The total liquid product was fractionated in a column equivalent to 45 theoretical plates, the toluene fraction, containing 3–5% olefins; acid-washed and re-run to give nitration-grade toluene. The estimated cost of production of toluene in the projected full-scale plant was RM382/te based on a raw material (C_7 fraction) cost of RM300/te.

d. Production of Aviation Fuel

Ruhrchemie considered that the most suitable process for obtaining substantial quantities of aviation petrol from the primary products of the Fischer-Tropsch process was catalytic cracking to produce C_3, C_4 and C_5 olefins and conversion of these to polymer petrol.

They had developed a process in which the 170–350°C fraction of the primary product was cracked in the vapour phase at atmospheric pressure and 500°C in the presence of "Granosil" (an acid-treated clay). The conditions were arranged so that the heat required for the cracking reaction was obtained by burning-off the carbon deposited on the catalyst (as in the case of the toluene process described above). The period occupied by the burning-off process was about one-half that occupied by cracking. The C_3, C_4 and C_5 fractions (90% olefins) were separated, polymerised and the polymerisates hydrogenated, the fraction 60–165°C of the hydrogenated product being separated as aviation fuel. A blend of the C_4 and C_5 polymer spirits gave aviation fuel No. 1, octane number (Motor) = 90 (without lead). If the C_3 polymer was included, aviation fuel No. 2, Motor octane number = ca.85, was obtained. In the pilot-plant trials of this process a catalyst life of about five months was obtained and the yields of final products were as follows:—

	Aviation Fuel No. 1	*Aviation Fuel No.* 2
Aviation fuel %	31·7	56·1
Motor fuel %	48·1	23·7
	(ON = 87Res)	(ON = 80Res)
Liquified gas %	8·8	8·8
C_2 (60% ethylene) %	6·2	6·2
$CH_4 + H_2$ %	1·6	1·6
Carbon %	3·6	3·6

A plant designed to treat 26–27,000te/yr cracking stock by this process was 60% complete when work was abandoned in 1944. The estimated cost of production, based on a charge of RM300/te for the cracking stock, was RM510/te aviation fuel.

e. The Oxidation of Fischer-Tropsch Hard Wax

The oxidation of wax was studied at Holten by Ruhrchemie with the object of producing emulsifiers and substitutes for Montan wax, which was in short supply. In order to produce the desired high molecular-weight acids, most of the work had been carried out with hard wax, mp ca.90°C. The most successful process developed involved oxidation with nitrosyl sulphuric acid obtained by saturating sulphuric acid with oxides of nitrogen obtained from Ruhrchemie's synthetic nitric acid plant. The process was as follows.

A batch of 100kg hard wax was stirred with 20kg of nitrosyl sulphuric acid at 120–125°C and gases from ammonia oxidation containing 8% NO_2 passed through at 65m³/hr. After 10–12hr the reaction was stopped, the acid layer removed and the upper layer washed with boiling water. The dried crude product which contained about 50% of unoxidised wax was known as "OP3." Its properties were:—

Acid no.	70–75
Saponification no.	80–85
Solidification point	80°C
Clear mp	90°C

To recover pure acids, this product was treated in a kneading machine with a 50% excess of 30% NaOH at 100°C until all the water had evaporated. The cooled mass was disintegrated and extracted with 80–100°C synthetic spirit and the acids recovered by treating the residue with sulphuric acid. This product, known as "OP32," had the following properties:—

Acid no.	145–150
Saponification no.	150–155
Solidification point	80°C
Clear mp	90–100°C

The wax recovered from the saponification could be returned for oxidation and in this way an 80% yield of OP32 could be obtained (based on wax converted).

The product was found to be suitable for preparing impregnants for the textile industry (water-resisting fabrics) and in the production of printing colours. By partial saponification very effective emulsifiers were produced for use in the preparation of shoe and floor creams, emulsion lubricants and drilling lubricants. Some of these products could be produced direct from the crude OP3. By bleaching OP32 with chromic acid-sulphuric acid mixture, a stable white product suitable for use in the preparation of skin-cream types of emulsion was obtained. The experimental plant produced about 3te/month of the crude product, OP3.

E—Crude Oil Production

1. INTRODUCTION

Although German oil supplies during the war were obtained from a number of sources, this report deals mainly with crude oil production obtained within the frontiers of Germany as it was before the invasion of Austria. Apart from a very small production obtained in the Upper Rhine Valley near Bruchsal, the whole of this production was obtained in the present British Zone (see Fig. 55). For various reasons it has not yet been possible to obtain an appreciation of the work done on petroleum production during the war throughout the "Greater Reich."

When the oilfields were overrun by the Allied Armies, it was found that the German technical men had made little effort to destroy the technical records, and the first task of the investigating party was to ensure that no essential data was lost; as a result it has been a relatively simple matter to compile an accurate account of the industry's activities during the war years. This report, however, does not confine itself strictly to war years as, for a proper understanding of the war developments in German crude oil production, it is necessary to review the preparations from 1934 onwards (Table LXV).

Table LXVI gives the 1944 monthly production figures sub-divided into finished products and well illustrates the high yield of lubricants amounting to nearly 50% of the crude oil production.

The following table extracted from captured documents, shows the monthly production in te during 1944.

TABLE LXV

SUMMARY OF CRUDE PRODUCTION AND FINISHED PRODUCTS

(In 1,000te/yr)

	Source	1940	1941	1942	1943	1944	1945
Crude:— Planned ..	Germany and Austria	1,609	1,603	1,590	2,213	1,788	1,969
	All controlled territory, including Rumania, etc.	—	—	8,650	9,005	8,678	2,901
Actual ..	Germany	1,052	898	753	715	711	—
	Austria	413	634	869	1,107	1,213	—
	TOTAL	1,465	1,532	1,622	1,822	1,924	—
Products:— Planned ..	Germany and Austria	—	—	—	—	1,575	—
Actual ..	Germany and Austria	1,400	1,520	1,670	1,750	1,498	—

TABLE LXVI

GERMANY AND AUSTRIA. PRODUCTION OF FINISHED PRODUCTS (1944)

1944	Aviation spirit	Motor spirit	White spirit	Kerosene	Diesel oil	Fuel oil and asphalt	Lubricants	Total
January	—	14,486	11,907	12,924	38,921	3,805	69,487	151,530
February	458	11,632	11,986	14,073	32,116	1,959	67,738	139,962
March	362	15,295	10,801	14,916	40,260	3,528	68,868	154,030
April	273	10,963	9,992	15,086	36,709	3,670	61,594	138,287
May	244	10,867	12,587	17,262	39,036	4,447	61,640	146,083
June	247	7,859	9,382	11,900	30,480	5,611	51,496	116,975
July	213	6,313	8,333	9,789	34,591	8,313	38,786	106,338
August	292	13,902	8,188	5,936	54,551	5,632	36,056	124,557
September ..	836	5,179	5,610	6,887	42,991	3,023	39,464	103,990
October	288	15,276	3,294	6,674	43,533	3,116	44,669	116,850
November ..	35	15,170	2,496	4,442	37,237	10,294	27,883	97,557
December ..	71	14,541	3,168	3,891	37,827	13,434	29,163	102,095
TOTAL	3,319	141,483	97,744	123,780	468,252	66,832	596,844	1,498,254

2. ORGANISATION OF THE INDUSTRY FOR WAR

In 1934, when the German crude production was 300,000te/yr, a number of measures were taken to step up the rate of exploration drilling. A law was passed nationalising the ownership of oil, enabling the government to allocate exploration and exploitation rights in separate areas to individual companies or groups of companies, so ensuring unit operation. To encourage new discoveries the Reich offered subsidies which in effect meant that it paid half the cost of all approved exploration wells. To centralise the collection of data and the control of exploration work, the Geological Surveys of Prussia, Bavaria, Baden and other German provinces were formed into a central survey called the "Reichsamt für Bodenforschung," with headquarters in Berlin and branch offices in the provinces.

The "Reichsamt für Bodenforschung," headed by Professor Bentz, was the chief instrument for the intensification of the search for new oil. It had a geophysical section, and the first work of this section was to carry out a reconnaissance survey of the whole Reich by all available means, but chiefly by gravity survey, to delimit the areas favourable for more detailed examination. The detailed examination of the favourable structures was carried out by the Reichsamt and by oil companies. Permission had to be obtained from the Reichsamt for the drilling of all deep wells and the drilling and production records had to be submitted in detail. The approval of the Reichsamt had, of course, to be obtained for all the exploration wells subject to the Reich subsidy mentioned above.

The effect of these measures was to increase greatly the amount of exploration drilling; in 1933 the proportion of exploration to exploitation drilling was 35%, in 1934 47% and by 1937 it was 54%. In 1937 the meterage drilled in exploration wells was over 100,000, more than three times the meterage drilled in 1933. These changes are illustrated in Fig. 56.

As a result, the following new fields were discovered:—

1935 Mölme.
Forst.

1936 Gifhorn.
Weiher.
Weingarten.

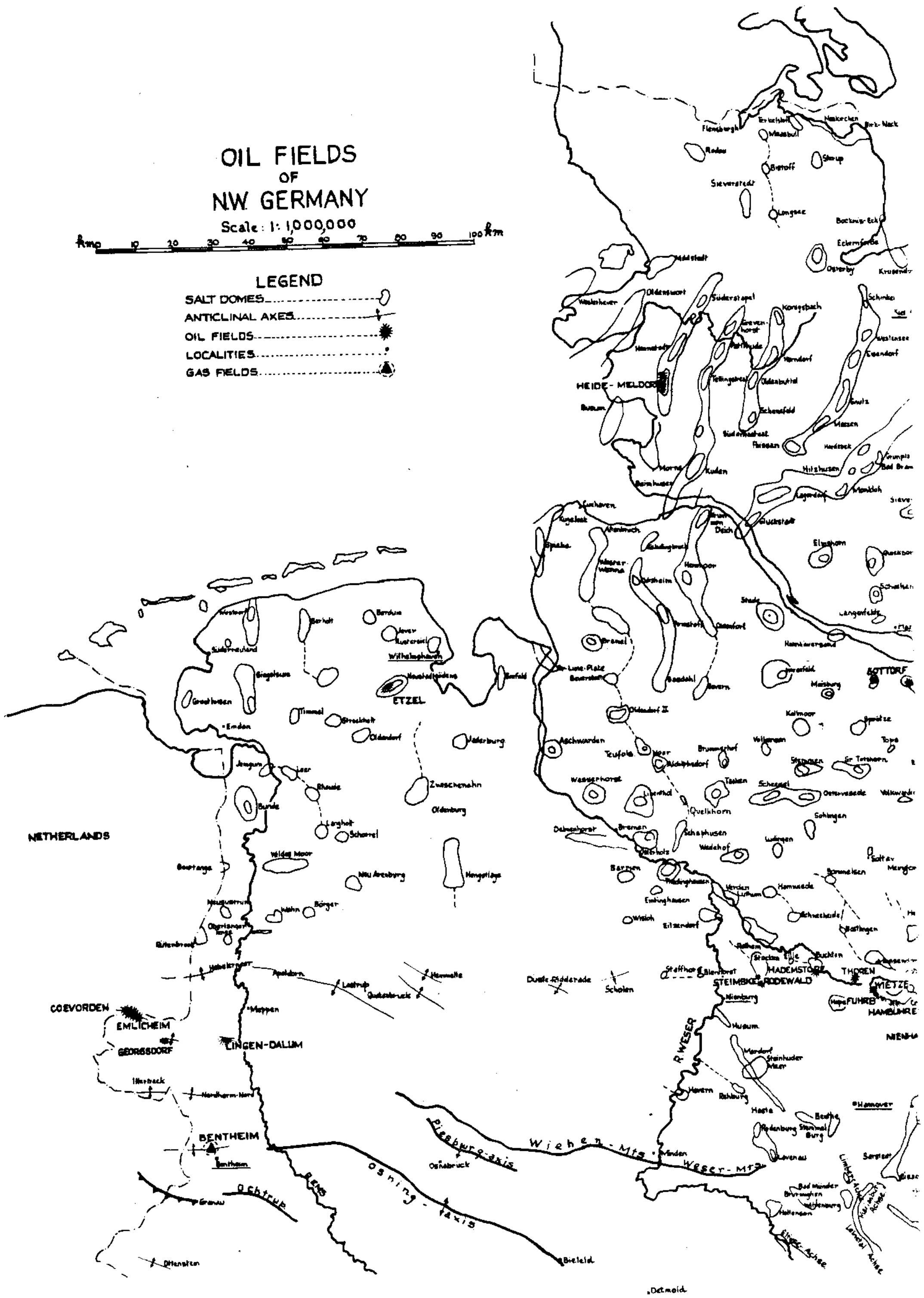
1937 Steimbke-Rodewald.
Eicklingen.
Reitbrook.
Sottorf.
Heide-Meldorf (Zechstein).
Broistedt.

1938 Meckelfeld.
Bentheim (Gas).

1939 Fuhrberg.
Ehra.

The importance of these fields during the early years of the war, especially Reitbrook and the deep production at Heide-Meldorf, is shown on Fig. 57.

The substantial discoveries of 1937 led to an increase in exploitation drilling in 1938 at the expense of exploration, and this change was greatly intensified in 1939, as is shown in Fig. 56.



A5575 Fosh & Cross Ltd., London.

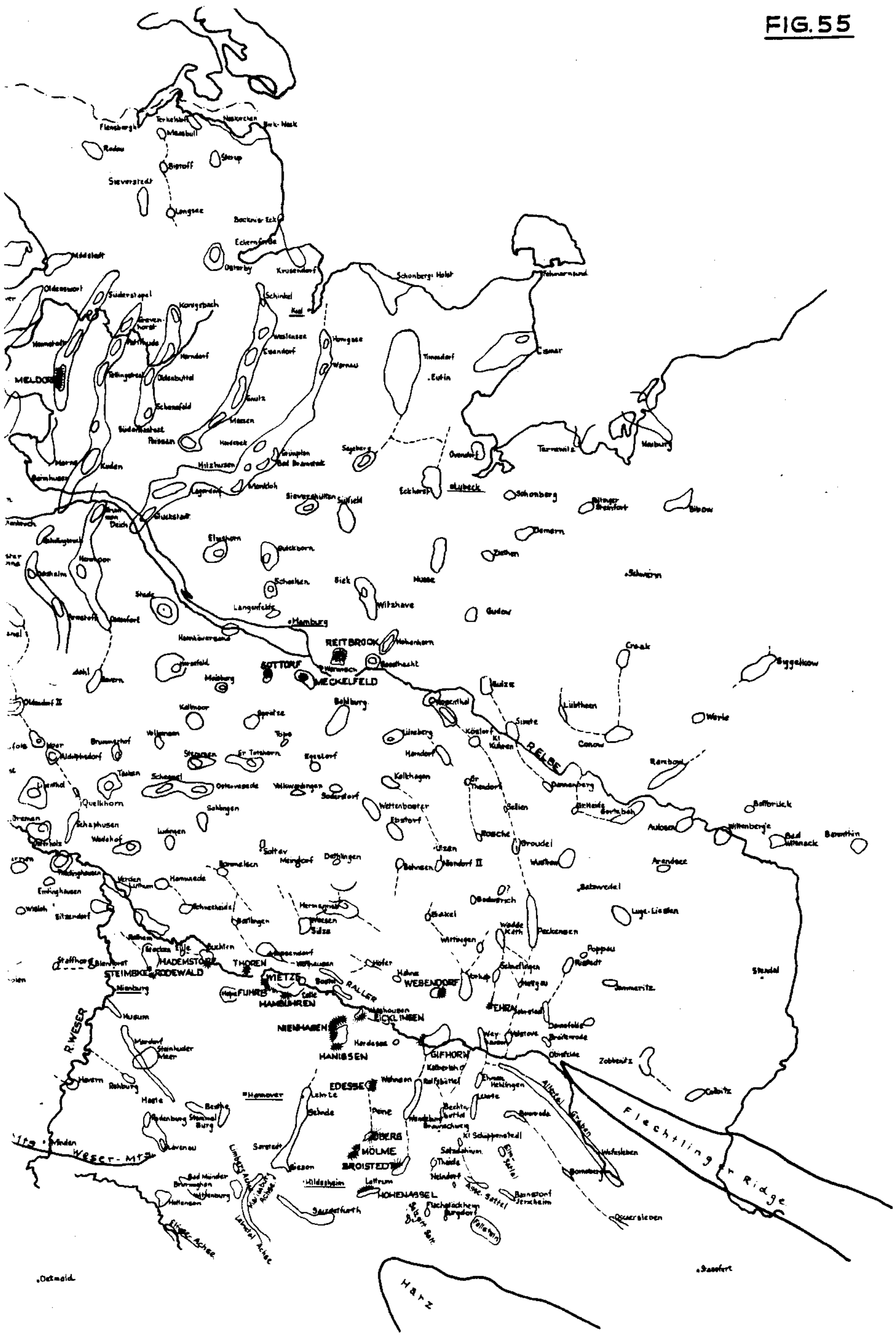

MELDORF
REITBROOK
MECKELFELD
Hamburg
Lübeck
Kiel
Eutin
Schwerin
R. ELBE
STEIMBKE
RODEWALD
THOREN
WIETZE
HAMBÜHREN
NIENHAGEN
EICKLINGEN
WEBENDORF
GIFHORN
EDESSE
MÖLME
BROISTEDT
HOHENASSEL
Hannover
Hildesheim
R. WESER
Flechtlinger Ridge
Harz
Ostmold

FIG. 55

Of the 25 fields (see Fig. 55) which are producing in NW Germany, 14 derive their production from the flanks of salt plugs where there is no accumulation on the crest of the salt intrusion; one (Heide-Meldorf) partly from the flanks and partly from the crestal area; four (Reitbrook, Sottorf, Meckelfeld and Etzel) from the crestal region but not the flank; and three from faulted structures closely associated with salt plugs. Of the remaining three fields, two (Emlichheim and Georgsdorf) are normal anticlinal folds and in the third (Lingen-Dalum) the accumulation is controlled by faulting. Of the 9,973,000te of oil produced in NW Germany to the end of 1944, 9,814,000te were derived from fields associated with salt plugs, and of this 8,180,000te were derived from flank fields.

The finding and exploitation of the salt plug flank fields entails the drilling of a large number of dry holes owing to the difficulty of finding the producing sands in the heavily faulted zones on the flanks of the plug. When found, the producing sands are often in a narrow belt. A remarkable instance of this is the Broistedt "field," which is a single gently curved line of eight derricks.

3. POSITION AT THE OUTBREAK OF WAR

In July and August, 1939, the German crude production amounted to between 55,000 and 60,000te/month, having been increased from an average of just under 20,000te/month in 1933; 14 new oilfields and one gas field had been discovered, of which two, Reitbrook and Heide-Meldorf, were major fields, and the old field of Nienhagen had been rejuvenated by the discovery of prolific extensions. Drilling was at the highest rate ever attained in Germany; about 220,000m were drilled in 1939. The proportion of exploration drilling had fallen to 33%, the rigs having been transferred to the new fields to speed up exploitation. Exploitation of the new fields was well advanced so that they were ready for a substantial increase in production.

4. DEVELOPMENTS DURING THE WAR YEARS

i. GENERAL

Summaries of the drilling and production data for the years 1939 to 1944 are given graphically in Figs. 56 and 57.

On the outbreak of war, production was quickly stepped up to 80,000te/month crude oil and everything was done to increase it further, drilling being concentrated in the newer and more prolific fields. In April, 1940, in Reitbrook alone there were 42 rigs running. By July, 1940, production was in excess of 100,000te/month, of which Reitbrook contributed nearly 40,000te. This was undoubtedly the right policy if the war was to be short, but as it turned out the reserves were quickly exhausted by drilling many more exploitation wells than were necessary. Had the surplus drilling capacity been allocated to exploration it would have speeded up the discovery of new fields to offset the decline of the older fields.

Throughout the war, the low proportion of exploration to exploitation drilling was continued:—

1939	33%
1940	24%
1941	27%
1942	29%
1943	26%
1944	25%

The following are the new fields discovered:—

1940 Hänigsen (southern extension of Nienhagen).
1941 Hademsdorf.
Hambüren.
Thören.
1942 Etzel.
Lingen-Dalum.
1943 Wesendorf.
Hohenassel.
1944 Netherlands Frontier Oilfields (Georgsdorf, Emlichheim and Coevorden).

This rapid development of the more prolific fields was followed by a rapid decline partly owing to production difficulties, especially at Reitbrook, and production declined from over 100,000te/month in July, 1940, to 60,000te/month in the autumn of 1942. Thereafter, until disorganisation caused by Allied bombing set in at the beginning of 1945, production was held at about 60,000te/month. During this latter period, the fields were exploited in a more rational manner. For example, Wesendorf, a high-pressure flowing field, was controlled most carefully to prevent avoidable water encroachment.

The discoveries towards the end of the war were of first-class importance. At Wesendorf, a salt dome flank field, only the eastern quarter of the possible producing area has been explored. The field is to the north of the Gifhorn basin. The discovery well was drilled for iron ore and oil production was found in the Dogger beta. Hohenassel, also discovered by boring for iron ore, is the most southerly field in the Hanover basin and extends southward the area of possible oil accumulation.

But the most important discoveries were the Netherlands Frontier fields, commencing with Lingen-Dalum. These fields are in no way associated with salt plugs and in this respect they are remarkable for NW Germany. At Lingem-Dalum the oil is in a SW dipping block cut to the north by an east-west fault which seals the reservoir rocks, a series of thin shell beds in the Wealden clay. The other fields, Georgsdorf and Emlichheim, are gentle anticlines. The latter is on the Netherlands frontier and no doubt continuous with the Coevorden field. These fields are in the early stages of exploitation and no water has yet been found. Exploitation has been slower than would have been expected, probably owing to the remoteness of the fields from refinery facilities, and the increasing transport difficulties.

ii. NATURAL GAS

In general, German crude is undersaturated, and the gas-oil ratios are small, but in the larger fields the amount of gas is considerable. Where the amount of gas available is sufficient it is passed through a charcoal absorption plant, and the petrol, butane and propane are removed, the stripped gas being used for raising steam or compressed and used as a fuel for motor transport.

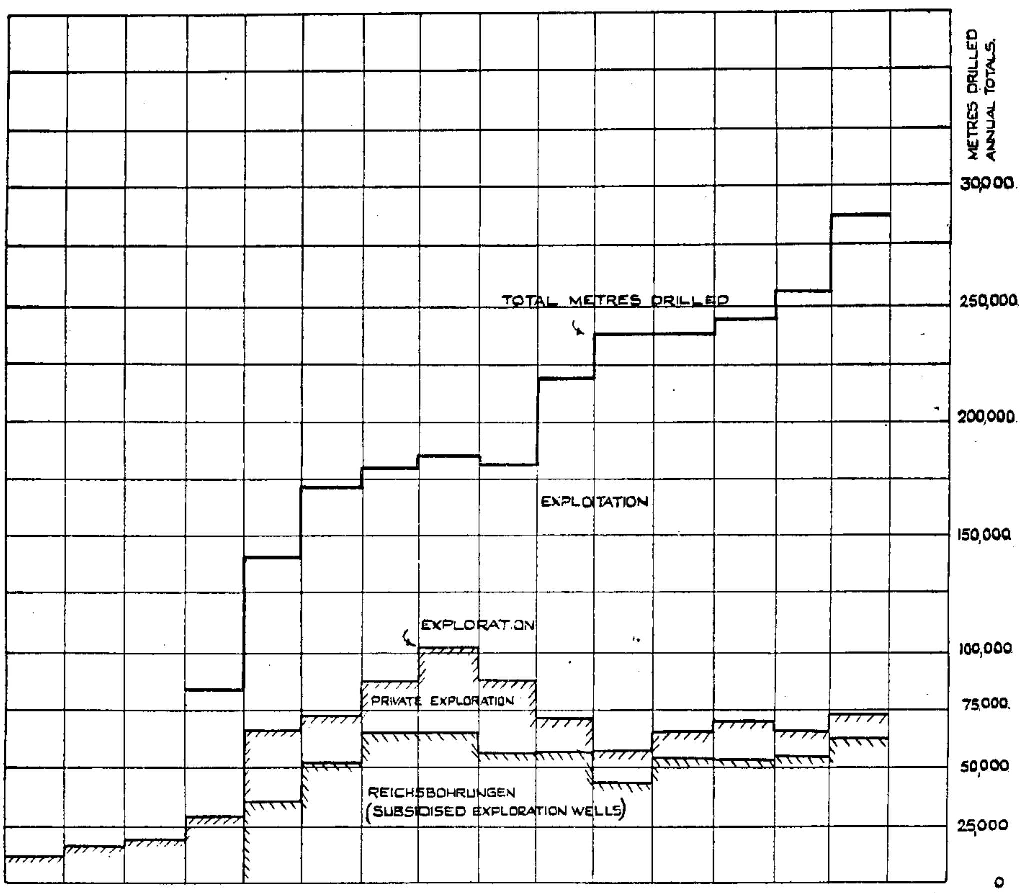
One gas field was discovered, Bentheim on the Dutch frontier (see Fig. 55). The discovery well blew in at the end of 1938, but development was slow owing to the difficult drilling. No use was made of the gas at first as it was hoped that it was associated with an oilfield, but after a number of wells were drilled, it was decided, in 1943, that no oil was present in the structure, and the field was put on production.

The field is a gentle anticline cut by cross faults. The gas is found in the "Plattendolomite," a dolomitic limestone of the Upper Zechstein, at 1,500 to 1,600m.

FIG.

DRILLING
ALTREICH,
(GERMANY LESS

METRES DRILLED



In 1943 an 8in line was laid to Hüls in the Ruhr where the gas was used for Buna rubber manufacture. The capacity of the pipe-line is 570,000m^3/day, but the offtake from the field was of the order of 300,000m^3/day. Production of gas to May, 1945, was 80,000,000m^3.

iii. EXPLORATION METHODS

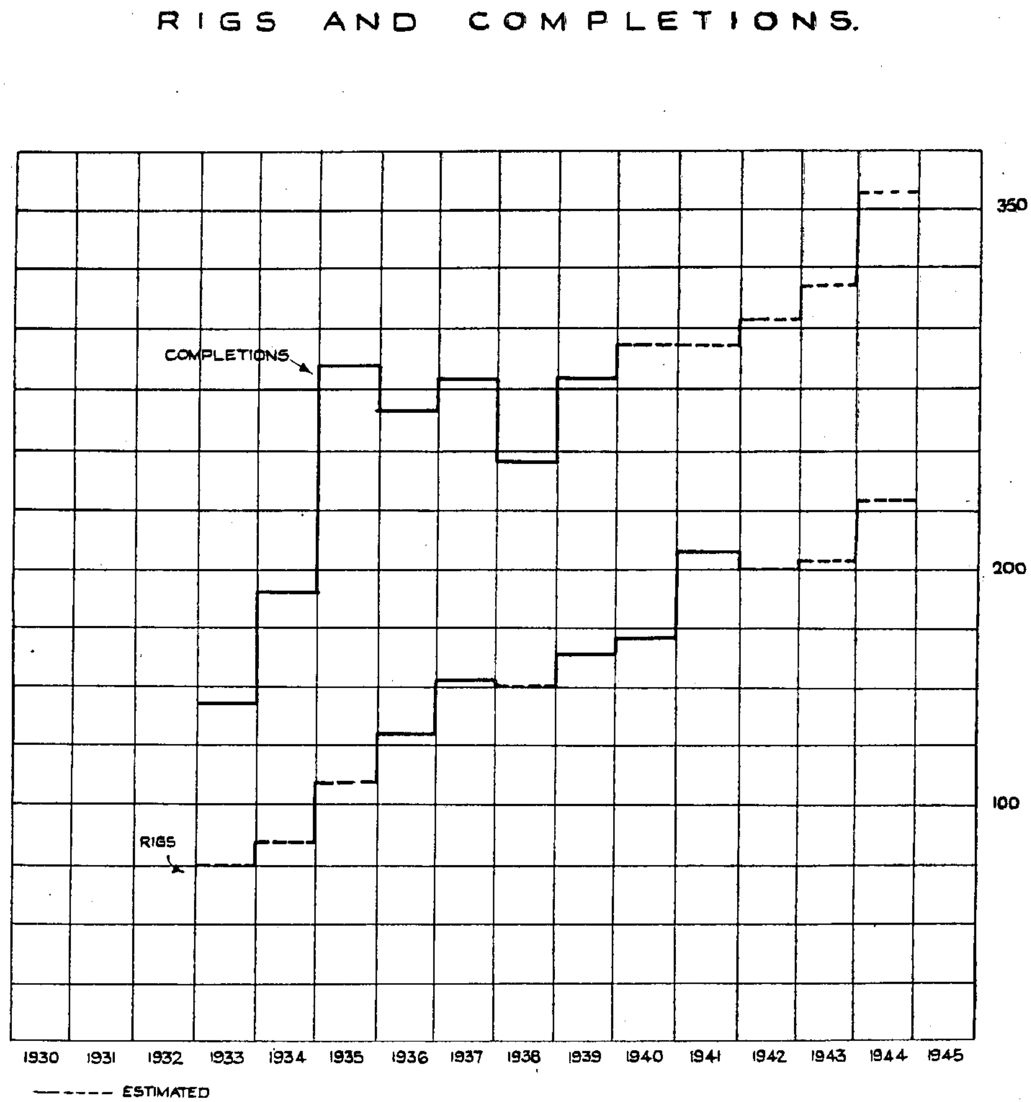
The foundation of the exploration campaign started in 1934 was the reconnaissance geophysical survey of Germany directed by the Reichsamt für Bodenforschung. Every favourable structure was then resurveyed in detail by seismic methods, often several times, before locating exploration wells. In general, the campaign was directed by the Reichsamt with the companies playing their part in the detailed geophysical surveys.

iv. DRILLING METHODS

Drilling was carried out almost entirely by ordinary rotary rigs of German manufacture. These are, in general, heavier than American designed outfits for the

56.

ACTIVITY
1930-1945
ALSACE, AUSTRIA)



same duty and, as a result, take a long time to move. Where electric power is available they are operated by electric motors, and elsewhere by diesels of the heavy, slow-running type. Drilling is slow, as drag bits are used where the formation would justify the use of rock bits. Where rock bits have to be used they appear to be of poor quality. Nothing new in the drilling line appears to have been evolved and the methods in general are rather out of date.

Mud control is poor and probably accounts for many of their drilling difficulties. Only gravity and viscosity are measured in the field, and mud samples have to be sent to a central laboratory for testing—often at infrequent intervals.

V. EXPLOITATION METHODS

On the exploitation side the technique is excellent. Competent geologists are on every field. Samples are

TABLE LXVII

TYPES OF CRUDE PRODUCED IN PRINCIPAL GERMAN OILFIELDS

Area	Oilfield	Crude sp.gr	Type	Producing formation	Remarks
Netherlands Frontier ..	Emlichheim	0·900	Paraffin base	Cretaceous	Benzine 5%, kerosene 5% and diesel oil 6%
	Georgsdorf	0·92	,,	,,	,,
	Lingen-Dalum	0·865	,,	Valendis	20–22% paraffin. Setting point of oil 17°C
Schleswig-Holstein ..	Heide-Meldorf	0·867	,,	Cretaceous	—
Hamburg Basin ..	Meckelfeld	—	—	,,	—
	Reitbrook	0·910	Mixed base	Eocene	—
	—	0·930	Mixed base	Cretaceous	—
	Sottorf	—	—	,,	—
Hanover Basin	Eicklingen	0·885	Paraffin base	Valendis and Wealden	—
	Fuhrberg	0·915	,,	Cornbrash	—
	Gifhorn	0·945	Asphalt base	Wealden	Useful source of bitumen
	Hademsdorf	0·905	Paraffin base	,,	Benzine 15%, gas-oil 11%
	Hanigsen	0·892	,,	Valendis and Wealden	—
	Hohenassel	0·875	,,	Corallian	—
	Mölme	0·866	,,	—	—
	Nienhagen	0·866 to 0·884	,,	Valendis and Wealden	—
	Oberg	0·855	,,	Wealden and Dogger	—
	Steimbke-Rodewald	0·935	Mixed base	Wealden, Serpuline and Cornbrash	—
	Thoren	0·942	Mixed base	Wealden	—
	—	0·847	Paraffin base	Dogger	—
	Wesendorf	0·847	Paraffin base	Dogger	—
	Wietze	0·942	Mixed base	Wealden	—
	—	0·878	Paraffin base	Rhaetic	—

taken at frequent intervals and cores where necessary. Vibrating mud screens are used so that sampling is reliable. Electric surveys (Schlumberger) are run in every well and, as a rule, the wells are surveyed directionally for deviation from the vertical. In many wells a temperature survey is run after cementing the casing to record the position of the cement.

Well completion methods vary according to circumstances from field to field. In some fields the casing is cemented right through the producing zone and is then gun-perforated. Elsewhere the casing is cemented above the producing zone and a liner is run. The liners are of various types according to circumstances—plain, perforated, slotted or wirewound.

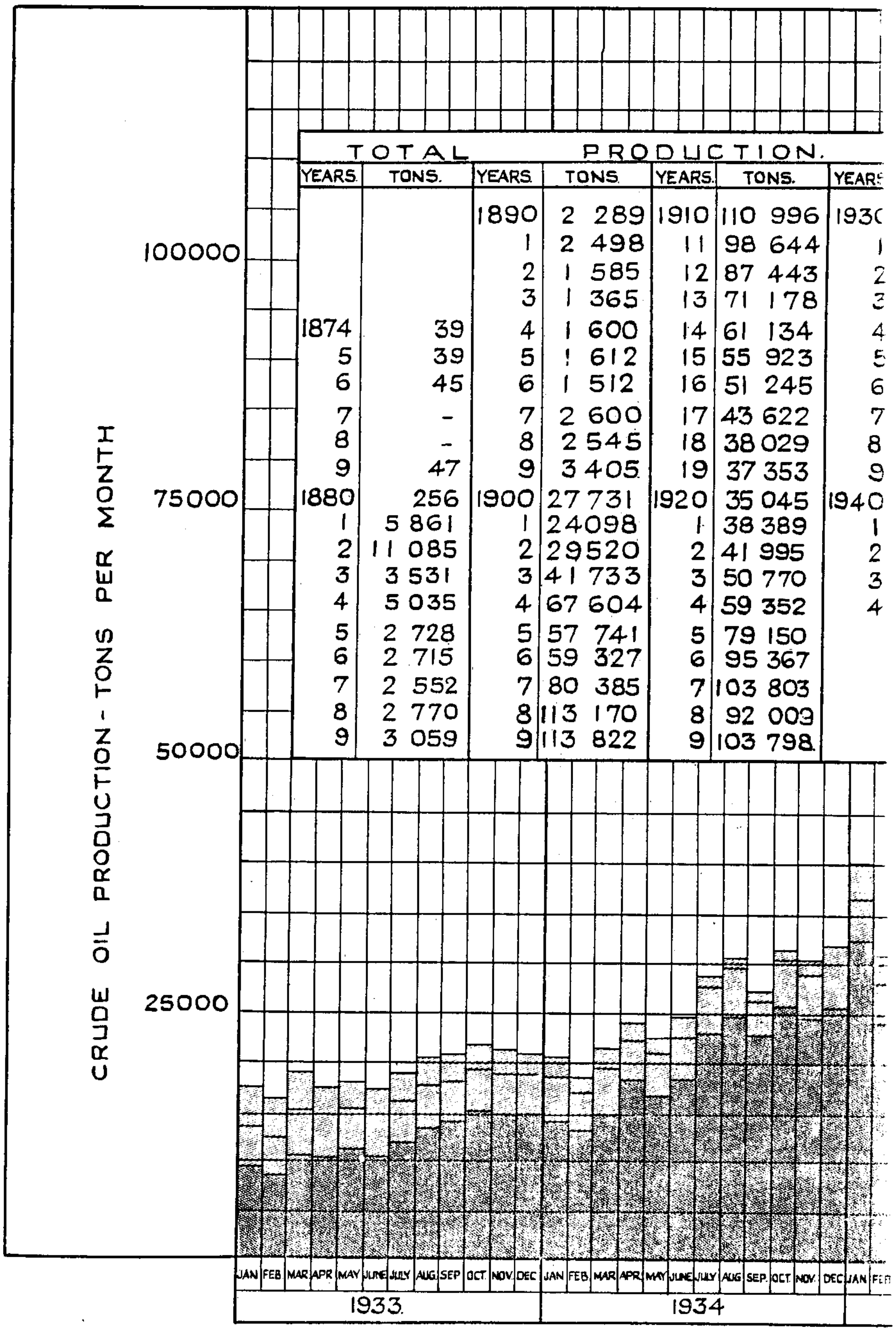
In the early years of the war when the emphasis was on production at any price, the fields were produced wide open, but after the disastrous collapse of Reitbrook more rational methods prevailed. Reitbrook itself is surveyed every six months by sub-surface recording pressure gauge and the production is distributed according to the results of the survey. The new flowing field, Wesendorf, has been carefully controlled from the start, production distribution having been guided by pressure surveys.

vi. INDUSTRIAL ORGANISATION

Although the State exercised a very considerable control of policy there was no nationalisation. The companies continued to operate from a business point of view on independent lines. Separate oilfields, however, were run on unit lines, and where more than one company had an interest in a field or new discovery a "consortium" was formed to run or develop the field. One of the participating companies as a rule managed the field in the interests of the "consortium," though in some cases the drilling was shared.

In common with other German industries, the oil-producing industry was organised in a "Fachgruppe" or council for representing the industry in dealings with the State and to transmit the instructions of the State to the individual companies.

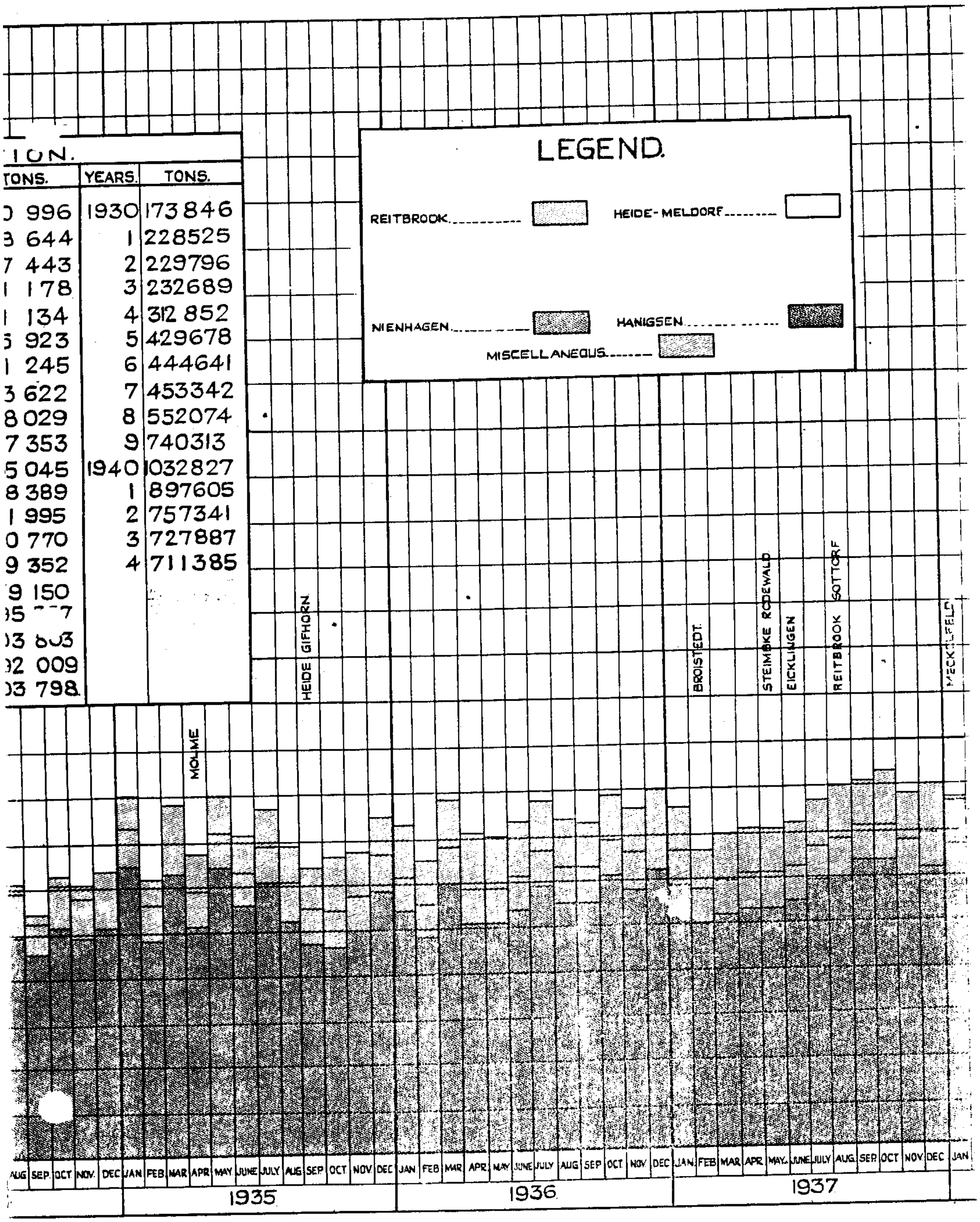
Data illustrating the types of German crudes are given in Table LXVII.



TOTAL		PRODUCTION.					
YEARS.	TONS.	YEARS.	TONS.	YEARS.	TONS.	YEARS	
		1890	2 289	1910	110 996	1930	
		1	2 498	11	98 644	1	
		2	1 585	12	87 443	2	
		3	1 365	13	71 178	3	
1874	39	4	1 600	14	61 134	4	
5	39	5	1 612	15	55 923	5	
6	45	6	1 512	16	51 245	6	
7	-	7	2 600	17	43 622	7	
8	-	8	2 545	18	38 029	8	
9	47	9	3 405	19	37 353	9	
1880	256	1900	27 731	1920	35 045	1940	
1	5 861	1	24098	1	38 389	1	
2	11 085	2	29520	2	41 995	2	
3	3 531	3	41 733	3	50 770	3	
4	5 035	4	67 604	4	59 352	4	
5	2 728	5	57 741	5	79 150		
6	2 715	6	59 327	6	95 367		
7	2 552	7	80 385	7	103 803		
8	2 770	8	113 170	8	92 009		
9	3 059	9	113 822	9	103 798		

…ION.

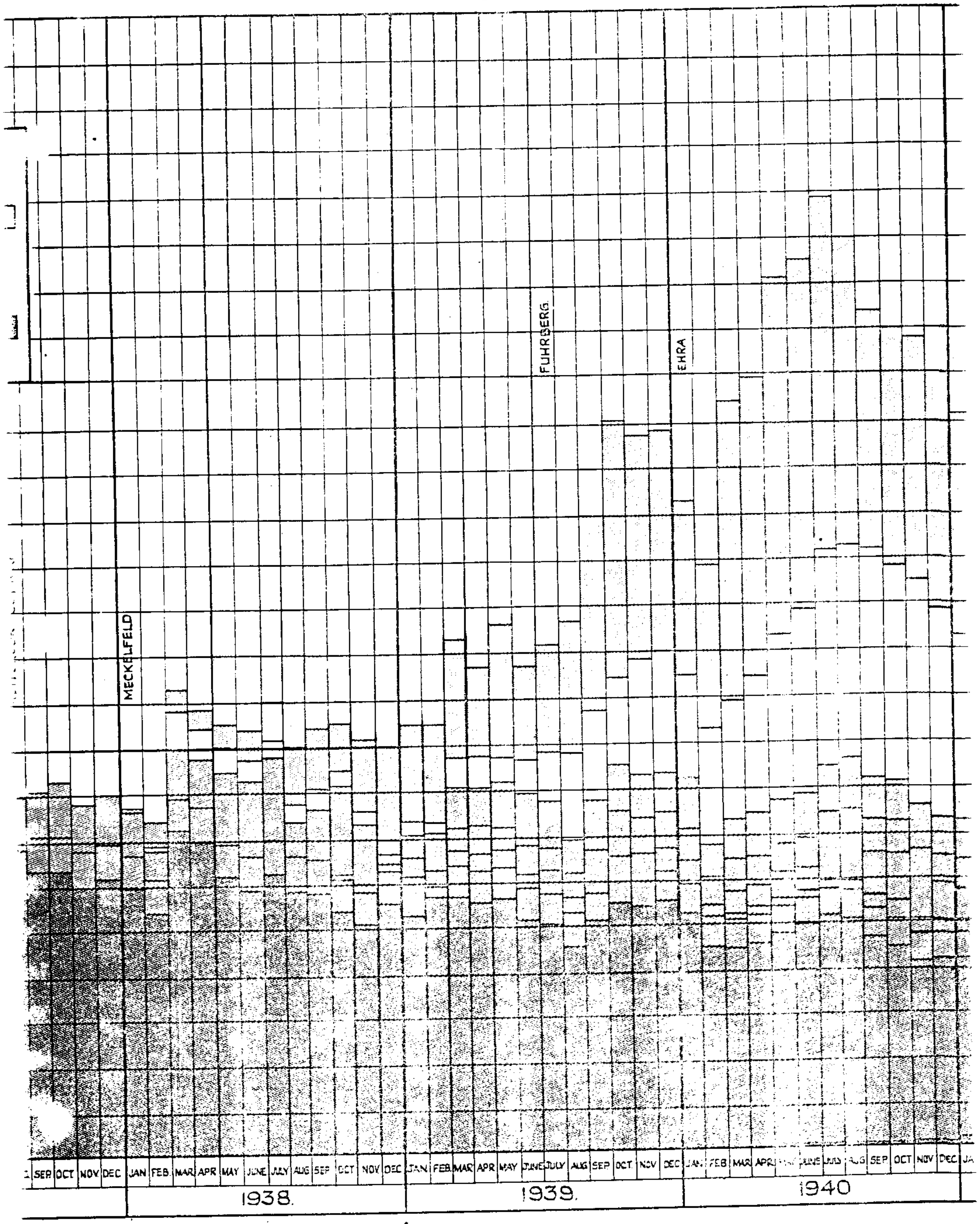
TONS.	YEARS.	TONS.
) 996	1930	173 846
3 644	1	228525
7 443	2	229796
I 178	3	232689
I 134	4	312 852
5 923	5	429678
I 245	6	444641
3 622	7	453342
8 029	8	552074
7 353	9	740313
5 045	1940	1032827
8 389	1	897605
I 995	2	757341
0 770	3	727887
9 352	4	711385
9 150		
35 [illegible]		
03 603		
92 009		
03 798		



GERMAN CRUDE OIL PRODUCTION.

(EXCLUDING GREATER REICH, AUSTRIA & FRANCE).

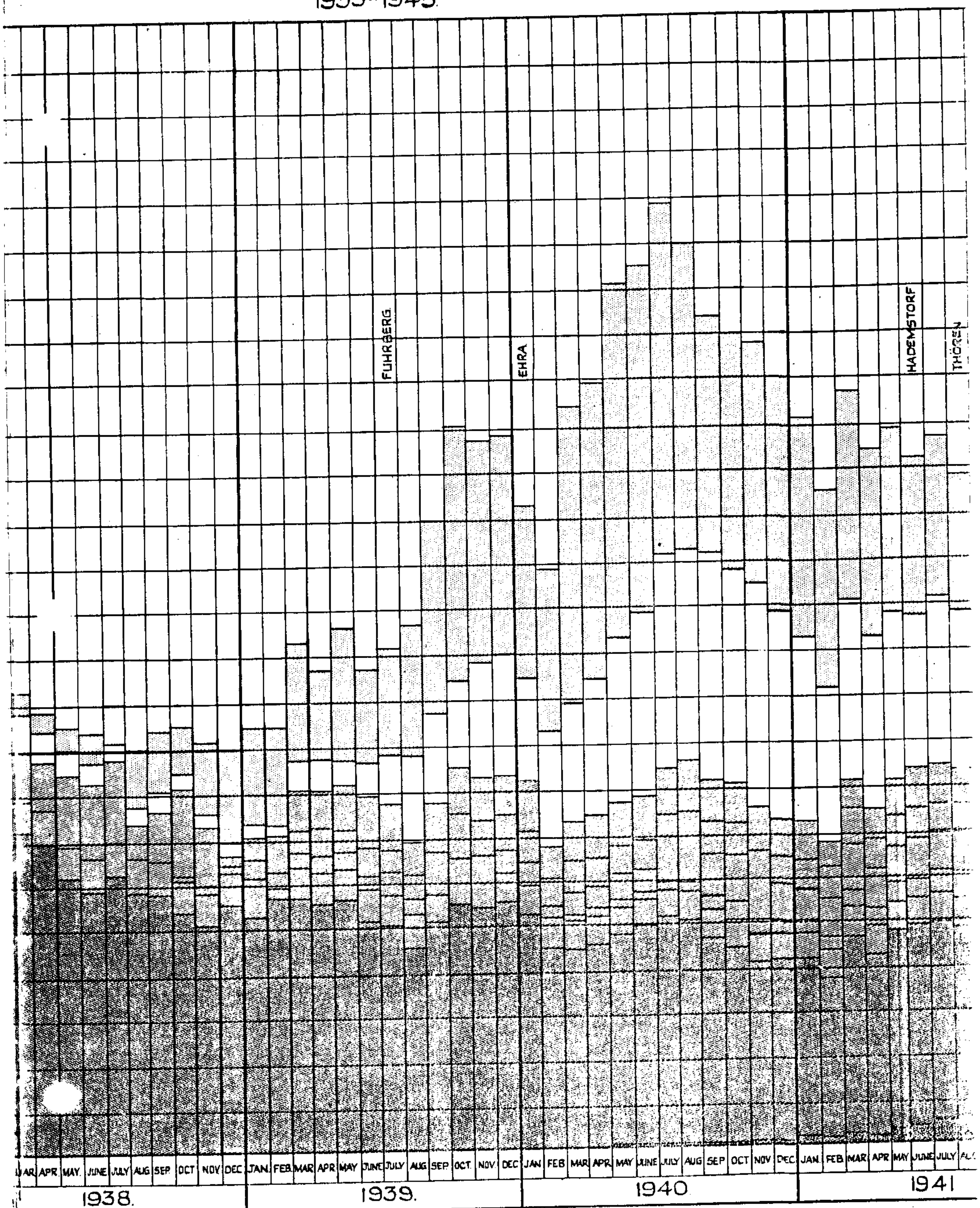
1933-1945.



GERMAN CRUDE OIL PRODUCTION.

(EXCLUDING GREATER REICH, AUSTRIA & FRANCE).

1933-1945.



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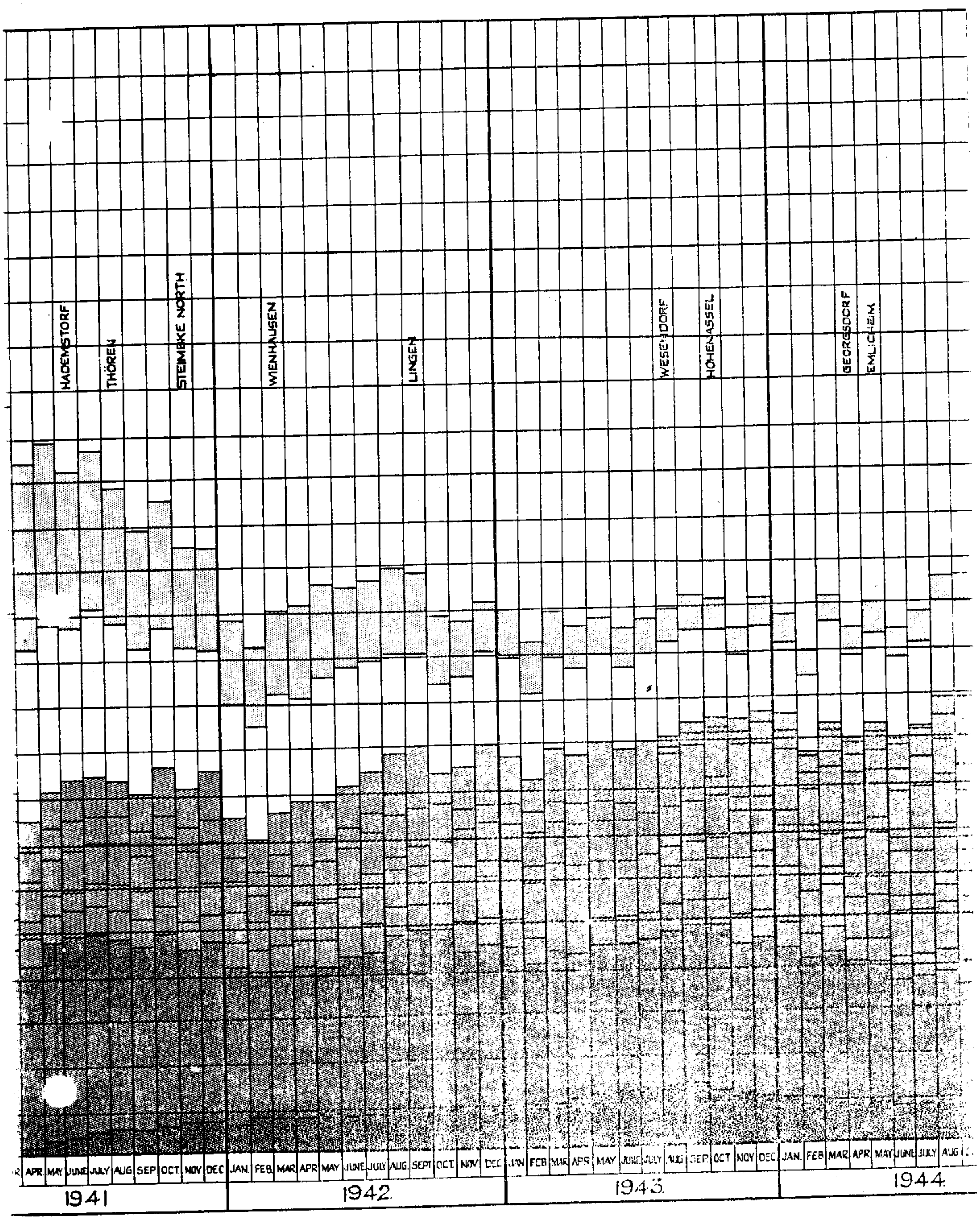
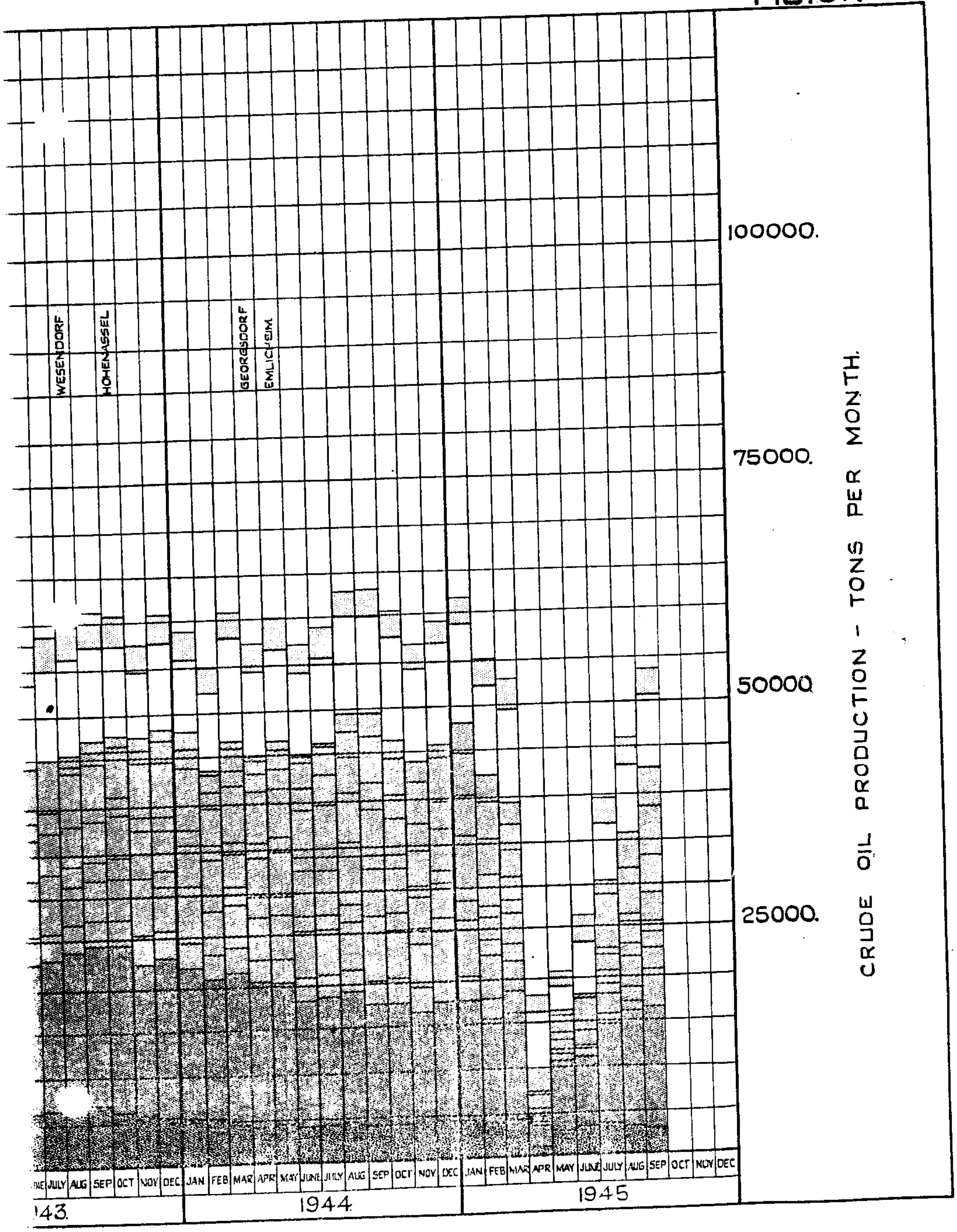

HADEMSTORF
THÖREN
STEIMBKE NORTH
WIENHAUSEN
LINGEN
WESENDORF
HOHENASSEL
GEORGSDORF
EMLICHEIM
APR MAY JUNE JULY AUG SEP OCT NOV DEC
1941
JAN. FEB MAR APR MAY JUNE JULY AUG. SEPT OCT NOV DEC
1942.
JAN FEB MAR APR MAY JUNE JULY AUG SEP OCT NOV DEC
1943.
JAN. FEB MAR APR MAY JUNE JULY AUG
1944

FIG. 57.


WESENDORF
HOHENASSEL
GEORGSDORF
EMLICHEIM
100000.
75000.
50000.
25000.
CRUDE OIL PRODUCTION - TONS PER MONTH.
JULY AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUNE JULY AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUNE JULY AUG SEP OCT NOV DEC
1944
1945

F—Petroleum Refining

1. INTRODUCTION

The refining industry of Germany at the outset of the war was largely employed in treating imported crude, : was well able to take care of the reduced quantity obtained from Germany alone. It played a much less important part in the German war economy than the British and US refining industries did in the Allied cause. The main reasons for this were:—

(1) The existence of very highly developed synthetic oil industries based on coal, especially those using the destructive hydrogenation process.

(2) The relatively small amount of crude oil available in Germany.

(3) The German method of distribution, which involved the refineries solely in making components or base stocks of important materials such as aviation spirit or lubricating oil, and allowed them no part in the main scheme of preparation and distribution of the finished products.

2. REFINERIES

The refineries were situated as reasonably near to the fields as possible, but Hamburg and district was the main centre of the industry. There were also comparatively large refineries at Bremen and Misburg (Hanover). Before the war these refineries operated mainly on imported topped crudes, principally of Mexican and Venezuelan origin, producing lubricating oils, waxes, greases, asphalt, and special cuts of light spirit.

During the war the refineries were called on to process various indigenous crudes from Reitbrook, Heide, Nienhagen, etc., supplemented by supplies brought in from Austria and Rumania. These crudes were topped and the residues were worked up into a somewhat similar range of products to that manufactured before the war, whilst the petrol and gas oil cuts were sent elsewhere for blending into engine fuels.

Broadly speaking, all the plant and equipment in the German crude oil refineries is of conventional pattern and no new types of process were developed during the war.

A brief description of the main German crude oil refineries with their locations is as follows:—

i. RHENANIA-OSSAG

a. Harburg (Hamburg)

This refinery had a capacity of about 450,000te/yr crude oil input and contained plants for the manufacture of raw white spirits, high viscosity index (VI) lubricating oils, and all grades of asphalt. The white spirit and high VI lubricating oil bases were sent to the refineries of the Rhenania-Ossag located at Wilhelmsburg and Grasbrook to be worked up into finished products.

The refinery had also contained a synthetic lubricating oil plant with a capacity of 400–700te/month, designed for cracking wax followed by an aluminium chloride 'ymerisation of the resultant olefins. This plant was later dismantled and transferred to one of the underground refineries but not re-erected.

b. Wilhelmsburg (Hamburg)

This refinery had a capacity of some 50,000te/yr and was designed particularly for the manufacture of white spirit and special boiling point products for use as general industrial and domestic solvents and diluents, cleaning spirits, etc. Raw stocks for refining were normally provided from the Harburg refinery, with additional supplies from other refineries or imported as required to meet market demands.

c. Grasbrook (Hamburg)

This refinery was designed for the manufacture of a wide range of fully refined high VI lubricating oils and greases from base lube stocks supplied from outside but mainly from the Harburg refinery. Production averaged 120,000te/yr lubricating oils and 5,000te/yr greases.

Considerable experimental work was done during the war to obtain suitable substitutes for standard grades of both lubricating oils and greases, but it is considered that none would have any real commercial value.

ii. DEUTSCHE VACUUM OIL AG

The above Company, with refineries at Oslebshausen and Schulau, had their own production of crude oil.

a. Oslebshausen (Bremen)

This refinery had a capacity of 120,000te/yr crude oil input and was designed mainly for the manufacture of finished high VI lubricating oils which amounted to some 35,000te/yr, the balance of the products being motor spirit, kerosene, industrial lubricants and fuel oils.

The most interesting feature of the refinery is the Duosol extraction unit, which has a two-stage extraction process, the first stage giving a product which in the second stage is converted into both high VI and low VI lubricating oils.

Stage 1.—4 volumes propane, 1 volume Selecto.

Stage 2.—Add a further 1 volume propane and 4 volumes Selecto.

The Selecto is 50/50 phenol/cresol mixture.

In practice the high VI oil from this type of two-stage extraction process is so well refined that a hot contacting process is not required for reduction of colour. The oil was, however, usually given a low-temperature contact treatment at 80–90°C with about 1% of earth to meet contract clauses.

b. Schulau

This refinery is very old and was designed for the manufacture of a fairly complete range of industrial lubricants and compounds as well as all types of greases. The plant had an overall intake capacity of some 60,000te/yr crude oil and raw distillates from the Oslebshausen refinery.

iii. DEURAG/NERAG (MISBURG, HANOVER)

This is one of the most complete of the German refineries from the point of view of the number of processes operated and is one of the largest, having a crude oil charging capacity of nearly 400,000te/yr, and was designed for the manufacture of finished petrol, kerosene, lubricating oils, fuel oils and petroleum coke.

The equipment consists of:—

(*a*) Atmospheric and combination atmospheric–vacuum distillation units.

(*b*) Dubbs cracking unit charging a mixture of reduced crude, furfural extract, wax and asphalt. With this are combined pressure distillate treating and re-run facilities together with a UOP polymerisation plant, although this last was never operated since no UOP catalyst was ever made available and the development of a substitute through co-operative work with Ruhrchemie proved unsuccessful.

(*c*) Complete solvent extraction lubricating oil plant using the furfural process. This included preliminary propane de-asphaltising facilities of the Kellogg two-stage type, together with acid-treating plant, contact plant and benzole-acetone dewaxing plant—this latter designed by Texaco.

iv. DEUTSCHE ERDÖLWERKE AG (HEIDE'SCHLESWIG-HOLSTEIN)

The refinery contained two topping plants of conventional type with a combined intake capacity of 120,000te/yr which had been erected to process the crude oil from the adjacent Heide oilfield.

In addition, an interesting process, more of the shale oil type, had been developed in the refinery area, where at a depth of about 100m there were deposits of an oil chalk of greasy consistency containing 15–18% oil. This material differs considerably from oil shales or sands processed in other parts of the world and special distillation technique had been developed for its processing.

The distillation of the oil from the chalk took place in two kilns, each about 2m diameter and 45m long, which had been constructed by Lurgi to an elaborated design of the type used for processing Esthonian oil shales. Using a number of hydraulically-operated gates to form a system of vapour locks, a train of small trucks, each holding 2–4te oil chalk, was passed through the kiln.

At each of about 20 stations, a truck was located over a pipe supplying hot flue-gas which flowed directly through the material in the truck. As the trucks intermittently progressed through the kiln by means of hydraulic rams, the flue-gas temperature was increased, finally reaching about 600°C, when nearly all the oil was supposed to be removed from the chalk. The spent chalk was quenched and returned to the mine as back filling.

The flue gas, which was recirculated without intermediate cooling, was heated indirectly by means of a furnace burning water gas made from coke. The process never operated anywhere near design capacity and considerable coking troubles occurred necessitating long off-stream periods for cleaning.

The design figures were 400–500te/day oil chalk per kiln with an oil recovery of 14%, equivalent to 60–70te/day oil. The best working figures obtained during the short period before the plant was finally bombed out of commission were an input of 250te/day with a recovery of only 10%, or little more than a third of design capacity.

Because of the disappointing results obtained, the authorities sponsoring the project had authorised the design of two new kilns which can best be described as very large bauxite or spent oxide roasting furnaces basically of the Herreshof design. This design was also extremely elaborate, but appeared to be more suitable for dealing with the oil chalk than the kiln system which had proved such a wasted effort.

The cost of all this work was borne by the German Navy and amounted to approximately RM20,000,000 for a possible output of little over 15,000te/yr.

v. EBANO ASPHALTEWERKE AG

a. Ebano (Harburg-Hamburg)

This refinery, with a capacity of 720,000te/yr crude oil, was designed for the manufacture of all grades of straight and blown asphalts. The raw distillate production, namely, motor spirit, kerosene and diesel oil, was not treated in the refinery, but was sold direct to outside marketers.

vi. GENERAL

In addition, there are a number of smaller petroleum refineries mainly engaged in the manufacture of special solvents, lubricating oils and asphalts, the more important of which are as follows:—

(1) Reisholz (Rhenania-Ossag): White spirit and special boiling-point benzine production.

(2) Monheim (Rhenania-Ossag): Industrial lubricating oils production.

(3) Salzbergen (Wintershall AG): HVI lubricating oils production.

(4) Ostermoor (Mineralöl und Asphaltwerke AG): Asphalt production.

(5) Hamburg (Euro-tank AG): Motor spirit, kerosene, fuel oils and asphalts.

3. UNDERGROUND PLANTS

Foreseeing the probability of further heavy air raids, German industry as a whole, working under what was known as the Geilenberg Plan, decided to construct a very large number of underground plants, making use not only of existing quarries, but of lime and sandstone hills which are particularly suitable for making rapid and large excavations. The greatest priority was given to the sites for factories for the manufacture and assembly of aircraft, rockets, etc., but in addition to this programme, plans had been made for the erection underground of a large number of oil refineries. Apart from the truly underground plants, there was a large number of small-batch distillation units known as "Rosts," which were mainly built in the ruins of refineries and factories throughout the country, and continuous distillation units known as "Ofens," which were generally erected in quarries and very skilfully camouflaged. The combined output of these dispersed plants was about 15,000te/month in October, 1944, when they began to produce, rising to rather over 50,000te/month in March, 1945, when the great majority were completed.

The underground refineries included four lubricating oil plants of which the most important was the one located at Porta, near Minden, and known by the code name of "Dachs I." This was a complete lubricating oil plant using the furfural process, comprising distillation, solvent extraction, solvent dewaxing, clay contacting and clay extraction plant. The installed plant was of conventional type and had not been specially designed for erection underground, and considerable ingenuity had been used in the erection of tall fractionating columns and the installation of complex ventilating facilities and fire precautions. The plant was designed for an intake of 80,000te/yr and all the units were in a reasonable balance for a production of about 30,000te/yr finished lubricating oil of high quality. Erection was about 90% complete, and it was hoped to have commissioned the plant in May, 1945.

Two other large synthetic lubricating oil plants using the aluminium chloride polymerisation of olefins process were planned for re-erection underground. These were the Rhenania-Ossag plant *ex* Harburg to be transferred to Osterode in the Hartz mountains and the Ruhrchemie plant *ex* Oberhausen-Holten to be transferred to Willingen, near Waldeck, but in neither case was the plant completed, the majority of the equipment having been destroyed by air attacks on railway sidings, etc., whilst en route.

4. COSTS

As all German refinery equipment was conventional and, in fact, judged by modern UK and US standards, rather old-fashioned, no attempt has been made to collect details of operating costs. Both from the desire to conserve oil and in view of the cheapness and availability of coal, it was very common to use coal, not only for steam and power purposes, but in many cases for the oil processes themselves, an interesting example being the firing of the solvent recovery furnaces of the Duosol plant at Oslebshausen with coal.

5. DISTRIBUTION OF PETROLEUM PRODUCTS

During the war, distribution from the refineries for military purposes was made in the first place to Government-operated depots known as WIFO (Wirtschaftliche Forschungsgesellschaft) installations where motor spirit, aviation spirit and lubricating oils were stored; here leading and blending operations were carried out on the products to meet the official specifications.

The Germans had no inland pipe-line distribution system corresponding to that constructed in this country during the war, and the main distribution of oil products was carried out using existing road, rail and water transport facilities.

An interesting result of the distribution through the WIFO organisation was that no tetra-ethyl lead deposition trouble due to long storage of leaded fuels was encountered as the supplies from these installations to airfields, base depots, etc., took place only a short interval after the leaded blends were completed. Some evidence of this trouble commencing was found when high-performance fuels of high aromatic content were introduced.

Civilian and industrial supplies, on the other hand, were controlled by the Zentral Büro für Mineralöl, which was a distributing organisation corresponding very closely to the British Petroleum Board, marketing a limited number of petroleum products standardised to meet pool specifications.

Most of the WIFO blending and storage installations had been designed and constructed before the war and were located at strategic sites throughout Germany. In general, these installations were self-contained and consisted of buried or partly buried storage tanks, underground blending and loading pump-houses, lead-blending plants and adequate facilities for bulk loading and for filling aviation spirit, motor spirit and lubricating oils into jerricans and drums. A typical installation of this type was that located at Achim, near Bremen, which had been specially designed to supply the German Navy with the full range of petroleum products. It was built almost entirely underground and included a large number of well-dispersed underground tanks, some of which were as large as 20,000te capacity, giving a total storage of over 250,000 tonnes. All these installations were camouflaged and were adequately serviced with special road and rail facilities.

Summarising, it may be said that the industry devoted its attention to converting German crude oil into the maximum possible production of lubricating oil. Its success may be judged from the fact that it was responsible for between 90 and 95% of the total lubricating oil production during the war.

G—Lubricating Oil Production

1. GENERAL

The preceding section on petroleum refining dealt with the production of natural petroleum lubricants, from which it will have been seen that no new developments in manufacturing processes had been made by the Germans during the war.

As Germany was short of natural petroleum and had produced the bulk of her fuels by synthetic processes based on coal, it was expected that new developments would have occurred in the field of synthetic lubricating oils.

To obtain a comprehensive view of German developments in this field, technical personnel of all the producers of synthetic lubricants were found and interrogated and most of the plants producing these synthetic lubricants were visited.

Table III in the summary of this report (page 6) shows the sources and methods of manufacture used for the production of the synthetic grades, and more details on the methods of manufacture form the substance of this section.

The synthetic lubricating oils produced fall into two main classes.

Hydrocarbons

These are mainly polymers of olefins made either from a single pure hydrocarbon such as ethylene or from a mixture of olefins such as a specially prepared distillate containing olefins from, say, C_8-C_{12}. As will be seen later it is also practicable to condense chlorinated paraffins and aromatics to give a lubricating oil of a more aromatic nature than is obtained from the olefin polymerisation.

Non-Hydrocarbons

The German developments were found to be almost entirely in the field of esters.

As it was the desire of several German industries to enter this field, it seemed that development might take place in different ways according to the raw materials most readily available, and this was found to be the case. IG were found to have played a very large part in this development, but Ruhrchemie, who might also have been expected to contribute largely, in view of the olefins available from their Fischer-Tropsch plants, had made little progress in translating the results of their developments to large-scale production.

2. HYDROCARBONS

i. IG DEVELOPMENTS

a. Research and Development

IG had carried out extensive research work between 1929 and 1936 on the subject of the relation of VI to constitution and the mechanism of formation of olefin polymers. From this work on well-defined chemically homogeneous hydrocarbons, a picture of the structural conditions necessary for producing a good viscosity-temperature behaviour was built up. This work was an indispensable aid to IG in the technical development of the two manufacturing-scale synthetic lubricating oil processes—the polymerisation of wax cracking products and ethylene polymerisation—both of which are described below.