F-T reaction along with selected paraffin cuts were considered high-value feedstocks for many processes.³⁰ Examples below are only a few of the many applications found by German scientists for these chemicals. I.G. Farbenindustrie chemists considered the F-T process much more valuable as a chemical feedstock source than as a transportation fuel source.

The Oxo process has also been investigated as a source of feedstock for gasoline manufacture. This process takes olefins from the F-T reactor and further treats them with CO and H₂ over 3-5% slurry of F-T catalyst at high pressure (200 psi) to produce aldehydes and ketones which are reduced to alcohols of one higher carbon number than the feedstock (see Eq. 1). Typical

catalysts were the same as for the F-T synthesis.³¹ This process was never implemented due to high cost of production.



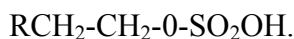
However, the OXO process was utilized to manufacture detergent alcohols from F-T olefins. C₁₁-C₁₇ primary olefins from the F-T reactor were converted to alcohols which are subsequently sulfonated. The resulting alkylsulfonates were superior to those made by direct sulfonation of olefins. The alcohols were also useful as plasticizer intermediates. Olefins obtained from the Medium Pressure F-T reaction were preferred over those obtained by cracking wax or higher alkanes since they were more linear and produced products with less odor than the branched olefins.

If narrow fraction of olefins were used as feed to the OXO process, the alcohols could be separated from the alkanes and 98% pure alcohols could be obtained.^{34,35} Ruhrchemie converted C₆-C₁₀ olefins into aldehydes, condensed the aldehydes into alcohols via the Cannizzaro reaction, and esterified them with fatty acids to produce a very high VI base oil with a pour point of -50°C.³⁶

The Synol process produced higher alcohols directly. I.G. Farbenindustrie believed that the F-T process was more likely to be of higher value as a source of raw material for chemical processes than as a source of fuels. A ratio of CO to H₂ of 1:0.7 was used at 18-20 atms and 185°F. The reaction gave the following yields:

Alcohols	35-50%
Olefins	25-40%
Paraffins	20-35%

The alcohols were separated from the hydrocarbons by formation of Boric Acid esters, distillation of water and lower hydrocarbons, distillation under vacuum to remove higher hydrocarbons, and finally hydrolysis of the boric ester to yield alcohols. The alcohols were used as feedstocks for other chemical processes.^{37,38} Sulfonation of the C₁₀-C₁₈ alcohols with chlorosulfonic acid produced soaps:



The C₇-C₁₀ alcohols were combined with acids produced from the same alcohol cut to make ester plasticizers. The C₉-C₁₄ Synol alcohols could be esterified with adipic acid to produce synthetic ester lubricants. The Synol alcohols with slight branching were superior to the OXO alcohols for this application. Nitrating the diesel fraction alcohols produced a fuel with a cetane rating of 280 which could be used as a starting aid for diesel powered aircraft in cold weather.³⁹

Alkyl sodium sulfonates were produced from Kogasin steams by the Mersol Process. This process converts paraffinic hydrocarbons boiling in the 230-320°C range in 82% yield to alkyl sulfonates by Eq. 2 over a Ni-W-S catalyst. Olefins were saturated prior to processing to avoid side reactions.



The products were shipped to soap manufacturers and the products, although inferior to natural soaps, were satisfactory for cleaning. Another use was for emulsion polymerization for the manufacture of PVC plastics.^{40,41}

Toluene and other aromatic hydrocarbons were produced from F-T hydrocarbons by cyclization over $\text{Al}_2\text{O}_3\text{-Cr}_2\text{O}_3$ (20%). The C_7 fraction containing olefins can be cyclized in 90-92% yield of a stream containing 50% toluene. Although valuable as a fuel blending component, it probably had more obvious uses as a feed for explosive manufacture.⁴²

Water-Soluble Oxygenated Chemicals

One by-product of the F-T synthesis is water, and a significant amount of organic compounds produced in the F-T reaction were isolated from the water fraction. Typically, 0.35% of the water was soluble organics, and acetic acid comprised about 66% of the products isolated. Oil soluble fatty acids comprised another 0.06% of the LP F-T product stream consisting of $\text{C}_5\text{-C}_{10}$ fatty acids. The MP F-T process produced about 1% fatty acids. Half of those acids were found in the diesel fuel fraction. 72,000 lbs/yr of C_{11} to C_{18} fatty acids were isolated and converted into soap.⁴³

Another 700,000 lbs/yr of light alcohols were recovered from the MP F-T process condensate water. They were comprised of ethyl, propyl, and butyl alcohols.⁴³ The Gasol fraction ($\text{C}_3\text{-C}_4$) containing 30% olefins could also be converted over dilute sulfuric acid to a mixture of isopropyl, secondary and tertiary butyl alcohols. Polymers formed in the reaction were used as alkylate high octane fuel, and the unreacted paraffinic gases were bottled and used for transportation fuels. At Rheinpreussen, 26-28 tons of feed were converted to 2.0 tons of isopropyl alcohol and 3.2-3.5 tons of iso- and tert-butyl alcohols and the remainder being LPG products.⁴⁴

Other fatty acids were recovered by neutralization and extraction methods. The acids being recovered by treatment with sulfuric-phosphoric acid mixtures. The volume recovered represented approximately 0.4% of the total products from a medium pressure F-T process. Rheinprussen used these acids to produce thickeners for grease manufacture.⁴⁵

Uses for F-T Wax

As is the case today, there are many uses for F-T wax in its solid form. Some examples are as a coating to water-proof paper products such as boxes, or a filler for some rubber products,

but the amount of material used in these applications is small. Many other uses for F-T wax were found in Germany. Some were quite unexpected.

An example of wax production from Ruhrchemie is shown in Table 6. Typical applications for the wax products is also included in the table.^{46, 47, 48}

Table 6
Typical Wax Production From A MP F-T plant

Wax Description	Melting Point, °C	Production, kg/day	Disposition
Soft Wax (Gatch)	35-45	22359	Fatty Acid Synthesis
Block Paraffin	50-52	2200	Olefins for Synthetic Oils
Plastic Wax	70-75	2688	Cardboard, Candles, Paints
Catalyst Wax	80-90	6360	
R.B Hard Wax	90-95	8976	Paper, Wood Barrels, Polish

Lower molecular weight wax boiling in the 230-450°C range (C₂₀-C₄₀) wax air-oxidized over an aqueous 2% permanganate catalyst for about 24 hours. Four major fraction were recovered: C₈-C₁₀ (16%), C₁₀-C₂₀ (45%), C₂₁-C₂₈ (10%), and a residue (9%). Thus 80% of the wax feed is converted to acids. Three plants alone processes 80,000 tons/yr of wax into fatty acids.⁴⁸

The bulk of the fatty acids were converted into soaps although there were some problems with a residual unpleasant odor.⁴⁸ Chemists attributed this to the inclusion of some branched chain components in the hydrocarbon tail of the soap. Use in toilet soaps was often limited to 30%.⁴⁹ Lower carbon number acids were used in various chemical processes including the esterification of cellulose, production of Calcium Propionate (a preservative for bread), and when saturated to alcohols, converted into plasticizer esters with phthalic acid. Mid-length acids were used for flotation of minerals, and heavier acids (C₁₈₋₂₄) were converted into calcium salts to be used as thickeners for greases, as they are also currently used. Even the residues were used for softeners for plastics and other purposes.

Synthetic Edible fats were produced by direct oxidation of wax followed by esterification with glycerol. Testing by the German Health Department concluded that the synthetic fat was non-toxic and non-irritating based on animal and human (concentration camp inmates) testing. However, natural fats contain only even carbon numbers, and synthetic fats contain all carbon numbers. Some physiologists were concerned about their use for human food.⁵⁰

Post-War Upgrading Efforts

All major Allied oil companies were exposed to the intelligence reports on the German Synthetic Fuels industry. This prompted large development efforts in F-T processes that could supplement the dwindling crude oils supplies. Less technology for upgrading F-T

processes was patented during this period, but the patent literature is significant in several respects. The roots of modern hydroisomerization and hydrocracking technology are found in the work by Shell Oil Company to upgrade F-T wax.

In 1946, Shell researchers Bernard Greensfelder and Robert Moore (in US Patent 2,468,746) noted that conventional diesel fuels have low cetane values and paraffinic diesel fuels have high cetane values but also have high cloud points. They developed a process to “for the more efficient conversion of normally liquid high molecular weight paraffins of straight and branched chain structure to paraffins of branched and more highly branched chain structure, respectively, having the same molecular weight, in the absence of any substantial hydrocarbon decomposition.”⁵¹ This work built on the knowledge that AlCl_3 converted n-butane to isobutene, but cracked pentane and higher normal paraffins. They developed conditions and a cracking suppressor to convert essentially linear F-T paraffins into branched paraffins suitable for use as diesel fuels with lower cloud points. The process “is to convert the normal and branched chain high molecular weight paraffins charged, to isomers thereof having an increased number of alkyl side chains in which the alkyl side chains formed during the reaction consist of essentially only of methyl groups.”

This process allows control of branching by controlling reaction time and conditions. Diesel fuels with cetane values above 50 and pour points below -10°C down to below -60°C have been produced. The low pour point diesel fuels were intended to be blending components to improve cetane of lower quality fuels, but they could also be used in other applications such as for insecticide spray oils. Examples of isomerizing n-cetane to iso-cetane are given. Conversions of up to 97% methyl-branched cetanes are shown.

Applications of this process to heavier hydrocarbons is addressed in US Patent 2,475,358, also by Moore and Greensfelder. This process is “for the efficient conversion of normally solid paraffin hydrocarbons to branched chain normally liquid paraffin hydrocarbons having the same molecular weight as the normally solid paraffin hydrocarbons charged, and comprising high quality lubricants and diesel engine fuels.” The same AlCl_3 catalyzed rearrangement of linear wax to methyl-branched paraffins occurs in this process.⁵²

The base oils produced are substantially different from those produced by either ethylene or alpha-olefin polymerization as practiced in Germany. The ethylene polymerization process creates multiple branching sites for polymer growth producing paraffins with branching significantly greater than ethyl branches. Polymerization of alpha and internal olefins produces oils substantially similar to current PAO base oils which contain branches of two carbon numbers less than the feed if alpha olefins are used, and various branches depending on the location of the internal olefin if that is the feed used. As described in the above patent, the effect of the reaction of this process “is to increase the number of alkyl side chains of the normally solid hydrocarbons treated and that the products obtained consist essentially of branched chain hydrocarbons in which the alkyl side chains formed during the reaction consist substantially exclusively of methyl groups.”⁵² Infrared analysis of the base oils confirmed this observation in that only C_2 , C_3 , and other methyl branches were found. This observation is very significant since the absence of branches greater than methyl (i.e. ethyl, propyl, and the like) imparts the highest viscosity index and lowest pour point for the chain

length of hydrocarbon produces. The properties of the oil depend on the extent of isomerization with VI decreasing as branching increases, but pour point also decreases with increased branching.

An improvement to this process is discussed in US Patent 2,668,866 in which a vapor-phase isomerization is disclosed utilizing a platinum-containing catalyst. The vapor phase conditions limit the feed somewhat to the lower carbon number waxes, but 3.0+ cSt base oils with pour points down to -70°C and VI of up to 169 have been produced by this process. Wax with an average carbon number of 37 was used in the example. Here again the VI of the base oil decreases with increased isomerization and reduced pour point.^{53,54}

These early attempts to isomerized wax into fuels and lubricants were followed by a cascade of improvement patents to these processes. These improvements include the modern hydrocracking and isomerization-dewaxing processes which now use shape selective supports to achieve very selective isomerization of only the long chain linear paraffins into methyl-branched paraffins. These processes either upgrade crude oil derived lubricants by dewaxing without yield loss or convert F-T wax into very high VI base oils such as described above.

Conclusions

The German chemical industry conducted a wide range of research on the upgrading of F-T products into a myriad of valuable products. These ranged from fuels to foods and the processes ranged from polymerization to oxidative degradation. Many of the lubricants we use today such as high quality synthetic automotive engine oils have their foundation based in these German processes.

Subsequent work in other countries builds on the findings of the interrogation teams and yielded improvements to these processes and products. Only a handful of them have been discussed in this paper. Perusal of the interrogation reports and patent literature will show one how much was known about F-T products and processes in the years 1938 to 1950, and how much our current processes and products are based on that work.

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