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Origin and Growth of the Synthetic-Fuel Industry

Introduction

The lack of petroleum resources in Germany instigated the development of the Berguis Process and the Fischer-Tropsch Process for synthetic fuel production in the early 1900's. Later, during World War II (1939-1945), there was an increase in the demand for petroleum products; the synthetic fuel industry expanded tremendously. World War II is responsible for the establishment of a large-scale synthetic-fuel industry not only in Germany, but also in the United States, South Africa and Malaysia.

What is synthetic fuel?

Synthetic fuel is defined as a liquid fuel obtained from coal, natural gas or biomass. Synthetic fuels are produced by chemical conversion, either by direct conversion(the source substance is converted directly into liquid transportation fuels) or by indirect conversion, (the source substance is converted initially into syngas followed by an additional process to liquid fuel)[4].

Need for Synthetic Fuels

When the Germans in the 1900s first began considering alternate sources of fuel, they did so because for the following reasons:
1. Germany's scarce natural petrol reserves were exhausting. However, Germany had abundant coal reserves that could be used to produce synthetic fuel.
2. Because of the lost World War 1 and consequent economic difficulties, Germany was short of hard foreign exchange required for the purchase of foreign oil. Hence, the only way to become self-sufficient was to produce synthetic oil. The Berguis and Fischer-Tropsch processes were developed to produce synthetic fuel in Germany.

Berguis Process (1913)

The Bergius Process produces liquid hydrocarbons by hydrogenation of high-volatile bituminous coal at high temperature and pressure [1]. The overall reaction is

$nC + (n+1)H_2 > C_nH_{2n+2}$ (where n is greater than or equal to1)

The coal is dried, pulverized and made into a "paste" with its own weight of heavy oil derived from the process. The paste is injected to the hydrogenation unit where an iron catalyst is added in the form of fine powder. Hydrogen is mixed with the coal paste and the mixture is heated to 450 Celsius. The reaction is carried out at 200-250 atm.

Hydrogen is obtained from the Bosch Process, where bituminous coal is first carbonized to coke. Coke reacts with steam in a water-gas generator.

$C + H_2O > CO + H_2$

After removal of sulphur compounds, the gas reacts with additional steam in the presence of iron oxide catalyst to convert CO by reducing steam to hydrogen.

$CO + H_2O > H_2 + CO_2$

The gas is then compressed and carbon dioxide is removed by scrubbing with water.

The first commercial plant using the Berguis Process(Leuna) started in 1927 with an output of 400,000 ton/yr synthetic-fuel. The capacity increased to 440,000 ton/yr at the outbreak of the war in 1939 and further increased to 4,000,000 ton/yr by the end of the war in 1945.
By 1939, six other plants had started in Germany, producing a total of 1155,000 ton/yr[5]. Table.1 shows the plants operating in Germany in 1939.

Name of Plant	Main Raw Material	Liquid Product Capacity ton/yr	Liquid Product Production ton/yr
Leuna	Brown Coal	440,000	440,000
Bohlen	Brown Coal tar	155,000	155,000
Magdeburg	Brown Coal tar	145,000	145,000
Zeitz	Brown Coal tar	170,000	170,000
Scholven	Bituminous coal	145,000	145,000
Welheim	Bituminous coal	100,000	70,000
Gelsenberg	Bituminous coal	200,000	30,000

Table.1: Plants using the Berguis Process in Germany in 1939

The major reason for Germany’s concentration on hydrogenation was for production of aviation fuel, needed for war. The Berguis process produces fuel with good antiknock qualities.

<u>Fischer-Tropsch Process (1920)</u>

The Fischer–Tropsch process is based on a catalyzed chemical reaction where synthesis gas, a mixture of carbon monoxide and hydrogen, is converted into various liquid hydrocarbons[2]. The most common catalysts are based on iron and cobalt, although nickel and ruthenium have also been used.

$(2n+1)H_2 + nCO \rightarrow C_nH_{(2n+2)} + nH_2O$

Here 'n' is a positive integer. The simplest of these (n=1) is gaseous methane that is generally considered an unwanted byproduct (particularly when methane is the primary feedstock used to produce the synthesis gas). Process conditions and catalyst composition are usually chosen to favor higher order reactions (n>1) and thus minimize methane formation. Most of the alkanes produced tend to be straight-chained, although some branched alkanes are also formed.

The Fischer–Tropsch process is operated within 150-300 °C (302-572 °F). Higher temperatures lead to faster reactions and higher conversion rates, but also tend to favor methane production. As a result, the temperature is usually maintained at the low to middle part of the range. Increasing the pressure leads to higher conversion rates and also favors formation of desired long-chained alkanes. Typical pressures are in the range of one to several tens of atmospheres. While even higher pressures would be favorable, the benefits may not justify the additional costs of high-pressure equipment. Table.2 shows the various products formed at medium pressure 2atm.

Product	% by wt	Olefin content (% by vol)
Condensable gases(C3 and C4)	14	45
Light Oil 25-165C	47	37
Middle Oil 165-230C	17	18
Heavy oil 230-320C	11	8
Soft wax 320-460C	8	-
Hard wax> 460C	3	-

Table.2: Various Products formed by the Fischer-Tropsch Process

The Fischer-Tropsch process gives some petrol of low quality, diesel oil of high cetane number and a large proportion of solid wax. The products were used as raw materials for further synthesis of useful products.

- The condensable gases, propane and butane were used as fuel for transport.
- Light Oil was used as motor fuel.
- Middle oil was used as aviation diesel fuel.
- Heavy Oil was converted into detergent.
- The soft wax was converted into synthetic fatty acids by oxidation. This was then used for the preparation of edible fat and soap.

Table.3 shows the various products produced by the Berguis Process and by the Fischer Tropsch Process in 1944.

Types of oil products	Berguis Process (ton/yr)	Fischer-Tropsch(ton/yr)
Aviation fuel	1,900,000	-
Motor Spirit	350,000	270,000
Diesel Oil	680,000	135,000
Fuel Oil	240,000	30,000
Lubricating Oil	40,000	20,000
Miscellaneous	40,000	160,000

Table.3: Types of Products produced by Synthetic Methods in Germany in 1944. (Berguis Process is used to produce aviation fuel as Berguis Process produces aviation fuel with good antiknock qualities)

An important requirement for industrial operation was the production and purification of synthesis gas(mixture of H2 and CO) prior to conversion to synthetic fuel.

1. Synthesis gas Production

Bituminous coal is first carbonized to coke. The coke is then treated with steam in a water gas generator.

C + H2O > CO + H2

In the presence of a cobalt catalyst, the synthesis reaction is-

$n(2H_2 + CO) > CH_3\text{-} (CH_2)n\text{-}CH_3 + nH_2O$

2. Purification of Synthesis Gas

The synthesis gas produced from coke contained 2-5gm H2S/m3 and 10-20gm organic sulfur compounds/100 m3. To prevent rapid poisoning of the synthesis catalyst, it was necessary to remove these impurities.

Purification was achieved by passing the gas through a bed of iron oxide at normal temperature.

This reduced the sulphur content to about 0.005g/m3.

The first commercial unit using the Fischer-Tropsch Process was completed in 1935. By 1939, a total of 6 Fischer-Tropsch plants had been built in Germany with an aggregate output of 335,000-ton/yr synthetic oil [5]. Table.4 shows the increase in the total output of synthetic fuel produced by the Fischer-Tropsch Process from 1938 to 1944.

Year	Ruhrchemie	Rheinpreusen	Gewerkschaft Viktor	Essener Steinkohle	Hoesch Benzin	Brabag	Winter Shall	Schaffgotsch	Total
1938	27,443	28,542	27,140			103,503			186,628
1939	49,371	54,684	31,192	31,795	15,635	116,990			335,382
1940	58,728	70,163	35,903	40,094	37,297	151,380			455,075
1941	57,145	73,271	37,740	48,355	46,719	149,120		18,609	505,424
1942	62,684	71,560	37,701	49,950	48,150	162,270		26,377	542,117
1943	46,273	70,250	39,834	54,020	39,781	179,665	22,045	33,658	569,179
1944	62,200	69,700	40,380	39,802	51,000	158,500	29,320	39,200	576,682

Table.4: Increase in the annual Production of Primary Products in tons

Growth of Synthetic-Fuel Industry in the World

Germany relied heavily on synthetic fuel during World War II. However, the problem of scarcity of natural petroleum reserves was not limited to Germany. The United States, Africa and Malaysia also realized that their petroleum reserves would not last forever. Therefore, they followed Germany's approach to produce fuel synthetically.

1. United States(1944)

The Synthetic Liquid Fuels Program was started by the United States Bureau of Mines to create technology to produce synthetic fuel from coal. The Synthetic Liquid Fuels Act of April 5, 1944 authorized the use of $30 million over a five-year period for research in Synthetic fuels.

The Bureau of Mines first studied the production of oil from oil shale between 1925 - 1928.

Between 1928 and 1944, the Bureau experimented with coal liquefaction by hydrogenation using the Bergius process. A small-scale test unit constructed in 1937 had a 100-pound per day continuous coal feed[4].

Between 1945 and 1948, new laboratories were constructed near Pittsburgh. A synthetic ammonia plant in Missouri was transferred from the Army to the Synthetic Fuel Program in 1945. The plant was converted to a coal hydrogenation test facility. By 1949 the plant could produce 200 barrels of oil a day using the Bergius process.

In 1948, the program was extended to eight years and funding increased to $60 million. A second facility was constructed at the Louisiana plant, using the Fischer-Tropsch process.

In 1979, after the second oil crisis, the U.S. Congress approved the Energy Security Act forming the Synthetic Fuels Corporation and authorized up to $88 million for synthetic-fuels projects[4].

Currently, several plants are under construction in United States for converting coal to synthetic fuel(discussed later in the section of "Proposed Projects in United States").

2. South Africa(1948)

Synthetic-fuel production, was started in South Africa to meet its energy needs during its isolation because of Apartheid(a system of legal racial segregation enforced by the national party government between 1948 and 1994). Synthetic Fuel Production has received renewed attention in the quest to produce low-sulfur diesel fuel to minimize the environmental impact from diesel engines. The leading company in the commercialization of synthetic fuel in South Africa is Sasol. It operates the world's only commercial Fischer-Tropsch coal-to-liquids facility at Secunda with a capacity of 150,000 barrels per day (24,000 m^3/d).

3. Malaysia

Shell in Bintulu, Malaysia, uses natural gas as a feedstock, and produces primarily low-sulfur diesel fuels.

Royal Dutch Shell operates a 14,700 barrels per day (2,340 m^3/d) Fischer-Tropsch gas-to-liquids plant in Bintulu, Malaysia.

Reasons for Growth of Synthetic Fuel Industry in the United States

The Synthetic-Fuel industry has been growing in US since the onset of the Synthetic Liquid Fuel Program in 1944.

There are several reasons why this industry gained a prominent position in the US-

1. Readily Available Supply- Because Synthetic Fuel is manufactured from coal, one of the nations most abundant natural resources, there will be an abundant supply for generations. The United States is blessed with affordable coal, possessing 275 billion tons of recoverable coal reserves, or about one-fourth of the world's total. The U.S. coal reserves are equivalent to four times the oil of Saudi Arabia, 1.3 times the oil of OPEC and equal to all of the world's proved oil reserves[3].
2. Significantly Lower Costs- Today for example, 61% of the cost of Diesel fuel at the pump is attributed to the cost of crude oil and refining. It is projected that synthetic fuel can be produced and sold for approximately 30% less than petroleum-based Crude initially, and that with the economies of scale, over time, the cost will be reduced more[3].
3. Earth Friendly- Synthetic Fuel does not contain carcinogens, heavy metals or aromatic pollutants, as does petroleum. This means that it will be significantly better for our environment than petroleum-based fuels. The synthetic fuel is much cleaner due to the absence of sulphur compounds.

Proposed Projects in the United States

In the United States, several synthetic-fuels projects are moving forward, with the first expected to enter commercial operation in 2013.

American Clean Coal Fuels, in their Illinois Clean Fuels project, is developing a 30,000 barrels per day (4,800 m^3/d) Fischer-Tropsch biomass and coal to liquids project with carbon capture and sequestration in Oakland, Illinois. The project is expected to come online in 2013[4].

Baard Energy, in their Ohio River Clean Fuels project, is developing a 53,000 barrels per day (8,400 m^3/d) Fischer-Tropsch coal and biomass-to-liquids project with carbon capture and sequestration. Pending close of a financing package, Baard hopes to begin on-site preparation work before the end of 2009, with plant construction starting in 2010. Initial project startup is anticipated in 2013, with full production capacity targeted in 2015[4].

Rentech is developing a 29,600 barrels per day (4,710 m^3/d) Fischer-Tropsch coal and biomass-to-liquids plant with carbon capture and sequestration in Natchez, Mississippi. The project is in an early phase, with receipt of permits anticipated by Rentech in 2010.

Conclusion

The scarcity of natural reserves in Germany led to the development of the Berguis Process and the Fischer-Tropsch Process in the 1920's. During World War II, the production of synthetic fuels increased in Germany; also spreading the use of the Fischer-Tropsch and Berguis Processes in the United States, Africa and Malaysia. In the US, several plants are under construction for converting coal to synthetic fuels. Production is expected to begin in 2013.

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