

FIAT FINAL REPORT NO. 755

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HIGHLIGHTS OF GERMAN IRON AND STEEL PRODUCTION TECHNOLOGY

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JOINT INTELLIGENCE OBJECTIVES AGENCY

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D C M O N T S A F E T Y ▼ 2129

OFFICE OF MILITARY GOVERNMENT FOR GERMANY (U.S.)
Office of the Director of Intelligence

FIAT FINAL REPORT NO. 755

30 April 1946

HIGHLIGHTS OF GERMAN IRON AND STEEL
PRODUCTION TECHNOLOGY

BY

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Joint Intelligence Objectives Agency

FIELD INFORMATION AGENCY, TECHNICAL

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HIGHLIGHTS OF GERMAN IRON AND STEEL PRODUCTION TECHNOLOGY

I. INTRODUCTION

The following survey of the process metallurgy of the German iron and steel industry during World War II is based upon interviews with German officials and metallurgists, personal visits to selected plants, and a partial review of reports of other American and British investigators, supplemented by the study of numerous unpublished documents and a limited search of published literature.

Prewar trends in German iron and steel practice are described briefly in an article (in English) by Fritz Springorum in Stahl und Eisen (Vol. LVI, Sept. 1936), and it was found that most phases of German war time practice have at one time or another been covered in prewar articles. References are given herein to such articles as will serve to elaborate certain details of practice as outlined in this report. War time practice, and research activities also, reflected necessary readjustments to abnormal conditions which became even more confused after Germany's final defeat. Early in 1946 many of the Ruhr plants had resumed operations at 20 to 30% capacity but conditions were still fantastically abnormal. Metallic mixtures were based upon what ores and other iron-bearing materials were already on hand or could be delivered under existing transportation and foreign exchange limitations. Fuel supplies were insufficient in quantity and variable in quality. Occasionally a furnace would have to be shut down for lack of coke or gas but again blast furnaces were operating occasionally not simply to produce iron but to contribute to the area supply of gas. Since necessity is the mother of invention, the chaotic state of the industry led to the testing and commercial adaption of practices that would never have been attempted in the course of normal operations.

In broad perspective German technology naturally tends to parallel American practice. German metallurgists are familiar with technical articles and scientific papers published in Great Britain and the United States and many of them have visited one or both countries. Conversely their own experience and ideas have been mostly written up and hence made available for study by their British and American colleagues. It follows that the present report contains much that is already known to well informed members of the profession in English speaking countries. Nevertheless it is hoped that it will serve to give perspective and also to disclose certain details which are novel and which may show the way to improvements in American technology even though they probably may never be transplanted bodily into American practice. The difference in economic environment is perhaps indicated by the fact that postwar German daily wages in marks are roughly the

same as they are in the United States in dollars.

Special acknowledgment is due to Dr. Walther Rohland, former Director of the United Steel Works who was visited at the Dustbin detainment camp near Frankfurt-on-Main and who previously supplied a written report covering various aspects of the iron and steel industry in response to a request from Dr. A. B. Kinzel, former European Representative of the Metals and Minerals Subcommittee, T. I. I. B. Acknowledgment is also due to a comprehensive review of the industry resulting from an interrogation by Mr. H. C. Dawson of the Control Commission for Germany (British element) or Dr. Hermann Röchling. Dr. Röchling was Chairman of the Reich Vereinigung Eisen and was also head of the Iron and Steel Works bearing his name. Finally the subject matter was checked and additional valuable information obtained from various officials from the German Iron and Steel Institute in Düsseldorf. Dr. Loh, the blast furnace specialist, and Dr. Ristow, the steel making specialist, were especially helpful. The author is also indebted to Dr. William Pollitzer who accompanied him on a dozen plant visits and interviews. Without Dr. Pollitzer's assistance in overcoming the language handicaps, many details of practice would have escaped this record.

II. ECONOMIC BACKGROUND

A. ORGANIZATION OF THE GERMAN IRON AND STEEL INDUSTRY

In Germany, perhaps more even than in the United States, war-time technology was developed to meet extraordinary conditions. More and better steel had to be made, in part from lower grade or substandard raw materials. New construction and equipment had to be kept to an irreducible minimum and various expedients had to be devised to meet new conditions with equipment designed for use under wholly different economical conditions. Inasmuch as recent changes in German process metallurgy are so largely in response to changes in the economic environment, it follows that the basic economic factors need first to be examined before attempting to evaluate the technology that was developed to meet emergencies as they arose.

When Hitler's legions invaded Poland, German ranked second only to the United States among iron and steel producing countries, contributing one-fifth of the total world output. In 1938, an all-time record year, the production figures were 17.8 million tons of finished steel products. Of a total of 175 blast furnaces, all but 30 were active in that year. Over 70% of the output of pig iron and almost 70% of the ingot tonnage came from Rhenish-Westphalia, chiefly from an area roughly 10 by 40 miles in the valleys of the Rhine and Ruhr where the famous high-grade coal mines are situated. Almost all of the steel plants in this area,

which stretches from Duisburg to Dortmund, have blast furnaces and produce their own coke. Many of them are important producers also of machinery, armament, and other finished products. They are linked to the Ruhr gas and electricity grids which supply consumers many miles from the Ruhr, covering what is generally recognized as the most intensively industrialized region in the world.

About 15% of the prewar output of German iron and steel was produced in the Saar within a rough triangle, 20 by 14 by 12 miles, whose corners are Dillingen, Saarbrücken, and Neunkirchen. The Saar industry is also based on local coal fields and the coke plants are integrated with the blast furnaces and steel works which are linked into a local gas and electricity grid. The coke, however, is much inferior to Ruhr coke and there is a much smaller concentration of other industries in the Saar than in Rhenish-Westphalia.

Much of the remaining iron and steel production came from Silesia, being concentrated in a few plants along the Polish frontier near Gleiwitz and using fuel from local mines.

Apart from a few foundry iron furnaces and other small operations, chiefly in Siegerland-Hesse and Bavaria, the extensive Hermann Göring plants under construction at Salzgitter constitute the only important example of German iron and steel plants situated close to iron ore deposits.

(1) Raw materials

In 1938 the output of ore in Germany proper totalled 11.1 million tons, having an iron content of only about 3.3 million tons. Consumption of iron ores was around 32.4 million tons of which 65% was imported. However, owing to their much higher average grade, foreign ores supplied a much larger percentage of the 26 million tons of iron contained in materials smelted in prewar Germany. Additional metal was derived from smelting slags and pyrite cinder, much of the latter being actually of foreign origin. In 1938 approximately 1 million tons of iron were charged to German blast furnaces in the form of scrap, about another 1 million tons in the form of pyrite cinder, and approximately 1.7 million tons in the form of slag and sinter. Germany's own chemical industry employed imported pyrite and much of the pyrite cinder from acid plants in other countries -- Belgium, The Netherlands, and Sweden, in particular -- was shipped to Germany where suitable sintering facilities were available to prepare this material for blast furnace use. For both low and high phosphorus ores German blast furnaces were largely dependent on Scandinavian, French, Spanish, and North African sources. Table I shows analysis of typical ores used in a large Ruhr plant (Krupp-Rheinhausen).

Domestic supplies of manganese and the various alloying metals were even more meager. Apart from vanadium, all alloying

metals, or their ores, had to be obtained from abroad and to a large extent from overseas -- chromium from Turkey or Africa, tungsten from China, molybdenum from North American, nickel from Canada, manganese from Africa and Russia, and cobalt from Belgian Congo and Morocco.

TABLE I

ORES SMELTED IN GERMAN BLAST FURNACES - TYPICAL ANALYSES

(Krupp-Rheinhausen)

	Swedish ---			Minette ---		Domestic ---		
	Kiruna "A"	"C"	A	B	Lahn Germany	Harz	Siegen and	Salzgitter
Fe	67.1	66.0	31.0	29.65	31.90	21.25	48.30	55.70
FeO	27.15	25.35	10.94	9.27	11.22	16.51	0	8.51
Fe ₂ O ₃	65.85	66.23	32.20	32.12	33.18	12.08	69.07	41.61
Mn	0.10	0.13	0.31	0.28	0.26	0.23	9.20	0.28
P	0.036	0.35	0.65	0.66	0.18	0.46	0.007	0.44
SiO ₂	2.30	3.10	8.20	6.85	18.72	15.26	10.90	23.2
Al ₂ O ₃	0.70	0.50	4.25	4.30	3.25	9.88	0.61	8.30
CaO	0.80	1.50	17.20	19.30	13.3	18.58	1.10	4.80
MgO	1.10	1.00	1.30	1.43	1.25	2.68	3.76	1.95
Cu	0	0	0	0	0	0	0.16	0
S	0.02	0.02	0.05	0.06	0.81	0.24	0.21	0.20
Zn	0	0	0	0	0.05	0	0.03	0
Pb	0	0	0	0	0	0	0	0
As	0	0	Trace	Trace	Trace	Trace	0.03	0.03
V	0.13	0.11	0.04	0.03	0	0.06	0	0.11
Cr	0	0	Trace	Trace	0	0.04	0	0.04
TiO ₂	0.80	0.50	0.17	0.17	0.33	0.28	Trace	0.25
BaO	0	0	0	0	Trace	0	0	0
CO ₂	0.20	0.20	15.7	17.80	13.5	16.60	0.85	2.90
H ₂ O	0.50	0.30	7.50	6.60	3.20	5.70	0.52	5.50
Alkalies	0.40	0.40	0.40	0.30	0.50	0.80	0.15	1.29
R	3.80	4.63	8.60	7.45	20.70	17.80	12.10	26.80

Limestone, for either blast furnace flux or steel works use, is abundant in Germany. A typical cost figure at a Ruhr furnace is RM 4.2 per metric ton. The principal iron and steel companies in the Ruhr own large deposits of limestone and dolomite which can be brought to their plants by short rail haul. Some of the best high-calcium stone comes from the vicinity of Liege, Belgium, but the main supply of lime stone for the Ruhr area is from local quarries. Dolomite comes into this area from nearby Stolberg which is close to Aachen. Lime stone quarries near Wülfrath, near Düsseldorf, have furnished most of the lime stone for the steel industry of the western Ruhr. Two companies operated in this area, the Rheinische Kalksteinwerke, with three quarries, and Rhenish-Westphalia Company with two large and eight small quarries. The former company produced about 14,000 tons a day of which 10,000 came from a single quarry. The stone is high-grade (98% CaCO_3) and the operations are mechanized. At the largest quarry there are two sizing and washing plants and also a lime plant. About 1 ton of lime is burned for every 1.2 tons of crude stone shipped.

As previously noted, the iron and steel industry of Rhenish-Westphalia lies virtually on top of coal beds. The coking coals of the Essen-Bochum area are excellent and good coke is also made from Westphalian and North German coals. The Saar and Silesian areas likewise provide the coal, coke and gas requirements of their local iron and steel plants, although the coal is less suitable for coking than that of Rhenish-Westphalia. The blast furnace concerns of Bremen, Lünebeck and Stettin normally take seaborne ores and coal from the Ruhr. The blast furnaces in Siegerland, Central and Southern Germany are based on ore fields instead of coal beds and obtain their solid fuel principally from Rhenish-Westphalia. Including a short rail haul coke costs around RM 20 per metric ton delivered at Ruhr furnaces.

Purely steelmaking units, of which there are a fair number scattered over Central Germany, require gas for their Siemens-Martin furnaces. This is usually manufactured on the spot in gas producers. The necessary gas coal is easily obtainable from the nearest German collieries.

The annexation of Austria and later of Czechoslovakia, some expansion of production of domestic ores, and accelerated collections of scrap helped slightly to reduce Germany's dependence upon foreign sources for supplies of iron-bearing material in 1939. Swedish ore deliveries continued by way of Baltic ports and a certain amount of low grade ore was obtained from Luxembourg and Switzerland. In 1940 the Wehrmacht had overrun France and the Low Countries and, after the extensive manganese ore deposits of Nikopol in the Crimea also were in German hands, virtually the entire industry of the Reich and a fair proportion of the iron and steel capacity of the occupied countries, were well supplied with basic raw materials, although various alloying elements still had to be employed as sparingly as possible. Iron and steel plants in Luxembourg and Lorraine, territories which were incorporated into the Reich and not regarded as occupied areas, reverted to German management -- mostly to the same firms as in 1918 -- and resumed their former membership in the German iron and steel syndicates.

(2) Production Statistics

The steel production in the later years of the war approximated 30 million tons annually, and pig iron output averaged over 23 million tons. These figures include the output of Czechoslovakia but not that of occupied territories including Italy. Production in Poland, Belgium, France, Netherlands, Luxembourg and Italy, although far below normal peacetime capacity, added more than 3.5 million tons of pig iron and 4 to 5 million tons of steel to the total supply available for the German war machine.

Production in the Ruhr came gradually to a standstill between October, 1944, and March-April, 1945, when the area fell into the hands of the Allied armies. Direct bomb damage was a factor but the main interruptions were caused by the failure of gas, electricity, and water supply, and general dislocation of all transport. Even in Essen where rubble filled the streets and virtually all structures were leveled for miles around the damage was mostly to buildings and cranes. Heavy machinery was generally intact or so slightly damaged as to be classed as repairable.

Additional damage was done by liberated slave labor, chiefly Russian, before Allied military rule was established, and subsequently by rust and neglect. In plants, such as Krupps in Essen, which were declared "available for reparations", the companies were unwilling to take protective measures and considerable loss occurred from exposure to weather, petty thievery, and sabotage.

Prewar ingot capacity was approximately 44% Bessemer, 52% open hearth, and 4% crucible and electric. Basic Bessemer (Thomas) steel is produced in the Rhenish-Westphalian and Saar districts which are big pig iron makers, the hot metal going straight from the blast furnace. Siemens-Martin and electric steel capacity is concentrated chiefly in Rhenish-Westphalia; production of these kinds of steel in the Saar is only enough to absorb plant scrap from rolling mills. Open hearth and electric steel furnaces are operated in the cold metal plants in Saxony and in parts of Central and Southern Germany where there are no blast furnaces.

The following tables, compiled from "Germany, Basic Handbook, Economic Survey" published by the Foreign Office and Ministry of Economic Warfare, London W. 1, (Sept. 1944) show the distribution of steel output in prewar Germany proper by process and district, and also by companies or financial groups.

TABLE II

ANNUAL IRON AND STEEL CAPACITY BY PROCESS AND DISTRICT
(Thousands of Metric Tons)

<u>District</u>	<u>Pig Iron and Ferro Alloys</u>	<u>Steel</u>			<u>Total</u>
		<u>Besse- mer 1/</u>	<u>Open hearth 2/</u>	<u>Crucible and Electric</u>	
1. Rhenish-Westphalia	13,250	6,500	8,750	750	16,000
2. Siegerland-Hesse	800	---	425	50	475
3. Saar	2,500	2,000	650	100	2,750
4. Silesia	275	---	650	50	700
5. Saxony	---	---	600	100	700
6. Southern Germany	425	325	225	---	550
7. North-east and Central Germany 3/	3,525	2,000	1,750	250	4,000
TOTAL	20,775	10,825	13,050	1,300	25,175

1/ Mainly Thomas (basic bessemer)

2/ Mainly basic

3/ Includes 2,000,000 tons of pig iron and 2,000,000 tons of steel capacity at Hermann G6rring Works, Watenstedt-Salzgitter

TABLE III
ANNUAL CAPACITY OF MAIN GROUPS

<u>Firm</u>	<u>Head Office</u>	<u>Capacity in metric tons</u>	
		<u>Pig Iron</u>	<u>Steel Ingots</u>
Vereinigte Stahlwerke, A.G.	Düsseldorf	7,600,000	8,400,000
Reichswerke Hermann Göring A.G.	Berlin	2,100,000	2,200,000
Flick Group 1/	Sulzbach- Rosenberg	1,125,000	2,150,000
Friedrich Krupp A.G.	Essen	2,170,000	2,100,000
Klöcknerwerke A.G.	Duisburg	1,010,000	1,350,000
Gute Hoffnungshütte Oberhausen A.G.	Oberhausen	900,000	1,300,000
Hoesch A.G.	Dortmund	1,000,000	1,250,000
Mannesmann Röhrenwerke A.G.	Düsseldorf	750,000	1,050,000
Otto Wolff Group	Cologne	600,000	1,050,000
Medium and Small Firms	--	3,455,000	4,350,000
TOTAL		20,710,000	25,200,000

1/ Includes Mitteldeutsche Stahlwerke, Maximilianhütte, Sächsische Gusstahlwerke A.G. (Doehlen) and Hochofenwerk Lübeck

(3) Leading firms

All but a small proportion of the capacity of the Vereinigte Stahlwerke was in the Ruhr district; the bulk (1,300,000 tons) of Krupp's capacity was at Rheinhausen (near Duisburg), the remainder in two plants at Essen. The Hermann Göring Works were at Watenstedt-Salzgitter, south of Brunswick. The Flick plants, mostly small, were scattered over Saxony and Northern, Central and Southern Germany. The Hoesch, Gutehoffnungshütte, and Mannesmann capacity was concentrated at integrated works at Dortmund, Oberhausen and Huckingen, respectively, in the Ruhr. Klöckner has six plants but its main operations are in Garmbrück and Hagen-Haspe. Most of the steel made by Otto Wolff is produced at the Neunkircher Eisenwerke, Saar.

All the concerns listed in Table II, in fact most of the individual German steel plants, have rolling mills. However, a number of steel plants produce a surplus of semi-finished steel over their own finishing capacity for sale or transfer in the form of blooms, billets, sheet and tin plate-bars to isolated mills, tube and wire plants. For example, Düsseldorf, although not a leading center for the production of ordinary steel, is the chief center of pipe and tube manufacture. Mannesmann, the tube specialists, have important tube works there, as have also the Vereinigte Stahlwerke. Klöckner have big wire works in Düsseldorf. At Hamm, in Westphalia, are situated two huge wire plants - the Westfälische Union, belonging to the Vereinigte Stahlwerke, and Westfälische Drahtindustrie, belonging to Krupp. Another important independent mill is that of the Vereinigte Stahlwerke at Dinslaken. Supplied with steel from Hamm, it produces wire rod, strip, sheets and tubes, and possesses the only fully-continuous thin sheet mill in Germany.

The combined rolling and finishing capacity of integrated and independent plants is closely geared to maximum crude steel output and doubtless the same condition existed in respect to the iron-castings industry although the latter comprises a considerable number of small and widely scattered units. Much of the pig iron made by works having blast furnaces but no steel plant is used in foundries to make castings. Several of these pig-iron producers such as Hüttenbetrieb Meiderich, Friedrich Wilhelmshütte, Mülheim and the Schalker Verein (all of the Vereinigte Stahlwerke), the Halberger Hütte of Brebach, and the Buderus'sche Eisenwerke, themselves make iron castings. Their output probably exceeds that of all the small foundries combined.

Leading makers of alloy steel are mentioned in a later section of this report. There are numerous small firms that specialize in alloy-steel production, whose importance is measured rather by the value than by the quantity of their output.

(4) Cartels, etc.

A full discussion of the history and organization of cartels and associations in the German iron and steel industry is available in a special memorandum "Problems raised by Germany's Use of Cartels in Heavy Industry" published by the British Ministry of Economic Warfare (Reference L. 529, July 12, 1943). The principal war-time organizations were as follows: -

Reichsvereinigung Eisen;
Eisen - und Stahlwerks - Gemeinschaft;
Reichsstelle Eisen und Metalle;
Wirtschaftsgruppe Eisen-Schaffende Industrie;

All firms producing or rolling iron and steel, ore-mines, foundries, scrap dealers, and iron and steel merchants -- some 6,500 separate enterprises -- were compulsory members of the Reichsvereinigung Eisen which also absorbed all associations and cartels in the industry. This organization, which was founded in May 1942, constituted the principal instrument of State control of the industry. Its chairman was Kommerzienrat Hermann Röchling who also headed the Wirtschaftsguppe Eisenschaffende Industrie which was in effect the National Federation of Employers. The offices of the two organizations in Berlin and local headquarters (Aussenstellen) elsewhere were identical.

The war-time task of stimulating production and furthering the substitution of Thomas for Siemens-Martin or electric steel as well as the activities of most of the former sales syndicates together with new powers delegated by the Government Price Commissioner were centered in the Eisen- und Stahlwerks-Gemeinschaft. This, however, was a subsidiary of the Reichsvereinigung Eisen which also took over certain functions of the Reichsstelle Eisen (later the Reichsstelle Eisen und Metalle) which was a Government body similar to the War Production Board in the U.S.A. or the British Iron and Steel Control.

The Vereinigte Deutsche Eisenhüttenleute, headquartered in Düsseldorf, was the quasi-official clearing house for technical information, most of which was freely disseminated in the world-famous magazine, Stahl und Eisen. This organization continued during the war under the able leadership of Dr. Petersen and was the focal point for reconversion under the British element of the Allied Military Government after the war.

Basic research was conducted by the Iron and Steel Branch (Eisenforschung) of the Kaiser Wilhelm Institute which was financed in substantial part by the iron and steel industry itself although receiving additional aid from the Government. In recent years the activities of this Branch have been centered at Clausthal although it was generally felt that it could function better in Düsseldorf.

B. FOREIGN TRADE

In 1913 Germany was the world's leading exporter of steel and notwithstanding the loss of territory under the treaty of Versailles maintained a large export trade during the inter-war period. In 1929, before reacquisition of the Saar, the Reich exported 5,575,000 tons of steel products and in 1938, the last full year before the second world war, some 2,831,000 tons. The Netherlands was easily the principal foreign market for German steel, but a half dozen other countries were also large buyers and nearly 40 countries were listed as fairly substantial customers.

Apart from ore purchases, German imports of iron and steel products have been very small in comparison to production and exports. Moreover, in recent years about half of the iron and steel imports were from Luxemburg and represented a continuation of agreements and trade relations antedating World War I when the Duchy was virtually a part of Germany. After Munich, however, and doubtless as part of the accelerated rearmament program, there was a significant increase in imports, especially of pig iron and ferro-alloys.

The record shows that export prices were well below home prices in Germany even in the boom year 1929. By 1932, when the international cartel had ceased to function and despite a decline in Germany the disparity was "incomparably greater". The German iron and steel syndicates held firm as a domestic organization and thereby strengthened their international trade position so that they could afford to dump their products abroad and meet any competition in world markets.

C. WARTIME ADJUSTMENTS

In World War I, iron and steel consumption increased in Germany but not enough to offset the loss of exports so the steel output of Germany and Luxemburg declined. However, the output of quality steel ("crucible and electric") and of steel castings increased. Pig iron output fell even more than steel production, largely due to increased use of scrap and the smaller demand for iron castings. Very little use was made of iron and steel plants captured in France, Belgium and Russian Poland, but lack of iron and steel was not a factor in the final defeat in 1918; the only serious threat to continuing production was the shortage of manganese and this was remedied after the collapse of Russia gave access to supplies from that country.

As a result of the Treaty of Versailles, Germany lost 80% of her iron ore, 40% of her pig iron capacity, and 35% of her crude steel capacity. During the inter-war period, however, new plants were built and existing plants were modernized. Technical changes also occurred. Chief among these perhaps was the switch in the Ruhr toward the greater use of high-grade ores. In order to free themselves from dependence upon their former subsidiaries in Lorraine and Luxemburg, the Rhenish-Westphalian firms used more ore from Sweden and other countries which could be transported cheaply by way of Rotterdam and the Rhine. This in turn accelerated a relative increase in the importance of open hearth as opposed to basic Bessemer steel capacity. Some increase in open hearth capacity would have occurred in any event due to the better average quality of steel produced.

As plans for a second war were being perfected, more emphasis was placed upon utilization of domestic ores and, in accordance with the general autarchic policy, construction was started on the Hermann Goering Works. As the fortune of war first favored and then turned slowly against the Nazis, new plans were made and old ones scrapped but the essential changes dictated by the war economy included: -

- (a) Change over to domestic raw materials;
- (b) Recovery of alloys from waste products or domestic low grade raw materials;
- (c) Recovery of alloying metals from scrap;
- (d) Improvement of quality and introduction of special processes;
- (e) Changes in alloy content.

D. UTILIZATION OF DOMESTIC LOW-GRADE ORES

As soon as Germany went to war importations of ore from North Africa and Spain became difficult and some reduction occurred in shipments from Sweden. As supplies of high-grade foreign ores declined there was a large increase in the volume of raw materials consumed per ton of iron thereby introducing treatment problems which will be discussed later and likewise placing a heavier load on the already overburdened transportation facilities of the country. Following the fall of France, in June 1940, the use of the self-fluxing minette ores from Lorraine and Luxembourg increased, thus replacing part of the limestone. The quantities of low-grade domestic ores consumed in the Ruhr area also diminished although still remaining substantially greater than prewar. The sharp increase in the use of domestic ores in 1943 was due to the large expansion in production in the Salzgitter district.

The advantages of using high-grade ore from the standpoint of economical furnace operation and increased output for a given unit of furnace capacity are well known. In Germany the cost of iron smelted from low grade home ores was commonly said to be twice as great as that of iron made from high grade imported ores. After the Treaty of Versailles, the trend was toward smelting more and more Swedish and other high-grade ores and less of the low-grade, but virtually self-fluxing, minette ores upon which the Ruhr iron masters had previously been largely dependent but which now were outside the shrunken borders of the German Reich.

Even without the Saar, which was returned to Germany after being under French control from 1920 to 1935, German steel making capacity increased during the interwar period, but when the National Socialist Government came into power the huge new plants were kept busy, first under the Employment Creation Programme (based upon low wages of workers), and later by home demand for undisguised rearmament. Recognizing the vital need for steel, and the vulnerability of industry depending so largely on imported raw materials in the event of war, the National Socialist Government took steps to expand the domestic iron ore mining industry. In 1936 the Four Year Raw Material Plan was introduced to develop greater national self-sufficiency in all raw material fields. Projects that hitherto had been regarded as uneconomic were encouraged. The Saar works, which had previously depended almost entirely on Lorraine ore, organized the Doggererzbergau G.m.b.H. to work low grade ores in South Baden. Output of iron ore in Germany as a whole rose from 6.7 million tons in 1936 to 8.5 million tons in 1937 and 11.1 million tons in 1938. The yield in iron

content, however, was still only 3 million tons, and the government was dissatisfied with this progress. Private companies, on the other hand, pointed out that they were being forced to make capital expenditures to produce a type of ore that not only reduced the output of their blast furnaces, but increased their coke consumption, and consequently raised their costs while they were forbidden by government decree from raising iron and steel selling prices. The increasing emphasis on utilization of domestic raw material supplies in order to develop wartime self-sufficiency is thus summarized in the Economic Survey of Germany, published by the British Foreign Office and Ministry of Economic Warfare (September 1944, Section H, page 111).

The principal action taken by the Government to speed up the Plan was to form the REICHSWERKE (HERMANN GÖRING) A.G. in the summer of 1937 to exploit vast ore deposits in Salzgitter and Franconia, the smelting of which required special processes owing to their very low iron content and the presence in them of an unusually high proportion of deleterious substances. Two huge integrated iron and steel plants were to be erected, one at Salzgitter to produce 4 million tons of steel per annum and the other in Franconia to produce 2 million tons per annum. Although iron and steel production could not begin for a considerable time, ore mining was to start almost immediately for use in Rhenish-Westphalia and elsewhere. Later on, the canal barges which were to bring the necessary coal from Rhenish-Westphalia to Salzgitter were to be used to take back very considerable tonnages of the ore.

The acquisition of Austria in March, 1938, led to considerable alterations in the Hermann Göring programme. Near Donawitz is situated the famous "Ore Mountain", whose non-phosphoric ore has an iron content of about 38%, and is very easily mined. Austria's record output of this medium-grade ore was about 2 million tons per annum, mainly for consumption by the ALPINE MONTANESSELSCHAFT, a subsidiary of the VEREINIGTE STAHLWERKE originally acquired by Stinnes during the inflation. The ALPINE MONTANESSELSCHAFT was incorporated into the HERMANN GÖRING A.G., which immediately planned to raise Austrian iron-ore output to 6,000,000 tons per annum. The plan for the Franconian plant was abandoned and one at Linz on the Danube was to take its place. The Linz works were to consume both Austrian and Franconian iron ore.

The extent of progress made under the Four-Year Plan by the eve of the war was such that in the first half of 1939 Germany Proper produced 7,333,500 tons of iron ore against 5,180,100 tons in the same period of 1938, while Austria produced 1,612,700 tons in the first half of 1939 against 1,890,000 tons in the whole of 1937 - its last full year of independence. Even so, iron-ore imports still totalled 21.9 million tons in 1938 and 11.2 million tons in the first half of 1939.

*The private iron and steel producers regarded these developments with increasing dislike. Not only were they inconvenienced by the compulsion to use low-grade ore, but they were alarmed by the growth of an enormous new competitor whose appearance nullified the value of the Group Protection Agreement. One of the heaviest blows came when they were ordered to subscribe half the capital of this unwelcome rival. Most of their former enthusiasm for the National Socialist regime evaporated and some of the frankest criticism of Government policy was to be found in the annual reports published by the leading iron and steel firms. On the eve of the war there was big dispute over the question of finding coking coal for the new coke ovens shortly to begin operations at Salzgitter and it appeared likely at one time that HERMANN GÖRING A.G. would acquire forcibly the amount of mining property in the Ruhr necessary to satisfy its needs."

Although the pattern of German's postwar iron and steel industry has not been agreed upon at the present writing, there is a growing feeling that autarchic policies will become even more necessary as Germany's export potential is curtailed, as a necessary accompaniment of minimizing her future ability to make war. This will mean an increased effort to keep down imports, due to the difficulties of obtaining necessary foreign exchange. Moreover, as employment opportunities in munition plants disappear, a broader base will be needed for home employment, thereby altering the economic balance in respect to home-produced raw materials of all kinds, including iron ore. It may be noted that increasing attention to low-grade or sub-standard mineral raw materials is not confined to Germany, but is gradually becoming world wide, as the more accessible, easily mined, and high grade deposits all over the world are depleted. Greater decentralization of industry likewise is a factor in developing new interest in low grade ore supplies, particularly inasmuch as transportation costs often represent a substantial proportion of the total cost of raw materials delivered at distant consuming points. Low-grade or sub-standard ores can often be mined economically to supply local industries, even though they may cost more to extract and process, by reason of the elimination of heavy transportation costs.

In Germany, as elsewhere, sub-standard iron ores are typically silicious. No real problem surrounds the utilization of limey ores containing as little as 20 or 30% metallic iron, inasmuch as they can be smelted economically in admixture with other ores, the resulting smelting mixture often being little, if any, leaner than the normal burden after barren limestone has been added as flux. Some of the cheapest iron in the world is made from such ores, which, though low grade, are virtually self-fluxing. The best known examples are the minette ores of Lorraine and Luxembourg, and the red iron ores of Birmingham, Alabama. A more recent development is the modernized operation in England at Corby. This plant which successfully operates on Northamptonshire ores can be considered as being virtually the pilot plant for the Hermann Göring works. Both plants were laid out by H. A. Brassart & Co. and embody many of the latest features of American design and practice.

The real problem is the utilization of low-iron, high-silica ores. To solve this problem a variety of methods have been devised. These methods divide naturally into two categories, depending upon whether it is proposed (1) to beneficiate the ore mechanically before undertaking,

the reduction to metallic iron or (2) to smelt the crude ore with a minimum of preliminary treatment. Certain German technical developments in this field are of considerable interest - for example the Lurgi process (a partial reducing roast followed by magnetic separation) and the Krupp-Renn process (a direct reduction process) together with the various modifications of blast furnace design and operation. This subject, accordingly, is being covered in a separate report by the same author in collaboration with Dr. W. M. Pollitzer.

Germany's main iron ore resource is in the Salzgitter area and comprises material which is similar to that found abundantly in various parts of the United States but which was outmoded and ceased to be considered workable as American industry became patterned about the soft-easily-mined, high-grade ores of the Lake Superior region. It follows that the wartime experience and possible continued operations at the Hermann Goering works are especially significant. These brown (limonitic) ores can be segregated into three types, each type being treated by a different process. The soft, clayey ores are separated by ordinary washing to remove clay and to concentrate the iron-rich oolitic portion. The harder ores are crushed, screened, partially reduced in the Lurgi kilns, and concentrated in magnetic separators before sintering. The most intimately combined ores were reduced to metallic iron (luppen) in the Krupp-Renn kilns.

III. PIG IRON MANUFACTURE

German blast furnace practice was undergoing evolution even before the war. The broad trend in 1936, as reported by Springorum (Stahl und Eisen), was toward smoother flow of materials, a clearer arrangement of plants, and a saving of human labor. Facing advanced practice elsewhere, overall heat economy was receiving the attention it deserved. The total heat consumption, at full capacity, in millions of kilogram-calories per ton of raw steel, had diminished from 9-1/3 in 1913 to about 7-1/4 in the early 1920's and was down to 5-1/4 in 1927-35. On the average the blast furnace and coke oven gases from integrated plants were expected not only to meet the entire heat and power requirements of the iron and steel works themselves but also to provide additional gas or power, which was distributed to other industries through interconnected grids. A typical figure for high grade coke (10% ash) was RM 20 per 1000 kg delivered at Ruhr furnaces. The fact that blast-furnace and coke-oven gas could be sold to outside industries and the relatively low cost of high quality fuel in the leading iron making centers tended somewhat to reduce the incentive for extreme fuel economy at the furnace. Nevertheless, German practice in general was relatively efficient as judged even by American standards although hard driving was the exception rather than the rule.

No attempt will be made in this report to record all the various extreme measures adopted at German furnaces to meet wartime emergencies. Postwar operations at most plants are even more abnormal due to part to the wide variety of substandard ores smelted and also to the fact that furnaces frequently have to be run primarily to supply gas rather than to merely make pig iron. The following recent developments, however, are deemed significant.

Most striking has been the progressive decrease in iron content of the burden due to the diminished supply of high grade foreign ores. Prewar (1933) studies showed that the cost of iron smelted in Germany was RM 35.9 for high grade (Normandy) ore and RM 45.5 for medium grade (Nassau limonite). The figure for hematite iron made from Nassau hematite and Siegerland carbonate ore was RM 51.2. During the war the German plants met the downward trend with varying success. Notwithstanding the large increase in the volume of metallic charge needed to produce a ton of iron it was possible in some instances to hold down coke consumption and manufacturing cost and even to maintain the rate of daily output. At some plants larger quantities of scrap and sinter were used on the burden. Elsewhere it was found possible to reduce limestone requirements by employing a larger percentage of self-fluxing ore for Thomas iron or slag for open hearth iron. Other plants resorted to acid burdening.

A. BETTER PREPARATION OF ORES

It has been estimated that fully half the blast furnaces in continental Europe still operate on unsized feed although the merits of proper sizing of ore and fuel and sintering or agglomerating fines are becoming fully recognized. The advantages of bedding systems for obtaining a uniform feed when ore deliveries are variable in quality and amount are well-known but have not been widely introduced because the necessary storage space is not available at many of the older plants. Experiments at the Belval works of the Arbed concern in Luxembourg, for example, proved that proper preparation, plus a proportion of sinter ranging from 0 to 14.5% of the total burden, increased the useful yield of a furnace from 29.4% to 34.2% on minette ores. Coke consumption with uncrushed ore was 1150 kg per ton of pig iron but dropped to 1103 kg with crushed ore containing all the fines. Simply by screening out the fines there was a further reduction to 1039 kg and by crushing, screening, and sintering the fine ore and fluedust (14.50%) in a rotary (Smidh) kiln, fuel consumption was lowered to 1000 kg of coke per ton of pig iron (British Iron and Steel Institute Translations: TS 122, 1942).

A large number of sintering plants were put in operation and equipment for crushing and screening ore was installed in several leading works. It was definitely established in monthly comparisons of operations that blast furnaces in the Saar showed more favorable fuel consumption than those of Lorraine and Luxembourg which worked up uncrushed ore. Moreover, furnace efficiency was about 25% higher in the Saar than in Lorraine and Luxembourg, and output per furnace was 15% higher.

The Hermann G6rting Works in Wattenstedt has one of the best arrangements for pre-mixing the charge for sintering machines, all ores and concentrates being sintered in separate layers on top of one another. The general practice here follows the ore-bedding practice at many non-ferrous metal custom smelters in the United States. Wattenstedt reported no variations in slag composition even with acid slags containing more than 40% SiO_2 . The pig iron did not vary, and furnace operations were uniform.

Usual practice was to crush ores to approximately 2 inches (50 to 80 mm), size on vibrating screens, and sinter fines (under 10 to 20 mm) with coke breeze (previously crushed to 3 mm maximum). Various types of sintering equipment are in successful use but sentiment seems to favor Dwight-Lloyd. Fines under about 4 mm are usually returned to the sintering plant.

B. ACID BURDENING.

At a typical Ruhr plant slags were figured on a lime-silica ratio of about 1.2 with Swedish ores. With larger admixture of domestic and other low-grade ores the ratio was raised slightly to 1.26 or 1.3, sometimes as high as 1.4. The apparent need for more lime on the burden may be attributable to the fact that the later slags carry 12 to 14% Al_2O_3 as compared with 8 to 10% when high grade ores are smelted alone or in admixture with calcareous minette ores. Ordinary Al_2O_3 is ignored in calculating the charge; however, bauxite is sometimes added to send more manganese into the pig iron.

Inasmuch as normal burdening in the case of low grade ores results in heavy slag formation and excessive fuel requirements, many furnaces were forced to resort to smelting acid slags. By this means Salzgitter ores were handled successfully on the basis of 50% crude ore and 50% concentrate, the process being patterned largely after the successful operation in the Stewart and Lloyd plant at Corby, England. One furnace, the Maxhütte works, in Thuringia, near Jena, is said to have operated with a lime-silica ratio as low as 0.3. Elsewhere, however, minimum ratio was about 0.6 and 0.9 was a much more common figure. Coke consumption with acid burdening generally ran high, ordinarily around 1200 kg per ton of iron, but wherever a large proportion of low grade ores had to be smelted it was shown to be more economical to treat low-iron, high-silica ore by acid smelting, say on one furnace, and run a normal charge, on say two other furnaces, rather than to mix the ores and then to operate all three furnaces on a lean burden.

Preliminary tests on Dogger ores, which were conducted for 15 years or more, demonstrated the feasibility of treating material containing as little as 20% iron. Adoption of acid smelting reduced the amount of slag produced from 3.3 to 2.6 tons per ton of iron and coke consumption dropped from 2.1 to 1.7 tons. A further saving in coke is possible if oxygen-enriched blast is used. Furnace capacity, however, was only 60% of that obtained when treating high grade ores.

In war time and recent practice this disadvantage was partly offset by melting relatively large quantities of scrap in the furnace but the fact remains that smelting these very low ores is expensive and causes severe wear and tear on refractories. The Ruhr metallurgists consider acid smelting a war time expedient and assert that in addition to the high cost the process is undesirable from the standpoint of quality of product. The iron is high in sulfur. Although they admit that the sulfur content can be reduced to normal by treatment with soda ash, they contend that the desulfurization step is a menace to the health of workers, that the iron gets cold, and that they cannot make good steel from it. One distinguished metallurgist went so far as to state that Thomas steel made from iron from acid smelting could not be marketed in normal times. On the other hand, the process has worked successfully in England and seemingly also in the Hermann Göring works at Wattenstedt-Saltzgitter.

The stubborn resistance of the Ruhr iron and steel men stems naturally from their experience with higher grade ores and they tend to ignore the possibility that the German economy, during the next several years at least, may not be able to afford the luxury of using its limited foreign exchange to purchase imported ores simply because they are easier to smelt. Domestic ores cost more to smelt, and may even cost more per unit of iron delivered at some of the Ruhr furnaces, but the use of such ores may become mandatory if the emphasis on national self-sufficiency, which began as a military measure, is forced upon the nation after the war by reason of a lack of exportable goods to exchange for imported ores.

Based upon Dogger ores, admittedly an extreme case, the comparison between normal practice using Swedish high grade ores and high-silica domestic (Gutmadingen) ores worked out about as follows at the Gutehoffnungshütte at Oberhausen:

	Normal burden (Swedish ores)	Acid smelting (Domestic ores)
Burden: Kgs. per ton of iron:		
Ores	2,150	3,860
Stone	125	180
Coke	910	1,418
Total	3,185	5,458
Slag produced per ton of iron, Kgs.	650	2,460
Volume, cu. m. per ton of iron:		
Ore and stone	1.2	3.15
Coke	2.2	3.55
Total	3.4	6.70

It will be noted that the volume of charge is almost twice as great when low grade ores are used, thus accounting in part for the 40% reduction in furnace capacity. In view of the fact that it ordinarily takes about 45 kg. of coke to melt 100 kg. of slag, and since additional calories are needed to drive off CO₂, moisture, and combined water, the foregoing figures for fuel consumption would seem to be conservative. In February, 1946, the Oberhausen furnaces were operating on a mixture of domestic ores with 30% scrap on the burden and making about 450 tons of Thomas pig in 24 hours. When working on a mixture of Swedish ore and limey minette ores, the daily output had been 700 tons of Thomas iron or 600 tons of hematite iron.

C. OXYGEN-ENRICHED BLAST.

The late Herr Lenning pioneered experiments in Germany on the use of oxygen-enriched blast for both normal and acid smelting at the Gutehoffnungs works. His experiments, which have been fully covered by several comprehensive articles in Stahl und Eisen, were conducted in a small furnace which had been dismantled at the time of my visit. Construction of a full-scale oxygen plant for converting the entire works to this practice was begun but never completed. Dr. Bulle, who has succeeded Herr Lenning as head of this works, strongly favors the use of enriched blast and proposed to proceed with the construction of the necessary plant as soon as practicable. It is planned to produce oxygen as a 75% product by the Linde process and to introduce it into the blast below the bustle pipe, just above the tuyere connection. The blast will carry only 26 to 30% oxygen, compared with the normal 20% in air, and will be heated to 800 to 900°C. Higher percentages have been tried out. When the oxygen content is raised to as much as 45% it was found that preheated blast becomes unnecessary. Thus it would seem to be possible to save not only the cost of the gas normally required for heating but also the expense of providing and operating stoves. From a practical standpoint, however, the use of much over 30% oxygen introduces complications, including liability of explosions, which would require redesigning of the furnace itself. Moreover, if the oxygen content rises too high, calcium carbide tends to form in the furnace which of course consumes fuel and flux to no useful purpose. The advantage of oxygenated blast is said to be greater with acid than with ordinary burdening. At least one other German plant is reported to have decided to adopt it on a full commercial scale. In addition to a 10 to 15% coke saving, this change was expected to allow the furnace to work at higher temperatures and with more lime on the charge and thus to make better iron.

D. CARBON LININGS.

Carbon linings for hearth bottoms, for the hearth itself, and for the bosh were coming into vogue in Germany during the 1930's and probably at least one-third of German blast furnaces are now carbon lined. Massive, preformed, baked carbon blocks were used exclusively at first and are still favored by a fair-sized segment of German

metallurgists. Others, however, contend that as good as or better linings can be made more cheaply by ramming carbon paste (coke plus tar). The latter operation is similar to putting in an open hearth bottom or lining a large converter. A built-up internal form is used. One argument in favor of carbon blocks is that any lead reduced out of certain ores would seep out of the lining. During the war a bottleneck developed in delivering carbon blocks so rammed linings became mandatory. Still another group of metallurgists prefer the ordinary fire brick lining and it is interesting to note that at the up-to-date Mannesmann works at Hockingen a veneer consisting of a single course of fire-clay brick is laid inside to protect the carbon lining while the furnace is being blown in. One furnace at this plant made 3,126,000 tons of pig iron on one lining which lasted 16 years. At Essen-Borbeck the last full run between relinings was from 1929 to 1936; during these 7 years the furnace made 1,200,000 tons of iron. At this works, all bosh and crucible parts are lined with carbon blocks and there are two layers of carbon blocks at the bottom of the crucible on top of two courses of fire brick. At some plants, as many as three courses of carbon blocks are laid at the bottom of the crucible.

The size of the massive carbon blocks is impressive. They are generally about 3 feet thick and as much as 10 feet long, being shaped especially to conform with the lines of the shell and the desired interior contour of the furnace after relining.

Carbon linings are considered equally advantageous for either acid or basic charging. They have also been employed alternatively for making speigeleisen and ferromanganese although their advantage in the case of such high-carbon materials is perhaps doubtful.

Fire-clay linings are ordinarily employed above the bosh but magnesite is commonly considered preferable when it can be obtained.

Inasmuch as molten pig iron does not wet carbon, and so runs off like mercury on a glass plate, there is a growing employment of carbon (blocks or monolithic) for runners and other uses around the blast furnace. After each cast, such carbon equipment is swabbed with a clay slip which protects it from excessive oxidation.

II. FURNACE DESIGN AND OPERATION

Although it was generally believed that internal lines of German blast furnaces had become virtually standardized during the inter-war period, there seems now to be a definite trend toward making them more nearly cylindrical. First the hearths, and later the tops as well, are being made larger while the diameter of the bosh remains unchanged. Drawings showing the construction at the Hockingen plant and representing the latest ideas before the war have been placed in the auxiliary file for this report in Washington and an outline drawing of the plans for the next remodeling at this same plant is reproduced in Figure 1. The statement has been made that acid smelting

TYPE A

Plate Thickness

Hearth 80 mm.
 Tuyere level . 40 "
 Bosh 30 "
 Shaft 18 "

Brick lining

Tuyere level . 800 mm.
 Shaft 500 "

TYPE B

Plate Thickness

Hearth 50 mm.
 Tuyere level . 40 "
 Bosh 30 "
 Shaft 18 "

Brick lining

Tuyere level . 1850 mm.
 Shaft 500 "

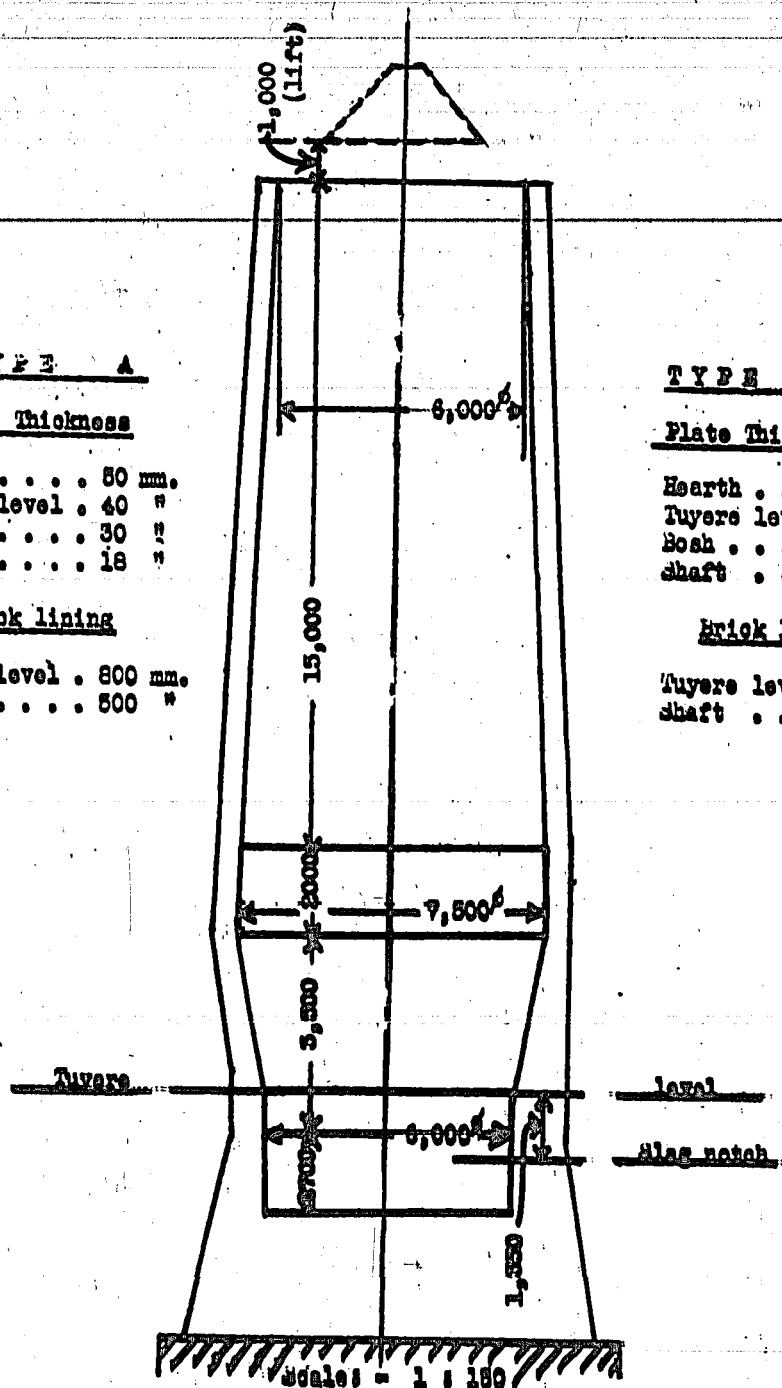


Figure 1. Proposed new lines of blast furnaces at Mannesmann works, Muckingen (Total contents about 625 cu. m.).

calls for larger diameters at the hearth level but a similar increase is also advocated in respect to furnaces operating on relatively high lime-silica ratios.

A striking difference in furnace construction in Germany as compared with American or British design is the fact that the shell is not self-supporting. The weight is carried on a four-column external frame of structural steel which also supports the charging mechanism. One design for a new furnace, which has not yet been built however, was based upon a self-supporting shell. Probably the main reason for the separate steel structure is the wide use of basket (bucket) charging.

Controversy exists as to the relative merits of basket and skip loading. But it may be significant that, although basket loading is employed in all the furnaces of the Gutehoffnungs works at Oberhausen, the same firm recommended and installed skip charging at the Hockingen plant of the Mannesmann concern just before the war. Although more cumbersome, basket charging still has its adherents who point out that it has special advantages. Notably among these advantages are (1) less coke breakage inasmuch as the great iron pots are filled at the coke ovens and no breeze is made before the fuel is dropped into the top of the furnace and (2) better mixing of varied ores. The latter feature is much emphasized that now that 10 or 15 different ores and miscellaneous iron-bearing materials are carried on the burden. As space for proper bedding is often not available, it is argued that a more uniform mixture results when the ores are placed in suitable proportions in the basket and dumped into the furnace altogether.

At several plants, furnaces originally designed to make 600 tons a day were able to turn out 1000 tons or more a day simply by giving them more blast. At a Lower Rhine plant a steam-turbine blowing engine with a capacity of 2300 cu. m. per minutes, at a pressure of 60 cm. of mercury, supplied two blast furnaces having a daily output of 1400 tons at a 45% yield. Common practice is to blow several furnaces from a single blast main but separate blowing units of ample capacity are found in the more modern plants and steam turbine blowers are used instead of the massive reciprocating gas engines. Generally, two hot blast stoves serve the regular requirements of each furnace, although usually there is a third stove in reserve. At Hockingen, however, only 5 stoves are provided for each pair of furnaces. As higher blast temperatures have been used with increased blast volumes, both gas burners and checkerwork had to be improved. This problem was solved by the use of perforated, corrugated, and insert bricks which provided the requisite heating surfaces. Remote control, wholly or semi-automatic, has increased the reliability of operation. Modern installations are fully instrumented with indicators and recorders in a central station equipped with push-button controls. At a typical plant the change from gas to air is made automatically by totally enclosed pneumatically-operated valves when the exit gas temperature reaches 900°C. Regulation of gas-air ratios at burners is fully automatic.

When working Swedish ores, blast temperatures were maintained at the furnace at 800 to 900°C but with lower grade ores now in use the temperatures are usually only 500 to 600°C. At Rheinhausen, the range was lower—600° C for Swedish and 450 to 500°C for German ores. It is contended that with easily-reduced fine ores, high blast temperatures are undesirable. They cause an increased ratio of direct reduction and the greater heat requirements, due to less efficient utilization of the carbon, more than offset the increased heat input from hotter blast. Manganiferous and high-silicon irons, of course, do call for hotter blast.

At the August Thyssen plant at Hamborn (Dr. Herzog) the problem of overcoming the handicap of low capacity when working with low grade ores was attacked by experimenting with blast pressures. A high-pressure jet was inserted into the ordinary tuyere, thereby enlarging the smelting zone and increasing output by 10 to 15%. Details of this operation and the basic theory thereof have been discussed by Alfred Müller, a translation of whose article forms an appendix to this report.

Depending upon the rate of working, German blast furnaces are usually tapped five or six times a day, alag somewhat oftener.

F. SYNTHETIC LOW-PHOSPHORUS (HEMATITE) IRON

To overcome the growing shortage of low-phosphorus ores, German pig iron makers developed two alternatives. One device was simply to add more scrap to the burden and thus dilute the phosphorus contents of the iron. The other method was to produce a truly synthetic hematite or acid-grade of iron as a substitute for Swedish pig iron by treating ordinary Thomas or other high-phosphorus pig. This practice, which was carried out on the initiative of H. B&sch&ing by Dipl. Ing. Holschu at Malm&ison, was previously tried out during World War I. The high-phosphorus iron is blown virtually to steel in a Thomas converter and then recarburized with petroleum coke. The product can then be used as a recarburizer for high-grade steel in the electric furnace. Although obviously uneconomical under normal circumstances, this expedient served its purpose quite successfully in wartime.

Refined iron was also produced by Krupp in the open hearth from "Stahleisen" containing approximately 1% manganese and 0.07% phosphorus. Prior to the war, this firm had imported considerable amounts of Swedish iron containing approximately 0.25% Si, 0.20% Mn, and 0.020% maximum P and S. When this high-grade iron was no longer available they had to depend upon pig iron from their own furnaces at Essen-Borbeck. Approximately 70 tons of this iron was poured into a basic furnace with about 2% CaO (burnt lime) and 5 to 8% Swedish ore. After about 3 to 5 hours, practically all of the impurities were oxidized and the metal had the following analysis: 3 to 8% C, 0.10% Si, 0.15% Mn, 0.015% S, and 0.020% P. This refined iron was cast into two-ton ingots and used in acid open hearth charges and also in basic furnaces for steels of special low S and

P quality. (CIOS Report No. XXI-44)

G. GAS CLEANING

Blast furnace gas is consumed not only to heat blast but also for making steam, running gas engines, and in reheating furnaces. Especially at older works, reciprocating gas engines are quite common. They are direct-connected to blowing engines and belted to generators which furnish electric power for the rest of the integrated plant. An analysis of the usage of blast furnace gas at Hamborn (CIOS Report No. XXVI-32) shows 34.3 per cent consumed at the blast furnace (10.6% for blowing engines, 22.2% for stoves, and 1.3% for sintering operations and ladle drying), 24.9% for central station steam and water, 2.2% in the power house, 14.9% at coke ovens, and the remainder (exclusive of a loss of 9.9%) in the steel works, chiefly for rolling mill furnaces and only a minor quantity for ladle drying and mixer heating.

Partly due to the larger fuel consumption in most furnaces in Germany, more attention is paid to gas cleaning there than in the United States. Furnaces treating low grade ores, particularly clayey ores, make an extraordinary amount of dust, some of which is difficult to settle. The greater employment of domestic ores has nearly doubled the amount of flue dust as compared with former years when Swedish ores were principally used. Recent averages are 7 to 8% of the burden as against a former 4%. At several plants the flue dust is briquetted before being charged back to the furnace. Elsewhere it may go to the sintering machine with fine ores.

Probably the most advanced equipment for gas purification as well as for other phases of furnace operation was installed at the Hermann G6hring works where, due to the low average grade of ores treated, the coke consumption per ton was much higher than at any modern American furnace, about 1-1/8 ton. The plans called for a gas turbine (Brown-Boveri) which was delivered although never actually erected before the war ended. Ordinary internal combustion engines as well as boiler plants can be operated with dry-cleaned blast furnace gas, but most of the more advanced German plants have adopted wet cleaning. This not only removes more dust but lowers the moisture content. Typical practice employs large wet towers for cooling and mechanically removing dust from gases, followed at many plants by wet electrostatic separators. Cyclones or "whirlers" may be put in circuit ahead of the towers for preliminary dust removal. The wet towers have wooden shelves or baffles with the water spray at the top. Gas cleaning equipment is supplied by Giesse Lurgi Apparate bau, Frankfurt. Dorr thickeners are commonly used for collecting the sludge after wet cleaning, in accordance with American practice. At Wattenstedt, two thickeners were installed for four furnaces. At Essen-Borbeck where there are two huge gas cleaning towers followed by a Siemens wet electrostatic precipitator, I was given the figure of 7 mg. of dust per cubic meter of cleaned gas.

H. SLAG UTILIZATION

Blast furnace slag is widely used as concrete aggregate,

railroad ballast, and road metal. One of the best-equipped plants for processing slag as aggregate is that at Lübeck-Hochofen, near Hamburg although several of the Ruhr plants as well as the Hermann Göring works produce well-sized products. Paving blocks made from cast slag are employed quite extensively and a fair amount of research has been devoted to methods of improving this product. Slag wool is manufactured at Gelsenkirchen. Slag cement is produced in several places from remelted slag. By suitable burdening it is possible also to produce directly in the blast furnace a "high-grade smelting cement" which is said to have good hydraulic properties and this is done at one or more plants. Inasmuch as phosphorus follows the iron, blast furnace slags are too poor in plant food to serve as fertilizer even in Germany but they are employed to a limited extent by farmers as a soil conditioner and sweetener.

IV. RAW STEEL MANUFACTURE

For many years the basic Bessemer process, known on the Continent as the Thomas process, was the principal steel-making process in Germany and at the beginning of World War II it still contributed 40% of the total steel output of Germany proper. Inasmuch as not more than about 10% of cold scrap can be added to the converter, this process does not absorb even the home scrap in a completely integrated works. Open hearth and/or electric furnaces, therefore, are likely to be installed in most plants as supplemental equipment and are absolutely necessary where any purchased scrap is to be handled. Virtually all the electric furnaces in Germany, in fact, were in steel works where they were used for duplex melting as well as to remelt alloy scrap and low-grade ferro-alloys for either duplex or "mixed steel".

In general this whole arrangement goes back to the fact that since ore supplies are predominantly high in phosphorus, it is metallurgical good sense to place the heavy refining load on the basic converter, using the product of the basic converter for bulk steels and using other processes chiefly for further refining. Normally, the manufacture of high grade carbon or alloy steel could be accomplished efficiently either by the straight or duplex methods of working. Due to the nature of raw materials available, however, the duplex method was much more common in Germany than in Great Britain or America. Practically no acid Bessemer steel had been made in recent years and the production of acid open hearth steel was relatively small.

The outstanding wartime developments were the result of the unbalanced demand for high-grade steel for munitions. Interesting methods were adopted first for upgrading Thomas steel sufficiently to permit its employment for uses normally demanding open-hearth quality steel, and secondly to upgrade open hearth steel so it could pinch hit for electric steel.

A. BASIC BESSEMER PROCESS

The Bessemer Process is eminently suited for producing soft rimming steel good enough for ordinary structural shapes, rails, sheet, plate, and artillery shells. The essential feature of this process, of course, is the utilization of high phosphorus pig iron (1.5 to 1.8% P.) such as is ordinarily produced from the minette ores of Lorraine and Luxembourg. An important by-product is basic slag which is one of the principal sources of phosphate fertilizer for German agriculture. Typical rail steels analyzed C .42/.48, Mn .30/.65, P .070 max., S .050 max., and Si .25%. Before the war the manganese content was .60/.75% but this was reduced as supplies of this alloy became short. Sheet bars analyzed C .06/.08, Mn .30/.40, P .025/.030, S .030 max., and Si .06/.08%, whereas tin plate bars .02% Al added. A good recovery of aluminum is said to favor production of non-ageing steel.

The worst feature of Thomas steel is age-hardening which limits its employment, in deep drawing for example, due to the liability to develop cracks. Occasional heats of Thomas steel have equalled the quality of Siemens - Martin steel. Systematic investigation revealed that such exceptional heats were low in both phosphorus and nitrogen content. Nitrogen is much higher in Thomas steel than in open hearth steel which in turn contains somewhat more nitrogen than electric steel; consequently it seemed reasonable to suppose that nitrogen was one of the causes of undesirable age-hardening effects. From this theoretical beginning was developed the so-called HPN, or Hamborn-phosphorous-nitrogen, process which was developed by Dr. Eichholz at the August Thyssen Works at Hamborn and by Dr. Daevies of Düsseldorf. The essential conditions necessary for low nitrogen and phosphorus were light blowing and/or additions of ore or scrap. Preliminary tests were made on a small scale by Dr. Daevies in a Bessemer converter and at the Mannesmann Works at Hockingen in an ordinary Thomas converter. The technical expert at the latter plant was Dr. Barre.

At the Hamborn plant, (CIOS Report LXVI-32, pp 6-7) seven basic converters, six of 30 tons capacity and one of 35, were said to produce 100,000 to 116,000 tons of ingots per month. A small additional tonnage was duplexed. Three mixers, each capable of holding 1,000 tons of iron, were provided. They were fired only when nearly empty. Spiegeleisen was melted at the rate of 10 tons per hour in two cupolas. Recognizing the deleterious effects of nitrogen in blown steel, the management of this plant concluded that nitrogen absorption was a function of temperature and length of exposure to air in the blast. They lessened the time of exposure by adding sodium carbonate and iron ore to the charge. They determined that a low metal level in the converter contributed to reduce nitrogen absorption. By using an elliptical vessel with the nozzle slightly inclined, it was possible to create one-way flow with less back pressure and not so much tornado effect. A side-blown horizontal converter was eventually developed which resembles in many respects the Pierce-Smith converters used in Canada for blowing nickel-copper matte. With this equipment operations can be conducted at low temperatures without additions of iron ore.

Recirculation of exhaust gases, lower in nitrogen and high in CO_2 was investigated. Since temperature was found to be more important than time, cold steel scrap was added after the blow was 70 to 80% complete. To avoid excessive exothermic reactions, additions of manganese and silicon to the charge were kept at a minimum. Ferroalloys were added after the blow to raise the temperature for pouring. Consideration was given to fixing the nitrogen content of the iron by pre-additions of aluminum, titanium, silicon, and zirconium, the thought being that nitrides of these metals might flux out during the blowing. Efforts were also made to minimize the nitrogen content of pig iron by selecting low nitrogen coke and employing oxygen-enriched blast. In this connection, Dr. Rohland remarked that Belgian iron is characteristically low in nitrogen and suggested that the high calcium limestone found near Liege might be a contributing factor.

Independently of the HPN process, an improvement of Thomas steel was undertaken at the Gutehoffnungs works at Oberhausen, under the leadership of Dr. Hautmann, employing aluminum additions. These attempts were also successful, the resulting steel being marketed under the trade name "Alto".

In March 1944 the output of HPN steel reached 85,000 tons and that of aluminum-refined Thomas steel was around 40,000 tons a month. During the later part of the war period "air-refined substitute steel ingots" were produced regularly at the rate of well over a 100,000 tons a month, thus representing 10 to 15% of the total Thomas steel output.

In Thomas steelmaking as in other branches of the industry, the trend is toward larger units. The converters range in capacity from 20 tons in the older plants to 60 tons in the Herman Göring works. Actual production rates were 170 tons an hour from a 7-unit installation at Hamborn to 200 tons an hour at Watenstedt from 6-units (including 1 acid converter). At several plants the monthly average exceeded 500 tons of nominal capacity.

Basic linings for Thomas converters are made from unstabilized burnt dolomite grains coated with tar and rammed around a removable internal form by means of pneumatic hammers. Bottoms last about 50 heats and the whole converter has to be relined after 300 to 350 heats, sooner if the iron is high in silicon. Jolting, in addition to ordinary ramming, is recommended as a means of obtaining longer service from linings, specially bottoms.

One hears some discussion of the possible employment of the electric eye, spectroscopes, and other instruments for registering the progress of the Thomas blow. Some 20 or 30 years ago, spectroscopic tests were experimented with but at nearly all plants the melder's experience and visual inspection of the flame are relied upon exclusively.

The one type of mechanical control that seems to have been employed to any extent is a built-in optical pyrometer which signals when the flame is hottest and hence when scrap should be added. This device, known as Bioprix, is manufactured by the Haase concern in Hamburg. A sufficient description of its installation and operation may be found in two published articles, one by Naeser (Stahl und Eisen, vol. 59, 1939, pp. 592-598) and the other by Naeser and Krächter (Stahl und Eisen, vol. 62, 1942, pp. 344-347).

Oxygen enrichment of converter blast has been tried experimentally and is favorably regarded by many German metallurgists. One small plant (Max Hütte, in Rosenberg, near Nuremberg) is said to have actually used oxygenated blast commercially and it is definitely scheduled for adoption at Oberhausen when, and if, the oxygen plant for enriching blast furnace air is built. With blast containing 30% oxygen it is hoped (1) to shorten the usual blow from 20 minutes to 15 minutes, (2) to develop higher temperatures so as to allow more scrap to be charged, and (3) to reduce phosphorus and sulfur limits in the blown steel. Scrap consumption can probably be doubled, from only 4 to 6% at present to 10 or even 12%. Oxygen additions to the blast would probably be reduced toward the end of the blow.

The metallurgy of the basic Bessemer process has been examined critically by Hans Wenstrup in Report No. 400 of the Stahlwerksausschuss of the Verein Deutsche Eisenhüttenleute (Stahl und Eisen, vol. 62, Sept. 3, 1942, pp. 749-756). Studies by the Kaiser Wilhelm Institute of the system Fe-Si-Mn-C-O have shown the possibility of deducing the theoretical progress of an acid Bessemer blow. These studies indicate that reactions between slag and metal should produce approximate equilibrium in the basic Bessemer process as well. If so, the progress of the blow can be measured by equilibrium studies. The Institute's work on the behavior of calcium-phosphate slags further indicates that the former attempts to explain slag-metal reactions in the Thomas process by postulating lack of equilibrium were wrong. From its fundamental studies of the system CaO-SiO₂-P₂O₅, the Eisenforschung branch of the K. W. I. came to the conclusion that a large improvement in citric acid-soluble percentage of phosphate in basic slag can be made by properly balancing the various members of the system and by suitable temperature control. It is fairly generally recognized that additions of sand sometimes help increase the availability of the phosphorus in basic slag, because they neutralize excess lime, but the Institute's researches go beyond this.

Thomas slag, which as previously noted is a principal source of phosphate for fertilizer purposes, is ordinarily allowed to solidify in a large ladle, then broken up and crushed. Recently however, it was found that it can be granulated by a stream of water in much the same fashion as blast furnace slag, and that this affords a better product. From the standpoint of the farmer the granulated form is preferable mechanically and there is the further advantage that the granulating process enhances the citrate solubility. It was rumored that phosphate slags were being enriched in

Germany by additions of raw phosphate rock. It is doubtful, however, whether such simple additions would be helpful unless steps could be taken to superheat the slags. Ordinary molten slag is not hot enough to render soluble the lime phosphate by volatilizing fluorine, according to the Jacob process.

The production of HFN steel is definitely a wartime expedient. It helped Germany to meet the demand for higher grade steel without increasing open-hearth capacity but the upgrading of Thomas steel has no apparent place in a peacetime economy. Actually the basic idea is not new. It was patented in England at one time but apparently was never tried out commercially until the emergency developed in Germany. The place to make open-hearth grade steel is in the open hearth--at last on the basis of present technology. If the raw materials available yield a Thomas grade of pig iron as compared with any metal likely to be made in the Thomas converter then duplexing is indicated. Duplex metal is likely always to be of better quality and more uniform and dependable. It is probably cheaper, too. Not only is the capacity of a converter reduced greatly by the HFN process (probably as much as 30%), but also there is the difficulty that heats are not reproducible. Considerable experience is needed before more than an occasional good heat can be made and even a good operator can obtain No. 1 or No. 2 metal in not more than about one third of his heats. This means that the bulk of the product will still be ordinary Thomas quality. Moreover, as indicated in the following tabulation, good open hearth steel is still better than HFN steel:

Nitrogen contents of specified grades of steel

<u>Percent</u>		<u>Percent</u>	
HFN Grade 1	0.008	Ordinary Thomas	0.012 to 0.025
HFN Grade 2	0.010	Good open hearth ...	0.003 to 0.004
HFN Grade 3	0.012 to 0.014	Duplexed Thomas	0.005 to 0.006

Regardless of the fundamental economics of the process some of the operating data are interesting to metallurgists. Optimum conditions for obtaining low-nitrogen steel by the Thomas process may be summarized as follows:

1. Low level of metal in converter (reduces capacity).
2. More dead space (e. g. corners) in converter (in order to avoid exposing too much of the metal to the blast at a given time).
3. Low nitrogen in the incoming pig iron. This may be helped by running the blast furnace with ample slag volume and by other measures).
4. Low temperature. (Ore or scrap and lime additions, properly timed to avoid rising above 1450°).
5. Low phosphorus (below 0.05%).

A simple floor test for nitrogen content is to take a flat oval sample cast and note possible cracking at the shoulder. Various tests leading to the conclusion that rimming HPN steel is as good as open hearth steel and better than killed HPN steel are described in CIOS Report XII-21.

Nitrogen absorption begins to be serious even before much of the phosphorus is eliminated and increases rapidly toward the end of the blow. Ore and/or scrap additions should be made at the top of the manganese hump to lower the temperature. Good results have been obtained by half-blowing a normal charge, adding ore to promote a vigorous boil, and then blowing again to an end point about 1-1/2 minutes short of normal. Converter design is important. With the conventional bottom, it was found impossible to keep the N content below 0.012/0.020% but with side-blowing it came down to 0.006 to 0.008%. At Watenstedt the converters were made ball-shaped so as to exaggerate the dead space where purification was by convection rather than by direct contact with the blast; but difficulty was experienced in holding the lining in place.

One of the proposed methods for reducing the nitrogen content of Thomas steel was to add soda before and during the blow. By this practice, experimental blows at the Krupp Rheinhausen plant (CIOS Report No. XXXII-67, p. 23) made steel with only 0.006% N instead of the usual 0.014 to 0.022%. The true explanation of the improvement, however, was that the phosphorus was extracted earlier, before the major oxidation of the carbon, resulting in a colder blow which in turn resulted in less nitrogen being absorbed.

At Watenstedt, steel having about as low nitrogen contents as HPN steel were produced by merely interrupting the blow at a suitable point by adding mixer metal and lime. The mixer metal apparently cooled the bath and the evolution of CO was thought to aid in elimination of nitrogen. A good deal of Thomas steel made in Belgium was classed as being as good as that made by the HPN process and was used for similar purposes. The Belgian converters are differently shaped than the German style but whether the better quality of steel was due to the shape of the vessel, to the manner of blowing, or (as suggested by one informant) to the quality of pig iron is not clear. It was further asserted that moderately good results (under 0.015% N) were obtained by ordinary blowing followed by killing the steel first with 0.06 to 0.10% silicon followed by 2 to 3-1/2 pounds of aluminum per ton. Titanium additions were tried to absorb the nitrogen but were not encouraging. Solubility was poor and reladling was necessary.

Mention may be made here of vanadium recovery from converter slag. This was another wartime expedient and will be discussed elsewhere in this report. It may also be noted that the Thomas steel produced at Watenstedt carried 0.14% arsenic which did not seem to be deleterious.

B. OPEN-HEARTH (SIEMENS-MARTIN) PROCESS

On the Continent, open-hearth steel is always referred to as "Siemens-Martin" Steel. Only insignificant quantities of acid open-hearth steel have been made in Germany. Virtually the entire output has been basic steel. The outstanding feature of wartime practice was the production of high-grade armament steels. Just as Thomas steel was upgraded to substitute for open-hearth steel, so Siemens-Martin steel was given special treatment to enable it to meet demands that ordinarily would be supplied by products of the electric furnace.

Three different processes were employed successfully to produce cleaner steel and also to make alloy steels which cannot be made in an ordinary open hearth without excessive loss. The most important product was an airplane steel (Plieg 12.65) containing about 2.8% manganese which was required in quantities far beyond the capacity of all the electric furnaces in Germany. One of these processes had been patented by Grundhöfer (D.R.P. 748,097), another was developed by Dr. Knüppel at the Stahlwerk Brandenburg, while the third had been kept secret by Fried. Krupp for many years. All three processes started from the theory that dosing the bath with deoxidizers tends to make dirty steel. To avoid secondary reactions, the first slag was removed. A new slag was then produced by adding lime and silica and the deoxidizers introduced into this clean slag. Deoxidation is effected in the Grundhöfer process by calcium-silicon, in the Brandenburg process by ferrosilicon and calcium carbide, and in the Krupp process by granulated aluminum. In a modification of the Krupp process at the August Thyssen works a combination of calcium-silicon and aluminum was tried out. In all these processes, the additions are made to the slag so that all reactions take place at the slag-metal inter-surface. Under no circumstances, therefore, could oxides remain in the metal as inclusions; non-metallic products of the reaction originate only at points where they must be taken up instantly by the slag.

For the detailed reports on the respective processes which are embodied in an Appendix, the author of this report is indebted to Dr. Ing. Arno Ristow of the Vereinigte Deutsche Eisenhüttenleute. Interesting though these developments are, they nevertheless represent principally another wartime expedient. Under anything like normal circumstances, the place to make electric furnace quality steel is in the electric furnace and not in the open hearth. There is even a question whether there is much national saving in electric current inasmuch as the consumption of ferrosilicon, calcium-silicon, and aluminum is heavy; the main difference is that the power may be used at a ferroalloy or aluminum reduction works instead of at the steel works. The substantial saving in certain alloys, notably the production of special manganese steels (Nos. 12.65 and 13.10) could probably be effected more economically in an electric furnace. The capacity of an open hearth is reduced by about 20% when these processes are employed and the higher temperatures and longer heats (about 10 to 15%) subject the refractories to extraordinary attack so that basic roofs are virtually essential. Finally, there is the extremely arduous work of

pulling the heavy first slag which melters may refuse to do in peace time. In postwar Germany, notwithstanding extensive employment of tilting hearths, it is quite possible that underfed workers may lack the necessary physical stamina to perform this task. And in other countries any such throwback to the days of "muscular metallurgy" is definitely contrary to present-day trends.

Still another wartime method of upgrading open-hearth steel--and one which may have economic applications even in normal times--is accomplished with the aid of an auxiliary electric furnace. Typical practice is to empty the entire contents of a 10-ton electric furnace into a 40-ton ladle and then to tap into the same ladle 30 tons of steel from an open hearth furnace. The electric steel at the bottom protects the ladle lining from excessive corrosion by the carbide slag which is the means of purifying the open-hearth addition. A 50% reduction in sulfur can thus be obtained together with further refining so that the end product is much superior to a simple mixture of products of the two furnaces. Thomas steel was also mixed with electric steel and carbide slag.

The foregoing description is reminiscent of the Perrin process which is generally believed to have been used only in France (Ste. Electriques d'Ugine) and perhaps in India. The essential feature of this process is to pour the impure steel through a synthetic dephosphorizing slag--probably a carbide slag--compounded from lime, iron ore, and a little fluorspar. The Perrin process was tried out in Germany at Krefeld. The idea there was to use an open-top electric furnace with a single electrode and to make a first slag which would remove phosphorus and, after treating the steel in a ladle with this slag, to draw it off and refine further with an acid slag. Like most ladle treatments, the principal objection, apart from the complicated nature of the procedure, was the liability of the steel getting too cold.

The all-basic open hearth had a considerable development in Germany. Chrome-magnesite (Radex E) roofs have lasted around 3,000 heats--making as much as 200,000 tons of steel--as against an average of 250 to 280 heats for silica roofs. Radex bottoms have a guaranteed life of 800 heats or better. Dolomite bottoms are not used. Construction practice is summarized by Colclough as follows (CICS Report No. XXXII-119, pp. 22-23):

" Chrome-magnesite roofs, and in many cases, entire basic upper structures, have been applied fairly extensively in German open hearth plants. Although occasional examples were encountered (e.g. Borbeck), general experience was that the basic roof is not an economic proposition on tilting furnaces. On fixed furnaces, however, it appears well-established but direct suspension of at least every third course of brick has been found to be necessary, with the intervening courses sprung from the supported rings. Details of four such systems are available. Roof lives of 1,000/1,400 heats were quoted for chrome-magnesite bricks in comparison with about 400 heats from silica roofs under similar operating conditions. The adjustable springloaded skewback is almost invariably used with the basic roof, and sometimes with normal silica roofs.

" Backwall, front-pillar and shoulder construction is usually in chrome-magnesite, backed with magnesite brick. One works obtains excellent results from a slightly-sloping magnesite backwall, faced with tarry dolomite blocks. Unburnt magnesite bricks are gaining favour for such locations as shoulders, front-pillars, etc.

" For producer, 2-gas (coke oven+ blast furnace) or 3-gas firing, the Vitkovice, Maerz and Venturi type ports appear the most popular. Extensive use was made of water-cooling for port ends, door frames, etc. Dry doors appear to be the general rule, water-cooled doors were seen only on one or two recent installations. For cold coke oven gas-firing, twin Hoesch-type water-cooled burners were almost invariably used, and in this regard the Germans appear to have lagged behind British practice, where the Hoesch arrangement has been largely superseded by modifications of the Broken Hill burner."

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Under postwar conditions, German furnaces have reverted to silica roofs because operations are intermittent. Even when there are plenty of orders, raw materials, and labor, it is usually necessary to shut down and clean the checkers on Sundays due to the poor quality of the gas.

High scrap charges are common, many plants working on 70 to 85% scrap. At Guss-stahlfabrikation, for example, the open hearth furnaces (although of the basic type) were not required to remove sulfur or phosphorus. At this plant (CIOS Report No. XXII-48) the normal charge for the 35-ton furnaces was 25% pre-refined mixer metal with 75% scrap and 1% burnt lime. Further additions of lime up to about 3-1/2% were made during the working of the charge. The time per charge was given as 5 1/2 hours with liquid pig iron and 6 hours with cold pig additions. The larger (60-ton) furnaces at this plant, however, were charged with 100% liquid mixer metal and fed with 10% high quality ore. Since the metal was low in sulfur and phosphorus, the refining process consisted simply of rapid elimination of carbon. The time per charge of 60 tons averaged 3-1/2 hours, or about 17 tons per hour; this practice was exceptional inasmuch as active mixers are not used at many other German plants.

At the Mannesmann plant at Ruckingen, the writer watched duplex heats with less than 20% of pig iron (stahleisen), up to 20% scrap, and the remainder Thomas steel. These heats were finished sometimes in 4 hours but usually took longer because on these relatively large (75 to 80-ton) furnaces the requisite quantity of molten steel had to be added in two ladles, sometimes with an interval between corresponding to the length of the converter blow. Hourly smelting rates on this basis ranged from 16.7 to 21.3 tons. Raw dolomite was used for patching bottom and a shovelful of sand was tossed in after each heat to clear the tap hole.

Common practice throughout Germany on straight open hearth work, as distinguished from duplexing, is to use 8 to 25% stahleisen (either solid or direct molten) with 40 to 50% occasionally for high-carbon heats. Emphasis seems to be placed upon melting down the charge with 0.50 to 0.60% C over and above the finishing point so as to allow sufficient refining. Anthracite may be added if high percentages of converter metal are charged. Burnt lime--say 5%-- is used as flux with no raw stone and little or no fluorspar. Pitch bricks are used occasionally to combat foaming and to promote a vigorous boil. They are cast 500x200x50 mm, and dusted with powdered coal. One or two of them thrown on top of the slag usually suffice. Oxidizing slags run 80% lime, 15% silica, 12% iron oxide, and 10% manganese oxide. A typical finishing slag for steel casting heats is 60% lime, 15% silica, and 15% calcium fluoride with less than 10% other oxides.

Several investigators have remarked upon the rigid exclusion of phosphoric iron from German open hearths, also upon the fact that so little acid open hearth steel is made, and upon the rather extensive use of the duplex process for high-quality carbon and alloy steels. Ore is often added only for a reboil. Slag controls were largely discontinued during the war.

Aluminum, usually in conjunction with silicon, is used for killing virtually all German open-hearth steels except high-silicon (over 1%) and special deep case-hardening steels. The American visitor is amazed at the wide use of low-manganese alloys--10% as well as 20% spiegeleisen and 35% ferromanganese. On alloy melts 45%, and rarely 75%, ferromanganese may be used. Ferrosilicon alloys are standard, mostly 45% and 75%.

Prewar research in collaboration with all German steel works emphasized investigation bearing upon the extent and influence of heat losses due to radiation, leakage, or infiltrated air, and on raising the output performance and furnace efficiency through better heat transmission. Studies were also made of the effect of preheating gas and air, the attainable combustion temperature, and of luminosity of flame as affecting the working of the open hearth. The use of producer gas was on the wane and mixtures of coke-oven gas and blast furnace gas, clean unheated coke oven gas, and lignite-briquette gas were coming into vogue.

German metallurgists attach a great deal of importance to luminosity in all furnace operations involving temperatures over about 1,000°C. Carburizing of coke oven gas is rated as one of the most important recent developments. A similar trend is noted in England where a recent installation is oil-fired simply to assure a luminous flame. Natural gas is not available and there is a possibility that German coke oven gas is stripped of more of its illuminants than American gas, owing to the high development of organic synthesis industries which use these hydrocarbons as raw materials. Its calorific power is said to average around 450. In Germany, tar oil was formerly used but long before 1939 this fuel was entirely absorbed for Diesel power, largely for the Navy, so ordinary tar was used instead. When ordinary tar also was commandeered for ship use in 1938-39, it was necessary to use pitch. This is a low-volatile fraction which melts at 50° C. A mixture of 75% pitch and 25% tar was used successfully in prewar burners but hard pitch can be used alone only after being powdered and necessitates special distribution and preheating equipment. One method is to atomize with preheated compressed air and to employ a hot-oil circuit to maintain the proper temperature throughout the pitch storage tank, pump, filters, and ring main. Generally, two pitch burners were employed at each end of the furnace where they are located in water-cooled tubes set at 45° through the sidewalls of the port end. In one case a single pitch burner was inserted through the wicket. At another plant the Steinheiser system is used. Here the coke oven gas is ignited and starts to burn with a smoky flame a little ahead of its entrance into the furnace. Additional air for complete combustion is added later. Another way to increase luminosity without introducing more carbon is to preheat the gas or air, or both, so as to crack the hydrocarbons. Brown coal additions are used at several plants and powdered solid fuel has the advantage that additions can be regulated easily. Dr. Bulle of the Gutehoffnungswerke proposes the use of oxygen-enriched air with blast furnace gas. At this plant there is a surplus of blast furnace gas whereas coke oven gas has to be purchased from outside interests. Coke oven gas is usually produced at the collieries and is thoroughly cleaned and desulphurized before it is fed into the Ruhr grids for distribution by municipal authorities. German steel works are not large users of city gas because so much of their steel is made by the Thomas process and because they make a relatively large amount of blast furnace gas. They use purchased gas principally in the open hearths and to a minor extent as an admixture with blast furnace gas in reheating furnaces.

C. ELECTRIC FURNACE PROCESS

In Germany, as elsewhere, electric furnaces have largely replaced crucible furnaces. They are used to make high-grade steel from scrap, including Thomas scrap, and to an important extent for duplexing. Most of them are in integrated steel works. Usually they are complementary to open hearth and Bessemer equipment, being used not only for duplexing or for melting metal or slag for ladle treatments but also for remelting alloy scrap and low-grade ferroalloys.

Arc furnaces account for most of the tonnage of electric steel and are apparently exclusively of the Heroult type. No important changes in design or practice were registered during the war beyond the gradual increase in average size. The latter trend, however, has not proceeded very far even yet. In pre-war Germany, the furnaces were quite small, mostly 20 ton. Although a fairly large number of 40-ton or even larger furnaces were built during the war, there is still a general belief that 50 to 60 tons is about the top limit for economical operation for alloy steel making.

Top charging is the general rule. One hears a good deal about removable tops and special methods of charging. Much of this talk, however goes back to the fact that the furnaces themselves are not big enough to allow for a door in the top. Opinion is divided as to the relative merits of moveable roofs or bodies. Inasmuch as linings tend to wear around the electrodes, it is possible to provide for rotating the hearths. This cannot be done during the melt without breaking off the electrodes--at least so long as solid scrap remains at the bottom--but one design provides for rotation up to 30° either way between successive charges, thus allowing for three different positions of electrodes in relation to the hearth.

"Graphite" (graphitized) electrodes were in general use before the war but as supplies became short and demand increased there was a gradual switch first to amorphous carbon and later to Soderbergs. If the war had lasted much longer probably all furnaces would have gotten around to using Soderberg electrodes. Some of the so-called "Soderberg" electrodes, however, are not baked in the furnace itself. The paste is sometimes formed into shape and gas-baked in an oven. Apart from the fact that the baking is done at the steel works itself, and also that the quality is generally far inferior to that of purchased electrodes, they do not differ greatly from those made by regular manufacturers. Ordinary Soderberg electrodes are also produced. At Hamborn, for example, they were prepared (CIOS Report No. XXVI-32) by tamping a mixture of crushed anthracite and tar into a long metal sleeve 400 mm. in diameter, the mixture being sintered by the heat of the furnace as the electrode gradually burned away. The coal tar mixture was purchased in the prepared state and mixed with a small percentage of sodium silicate just prior to use.

Basic refractories for electric furnace lining include Ankrit (pure magnesite), Radex E (66% Cr_2O_3 , 34% MgO), and Radex EK (22% Cr_2O_3 , 78% MgO). Stabilized dolomite, advocated by certain British metallurgists, is not employed in Germany.

(1) Duplexing

At many steel plants the electric furnace is employed for finishing, particularly for high grade steel for munitions. Duplexing in both

electric and open hearth furnaces is much more common in Germany than in the United States. The Germans complain that capacity was much less in duplexing than when the same equipment was used separately, perhaps 10% less on the average. In the past, especially in America, there has been much criticism of duplexed steel. Much of this criticism can be traced to the fact that the steel was blown soft in the converter and no subsequent refining was done. The open hearth or electric furnace was employed almost exclusively as a mixer. In Germany, however, although the main metallurgical load properly falls upon the Thomas converter, the finishing process seems to have been effective in producing armament grades of steel. A refining period of 2 or 3 hours per heat, finishing under a white carbide slag, was usual practice for both carbon and alloy steel production. One slag was commonly used if the melt-down phosphorus was low enough (as it generally was) especially on heats where alloy conservation was desired. At Hamborn (CIOS Report No. XXVI-32) duplex metal was produced in 20-ton electric furnaces from basic Bessemer metal blown down to a carbon content of 0.03 to 0.05%. The slag was decanted before the metal was poured into the electric furnace where a new slag was prepared with burnt lime. Instead of the usual carbon or carbon-ferrosilicon reduction a white carbide slag was obtained by reduction with aluminum chips or granulated aluminum. After making necessary alloy additions the melt was ready to tap. Due to the violent boil and dephosphorization in the converter the results obtained were comparable with those normally had with two-slag basic practice although the steel was finished quickly. Only 1-1/2 to 2 hours were required in the electric furnace step so the 20-ton unit was able to produce as many as a dozen 30-ton heats, or 360 tons, in 24 hours.

At Hoesch (CIOS Report No. XXIX-17) cold scrap charges were normal practice but a certain amount of converter-blown metal was also used. Heats that melted low in phosphorus were finished under one slag but two-slag practice was more common because Thomas scrap as well as blast furnace pig metal and even ferromanganese were high in phosphorus carbon-ferrosilicon slag practice was used on all heats. Aluminum additions, averaging 0.5 kg. per ton of steel, were all made in the furnace before tapping. Larger additions and ladle treatment with aluminum were discontinued, due to inclusions.

A certain amount of duplexing of open hearth steel has been done in the electric furnace but this involves difficulty in synchronizing the two furnaces. The Thomas blow is short but since very little alloy scrap can be absorbed, a duplex method based upon Thomas metal demands a higher use of virgin alloys low in phosphorus and sulfur. These reasons led to the elaboration of the Watanstedt process for large scale production of alloy steels. It is claimed that this process yields products equal to the best electric furnace grades and offers great possibilities for low-cost production under post-war conditions when alloy scrap should be in ample supply. This is a combination or "mixing" process and resembles the process previously described in the section on open hearth melting. Its operation at the Herman Goering works is described by Colclough as follows (CIOS Report XXXII-19, Appendix 18, pp. 12-13):

"A 60-ton electric furnace was charged with chrome-bearing scrap and melted under reducing conditions and without any removal of slag in order to minimise alloy loss to the slag. The chromium and manganese content of this metal was then adjusted by the addition of low-cost ferro-chrome produced in the blast furnace (10-25% Cr, 5-6% C, and up to 0.5% P), and of spiegel instead of ferro-manganese. No attempt was made to adjust carbon content or to reduce the phosphorus content of the electric furnace metal as this involves oxidation with loss of alloy.

"Simultaneously in one of the 160-ton open hearth furnaces, a straight carbon steel heat was made of very low sulphur and phosphorus content, - S under 0.02%, P under 0.01%, - by double slagging if necessary and of the required carbon content. Synchronisation of the two furnaces, - open hearth and electric - was facilitated by adjustment of the proportion of blown Thomas metal used in the open hearth charge to regulate the time required to work the charge.

"The impure liquid alloy steel from the electric furnace was then mixed in a ladle with the necessary amount of high-purity open hearth steel to give the desired alloy content of the product.

Three mixtures were made:-

- M.I - A ladle of 40 tons of the highly alloyed electric steel was filled up with 40 tons of the open hearth steel, giving 80 tons of the specified analysis.
- M.II - Two ladles of 25 tons each of the electric steel were filled up with 50 tons of the open hearth steel, giving 150 tons of mixed steel.
- M.III - Three ladles, each containing 20 tons of the electric steel, were filled up with 60 tons of open hearth steel to give 240 tons of alloy steel.

"A fourth variation, M.IV or Th.-M-process, consisted of taking 25 tons of the highly alloyed steel in a ladle and filling up with 50 tons of soft-blown Thomas steel of under 0.015% S and P, resulting in 75 tons of mixed steel."

(2) Induction furnaces.

Many German metallurgists consider that the wider use of the induction furnace was one of the outstanding developments of recent years. Edgar Allen & Co., Sheffield, England, claim to have installed and operated in 1927 the first high-frequency electric crucible furnace in the world to be used for commercial manufacture of tool steel. According to O. Dörrenberg and W. Bottenberg (Stahl und Eisen, vol. 60, Feb. 8, 1940, pp. 116-119) there were 40 of these furnaces producing steel in Germany in 1938. High-frequency coreless induction furnaces, therefore, were not uncommon before the war but in most countries their use was restricted to melting or re-melting, especially for making castings. The Germans had already begun to use them for making high-carbon ferrochromes and to a limited extent for removing carbon, phosphorus, and sulfur from high-grade steel, but it was well along into the war period before such furnaces began to be considered for general use in refining steel. No information has been obtained as to any actual installations for either melting or refining in large units, over 5-ton, but it was stated that a small plant near Cologne was using this type of furnace.

The theoretical advantages of induction melting are well known. Since the heat is generated within the bath, there is no contamination from fuel; high temperatures are obtainable; active circulation of the bath, due to electromagnetic currents, causes thorough mixing and avoids segregation in the melt; and results can be repeated accurately.

A far more active circulation of bath than can be obtained in the high-frequency furnace is characteristic of the low-frequency induction furnace developed by Dr. Rohn of the Heraeus Vakuumschmelze A. G., Hanau. Conditions in this furnace approach the desideratum that certain metallurgists have described as an "emulsion" wherein ore, slag, metal, flux, and gases are maintained in intimate contact over a multitude of surfaces, thus favoring the speedy and complete accomplishment of desired reactions. No data have been obtained as to any commercial installations of this furnace although it was tested by Krupp and probably elsewhere. No progress seems to have been made toward the development of a suitable lining. Mere adjustment of slag compositions so as to avoid chemical attack fails to prevent excessive wear of refractories. Thus in their excellent summary of the tests of such furnaces A. Niederthal and H. Wentrop (Stahl und Eisen, vol. 61, June 12, 1941, pp. 588-699) state that, even with a silica-saturated slag and an acid lining, purely mechanical erosion is so great that this type of furnace cannot be used for steel making. They also point out that since the movement of the bath brings the metal in contact with the air, there may be a strong tendency to absorb nitrogen. This may be advantageous in respect to nitrogen-rich chromium or chromium-nickel steels, but must be combated in making other steels by modifying the boil. They further note that care must be taken when making additions of carbon, aluminum, silicon, or other reducing agents so as to assure that these elements react only with the slag and do not form alloys with the metal.

The main point in favor of this furnace is the important fact that reactions between the bath and additions take place at high velocity. The reason for this is not alone that the contents of the bath are intimately mixed but also the penetration of heat through nonmetallic materials. This heat effect is so great that high-melting point slags, either acid or basic, which are normally quite viscous, can be made fluid enough to become exceedingly reactive.

Dr. W. Rohland proposed some years ago a two-stage unit. The upper unit would be an arc furnace superimposed upon a Rohm low-frequency furnace. After the initial melt and preliminary refining, the metal could be tapped into the lower furnace for final refining and alloy additions. Despite certain theoretical advantages this proposal seems never to have been actually tried.

Another of Dr. Rohland's ideas is to apply the agitating principle of the induction furnace to refining steel in a ladle. The same general idea is embodied in a design, which probably originated in England, wherein conducting coils are embedded in the refractory concrete bottom of an ordinary arc furnace. By passing current through these coils and altering the phase relations between this current and the melting circuit as represented by the current flowing through the metal between the electrodes, it is possible to develop any desired degree of electromagnetic circulation for speeding reactions and assuring homogeneity.

(3) Electric smelting.

Production of pig iron in a low-shaft electric furnace of Siemens design has been discussed by Michael Kauchtschischwili (Stahl und Eisen, vol. 61, Nov. 13, 1941, pp. 1033-35) who indicates its possible economic employment in Italy or wherever power can be obtained for 1.0 to 1.3 pfennigs (0.03 to 0.10 lire) per kilowatt-hour. This is doubtless the same furnace described in an unpublished T. I. I. C. report by Dr. Harry Curtis who obtained drawings which were subsequently forwarded to the office of the Metals and Minerals Subcommittee in Washington.

(4) Quality standards.

The quality of steel was generally tested at the furnace by breaking a specimen at temperatures of 300° to 400° C. and examining the "blued" surface with a microscope for inclusions. Oxygen analyses were discontinued during the war. The standard scale of purity based upon microscopical examination, is reproduced in the Auxiliary File for this report.

D. UNCONVENTIONAL STEELMAKING PROCESSES

Attention has been given to the production of sponge iron and to other methods for making steel direct from the ore. The only sponge iron process that appears to have been tried out extensively in Germany, however, was a modification of the Edwin or Norsk-staal process. An experimental plant to test this process was established at Bochum under the sponsorship of three leading firms but the experiments were discontinued in the early 1930's. The reason given for stopping the work was the world-wide depression but Dr. Edwin's subsequent efforts to obtain suitable financial backing failed to revive interest and eventually further research was ruled out by the outbreak of the war. A complete description of this process was obtained from Dr. K. Gebhardt, of the Krupp staff in Essen and formerly in charge of the pilot plant under Dr. Edwin. This process employs individual drums containing successive batches of iron ore but arranged in vertical columns so that they can be progressed. The whole process thus becomes in effect continuous. An earlier type of Edwin process, it may be noted, (cf. Hodson and Smalley: American Electrochemical Soc. Trans., vol. 51, 1927, pp. 234-236) performs the reduction in a rotary kiln, but this type of equipment was not tested in Germany. Both modifications of the Edwin process are based upon reduction of high-grade Swedish ore by means of coke oven gas superheated in an arc furnace. Apart from the need for imported raw material, the process was not well-adapted to German conditions by reason of the high power cost. It was estimated that it might have possibilities, however, if power could be had for 1 pf. instead of 2.8 pf. a kilowatt-hour which was a typical prewar figure.

Fairly large quantities of granular Swedish sponge iron were employed during the war for use in driving bands for projectiles. Low-temperature reduction methods of manufacturing powders for powder metallurgy, however, were never employed extensively in Germany. In fact, it is doubtful whether sponge iron manufacture promises any economic advantages in Germany inasmuch as virtually all low-temperature reduction processes for making high-grade iron or steel direct from ore are difficult or impossible to operate on any but high-grade ores which, of course, are not readily available from domestic deposits.

The Krupp-Renn process, on the other hand, was employed successfully on silicious iron ores for several years at Essen-Borbeck and for several months at Watenstedt, and elsewhere to treat low-grade nickel ores. This process, which may have much wider application in the future is described in another FIAT Final Report by the author in collaboration with Dr. Pollitzer. The product of this process is metallic iron in the form of "luppen" or rounded lumps. With suitable ores to start with, this iron can be remelted in an open hearth or electric furnace but with German ores and low grade fuel the luppen ordinarily contained so much phosphorus and sulfur as to require that they go to the blast furnace.

Somewhat sketchy information was obtained regarding a process used for treating pyrite cinder at Stürzelberg Rhein. Owing to the high zinc contents this material could be used only sparingly as an admixture in

ordinary iron blast furnace charges and early experiments to treat it in a rotary kiln were not successful. Finally a process was worked out which seems to be a modification of the well-known Waelz process. The material was treated batchwise with coal and limestone in a rotary kiln, 10 to 11 meters long. The zinc is volatilized in about 4 hours after which the reduction of the iron is completed and finally the slag is tapped out. This slag is high in lime and is used for Portland cement.

A British investigator, Dr. Leckie of the British Iron and Steel Research Association, made inquiries regarding the Solutier process. This process, which apparently has not been tested on even a laboratory scale, proposes to separate the constituents of iron ores by carbon reduction and fractional distillation in an electric furnace. It proposes to recover silicon, calcium, and other elements in suitable condensing equipment, as well as the iron. Even assuming that technical difficulties are surmountable, this process looks unattractive by reason of the doubtful economics of producing and marketing such huge quantities of these joint products.

At the Gutehoffnungs works, I saw the remains of an ambitious plan for direct-steel making. The idea apparently was to feed coke and raw materials down through two or more shaft furnaces rising from the roof of a horizontal tank or open hearth furnace. The installation was a complete failure.

E. RÜCHLING CONTINUOUS PROCESS

A proposal for streamlining steel production from ore to finished rolled product has been made by Hermann Röchling of the Röchling Iron and Steel Works at Völklingen in the Saar. Röchling, who is now in his middle seventies, has been a prominent figure in Germany for many years. In addition to managing the family works since 1897 he has acted as consultant for various other iron and steel concerns and, during the war, he was the active head of the entire industry under the Speer Ministry, being Chairman of the Reich Vereinigung Eisen.

(1) General description.

The principal feature of this proposed process is the employment of a continuous decarburizing and refining furnace for converting pig iron to steel. This furnace is an outgrowth of the drum used in a continuous process for recovering vanadium which was developed during the war. It employs an air blast which is directed through tuyere bottoms into a flowing stream of molten pig iron. Experience proved that this initial rapid oxidation removed not only the vanadium and a little carbon but also most of the silicon and manganese. Instead of passing the metal on to a mixer and thence to the ordinary basic Bessemer process, Röchling now proposes to lengthen the drum so that it becomes in effect a combination of a Bessemer converter and an open hearth furnace. Metal flows over the hearth until it comes over a "blow bottom" and then continues to flow to the discharge end.

Much of the required heat comes from the blowing operation but additional heat is supplied by a top flame entering at the feed end of the drum. By combining the blowing and heating processes it is claimed that the whole process takes less time even than the Bessemer or basic Bessemer process. By doubling the length of the vanadium-slugging furnace, and by placing the blow-bottom within the first one-third of the hearth, Röchling feels that ample time is provided for refining the steel according to the open-hearth part of the process so that the finished steel will equal duplex or even straight Siemens-Martin quality steel. He recommends that deoxidation, the last step in the furnace, should be accomplished by means of coal instead of ferromanganese or other additions that may leave solid inclusions (CO being volatile).

The proposed design shows a siphon tap, similar to that commonly employed on a lead blast furnace, for removing the steel from the "oxidizing drum". Further to improve the deoxidation and quieting of the metal, the finished steel is passed through acid blast furnace slag which has been heated to steel temperature. This purification feature is emphasized; in fact the claim is made that the slag treatment alone will serve to produce a soft, quiet steel without employing any other deoxidants or means of killing.

Finally, the steel is cast - not into an ordinary ingot but into a bar of any desired section (up to 10 ft. or more in length and as thin as 0.4 in.) - and rolled or forged as usual.

(2) Inventor's claims

Dr. Röchling summarizes the possibilities of his process essentially as follows:

1. Continuous operation with all its concomitant advantages.
2. Lowest treatment cost for all kinds of --
 - (a) Pig iron of any range of composition as regards Si, C, Mn, S, and P.
 - (b) Scrap, including alloy scrap.
3. Wide range of special as well as ordinary qualities of finished steels other than those of higher alloy content which are preferably made in an electric furnace.
4. Substantial reduction in cost of production of semi-finished products for conversion into mass-produced duplicate products, including --
 - (a) Rolling mill products (sheets, bars, etc.)
 - (b) Drop forgings
 - (c) Steel castings
5. Elimination of capital expenditures for certain ordinary equipment and of process steps, notably--

- (a) Blooming mills and accessory heating pits, fuel requirements, scaling losses (0.5% of ingot weight), and cropping losses of bloom ends (9% for sort ingot iron and upwards to 25% for high-carbon, killed steel)
- (b) Semi-finished mill trains with scaling losses (1.5%), cropping losses (3 to 5%), and operating costs.

On the basis of an assumed ratio of hard and soft steel of 40% and 60%, respectively, the average saving, according to Röchling, would amount on a national basis to RM 18.85 per ton at the blooming mill stage plus RM 9.66 at the semi-finished rolling mill stage, or a total of RM 28.51 per ton. Detailed estimates of cost savings in reichsmarks per metric ton follow:

	Soft steel	High-carbon steel
At blooming mills:		
Cost of rolling	RM 5	RM 6
Ends	40	80
Scaling loss	70	100
At semi-finishing mill trains:		
Cost of rolling	5	6
Ends	60	90
Scaling loss	80	110

(3) Technical Difficulties and Comment

Several German metallurgists with whom I discussed the foregoing proposal -- none of whom wished to be quoted directly -- doubted whether this revolutionary procedure could be made practical within their lifetime. All agree as to the desirability of accomplishing the various ends sought by Röchling but they question the means and are appalled by the enormous cost of full-scale experimentation that would be necessary before any such drastic change in current practice could be made practical. They see difficulties in balancing the successive steps in the process so that metal will not pile up anywhere along the line but they are most skeptical about the new furnace. They admit that the idea has been partially tested in principle in the vanadium recovery program but they recall difficulties even in this relatively simple procedure. Refractories gave a great deal of trouble. There seems to be no way to prevent roof attack above the blow-bottom. No presently-known material can long withstand the washing-out action of the long flame and the spattering with corrosive iron oxides and flux. On the other hand, Röchling himself asserts that the durability of linings in the vanadium-oxidizing drum, actually had in some cases been lengthened to 6 months except for renewing certain plugs at regular intervals. He advocates using "a stronger dolomite lining". Moreover, he points out that his process avoids the use of sundry other mechanical installations that normally require in the aggregate a great deal of upkeep--such as ladles, locomotives, cranes, mixers, etc. It would be unfair, therefore, to base the comparison solely as against the life of converters and/or open hearth furnaces. Another question, less important, is whether the finished steel can be kept hot enough to flow readily through the siphon tap.

In sum, the process has intriguing possibilities but, like most revolutionary ideas, it probably cannot be made to work without an enormous amount of additional experimentation and possibly certain fundamental modifications.

F. POURING, MOLD, AND INGOT PRACTICE

Thomas steel is generally top-poured, usually in big-end-down molds with "bottle" (semi-closed) tops. Casting cars were employed at large works but molds were generally set in wide shallow pits. On the other hand, it is estimated that 80% of all German high-quality steel ingots were bottom-poured. This meant more cropping as compared with top-pouring but the steel contained fewer inclusions and the surface was much better. Although electric hot-topping was virtually abandoned, hot top mixes were not uncommon and some kind of hot top was usually employed. Typical mixes comprised calcium-silicon and clay together with various salts (fluorides or carbonates). Top crops were claimed to be reduced by this practice to 6% without secondary pipe. On large castings some firms still used electric-arc heating to keep the heads fluid.

Molds varied notably in size and shape; the American visitor is impressed by the extraordinary number and variety at most plants. Small round ingots were used extensively although Martin steel ingots were generally square in section. Plate ingots (of sheet bars) were generally slab-shaped. Gun-tube ingots were cast in hexagonal, fluted big-end-up molds weighing 2-1/2 to 3 tons or more. Usually two tubes were made from each ingot, the breech-end of each tube coming from the center of the ingot. Such ingots were cooled slowly (about a week) in pits under a cover of "Fuller's earth". The maximum size bottom-poured ingots were about 16 tons and the number of molds fed from a single trumpet varied, according to size, up 32. At the Hoerder works, large ingots (200 tons) were rotated on a turn-table while being filled. The slag was segregated by centripetal force and the rotation insured homogeneity. Two or even three runners might be used to feed the ingot simultaneously. At one or more plants the life of molds was limited to not more than 90 pours.

Molds were generally coated with tar-benzol lacquer. Trinidad asphalt was used before the war and "coumarone" residues, low in free carbon were substituted for a high melting point asphalt when this became necessary. At Hamborn (CIOS Report XXVII - 32, p.5) molds were cleaned and coated while still warm with a mixture of pitch or coal tar dissolved in benzol. At this plant hand-brushing is preferred to mechanical spraying. No coating is used for rimmed steel or for ingots that were subsequently machined.

More attention seems to be given to conditioning ingots in Germany than in the United States or Great Britain, although practice varies at different plants. Strong emphasis is placed on surface soundness as a factor in internal cleanliness, freedom from axial weakness, ease of stripping and handling. The Germans do a great deal of turning, square-turning, or planing, and not so much hot-seaming, hand torch-, or machine-scarfing. All high quality steel ingots are commonly cleaned by removing as much as 1/2 inch by machining, about 10% by weight. Armor plate steel may be only spot-chipped. Ingots or blooms for rails, structural shapes and other less critical items often receive no surface cleaning whatever. Scarfing with oxygen was employed to remove surface defects in fabricating sheet bars for conversion into cartridges and other munitions. This practice was also tried at Neunkirchen (Hans Puppe, General Director) for

cleaning ingots. A machine which was said to be good for cleaning blooms and billets was made by the Waldrich concern in Siegen.

The practice of turning 5 to 6% from the surface of ingots after slow cooling seems to have been fairly standard throughout Germany. A long furnace is provided for annealing and the machining was done in large lathes some of which were capable of running two-tipped-roughing tools each taking up to a 1/2-in. cut at different locations on the ingot surface. Conical-shaped ingots facilitated the machining operation at Krefeld. In addition to eliminating the troublesome and uncertain chipping of billets this heavy initial cut from the ingot removes the undesirable layer of chill crystals along with surface blemishes and defects. In consequence the yield of products is said to average better than 70%. At the Deutsche Edelstahlwerke the yield of alloy steel was approximately as follows (CIOS Report No. XXV-38):

	<u>For operation</u>	<u>Cumulative</u>
Cast ingot to turned ingot	94%	94%
Turned ingot to bloom	80	75
Bloom to bar	95	71
Inspection	99	70

Fireclay (chamotte) pouring nozzles were employed in most small ladles but for larger ladles (say 30-ton or over) graphite-mixtures were employed. For high-manganese steels a magnesia nozzle was designed.

Considerable thought was given to rolling from the molten condition without casting into ingots. I learned of no actual employment of continuous casting of steel billets or sheet bars but there was some belief that such practice might be feasible following methods successfully employed in the aluminum industry. Other authorities regarded the idea unfavorably due to the high temperatures involved.

Equipment for compressing large ingots while they are solidifying was installed at Hamborn and before the war the August Thyssen Co. contended that this practice, known as the Harmet compression method, resulted in complete freedom from blow-holes, shrinkage cavities, drawpipes, and structural weaknesses. It is now reported, however, that later tests showed no improvement as compared with steel poured from the same ladle into regular hot-topped molds.

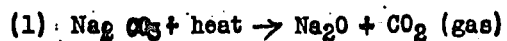
There was considerable development of centrifugally cast or spun steel. This technique was employed for the production of guns up to 150 mm bore, special alloy steel tubes, special cylinder liners, and ingots for heavy forging or radial rolling. Centrifugally-cast hollow ingots, up to 45 tons each were produced at Hamborn and were subsequently rolled on a tube mill for special applications in competition with hollow-forged ingots. Coincidentally gun production was also speeded by improvement in rolling and pilgering. Pilger ingots for this special-tube making process are solid ingots cast in a cylindric mold. However, hollow ingots were also made for the tube industry in the stationary mold at the Thyssen plant at Mulheim.

Large horizontal centrifugal casting machines for hollow ship shafting, pilger-shell blanks, gun tubes, and miscellaneous tube blanks were developed at the Hochfrequenz-Tiegelstahl division of the Deutsche Edelstahlwerke in Bochum. After bringing these machines up to speed (e. g. 1100/1200 r. p. m. for 88 mm gun tubes and 800 r. p. m. for 105 mm. tubes) a slit tube filled with a measured amount of sand was inserted in the mold and then turned so as to distribute a thin, even layer of fine sand on the inner surface of the revolving mold. This coating, which is held by centrifugal force, prevents sticking and improves the quality of the casting. A weighed amount of liquid steel is next poured into a crucible which has a hole in the bottom for feeding the metal into the mold which is kept revolving until after the steel solidifies--for 15 to 60 minutes, depending upon the wall thickness.

Theoretically, the manufacture of hollow steel blocks should be preferable to making a solid ingot and drilling or otherwise making a hole in it, for the reason that large solid ingots cast in the usual manner in chill molds are likely to develop segregation streaks and unsound parts in the interior. A novel method for making hollow cast ingots was called to the attention of J.I.O.A. investigators by Dr. P. Herasymenko. He claims to have made test ingots up to two tons which had no inner cracks and which developed no cracks on forging. He employs the usual outer mold and to form the hollow center he uses two concentric steel tubes. The inner of these steel tubes has thick walls and the cooling water flows through it. The outer of these tubes, however, is made of thin sheet and the space between is filled with a low-melting material, such as lead, thus forming a thin-walled outer jacket which, being backed only by molten material, will collapse sufficiently to allow for the contraction of the ingot on cooling. The principle is not new and therefore is not patentable, but Dr. Herasymenko affirms that it can be employed to advantage to make hollow billets up to 10 or 12 tons. As any segregations tend to be inside the walls of the finished product, he believes that hollow cast billets should be much preferable to pierced billets in the manufacture of pressure vessels, guns, and other products subject to high tangential stress, whether from plain carbon or alloy steel.

G. DESULFURIZATION

As elsewhere noted, the successful method for desulfurizing pig iron outside of the blast furnace, which had already been worked out before the war, was an important factor in conserving manganese as well as rendering more economical the utilisation of low-grade domestic iron ores. The method is simple and consists essentially of treating molten iron with sodium carbonate in the ladle, on the way to the converter or open hearth. The essential chemical reactions are principally:



Both products of the second reaction float on the molten pig iron, and are skimmed before the iron goes to the steel making process.

Consumption of soda ash varies according to the amount of desulfurization required. At Hoesch, for example, 3 to 5 kgs. sufficed to reduce sulfur contents of a ton of Thomas iron from 0.068% to 0.052%. On high-sulfur iron obtained from the acid-smelting process, the consumption is reported to have averaged 6 or 7 kgs. per ton of iron.

In recent German practice up to 4% of lime was added to the soda ash. At the Hermann Goering Works, for example, (CIOS File No. XXIX-30, page 14), the desulfurization treatment just prior to placing the iron in the converter was carried out with a mixture of two parts of soda ash and one part lime. This mixture produced a more viscous slag than soda ash alone. This more viscous slag rises slowly in the ladle, and thus was considered more efficient. The results obtained on some experimental treatments with soda ash-lime briquettes were so satisfactory that two roll briquetting machines were scheduled to be installed. The briquettes were approximately $\frac{1}{2}$ " x 1" x 2".

At this plant low manganese iron of .25% sulfur was given a double treatment. It was first treated with sodium carbonate and the slag removed before going to the mixer. A second treatment was given before charging in the converters. Whereas the preliminary treatment with powdered soda ash was inefficient, due to insufficient agitation in the ladle, the second treatment with both soda ash and lime brought the final sulfur content down to 0.04, as compared with 0.14% in the mixed iron. The briquetting treatment was expected to reduce the sulfur from 0.25% to 0.04% (maximum) in a single operation, using only 6 Kilos of briquettes per ton of iron. Iron with a sulfur content of 0.05% was considered satisfactory, approximately 0.012% being removed in the converter.

H. Kärber and W. Oelsen (Stahl und Eisen Vol. 58, August 25, 1938, pp. 905-914; September 1, 1938, pp. 943-949) have called attention to the fact that all the heat reactions between Na_2CO_3 and pig iron are exothermic, and that these reactions are much more rapid in the ladle than they are in the cupola (due to agitation by CO_2 gas), and that losses due to silicon are also less in the ladle. Although directed principally to the foundrymen, their article gives the following summary of the subject:

- (1) When SiO_2 is absent in melt, Na_2CO_3 is excellent desulfurizer;
- (2) Na_2S remains stable at 1300-1400° C and needs no Na silicate as solvent;
- (3) Even when S content is too low to form much Na_2S it removes FeS from melt;
- (4) Apart from C no other reducing agent is needed;
- (5) When thoroughly mixed with metal, reduction of the sodium (recognized by thick fumes) takes place only at the end of desulfurization;
- (6) Any silica present will increase residue of S after treatment, although sodium metasilicate ($\text{Na}_2\text{O}, \text{SiO}_2$) is a good desulfurizer.

In a long series of tests at the Röchling plant at Völklingen, it was demonstrated that Thomas iron containing as little as 0.55% manganese could be sufficiently desulfurized (down to 0.035% max. S) by treatment with 6.5 kgs. of soda ash per ton of iron. Iron made with the same slag (41% CaO, 32% SiO₂) would have to contain 2% manganese to come within this maximum sulfur limit without subsequent treatment.

Instead of using dry powder, many German plants used to premelt the soda so as to conserve heat. Nevertheless, as previously noted, many metallurgists in the Ruhr area are opposed to any desulfurizing process--partly because it introduces a further complication and may cool down the iron but also because soda ash is scarce in postwar Germany and because the workers may be subjected to obnoxious fumes.

Attempts were made to utilize slag from the desulfurizing process for making superphosphate by the Kali process, replacing Na₂CO₃, but the material did not work out satisfactorily on a plant scale.

H. MISCELLANEOUS MIXER AND LADLE TREATMENTS

Opinion is divided as to the merits of various intermediate treatments in the mixer or ladle, apart from desulfurization, largely because of their tendency to chill the metal. For the same reason there has been some reluctance to attempt any intermediate refining of blown metal on its way to the open hearth or electric furnace in a duplex process, notwithstanding the fact that there is generally a 15 minute lag between the two steps. At one or more plants, active mixers are employed for pre-refining hot pig iron before charging it to the open hearth. Mention has also been made of the practice of employing an auxiliary electric furnace to sweeten and upgrade open-hearth steel which is mixed with the electric slag and metal in the ladle. These are isolated examples, however, for ladle treatments are the exception rather than the rule and mixer treatments are less common than they are in England. Even additions of de-oxidizers are generally made in the furnace instead of in the ladle. The Perrin process has not been used commercially in Germany, although it was tested at one time at Krefeld.

The Girond process was employed at the old Thyssen plant at Hagendingen (near Metz, Lorraine) before the war. In this process, fluorspar, soda ash, carbon, lime, and mill scale are thrown on the bottom of a hot ladle and thereby sintered. When the metal is tapped into the ladle, the resulting boil removes part of the phosphorus.

Reports as to the operation of active mixers at the few German plants where they are employed are quite favorable. Properly used they relieve the open hearth of much of the burden of refining so that in effect the operation becomes simply a rapid boil to remove carbon. Silicon is eliminated and the sulfur and phosphorus contents much reduced by the mixer treatment so that the open hearth may be completed in 2 to 4 hours. At Bochumer, for example, there are 3 @ 250-ton basic tilting mixers which take direct metal from the blast furnace and produce a semi-refined product analyzing about 2.5 C, 0.25 Mn, 0.020 P, and 0.030% S, and no Si. The pig iron carries 4.5% C. The average refining time is 8 hours and 10% Swedish (Kiruna) iron ore and 2% limestone are the only additions.

V. ALLOY STEEL

In Germany, as in other countries, the trend to use more alloy steels as compared with ordinary plain carbon steels was accelerated by the needs of the armed forces. Anticipating these enlarged requirements, stockpiling had been in progress for some years and early in the war a central control board was established to govern the consumption of all alloy elements. By exercising close control over allowable compositions and enforcing changes in specifications and other conservation measures, the government avoided any critical shortages although few of these elements were ever abundant. Various substitutions were necessary almost from the start but it was not until about September 1944 that the situation became so tight as to necessitate reducing alloy limits to a point where the size of steel sections had to be increased enough to impair airplane performance, for example. Long before that, however, the conservation program had necessitated the use of higher carbon and other steel compositions that required rather careful heat treatment and less drastic quenching than ordinary compositions to avoid cracking or to develop the desired strength and other properties. High-heat resisting steels also were substandard; compositions possessing optimum creep strength at elevated temperatures were virtually unobtainable.

A. CRITICAL ELEMENTS

The outstandingly scarce alloying element was nickel. Molybdenum steels were simply eliminated at the outbreak of the war and scanty supplies of this element were reserved almost exclusively for high-speed steel for tools. Enough molybdenum for this restricted use came from Norway and Finland until these countries were lost after which, of course, the shortage became serious. In structural fields, chromium-molybdenum steels were replaced by chrome-vanadium or manganese-vanadium. Ample tungsten was available for tool steel and as new high-speed steel compositions were developed and with the larger employment of tools tipped with hard carbides (including a new tungsten free composition) fairly large quantities of tungsten were released for use in armor-piercing projectile cores. Very little cobalt or columbium were to be had and chromium was so scarce as to require careful control of its use and full recovery from scrap. Vanadium, on the other hand, was relatively abundant so this versatile element was used to replace other alloying elements. Actually the monthly output of ferro-vanadium, chiefly as a result of recoveries from Thomas slag, increases from 60 tons before the war to a peak of 300 tons in 1944. Manganese, which in addition to its essential employment as a deoxidizer in all classes of steel is likewise a fairly versatile alloying element, was also used to replace scarcer elements. Manganese conservation varied with the supply situation at individual plants.

The measures taken to assure supplies of manganese and vanadium were interesting enough to justify treatment in separate sections of this report. The supply situation with respect to other important elements is briefly reviewed below:

Nickel stocks were small even in 1939 and were reduced to the danger point before new supplies could be obtained from the Petsamo mine in Finland. When access to this supply was cut off later, the situation became desperate. Attempts were made to substitute manganese for nickel in stainless steels of the 18 and 8 type, but without much success, and a similar substitution was tried unsuccessfully in armor plate. Replacement of nickel by manganese was more satisfactory, however, in certain other steels, especially in deep-hardening steels. Ferronickel (8%) was produced from Greek and domestic (Frankenstein) ores by the Renn process. The lumps (luppen) from this process, which was operated at Salzgitter and also at Bremen (Oalebshausen), went through the blast furnace and basic Bessemer converters before being shotted. Only about 10% of the national requirements--about 400 to 600 tons monthly--were available from this source.

The Renn furnace slags contained as much as 12% chromium, but attempts to recover this element from these low grade nickel ores were unsuccessful. The chromium shortage that existed during the early months of the war was partially relieved as the Balkans were overrun but appeared again when shipments from Turkey became more and more irregular. In broad perspective, however, the chromium situation never became really critical. Although African ores were cut off immediately, deliveries from Turkey, Serbia, Roumania, and Greece were quite substantial and deficiencies were largely offset by wartime economy measures.

Of considerable interest was the wartime high speed steel composition known as "Dreierstahl" by reason of the fact that it contained approximately 3% of each of three elements -- molybdenum, vanadium, and tungsten -- together with as much as 4% chromium. Excellent service was obtained from this steel according to several reports although all agreed that it was much more sensitive in its heat treatment than high-tungsten compositions. The tungsten contents of other types of tool steels were strictly reduced or eliminated, but these conservation measures were perhaps overbalanced by the large expansion in the use of tungsten carbide. According to one estimate as much as 50 tons of tungsten was required monthly for carbide tool tips. In view of the large quantities of sintered hard carbides employed for armor-piercing projectile cores, the total consumption of tungsten remained at rather high levels. Efforts to substitute uranium for tungsten in projectile cores failed, but a reasonably satisfactory tungsten-free carbide tool composition was produced. The tungsten shortage eased considerably after the occupation of France, but there was never enough tungsten to satisfy all demands. The steel industry, within the frame of specified allowable compositions, had No. 1 priority at all times. Next in line were the rather insignificant requirements of the lamp and radio tube makers, and projectile cores came third. Portugal and Spain were principal sources of new supplies and special attention was given to working up complex and low-grade ores from domestic as well as accessible foreign mines.

Ferrosilicon came mainly from Norway and Italy and was in ample supply. Bessemer ferrosilicon (15 to 20%) is made in Germany, however, as are also high silicon alloys (75, 80, and 90%). Titanium alloys were likewise available freely.

Boron has never been employed as an intensifier in steel in Germany. In the opinion of several German metallurgists it is still best-described as a "question mark". There was a shortage of borax but this was not the reason for the absence of boron steels. Copper is another element that was used sparingly, if at all, and here again the reason does not seem to have been the shortage of supplies as the possible requirements of the steel industry would have been almost negligible.

Beryllium was used only experimentally in the steel industry. Many Americans were surprised to find that the total consumption of beryllium by the Axis nations was quite small and that even in Germany the consensus seems to be that beryllium imparts no special properties that would justify its use as a steel alloying element either in war or peace. At the Annen plant of Ruhrstahl A. G. (CIOS Report No. XXIX-26) where a few beryllium heats were studied, the best results were obtained with a steel containing approximately 0.20 C, 0.70 Mn, 0.45 Si, and 0.10 to 0.20% Be, other elements being normal. After water-quenching at 880° to 900° C. and tempering at 450° to 500° C., the tensile strength of this material was 100 Kg/mm². Beryllium, however, was employed in a steel for watch springs.

B. ALLOY AND SPECIAL STEELS

Extraordinary changes occurred during the war in the composition of certain German steels. In general these changes followed the pattern of the National Economy (NE) steel developments in the United States and such of these changes as were dictated by shortages of alloying elements have been briefly noted in the previous section of this report. A number of American and British investigators have accumulated a vast collection of analyses of steels employed for specific purposes. Probably the most comprehensive listing of analyses is that made by James P. Gill (CIOS Report No. XXXI-26) but much detailed information will be found in numerous other reports. Krupp's alloy compositions, for example, especially those for high-temperature applications, are tabulated by Hutton (CIOS Report No. XXXII-99) and Pollitzer (FIAT Report No. 419); Emerson (FIAT Report No. 483) covers steels used in boiler tubes, cracking tubes, and superheater service; and Loeb (CIOS Report XXVII-19) describes those used in aircraft production by Messerschmitt. However, there are other generalized reports and many reports on individual plants give analyses of products and other valuable data.

An optimistic view of Germany's wartime alloy steel position was given by Röchling in the following quotation from his interrogation:

"Naturally, we must attempt to basically produce high-tension steel with those alloy elements that serve our purpose and were at our disposal. When we compared the English or American war material, which fell into our hands, with our own, we found that we had achieved the same quality in the most essential parts, with much less alloy additions and many times in completely different ways. For example, our armour-plates

on the tanks were certainly not worse than those of our opponents; at one time they were actually superior. They were made, essentially, however, with an exceptionally low content of alloy elements. It concerned the individual parts of the alloy and the surface hardening, through the heating with the welding burner, the subsequent quenching with water, as well as through the heating with high frequency."

In contrast with the foregoing appraisal, G. M. Butler (CIOS Report No. XXX-29) affirms that "German metallurgists were unanimous in claiming that no new materials had been found worthwhile, except as noted below and that all of their time had been devoted to conservation of alloy and production work".

Mentioned as of possible interest were a cold-worked austenitic steel for hot extrusion dies and the previously-noted new high-speed steel. This low-tungsten substitute for conventional 14 or 18% tungsten types was widely promoted by the leading steel companies and was variously evaluated. Just as in the case of the molybdenum-tungsten tool steel compositions in the United States, no real agreement exists as to comparative performance. Where alloy content was essential, as in hot work steels for die-casting, etc., users generally managed to get the usual steels with tungsten up to 10%. However, there is a number of hot-work steels that contain less tungsten, one most favored being one with 4-1/2% tungsten and 1-1/2% chromium.

Three German companies--Edelstahl (Krefeld and Leipzig), Krupp (Essen), and Röhring (Wetzlar and Leipzig)--and two companies in Austria and Czechoslovakia (Böhler and Roldi, respectively), supplied virtually all the tool steel requirements of the Reich. All these companies produce rolled and forged bars, cold drawn and ground bars, wire, plate and sheet from electric furnace steel plus some open hearth steel. Ingots vary from 300 pounds to 8 tons. Including both round and square sections they are annealed immediately after casting and surface turned. All high-alloyed steels are hammered and all SAE types pressed. The largest rolling size for high speed steel is 50 mm. and for carbon and low-alloy grades, 150 mm. Upset forging is used for heavier sections. Most manufacturers heat-treated high-speed steel in salt-bath furnaces using three or four pre-heats and two or three high draws. Nitriding after final drawing was common practice. Subzero treatments were unusual in Germany.

Among the numerous Krupp steels and patents attention may be drawn to the one described as V 4 AB Supra which is claimed to be resistant to intergranular corrosion and pitting. Its nominal composition is an 18% chromium, 8% nickel steel with 2.4% silicon and 2% molybdenum. With the chromium slightly on the high side it is also used in welding rods, preferably with columbium or tantalum additions. In view of the ill-repute of similar steels in the United States, it may be significant that Krupp emphasizes melting practice, including nitrogen control, as a primary factor in the behavior of these steels. In the turbine-blading field, an austenitic stainless steel with high tantalum-columbium and nitrogen was used as well as two of Krupp's specialties: Tinidur, a

30% nickel, 15% chromium stainless with about 2% titanium and low carbon (0.10%) and Chromadun (used when the alloy shortage became critical) which carries 18% manganese, 12% chromium, 1% vanadium and 0.20% nitrogen and medium carbon (0.50%). A number of alloys for jet propulsion and for supercharger turbine blades were developed experimentally. Probably the best of these was never used because its alloy content was too high; it contains 30% nickel, 15% cobalt, 15% chromium and up to 8% each of tungsten and molybdenum.

In cast steels one foundry specialized in forging die blocks weighing 50 to 100 tons. Armor turret and steel castings were typically chrome-molybdenum steels but a wide variety of compositions were employed to conserve scarce elements. A sliding scale of type analysis specifications was established by the German government according to plate thickness. The maximum thickness rolled for tank plate was 180 mm. and not much of that was actually rolled. For cast armor Krupp's idea a suitable composition before the war was 2.5% chromium, 0.45% molybdenum, 0.35% silicon, 0.40% manganese, and 0.35% carbon. Wartime compositions generally contained 0.10% vanadium to compensate for other deficiencies.

Aircraft castings were restricted to two types: Medium manganese-vanadium and 120 chrome-vanadium.

The most popular steel for high-pressure power plant use is a chrome-molybdenum steel which corresponds roughly to the new U. S. specification for non-graphiting steam station piping. Bolting is chrome-molybdenum, chrome-nickel having been rejected after some short-time service failures. Flanges previously made of chrome-molybdenum-vanadium are now straight chrome-vanadium. Special steels are necessary to resist hydrogenation. In general, a chrome-tungsten-vanadium steel is recommended although lower alloyed steels without tungsten may be used where alloy-economy or cost considerations must be emphasized. In using common alloy steels it is important that they should be fully annealed.

Magnet steels used in Germany are mainly of the precipitation-hardening (ausscheidungs) type. Magnets are frequently produced by blending and sintering powdered metals. Alnico compositions are employed, among others. A magnet developed by the R. Bosch Co., and claimed to have approximately 50% more strength than the Alnico type had the following composition: 14% nickel, 8% aluminum, 23% cobalt, 3% copper, 0.1% carbon, and remainder iron. (CIOS Report No. XXXI-4)

High-manganese steels are not used extensively. German tank treads, for example, were made with steel containing only 2% manganese and surface-hardened. Malleable iron was used for various parts, especially during the latter part of the war period, but the extent to which this may have been attributable merely to alloy shortages was not investigated. German firms were licensed to use lead to produce free-cutting low-carbon steels although this type of material was not commonly used.

Among leading makers of alloy steel are: BOCHUMER VEREIN (VEREINIGTE STAHLWERKE), the KRUPP GUSSTAHLWERKE, Essen-RECHLING of Völklingen, and EDELSTAHLWERK MALAPANE of the VEREINIGTE OBERSCHLEISISCHE HUTTENWERKE, which account for a high proportion of the total output. The special steel producer par excellence is the DEUTSCHE EDELSTAHLWERKE A.G., Krefeld. This is a subsidiary of the VEREINIGTE STAHLWERKE and has two plants in Krefeld, whose combined capacity is some 250,000 tons per annum of Siemens-Martin and electric steel, as well as other plants at Remscheid and Bochum.

Düsseldorf is only slightly less important than Krefeld, Essen and Bochum as a center of alloy steel production. The main firms here are GEBRÜDER BOEHLER A.G., EDELSTAHLWERK DÜSSELDORF-HEERDT, G.m.b.H., STAHLWERK KRIEGER (RUHRSTAHL A.G.) and RHEINMETALL-BORSIG, the great engineering and armaments concern absorbed shortly before the war by the HERMANN GÖRING combine.

There are numerous other firms that specialise in alloy-steel production, whose importance is measured rather by the value than by the quantity of their output. Remscheid and Hagen has each several of these works.

C. MANGANESE SAVING

Although manganese supplies caused some anxiety in Germany, the manganese situation never became as desperate during the second World War as it did during the early part of the first World War--before Germany regained access to Russian ores. Actually, there was no great reduction after 1939 in the quantity of manganese used per ton of steel; the principal wartime economy measure was the mandatory substitution of spiegeleisen instead of ferromanganese, wherever possible. As reserves of high grade (chiefly South African) ores were depleted, certain changes in ferro-manganese blast furnace practice were necessary and as much as 50,000 tons a year of ferromanganese was produced from slag, much of it by a double smelting process from domestic ores that normally would be usable only for making spiegel. It is estimated that 40 to 50% of all manganese requirements in steelmaking were supplied in the form of spiegel, and some time elapsed before the percentage of manganese in ferromanganese had to be lowered much below the standard 75 to 80%. In May, 1944, however, the situation had deteriorated so that only 3,786 metric tons of blast furnace ferromanganese containing over 60% manganese was produced and 8,859 tons contained 30 to 60%. The grade of spiegeleisen also had to be lowered in 1944 as revealed by production figures which show that the output of spiegeleisen containing over 14% Mn dropped further from 23,669 tons in April to 14,998 tons in May whereas that of low-grade spiegel (6 to 14% Mn) increased from 32,075 to 41,226 tons.

Apart from some substitution of silicon and/or aluminum for manganese in the Thomas process and a notable extension of the pre-war practice of desulfurizing pig iron with soda, other methods of saving manganese never assumed much importance. However, all the following

practices were employed to a greater or less extent: -

- (1) Predeoxidation (in converter) employing -
 - (a) Spiegel in converter - 10 to 20%;
 - (b) Pig iron:
 - (i) Cold;
 - (ii) Preheated;
 - (iii) Liquid.
 - (c) High-phosphorus iron scrap;
 - (d) Aluminum;
 - (e) Ferro-aluminum (20% Al)
 - (f) Ferrosilicon
- (2) Predeoxidation while pouring into ladle - pulverized coal;
- (3) Predeoxidation in open-hearth furnace - usually with blast furnace ferrosilicon;
- (4) Desulfurization -
 - (a) Soda;
 - (b) Superheat (oxygen plus coke oven gas) and remove silicon in top pot and then tap slag into bottom pot ahead of the iron. (Tried at Oberhausen but no details available)
- (5) Reduced carbon and Mn content of low alloy steel;
- (6) Use of high carbon (high strength) steels for structural uses (smaller section, less metal).

The principal means of lowering the net national consumption of manganese was the adoption of the Brassert or acid-smelting process. As elsewhere noted, this process, including the subsequent desulfurization treatment of the molten iron, not only enabled lower grade ores to be smelted economically in the blast furnace but also avoided the necessity of large manganese additions to offset the low lime-silica ratios. When a blast furnace is operated without regard to sulfur content the manganese content of the iron can be reduced from the usual 1.4 or 1.5% to as little as 0.08% and still cut down the stone on the charge. The reduction in total manganese charged is roughly in the same proportion as the percentages found in the metal. Another method of cutting down on the manganese requirements of the blast furnace was to increase the fluidity of the slag by adding alumina. Thus at Hamborn (CIOS Report No. XXVI-32) high grade alumina (from a plant near Cologne) was added to the charge with good results.

The extent of manganese saving was greater at some plants than at others but perhaps the most drastic economy was instituted by the Reich authorities at the Arbed works in Luxembourg. Prior to the war it had been common practice at this plant to use 15 kgs. of manganese per ton of pig iron. High-grade ores--obtained from India, Russia, or South Africa--

were charged to the furnace to assure a manganese content of at least 1.20% in the iron and a sulfur content of 0.06-0.07%. During the occupation, the use of imported manganese ores was stopped and their place was taken by Thomas slags plus some slag from blast furnaces making spiegeleisen. These slags carried only 6 to 8% manganese and the operations of the furnaces were affected so that the sulfur in the pig iron jumped to as much as 0.1%.

In steelmaking at the Arbed plant (CIOS Report No. XII-21), prewar practice demanded some 5.5 kgs. of manganese per ton, of which 2.0 kg. was consumed for deoxidation in the Thomas converter and 3.5 kg. to assure the desired 0.4 to 0.5% content in the metal. During the war, deoxidation had to be carried out largely by the use of anthracite and powdered coke with varying amounts of ferrosilicon and iron-aluminum alloys added at the ladle stage. The use of "aluminized spiegeleisen" had been recommended but was not a success because the alloy floated on top of the steel thereby making it difficult to obtain the necessary mixing for complete deoxidation. A further saving in manganese was effected by reducing the manganese content of the finished mild steel from a minimum of 0.4% to around 0.28% and that of Bessemer rails from 0.9-1.0% to 0.65%. As the situation tightened during the summer of 1944, the Wehrmacht ordered that the manganese content of anti-aircraft shell steel should be halved. The previous specifications for this type of steel had called for "less than 1% manganese" and under the new rulings this was reduced to "less than 0.5%"; the actual composition which formerly had ranged from 0.85 - 0.90% manganese and 0.55 - 0.75% carbon was dropped to 0.40-0.45% manganese with either 0.25 - 0.35% (Th. 30) or 0.35 - 0.45% (Th. 40) carbon. It was affirmed that the new compositions resulted in no impairment of fragmentation as compared with the original and that they were more machinable.

The Röchling interrogation mentions efforts to improved manganese recoveries in the blast furnace by hotter work with shorter slag. As long as minette was available in sufficient quantities, this was relatively easy. He also called attention to the efforts to conserve the manganese contained in the Austrian iron ores from the famous Erzberg (Ore Mountain) in Styria. These ores, previously mined and smelted by the Alpine Montangesellschaft and subsequently taken over by the Herman Göhring A. G., carry approximately 2.5% manganese. Formerly more than 60% of this manganese was lost in blast furnace slag unless 15 to 20% additional coke was used. After some experimentation at Linz it was found that a good recovery of the manganese could be made by boosting the silicon contents of the pig iron to 1.0 - 1.5%; the iron was of open-hearth (Siemens-Martin) grade but carried 4 to 5% manganese.

Studies in the Krupp laboratories at Wolfrath showed that savings could be effected when manganese was added to basic bessemer blows which were on the hot rather than on the cold side -- notwithstanding the known fact that volatilization losses are excessive at high temperatures (CIOS Report XXXII-67, p. 23).

In ordinary open hearth operation blocking was done with manganese only. As manganese became more critical the amount of manganese was reduced and aluminum or calcium silicon was added directly after a partial initial manganese block. In order to do this the furnace was run extra hot and after the block a flame somewhat reducing in character was used with a falling temperature in the bath. The major amount of manganese was added together with the ferro-silicon in the ladle. Open hearth slag was always sent to the blast furnace to recover the manganese. An overall usage of 11 lbs. of manganese per ton was achieved. When operating with the reducing slag mentioned above chrome recovery in the open hearth was reported to be better than 95%.

Substantial amounts of manganese were recovered from unconventional sources through the medium of high-manganese slags produced either by the Ischebeck process or the Hahl-Rosenbaum process. Matte-smelting of manganiferous iron ores was not attempted in Germany.

The Ischebeck process (August Thyssen foundry, Hamborn) - In this process the manganese contents of Spiegeleisen was reduced by at least 4% by adding ore to the runner (Rinne). The manganese content of the pig iron decreased in this way by about 1% with the simultaneous formation of a slag containing up to 30% manganese. The process was in use at various places including the A. Thyssen works, Hamborn, at the Henrichs works, Hattingen and at the Friedrich works, Herdorf/Sieg.

The Hahl-Rosenbaum process - In this process the manganese was transferred to the slag by an acid-smelting of the ore-flux mixture of slight Mn content. Depending on the composition of the ore-flux mixture a slag containing up to 35% of Mn was obtained. The simultaneously produced pig iron could be used in the open hearth (if the phosphorus was not too high) but was too cold to blow in a converter (Thomas iron). In use at the A. Thyssen foundry, Hamborn. Friedrich-Alfred foundry, Rheinhausen, Bochumer Verein, Bochum, Gute-Hoffnungs foundry, Oberhausen. Exact details of the process can be obtained from the above-mentioned places and from the Verein deutscher Eisenhüttenleute, Düsseldorf. Herr Rosenbaum who discovered the practical application of the process, cannot at present be found.

I obtained information, however, on the two stage procedure employed at Essen-Borbeck, which permitted the manufacture of ferromanganese from manganiferous domestic ores and also enabled full use to be made of the high phosphorus Nikopol ores. The principal domestic source of manganese are the Siegerland ores which contain up to 8 to 9% Mn and 46% Fe. In the two-stage process the first step is to smelt in the blast furnace so as to produce an iron containing about 2% of manganese and suitable for steel making, allowing most of the manganese to go into the slag. This is accomplished by using low blast temperatures and acid slags. Coke consumption on smelting an all-slag charge is extraordinarily high, probably 6,000 kg per ton of iron as compared with only 1,800 kg in standard prewar ferromanganese practice by direct smelting of high grade ores. Accordingly, the typical wartime practice was to use about 80% slag and 20% of the regular charge, the final product being a 40% ferromanganese. By this procedure the high phosphorus content of Nikopol ores was diluted. Phosphorus

is more volatile than manganese and hence can be partially eliminated but any attempt to volatilize substantial amounts of phosphorus in a blast furnace results in high manganese losses as well.

A typical prewar Spiegel charge was as follows: -

80% roast spathic (Siegerland) ore;
15% ferromanganese furnace slag;
5% raw spathic ore
Coke requirements about 1,100 kg per ton of 18 to 20% spiegel.

I obtained details of an experimental blast furnace run employing the following mixture per ton of steel making iron

810 kg of Mn-agglomerate	=	30.1%
625 " " roasted spathic (Siegerland)	=	23.2%
220 " " crude spathic (Siegerland)	=	8.2%
817 " " Geyer ore	=	30.3%
220 " " Slovak Mn-ore	=	9.2%
2,692 kg		100.0%

190 kg of limestone

The volume of slag was 1,044 kg per ton of iron, the consumption of coke was 1,252 kg, and the lime-silica ratio was 0.5.

In this case, due to the high manganese content of the slag (3%), the iron was low in sulfur and silicon. Since the Geyer ore contains more phosphorus than the Nikopol ore, the phosphorus content increased to 0.21%. The carbon content was 4.1%.

As soon as the experimental mixture was down to the tuyeres, the blast temperature was reduced from 700° to 300° and later on to 200°. The average temperature was 200 - 300°. The blast quantity amounted to 45,000 cbm/per hour with a mercury column of approximately 58 cm. The slag was thinly fluid. 607 tons of a 6 to 12% spiegel and 581 tons of pig iron with 2 to 5% manganese were produced. Roughly 1,200 tons of a high-grade manganese-slag were obtained. This slag averaged 23% manganese and 1.4%, the complete analyses showing --

29.7% MnO, 0.005% P, 1.34% S, 30.6
SiO₂, 9.4% Al₂O₃, 16.8% CaO, 5.4% MgO,
1.5% BaO and 3.8% alkalis.

The intention was to take 50% of Geyer and 50% of roasted carbonate ores into the charge; this, however, was not successful, because the Geyer ore hung up in the chute gates and stuck to the runway due partly to the unfavorable, very damp weather. Therefore, 8.2% of Slovakian high-manganese ore was added from the available stock.

The manganese content of the slag rose comparatively quickly to 20-22%, but it was possible to attain a maximum value of only 24.4% Mn although the Mn-content of the iron came down to 2.5%.

In the night of the 20th December 1943, the nozzle tips (Düsenpitze) burned through. Although tapping had been completed an hour before and equilibrium should have been established, all tuyeres were stopped up and signs of incomplete reduction were displayed for 2 hours before the furnace was converted to making 40/50 ferromanganese.

The conclusion can be drawn that during the experiment smelting was carried out with the lowest possible temperature and the lowest Mn-content of the accruing pig iron so as to keep control over the operation of the furnace. This experience, however, does not check with the report, confirmed by Dr. Rohland, that slags containing as much as 35% Mn can be made by this process.

D. BY-PRODUCT VANADIUM RECOVERY

A notable feature of the wartime supply situation was the by-product recovery of vanadium. After the small stocks of foreign vanadium--largely African--had been exhausted, Germany obtained 90 percent of its vanadium from Thomas steel works slags and 10 percent from a crude salt produced at alumina plants from vaniferous bauxite. Each Thomas steel plant was ordered to produce slag containing 0.25 kg. of vanadium for every ton of steel made; in mid-1944 the ratio of recovery was boosted to 0.30 kg. Additional vanadium was recovered from dust collected from the regular basic Bessemer blows as well as from slags made in a special blow in an acid converter before the metal went to the final blow in the regular basic converter. Vanadium-bearing slag was also produced by adding mill scale or iron ore to blast furnace ladles or runners.

The methods of vanadium recovery at various plants are described in a number of CIOS reports and are partially summarized in two reports (CIOS Report No. XXII-119 and JIOA Report No. 23). Somewhat more comprehensive is a report prepared at the request of Dr. A. B. Kinzel, one-time European representative of the Metals and Minerals Subcommittee of T.I.I.C., by Dr. Heinz Gehm of the Gesellschaft für Elektrometallurgie in Nürnberg. Reference is also made to an article by H. Ziegler (Stahl und Eisen, vol. 62, September 17, 1942, pp. 795-798). (The Gehm report is listed as PB6202.)

Vanadium is a common trace element in iron ores and certain other mineral materials all over the world. It was found that the minette ores of Luxembourg and Lorraine contained vanadium (probably as the pentoxide) ranging from 0.015 percent in the limey ores with 20-24 percent iron to 0.035 percent in the silicious ores with 30-40 percent iron. When these ores are smelted in a blast furnace, a large proportion of the vanadium (60-80 percent or more) is reduced to metal with the result that the pig iron produced in Belgium, Luxembourg and the Saar ordinarily contains 0.10-0.15 percent of this element. The Dogger ores of Baden carry 0.10-0.20 percent, Swedish ores 0.10-0.25 percent, and the Salzgitter ores 0.085 percent or more. Since the ratio of vanadium to iron is more than twice as great in the Salzgitter ores as in the minettes, the pig iron produced in the Herman Göring works at Watenstedt contained 0.3 percent vanadium. Thomas iron from blast furnaces in the Ruhr ranged from about 0.13 percent to 0.25 percent or more, depending upon the relative proportions of different ores on the burdens. Even coke ash contains around 0.015 percent vanadium.

Assuming that vanadium is commonly present in ores and furnace products as the pentoxide (V_2O_5) combined with lime, it can be reduced more readily by carbon than phosphorus or silicon but not so readily as iron or manganese. Theoretically so long as most of the phosphorus passes into the pig iron the bulk of the vanadium is likely to be recovered in the blast furnace. Conversely, when the liquid metal is subjected to oxidation, the silicon should be removed first, followed in order by phosphorus and vanadium with manganese and iron remaining more or less completely in the melt. If the liquid iron is blown in a Bessemer converter the slag formed in the early stages of the blow contains almost all the silicon and most of the vanadium. Some phosphorus may be oxidized as well but if the slag is deficient in lime it will tend to be reduced back into the metal.

(1) Preparation of Enriched Slag.

Processes for concentrating vanadium in the form of an enriched slag can be listed as follows:

- (a) Oxidation with solid materials (Millscale, magnetite, etc.)
 - 1. Additions to runner or ladle
 - 2. Rammed linings or Naeser spout-bottom (Rinnenboden Verfahren) process.
 - 3. Mixer treatments
- (b) Blast oxidation
 - 1. Treatment of ordinary Thomas iron
 - 2. Preliminary manufacture of concentrated iron (vanadin eisen)

In addition to obtaining the maximum economical recovery of vanadium in slag, the problem is to get a slag that can be easily processed.

Probably the simplest way to recover vanadium from pig iron is to shovel mill cinder or high grade Swedish ore into the ladle or, as in the case of the Naeser process, to line the furnace spout or runner with these solid oxidizing reagents. This process, which resembles the Ischbeck process for manganese, makes a poor recovery of vanadium (under 50 percent) and yields a slag containing usually less than 2 percent of the desired element. A partial recovery of vanadium was made at Hamborn by adding 30 to 40 kg. of fine Swedish ore per ton of iron in the mixers and skimming the resulting slag which was shipped along with dust from the converter hoods to Ruhrort-Meiderich for resmelting.

Any process that depends upon oxidation with ore or mill cinder suffers from the disadvantage that reactions can proceed only to equilibrium between the vanadium contents of slag and

metal. By using atmospheric oxygen, however, the reaction can proceed virtually to completion, particularly if the slag is maintained in a viscous or dry-almost solid condition.

When iron containing say 0.1 percent vanadium is blown in the Thomas converter in the ordinary way, virtually all of the vanadium goes into the slag, but the slag volume is so great that the content of vanadium (say 0.3 percent) is too low to justify economical recovery. However, if the slag is skimmed after a restricted blow, before much of the phosphorus and manganese are oxidized and before lime is added, then a greatly enriched product is obtainable. In the process devised by R. von Seth, this preliminary blow is conducted in an acid-lined converter and the metal is finished as usual after being transferred to a basic-lined converter.

It is possible to conduct the double blow in the same converter but this involves numerous difficulties in addition to causing too much wear on the lining. The acid slag obtained by the von Seth process usually contains only 2 to 4 percent lime. Inasmuch as no plant seems to have had more than one acid-lined converter, it would appear that only a part of the output was ever subjected to the double blowing process. In the Gehm report, for example, emphasis is placed upon the fact that only every fourth or fifth charge in the converter cycle can be so treated and consequently about three-fifths of the vanadium is lost by the von Seth process. The inference is that this is due to lack of acid-lined converter capacity although the present writer is not quite sure on this point.

At a number of plants none of the regular Thomas iron is subjected to a double blowing process, but one blast furnace was reserved for the manufacture of vanadium pig iron (vanadin roheisen). Instead of dividing all vanadium-bearing wastes among all furnaces, such materials are all added to only one. The charge for this furnace comprised spittings plus whatever other high-vanadium material was available, including the acid-converter slag obtained at plants where double-blowing was practiced. At Volklingen (CIOS Report No. XXII-3) it was found that the globules of metal or "spittings" which are ejected in the early stages of the normal blowing operation contain from 0.5 to 1.5 percent vanadium, 1 percent carbon, and over 10 percent phosphorus. At this plant the acid converter is replaced by a Frisch-trommel, which is a cylindrical tube, about 5 feet outside diameter, with a jet of air blowing on the surface of the metal to effect the preferential oxidation. Another departure from usual practice is at the Burbach works in the Saar (CIOS Report No. XX-6), where about one-fourth of the metal is partially blown in a special converter which was built in the mixer house. This converter was first lined with silica brick as in

other works but subsequently it was found more satisfactory to operate with a dolomite lining and to form a neutral slag, adding suitable proportions of lime.

At Burbach the vanadium iron furnace had a coke consumption of 1350 kgs. per ton of iron as compared with 1120 kgs. for ordinary Thomas iron, and furnace capacity was reduced approximately 10 percent owing to the high slag volume and metalloid contents of the iron which carried 4-5 percent manganese, 5-7 percent phosphorus, and 0.50 percent vanadium. In Belgium (CIOS Report No. XII-21) a furnace was operated on a burden consisting of 80 percent minette ores plus 6.5 percent of Thomas slag carrying 0.34 percent vanadium and 13.5 percent of "primary slag" carrying 1.39 percent vanadium. This furnace made iron containing 0.48 percent vanadium and higher in manganese and phosphorus than ordinary pig iron. Typical analyses of vanadin eisen made in the Ruhr show 0.3-0.8 percent vanadium and 3-8 percent phosphorus.

The whole of the vanadin eisen at various plants is subjected to a short blow of 7 or 8 minutes, roughly twice as long as the pre-blowing period for ordinary Thomas iron in the double-blowing process, and the metal and slag are poured into a ladle. After skimming the slag, the metal is transferred to a basic converter. The blowing operation in the basic vessel occupied about 20 minutes, about 5 minutes being required for the "after-blow." Notwithstanding a loss of 70 to 100° C in temperature of the metal during the transfer from the first to the second vessel, the finishing temperatures tend to be abnormally high, due to the high-phosphorus content, requiring additions of scrap to cool the metal. Actual temperature measurements show 1100° C for the liquid iron, 1350° C after the acid blow, and 1650° C or more after the basic blow. Considerable loss of vanadium is indicated by the fact that the slag from the basic blow carries 0.45 percent vanadium. Enriched slags from the primary blow of vanadin eisen probably averaged around 8 percent vanadium. The price paid during the war for slag of this grade was RM 10.25 for each 1 percent of vanadium contained. This is roughly equivalent to RM 1 per kg. as against RM 18 per kg. in the form of vanadium oxide or RM 25 per kg. in ferro-vanadium.

Since the Salzgitter ores are so much richer in vanadium than other ores smelted in Germany, the normal Thomas iron made at Watenstedt contained about 0.3 percent of vanadium and the ordinary slag of the basic Bessemer operation about 1.3 percent, almost as much as the product of the primary blow at other plants. One blast furnace was operated to produce vanadin eisen, using a proportion of the Thomas slag along with suitable quantities of raw lump ore and sinter so as to produce an iron containing 1.0 to 1.9 percent vanadium. Owing to the slag on the

burden the iron is high in manganese and contains as much as 10 percent phosphorus. This liquid iron is blown for a few minutes without any lime additions in a special converter lined with fire-brick but with the usual dolomite bottom and yields metal which may be considered as low grade ferrophosphorus. One analysis shows 9-10 percent phosphorus, 0.05 percent vanadium, under 0.01 percent silicon, and under 0.05 percent of either manganese and carbon. Iron of this character is normally difficult to dispose of although it may be useful in small quantities as a source of additional heat in a Thomas converter, particularly when large amounts of scrap have to be handled. The Watenstedt product however, seems to have been used largely to make high-phosphorus foundry iron. The slag formed by this process was the richest in Germany, averaging 14.5 percent vanadium with less than 2 percent lime.

An interesting point, whose significance may not be apparent from the preceding discussion, is the fact that the vanadium contents of a slag bear no fixed relation to the vanadium content of pig iron. It would be possible to obtain just as rich a slag from ordinary Thomas iron as from vanadin eisen, under certain circumstances. Of more importance is the ratio of vanadium to various impurities, including not only silicon and manganese but also chromium and titanium. In the light of this observation it might be useful to consider the possibility of obtaining these additional elements as by-products of the vanadium operations, but the present writer failed to develop any comment on this feature.

Dr. Gehm speaks favorably of the Naeser spout-bottom process as a cheap and reasonably effective means of recovering vanadium concentrates from any pig-iron containing vanadium. Mention may also be made of the refining drum (Erschtrummel) devised at Volkingen. One type has a blow bottom (Blashoden) and is designed for continuous discharge of the molten metal. The slag being too thick to flow must be raked out from time to time. It has been suggested that this drum can be placed directly in front of the blast furnace ahead of the ladle or casting machine (in case one were used). Production of vanadin eisen is the most costly part of the process of producing vanadium-rich slags. It usually costs about twice as much as ordinary Thomas iron at the same works.

(2) Recovery of vanadium from slag.

Much of the vanadium in slag occurs as an iron-vanadium spinel. As summarized by Fischer (JIOA Report No. 23), research indicates that the simple compound ($\text{FeO.V}_2\text{O}_3$) is rare. Excess iron and manganese oxides enter the crystal, forming something like $2\text{FeO.V}_2\text{O}_3$. It was found, too, that MgO can also be present, replacing FeO or MnO , and similarly oxides of chromium, aluminum, or iron (trivalent elements) can replace the vanadium oxide. All of these various combinations, however, tend

always to occur in a spinel-like crystal, embedded in a ground mass of iron and manganese silicates. Vanadium-rich slags produced from Swedish iron ores are relatively easy to treat and yield a high percentage of their vanadium contents, presumably because they carry a good deal of the iron-vanadium spinel. German ore slags, on the other hand, are more difficult to treat with a satisfactory recovery and they carry a good deal of manganese-vanadium spinel. As shown in the table below, the composition of German vanadium-enriched slags vary widely. It was found that the vanadium recoveries are best when the vanadium, along with the manganese and silicon, is oxidized either in the furnace or converter before any additions of lime. The properties of acid and basic slags are quite different. Those made from Thomas slag (basic) were especially rich in vanadium and high in phosphorus, but relatively free from other impurities, such as manganese and silicon.

Slag No.	Percent							
	V	Fe	Mn	Cr	CaO	MgO	P ₂ O ₅	SiO ₂
1	8.7	17.2	28.0	1.5	0	n.b.	4.8	19.4
4	8.1	15.7	17.3	2.9	6.4	n.b.	4.0	17.0
7	6.5	23.1	18.6	2.2	8.9	1.9	5.9	11.1
11	16.1	34.4	9.1	2.5	2.1	0.4	9.4	12.2
12	10.9	25.6	7.9	2.1	9.3	4.4	7.3	19.3
19	8.4	24.3	2.0	0.5	0	n.b.	n.b.	n.b.

Laboratory roasting and leaching tests with specified additions of salt or soda ash are shown in the following table. Material taken from the furnace at the maximum temperature (750° C.) and quenched and leached immediately gave best results but this practice was not feasible with large batches in commercial practice. However, it was shown that nearly all slags leach better when roasted in the presence of water vapor, although some require additional factors to yield satisfactory results.

Roast tests on vanadium slag No. 12
(2 hours at 750° C, electrical muffle furnace)

Addition	Percent soluble vanadium	
	Quick cooling (quick quench)	Slow cooling
24% NaCl	68.1	6.9
24% Na ₂ CO ₃	90.5	60.0
30% Na ₂ CO ₃	100.0	94.9

Work with artificial (synthetic) slags was carried on at the Kaiser Wilhelm Institute, but the information so obtained was not considered especially valuable from the standpoint of practical plant operations because the compounds and reactions in actual practice are quite complex.

Although not enough experiments have been made to uncover all important points, the following conclusions are indicated: (1) The preliminary roast should effect the oxidation of V_2O_3 to V_2O_5 under the conditions employed unless a large amount of chromium oxide is present; (2) Even though considerable sodium salts are used, it does not follow always that there is enough sodium present because this element combines also with other compounds in the slag, such as iron, manganese, chromium, and aluminum oxides. Moreover, vanadates may be formed which contain less than 1 molecule of Na_2O to 1 molecule of V_2O_5 ; this leads to loss of oxygen on cooling the roast, and the formation of a poorly soluble compound containing V_2O_4 . (3) The composition of the ground mass, especially the lime content, and the grain size of the slag, ground mass as well as spinel, have an important influence on the reactions during roasting.

The extraction of vanadium from slag was conducted at chemical works, some of which received slag from several steel works. Two methods were employed, according to whether the slags were acid or basic.

In the normal method of treating slags low in lime, the slag was crushed and ground to 0.15 mm., roasted with soda ash and/or salt at about $800^\circ C$, and then extracted with water to remove the soluble vanadate. If the insoluble residue was still high in vanadium it might be returned to a nearby blast furnace. The extract was boiled with acid (either hydrochloric or sulfuric) so as to decompose the vanadate and thus precipitate the vanadium oxide (V_2O_5), which might be sold as such or converted into ferrovanadium.

In the case of basic slags, there was a preliminary wash with sulfuric acid and then the residue is roasted with common salt, leached with water, and the extract treated with lime to form the insoluble calcium vanadate which was converted into ferrovanadium.

Vanadium slags are typically crumbly and dry, rarely glassy. Usually they are ground at the steel mill, especially where ground basic slag is made, and metallic iron shots removed. Magnetic separation is employed; high phosphorus iron is brittle and so cannot be removed completely enough by screening.

Gehm recommends the addition of 12 kg. of soda and 6 kg. of common salt per 100 kg. of ground slag carrying 6 percent vanadium, correspondingly higher additions being made to more concentrated material. The proportions of alkali additions, however, vary with different slags. Mixing is performed in a horizontal mixer, barrel, or concrete mixer. It should be done thoroughly.

The slag-alkali mixture is roasted for about two hours at 720° to 800° C with suitable precautions to insure free access of atmospheric oxygen to complete the conversion of trivalent vanadium into the water-soluble (pentavalent) sodium metavanadate. Both rotary and multiple-hearth roasting furnaces have been employed successfully. The latter type is preferred at Nürnberg, for example, because conditions of roasting are under better control on each hearth and because the presence of metallic iron has no serious effect. Rotary furnaces have larger capacity and are employed by the Lautawerk and by the I.G. Farbenindustrie A.G. at Leverkusen. At the latter plant the slag is put through once to oxidize metallic iron before mixing with sodium salts and beginning the regular roast. A rotary furnace 60 m. long by 3 m. diameter has a daily throughput of 60 to 100 tons of slag as against only 20 tons for a 7-hearth roaster 5.23 m. in diameter. Sintering must be avoided and the hearths have to be cleaned occasionally by hand to avoid accumulation of crusts that would impede the passage of the charge. Dusting must be minimized and Cottrell precipitators may be used. Tests at Nürnberg have indicated that a CaO (lime) content of 4 percent gives no trouble, that "partly worse, partly better results are obtained with from 4 percent to 6 percent." and that yield decreases up to 50 percent as the CaO-content is increased up to 10 percent. MgO is disadvantageous but to a less degree. Dissolving the lime out with acid before roasting does not improve the yield although a satisfactory yield can sometimes be obtained by repeated roasting. High-chrome slags also give trouble.

Two methods of extraction are carried out. The slow method (8 to 14 days) is used at Leverkusen and a rapid extraction is accomplished at Nürnberg, using hot water and stirrers instead of large suction filters. By either method the leached residues are washed so as to contain not more than 0.1 percent of soluble vanadium and wash waters are recycled for leaching so that the extract contains 20 to 30 g. of vanadium per litre. Inasmuch as soluble sodium phosphates are always formed, the liquor may carry from 0.5 to 2.0 g. It must be kept below 1.0 g. per litre to avoid the formation of complex compounds that might interfere with the subsequent precipitation. This can be done by dilution or by treatment with calcium chloride in a known manner.

Precipitation can be accomplished with either hydrochloric or sulfuric acid but care is needed to avoid a slimy product. To assure a filterable, grainy precipitate a high temperature is necessary and if too much silicic acid is present it must be removed by first acidifying only to pH3 and allowing the solution to stand for a half an hour or more. Vanadium can be removed from the silicic acid precipitate by treating it with very dilute caustic soda. If phosphorus is absent, precipitation of the vanadium takes place rapidly at boiling temperature, while stirring,

Acid content is adjusted so that the filtrate carries 1-2 g. per litre of free acid (after acidifying with commercial sulfuric acid of 60 percent strength); Congo paper is colored feebly blue. The grainy, "red" vanadic acid is washed until the washings are virtually free of SO_4 ions.

The yield of the process in one extraction is stated to be 80 percent or better and may be increased to 90 percent if the residues are extracted again in "a suitable manner."

Ferrovandium is produced at Nürnberg by aluminum reduction. Silico-thermal reduction is ruled out because steel men will not accept high-silicon in their ferrovandium. The vanadium content, formerly 60 percent, was boosted to 80 percent, which was the only grade being produced in 1945. After drying and melting the vanadic acid, it is mixed with suitable proportions of granulated aluminum and iron and charged by hand into magnesite-lined furnace holding 500 kg. After cooling in the furnace (16-20 hours), the metal is broken away from the slag and subsequently crushed.

E. RECOVERY OF ALLOY CONTENTS OF SCRAP

The numerous downward revisions in alloy specifications created a condition in Germany somewhat comparable to the benefits that flowed from the employment of NE (National Economy) steels in the United States. The development of less highly alloyed steels favored the utilization or recovery of residual alloys from melting scrap. Great care was given to scrap selection, thorough boiling and slow finishing. Alloy scrap was consigned to electric furnaces at first for straight melting down but later as electric furnace capacity fell far behind the needs of war, the job had to be done in the open hearth. Acid open hearths were used at works that had them but the main task of preventing avoidable waste fell upon the basic open hearths notwithstanding the semi-silicious nature of the slags. Oxidation losses were kept to a minimum during melting and refining, the steel was finished under a large volume of reducing slag, and suitable reducing agents (usually aluminum or calcium-silicon) were added to effect high alloy recovery. The primary purpose was to avoid loss of chromium. Almost two-thirds of the total consumption of this element was in structural steels, chiefly of relatively low chromium content.

As indicated by the following excerpts from the Röchling interrogation supplemented by Dr. Rohland's testimony, the principal changes in regular open hearth practice were those previously mentioned in this report, including the mixed steel process and also the three special processes for which details (as furnished the writer by Dr. Ristow) are given in the Appendix--namely, the Krupp (or Badenheuer), the Brandenburg (or Knüppel), and the Grundhofer.

"...But the main point was that scrap alloys were treated in such manner as not to lose alloyed components. Dr. Gehr, the general director of the United German Refined Steel Works (D.G.R.W.) in Krefeld had the additional duty as manager of the Main Group for Iron Alloys of supervising the whole scrap system. Chief point in treating the alloyed scrap was that it was done as much as possible in an electric furnace since S.M. pig iron was unnecessary, which had up to 0.25% phosphorus because of our war economy and hardly needed to produce a boil in the bath. But the quantity of steel alloys increased so much that construction of new electric furnaces could not at all keep pace of the increasing need. Consequently a process was evolved in Westphalia of smelting scrap alloy in an electric furnace, tipping it as a finished smelt into a steel ladle, and then pouring an additional quantity of steel from a Martin furnace but without alloy components. This process proved thoroughly successful. It was followed in many places, principally in the Bochumer Union and the Horde Mining and Foundry Union at Horde.

"Another process that was wide spread was used by Dr. Bardenheuer, Chief of the Steel Works of the Friedrich Krupp A.G. concern in Essen and many other plants, including mine in Volklingen. It consisted in avoiding as far and as much as possible oxidation of the alloy components on casting by placing a certain amount of silicon first in the charge. In this way a certain boiling out of alloy components was stopped. For this reason Krupp produced a comparatively low-phosphorus S.M. pig iron, which worked well. The Central German Steel Works in Brandenburg used a similar process."

Dr. Rohland pointed out that chromium reduction was first worked out by Dr. Bardenheuer of Krupp at Essen-Borbeck, who employed an especially pure charge (Stamm pig iron) and aluminum in a hot furnace. Mr. Klappe, Krupp's open hearth Superintendent stated (CIOS Report XXXII-67, p. 21) that by using small slag volume and ferrosilicon at high temperature, it was possible to get 80 per cent recoveries of chromium from scrap in basic open hearths. Quite independently, Dr. Knäppel of the Brandenburger Eisenwerke achieved the same result with a normal charge by using a carbide slag, similar to an ordinary electric furnace slag, and the highest possible temperature. The idea of using a carbide slag in the open hearth is based upon the patent application by Dr. Grundhoffer. Both of these processes successfully recovered 70 to 80% of the chromium contents of scrap and they also resulted in an improvement in quality such that the Siemens Martin steel so produced was virtually as good as electric steel.

At the Hermann Goering Works in Watenstadt-Salzgitter (CIOS Report XXIX-30, p. 17) an 80 percent recovery of the 0.90% of chromium in scrap was obtained in 1943 in an acid open hearth. Later, as the shortage of manganese became more critical, this furnace was reconverted to basic practice, chromium recoveries still remaining at 80%, with much less loss of manganese. Charges high in silicon were then melted, using high-silicon scrap, when available. No lime was charged, and burned lime was added sparingly so as to keep the slag "just slightly basic." This slag, being highly reflective, caused extremely short roof life. Moreover, as the heats had to be worked to cause reversion of the chromium from slag to metal, temperatures were on the high side.

The following figures relate to recoveries of the various elements at Krupps (CIOS Report No. XXXI-44):

	<u>Martin</u>	<u>Electric Arc</u>
Nickel	95%	95-100%
Chromium (up to 2%)	70-75%	25% under oxidizing slags.
Molybdenum	100%	85-90% " reducing "
Vanadium (up to 0.2%)	80% (acid)	80-90% under reducing slag

All scrap was carefully selected first to have the proper chromium content and second, to minimize sulfur and phosphorus contents. The pig iron used in chrome charges was low in sulfur and phosphorus to minimize the amount of ore required for oxidation and to keep the oxidation under better control, and finally only high-grade ore was used. By these precautions the volume of the first slag was kept to a minimum. At most German works the refining slag was treated with aluminum or granulated ferrosilicon but at Volklungen the chromic oxide was reduced by working under a heavy lime slag at high temperatures so that the carbon (or iron) of the steel charge acts as the reducing agent.

Alloy steel scrap was segregated in machine shops and steel works in accordance with 27 main classifications, many of which were broken down into subgroups. Steel-makers were required to declare the details of their monthly melting program in advance and virgin alloys were not allocated to their use until after a careful estimate had been made of the alloy content that they should recover from scrap. Such estimates were made upon a percentage basis, based upon practical experience, and in the case of certain elements, especially chromium, allowable losses through oxidation were pared down progressively to the point where they taxed the ingenuity of the metallurgists and required constant care to maintain the necessary conditions at the furnace.

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VI. MISCELLANEOUS PRACTICES

Heavy forging procedure in Germany is said to have been "completely orthodox" while drop forging plants and most foundries were less well-equipped and generally behind the best practice found in the United States. Centrifugal casting, however, was developed in Germany to a degree comparable with the most advanced American practice. (FIAT Report No. 81). Tube making is well advanced in Germany, particularly hot extrusion, but details of practice have been described in American publications before the war. Cold extrusion, virtually unknown in the United States, was highly developed in Germany. One investigator (W. W. Galbreath in FIAT Final Report No. 145) reports that the Germans were able to make cold steel flow under pressure. The dimensions of cold extruded parts are accurate enough so that they will replace parts ordinarily made of malleable iron, gray iron, drop forgings, or parts completely machined from bare stock.

The Bonder drawing process also seems to be in general use throughout Germany whenever metal is cold drawn or cold reduced. This process simply bonderizes the plate or part after it has been annealed and pickled. The phosphatized surface acts both as a lubricant and as a means of preparing the surface to carry ordinary lubricants better during a number of subsequent drawing operations, thereby permitting longer draws with greater reductions of metal. This process was used successfully by more than 600 firms for cold drawing and cold forming steel for wire, screw threads, pipe, and various other articles requiring great reduction. Cold drawn pipe, for example, was made in four and five draws, with 87 percent reduction of metal and with no intermediate anneal.

The latest trends in German rolling mill practice are embodied in the installation at the Herman Göhring works, Watenstedt. British visitors have remarked upon the completeness of the layout, the streamlining, and of course the ample space provided for each operative step. There is first a primary cogging mill (1050 mm. dia. rolls), followed in turn by a single-stand reversing secondary cogging mill (800 mm. dia. rolls) and a continuous 6-stand billet mill (650 mm. dia. rolls). The billet mill was unusual insofar as the rolls were mounted alternately on vertical and horizontal stands and in the last four stands the billets were rolled on the diamond. Blooms and billets from this combination formed the feed for four secondary mills. They consisted of a 575-mm. staggered mill (capacity 400,000 tons a year), a 400-mm. continuous mill (capacity 200,000 tons), a 300-mm. continuous and cross-country mill, rolling two strands in parallel (capacity 200,000 tons); and a 200-mm. wire rod mill (capacity 300,000 tons).

Colclough (CIOS Report No. XXXII-119) mentions as notable a hot Steckel mill at the Hoesch works, Dortmund; a 4-high plate mill capable of taking slabs weighing 100 tons to produce the heaviest armor plate at the Dortmund Hoerder Verein; a tire mill at the Hontrop works of the Bochumer Verein; and a special radial rolling mill for producing boiler drums and similar vessels at the August Thyssen works of the Deutsche Rohrenwerk at Mulheim. The Steckel mill for hot-rolling slabs into coils or strip for cold rolling is designed so that heat can be maintained by coiling the strip between each of the later passes in a heating furnace situated on each side of the rolls.

After investigating more than 15 plants in cooperation with other members of teams, Hubert C. Smith (CIOS Report No. XXVII-29) summarizes rolling mill practice as follows:

"Plates were rolled on two, three and four-high mills, both directly from slab-ingots as well as slabs. Heating of ingots for rolling was accomplished in a variety of soaking pits from the Salem type with excellent controls to primitive fired and unfired cylindrical pits. In some plants machined ingots were preheated by open flames on beds before charging in heating furnaces. Sheet rolling was largely on hand mills although continuous and hot Steckel-type mills were in use. Single stands of reversing cold reduction mills were preferred to tandem mills because of the limited market and the investment. Double-duo mills were in common use. These mills are merely two staggered two-high stands in the same housings. Double-duo mills were said to combine the thickness accuracy of two-high mills with the ready reversibility of three-high mills. One double-duo stand is believed to cost less than two stands of two-high mills."

The hot rolling of special shapes is highly advanced. Thousands of special shapes are produced, ranging from simple light weight angle sections for window casements to heavy pieces 6 sq. in. in cross section. This means keeping thousands of rolls in stock and maintaining a great many rolling mill stands.

To meet the demand for a steel spar to substitute for light alloy spars for aeroplanes, the time allowance was too limited to tool up for making the desired section by rolling without further machining. Accordingly the bloom was rolled into a cross-sectioned bar and oxy-acetylene cut diagonally across the whole length of 8 meters, so that two rough spars were cut in 45 minutes. This method allowed inspection of the steel quality with regard to non-metallic inclusions and similar defects. For the fastening of the spar flange and web to the end form of the spar an automatic machine with two gas welding torches was used. This machine cut the spar to final dimensions. To remove a decarburized zone of max. 0.3 mm. thickness the surfaces of the cut planes were lightly ground. Then 750 holes had to be

drilled in a special jig. The spar was hardened horizontally, using a pneumatically controlled hardening die. Subsequent tempering was in packages of about 100 spars clamped together.

In the roll-making department of the Klöckner works intricate roll designs are hand tooled in rings in the annealed condition, the impressions made being checked with clay models against plaster-of-paris models. After engraving the rings are heat-treated and shrunk, and keyed to the roll bodies.

Closed box shapes are sometimes roll-formed from special hot rolled shapes and then arc or seam-welded to form solid boxes. Many non-straight products are fashioned from hot-rolled shapes by hot or cold pressing. Thus, an internal expanding brake shoe is made by cutting a special tee-section to the desired length and then hot forming in a press to about a half circle with the standing leg of the tee on the inside. Roller-bearing races have been produced by electric butt welding of two half circles made from hot pressed sections of hot rolled channels.

A. HEAT TREATMENT, SURFACE HARDENING, ETC.

The final treatment of forgings showed no special features. Furnaces were mainly gas-fired. Quenching was carried out vertically in most plants. However, Krupps did it horizontally on large jobs, gun tubes being supported along their length by hangers suspended from a cross beam. Emphasis was placed, however, upon thorough annealing. Large ingots, both alloy and carbon, were ordinarily sent to reheating furnaces and forged before cooling down. At Hoesch, however, gun steel ingots were slowly cooled in pits covered with "Fuller's earth" requiring a 7 or 8 day cycle to reach 200° C. Then they are placed in a reheating furnace at this exact temperature and reheated very slowly to 950° C and then rapidly to 1100° C. Forging was finished in one heat and finished forgings were put back in a cooling pit for a 12-day cooling cycle. (CIOS Report No. XXIX-17). After boring the barrels were heated in a vertical furnace and all analysis pieces were oil-quenched, muzzle down, in oil and then tempered.

The greatest stress seems to have been laid upon melting and refining procedure to lessen the tendency to hair-line cracks in the annealing of low-alloy vanadium steels. Every effort was made to eliminate hydrogen in the manufacture of forging steels by reducing the time spent under deoxidizing conditions, by preheating all ferroalloy additions (especially ferrosilicon), and excluding moisture by adequately drying lime and other materials charged. Flaking was combatted by slow annealing. In general small forgings were covered in sand and took from four or five days to four or five weeks to cool. Larger forgings were soaked at 650° C., heated to 890-900° C, soaked, cooled in the furnace or air to 650°, held at this temperature for a while, and then cooled in the furnace to below 100° C from a period of anywhere from ten days to five weeks.

Steel castings for hammer blocks up to 100 tons in weight were water-hardened and tempered. Details of treatment of various castings are difficult to summarize but practice in most foundries presents few notable features. Most of them were well-equipped with heat-treatment furnaces and great care was taken in annealing large castings. In Bochum (CIOS Report No. XXVII-42) centrifugally cast gun tubes were first pit-cooled from 1000-1100° C. Lack of floor space prevented the installation of furnaces, but the cast tubes were slowly cooled to prevent formation of flakes. After cooling to 200° C, the castings were subjected to a diffusion anneal at 1000-1100° C, for six to eighteen hours after which they were normalized and annealed for best machinability. After homogenizing, gun tubes are sometimes furnace-cooled to 700° C, reheated to 850° C for 4-6 hours and air-cooled. After rough-machining they may then be heated to a suitable temperature (according to carbon), quenched and drawn.

Armor plate was surface-hardened with the acetylene flame, but this practice was superseded at certain plants by electric hardening, equipment for which was furnished by Siemens. Dr. Scheer

was named as an expert in this field, and Dr. Wilhelm Fischer in Langenberg/Rheinland did a good deal of work on it for the Electrical Heating Institute (Elektrowärme Institut) affiliated with the Haus der Technik in Essen. Electric hardening was also introduced by the Dortmund-Hörder Verein for gun tubes and cold roll shells. This concern used frequencies of 50 to 500 cycles, up to 4,500 K.V.A., and obtained a penetration of 3-in. over a width of 2.5 metres at a speed of 22 cm. per minute. According to Colclough, this plant was shipped to America. Dr. Rohland, however, believed that the process was covered by patents held by General Electric. Details of face hardening by both gas flames and inductive eddy currents and also the conventional heat treatment of homogeneous armor at the Hoerder works are described by Queneau (CIGS Report No. XXVI-43). Krupps, the other great armor plant, did not alter their methods from those used before the war, except that they introduced gas-carburizing for charcoal packing.

Prof. Dr. Wagener, of the aforementioned technical organization, worked in Langenberg on gas surface hardening of armor plate and Peddinghaus in Altenvoerder (near Hagen) in Westphalia specialized in flame hardening; Engineer Graengress is mentioned as the proper authority.

Crankshafts, valve seats, etc., for aircraft were nitrided.

Replying to my question as to whether deep-freezing (say 84° C) had been employed in German heat treating practice, Dr. Rohland stated that he did not think that it had. He also disclaimed any knowledge of any provision being made for age-hardening of cold-drawn steel previous to further forming operations, such as cold-heading.

The following is quoted from the Röchling interrogation report (p. 16):

"Hardening directly from rolling heat is basically new; its results are good because the steel is held for a long time before rolling, longer than any transformation point, so that all the carbon is always dissolved. This is not changed by rolling. If the steel is held for more than ordinary transformation points before chilling, better qualities can be had. On the other hand, a big loss of time can be saved by hardening in rolling heat, so that this process is practicable for all kinds of steel, both for high grades and low grades."

B. SPECIAL TESTS

The Kriegeliste of approved steels formed the basis of the German Control organization in periodically reviewing compositions to be adopted for a wide range of uses. These compositions were reviewed from time to time in the light of anticipated availability of the alloying elements and also as a result of laboratory tests or field experience. The Kriegeliste, however, did not cover mechanical properties; and uses also were not specified although a draft of a list of the most usual end-uses was prepared later. Experience largely dictated the choice of alloy or alloy content for a given application or "ruling section." Little use was made of end-quench hardenability tests except in connection with sundry experiments with armor compositions.

Research laboratories were attached to several of the large steel works and a certain amount of routine testing and control work was conducted in these laboratories. Mechanical testing equipment was generally available together with all necessary accessories for microscopic examination.

Procedures at Hoesch A.G., Dortmund are probably typical (CIOS Report No. XXIX-17). On cartridge case steel, microscopic tests were made on rolled plate and ratings were based upon the Swedish J.-K. chart. No tensile tests were taken on finished cases, but Brinell hardness was checked at critical points. Finished shells were subjected to hydrostatic pressure test at 1,000 atmospheres and rocket shell bodies were hydraulically tested at 400 atmospheres. Rolled armor plate was shipped subject only to a heating of test pieces followed by fracturing and visual examination for soundness. Gun barrel forgings were subjected to more elaborate tests described as follows:

1. Cut a 30 mm. thick slice from each end of the forging prior to heat treating and longitudinally break for a "blue fracture" test for inclusions.
2. After heat treatment a full section is cut from both breech and muzzle ends at least 80 to 100 mm. back from the ends.
3. From each section the following tests were cut, all spaced midway from the bore to the outside diameter.
 - a. Three longitudinal tensile tests
 - b. " transverse " "
 - c. " longitudinal charpy impact tests
 - d. " transverse " " "
4. From every fifth barrel, an explosion test cylinder was taken at both the breech and muzzle end.
5. Occasional barrels were magnafluxed, but this was done usually at the machining plant.

In the larger laboratories facilities were provided also for creep, fatigue, hardness, Magnaflux, and impact testing. Systematic studies of machinability were conducted at a few places and tentative plans were made for a British team to go to Germany and report upon such studies. Aircraft castings are often subjected to Magnaflux and hot oil soak as well as visual tests and perhaps 10% at some works were radiographed. Castings for use under pressure were pressure-tested. Other high-quality castings were cut up for tensile tests on fully machined test bars, probably 1% of the total.

Radiographic inspections were not common, particularly in respect to castings, but radiographic requirements were employed to qualify welders for Navy work. No radium was used; there was a shortage of the element in Germany. Two types of inspection machines were supplied by the Rich. Seifert firm in Hamburg and another machine was made by Siemens. Applications of these machines in shipyards are described in a report by Hutton (CIOS Report No. XXII-102) which likewise covers magnetic inspection. The latter method was used in most yards for weld inspection and miscellaneous work. Only wet methods were used and persons interrogated had little knowledge of either dry powder or "prod" methods. One firm, however, was using the leech method for laboratory or shop inspection, passing a heavy current through the work by means of copper contacts held securely in place by small separately-excited electro-magnets. The equipment for the leech method was made by Bruno Suschyzski of Berlin and marketed under the trade name "Ferrolux." A member of one of the British teams mentioned the employment in Germany of aluminum flake powder "for detecting cracks in forgings or castings" but was unable to furnish details.

Supersonic methods were applied to the detection of air bubbles between the lining and the main steel body of aircraft bearings (CIOS Report No. XXXI-80) but appear to have had little if any employment for detecting subsurface flaws in steel or nonferrous metals. This seems surprising in view of the apparent attention given to avoiding "flakes" in castings. This method can often spot such cracks after they are missed by radiographic examination. However, the whole subject of non-destructive testing might be studied more thoroughly despite the accumulating evidence that indicates that Germany lagged far behind the United States and Britain in this field, especially during the war.

One of the tests for screening ballistic steels was to drill a hole in a sample block, fill it with explosive, detonate, and examine the fracture.

Special methods of analyzing several elements were reported by various investigators--including quick methods of conventional analysis as well as potentiometric, electrolytic, colorimetric and spectographic methods. No general study of laboratory analytical methods or controls has yet been made, however.

In testing, as well as in production technology, new ideas were usually promulgated and made common property. The following quotation from the Röchling interrogation bears on this point:

"All the rolling mills adjusted their works for war economy in this field. But by far the largest part of these efforts is much more important for the peace economy since a great number of discoveries became common property of all the steel works through the war. For example, the Iron and Coal Institute of the United Steel Works in Duesseldorf, under the direction of Dr. Daeges, determined through its experiments how to determine the nitrogen content in steel in the production of Thomas steel, and with that to make the soft Thomas cast steel especially suitable for deep drawing purposes and every type of cold working. We took their discovery over from the Reichsvereinigung (Government unification) for Iron and placed it at the disposal of all the rolling mills, which the Thomas works had. The main licence fee was paid by the Reichsvereinigung, and only a small tonnage tax was exacted from the individual mills. This was also eliminated as soon as a certain total sum was reached. In 1943 and 1944 we produced constantly increasing quantities of this HPN steel, and through this freed a great deal of Martin steel for other purposes. HPN steel is characterized by a nitrogen content which fluctuates around 1/10%. Other very important tests were made in all other fields, but it would lead to too much here if I should go into all the individual details. The different mills can give much more exact information about all this than I can. Dr. Roland can also give essentially more in this line."

C. POWDER METALLURGY

The outstanding development in powder metallurgy during the war was the extensive use of sintered iron rotating bands for shells.

The use of soft iron rings to replace copper began as a result of tests during the first world war under the direction of Professor Körber and Professor Pomp at the Kaiser Wilhelm Institute at Düsseldorf (subsequently moved to Clausthal). It has been stated that unsintered iron rings were suitable for large calibers, but emphasis during World War II was on sintered bands. Although the latter were not used exclusively, they accounted for a consumption of some 3 1/2 million lbs. of powdered

iron monthly, and annual production of iron powder increased from 200 tons in 1938 to 56,400 tons in 1945.

Following is a brief abstract of the comprehensive report (still unpublished) of this subject by Gregory Comstock:

(1) Hard Carbides

The armor piercing properties of cemented carbide projectiles were recognized in Germany as early as 1928 and were used successfully in small calibre projectiles in the Spanish Civil War in 1936. German production of hard carbides was given high priorities for both military and industrial uses throughout the war and despite ever-increasing handicaps was kept operating as long as possible. The 10 principal carbide plants were physically in every stage of condition from those that suffered virtually no war damage to those that were so badly destroyed as to render almost every piece of equipment unusable. Relative importance of various firms is indicated by allocations of raw materials, based upon pre-war outputs; 84% to Krupp (6 plants), 12% to Deutsche Edelstahlwerke (2 plants), and 4% to Boehler Bros. (1 plant). The tenth plant in the German economy was that of Földihütte, Pragus. Additional quantities of tungsten were made available for military use following the development of a high-efficiency tungsten-free cutting-tool material in 1943 and 1944 but there was always the objection that projectiles constituted a completely dissipative use of this strategic raw material which was allocated in Germany, as in the U.K., first to the steel industry, second to lamp and tube (valve) makers, and third to projectile-core manufacturers. Apart from standardization of products and streamlining operations, the most outstanding war development was the use of the hot press, not only for A.P. cores but also the W-free cutting materials. Research activities included studies of various metal carbides for cutting tools and among new elements Columbium (niobium) showed promise whereas uranium did not. German hard carbide products are believed to have been no better, on the average, if as good, as similar products made in the U.S. or U.K., but definite statements on relative performance should await comparative tests based upon large samples which the investigators had shipped to U.S. and U.K. In addition to various cores and standard tool materials, large numbers of W-free tips (45 TiC, 45 VC, 10 Ni, 3 Co) were also secured for testing as were also tips made from Mo-bearing powders.

(2) Powder Manufacture

Iron powders were produced in Germany by the mechanical or Hametag process, by the reduction of mill scale, by electrolysis, by atomization with steam or air jets, and by the Degussa rotating disc. Sponge iron powder was also imported from Sweden. The rotating disc process represents a universal method for disintegrating all kinds of molten metals, alloys, or even emulsions of non-alloying metals. Its only limitation is that the metals must not be such as

oxidize excessively from contact with air or with the fluid employed to collect the particles. In this process the molten metal, superheated if necessary to make it highly fluid, is flowed through a nozzle (7 to 9 mm dia.) so as to impinge on a rotating disc. The stream is enclosed by a water cone, formed by a ring nozzle, which helps to disintegrate the metal which is further broken up by knives mounted on the disc which rotates at exceedingly high speeds. The metallic slimes recovered from the water is dried carefully to minimize oxidation but iron or alloy steel powder made by this process is coated with an oxide film (equivalent to a content of 2 or 3% oxygen) which requires that it be treated in a hydrogen-reduction furnace before it can be used in sintered shapes. Details of manufacture of iron driving bands are given and also methods for making sintered steel powder parts and various nonferrous metal products.

D. COATINGS

It is generally conceded that German practice in producing tinplate and zinc-coated sheets has not overtaken American or British practice in these fields, including electro-deposition as well as hot-dip coating. No reports are available as yet on these industries, but British teams were organized early in 1946 to investigate tinplate and general tinning processes, respectively. Steel-backed zinc sheets have been investigated in connection with their use in the thin-wall sleeve-bearings industry. (FIAT Report No. 666). Production of aluminum-clad steel has also been described in respect to their use in this and other industries. The Deutsche Rohrenwerke at Mulheim is said to have introduced a process for plating steel with aluminum, nickel, copper, or stainless steel (18 and 8); Dr. Rohland suggested that Dr. Nehl of this concern could give details of operations which at the present stage of operations may still be somewhat crude. Friedrich Blasberg Elektrochemie Fabrik, Solingen-Merscheid, is listed as a leading manufacturer of electrolytically deposited coatings of zinc, tin, lead, cadmium, brass and chrome. Lead-clad steel has been made in Germany and perhaps Dr. Nehl could furnish information on this subject as well. Several investigators have described the production of steel tubing lined or clad on one or both sides with copper or bronze, bonding being obtained by either of two processes under high temperature and pressure. The lined product is used for bearings, and British investigators have studied the production of bimetallic strip such as are used for heat regulating devices (BIOS Report No. 84), including various alloy steel high-expansion elements. Copper-clad sheets for this purpose are made by attaching a flat piece of gliding metal (brass) lightly to the freshly ground side of a small steel sheet bar, sealing the edges, and then heating and rolling the assembly. A novel method of producing an antifriction metallic (tin-bronze) coating on steel gears has also been described (FIAT report No. 597).

Chromium-plating of gun barrels is the subject of one report (CIOS Report No. XXXII-64); a special electrolytic chromium plating is employed where extraordinary hardness, wear resistance, and/or corrosion resistance (in the tropics, for example) are sought.

Some attention has been given to nonmetallic coatings. One American investigator (Galbreath) has studied enamelling and also the production of phosphate coatings. A British team under the leadership of Dr. Clark was formed to report on this subject which has been studied by several other investigators,

Although preliminary information leads to the belief that German enamelling practice was far inferior to that in the United States and Great Britain, certain research activities in this field might bear further study. Much work was done during the war in connection with soldiers' mess kits and other items. The principal changes in the industry after 1939, however, were wartime expedients dictated by raw material shortages, and have no peacetime significance. Some of the theoretical aspects of research on the other hand may be of interest to our own inventors. Boron compounds lower surface tension, and consequently give better adherence due to better wetting of metal when used in base coat enamels. Lack of borax forced the Germans to use other wetting agents, especially sulfur, of which only one half of 1% was required, and much of which was burned off. Cobalt oxide, also scarce, was replaced by arsenic trioxide, wherever the poisonous character of the latter could be tolerated.

VII. AUXILIARY FILE

The following supplementary articles and exhibits have been deposited in Washington in an envelope, forming an auxiliary file to the present report.

Exhibit

- No. 1 Wartime organization of German Iron and Steel Industry (Chart).
- No. 2 Interrogation of Dr. H. Röchling by Mr. H. S. Dawson of British Control Commission.
- No. 3 Statement by Dr. W. Rohland (Translation).
- No. 4 Acid smelting: Chart showing manganese and silica content of slag produced in experimental run at Essen-Borbeck.
- No. 5 Detailed drawing of Blast Furnace top distribution gear: Mannesman works, Huckingen.
- No. 6 Waste Reduction through measurement of brightness of flame with the Bioprix pyrometer (Reprint of article by V. G. Naesser, Stahl u. Essen. Vol. 59, 1939, pp. 592-8).
- No. 7. Control of basic blow by measurement of radiation of the converter flame (Reprint of article by Naesser and Krächter, Stahl u. Essen, Vol. 62, 1942, pp. 341-7).
- No. 8 Miscellaneous information (in German) on alloy recovery, electric steel, and mixed steel furnished by Dr. Ristow, Verein Deutsche Eisenhüttenleute.
- No. 9 Coreless Induction Furnace (Abstract in English of Dürrenberg and Rottenberg article in Stahl und Essen, Vol. 60, February 8, 1940, pp. 116-119).
- No. 10 Development of Arc Furnace for large scale operations (Reprint of article by Dr. Rohland in Stahl und Essen, showing combination arc and low frequency induction furnace).
- No. 11 Standard German Scale for Classifying Quality of Steel according to Non-metallic Inclusions.
- No. 12 Herman Röchling continuous process: (Copies of original prospectus and correspondence).
- No. 13 Copy of Report by H. Gehm on production of vanadium from slag and methods of analysis (PB6202).
- No. 14 Untersuchung über die Eignung warmfester Werkstoffe für Verbrennungs-Kraftmaschinen. Part III. (Reprint of article by Von H. Cornelius and W. Bungardt in Luftfahrt-Forschung, Vol. 18, August 20, 1941, pp. 275-279).

VII. AUXILIARY FILE (continued)

Exhibit

- No. 15 Untersuchung über die Eignung warmfester Werkstoffe für Verbrennungskraftmaschinen. Part IV. (Reprint of article by Von H. Cornelius and W. Bungardt in Luftfahrt-Forschung, Vol. 18, September 20, 1941, pp. 305-310).
- No. 16 Die Dauerstandfestigkeit von Nickel-Chrom-Kobalt- und Eisen-Chrom-Kobalt-Legierungen. By Friedrich Kürber. KWI-Eisenforschung Mitteilungen, Vol. 27.
- No. 17 Das Verhalten eines warmfesten Sonderwerkstoffs im Zeit-Standfestigkeit-Versuch bei 620°. By Von Eberhard Both in Zeitschrift für Metallkunde, Vol. 36, 1944, No. 6, pp. 149-52.
- No. 18 Möglichkeiten zur Beeinflussung der Oxydationszone des Hochofens. By Von Alfred Möller.

VIII. APPENDICES

Appendix

- No. 1 Possibilities of varying the extent of the oxidizing zone in the blast furnace (Translation of article by A. Möller--Original in Auxiliary File).
- No. 2 Description of Grundhofer, Brandenburg (Knoeppel), and Fried. Krupp processes for upgrading open hearth steel (Report furnished by Dr. Arno Ristow, Verein Deutsche Eisenhüttenleute).
- No. 3 The Edwin Sponge Iron Process (Report of interrogation of Dr. K. Gebhardt, Essen).
- No. 4 Notes on German vs. American Costs.

APPENDIX NO. 1

POSSIBILITIES OF VARYING THE EXTENT OF THE OXIDIZING ZONE IN THE BLAST FURNACE

(Translation of article by A. Müller--
Original in Auxiliary File).

Previous investigations into the operation of blast furnaces have shown that the oxidising zone in front of the tuyeres extends approximately one meter into the furnace, independently of the hearth diameter. F. Bartscherer suggested a process for increasing the output of shaft furnaces, especially blast furnaces, which is essentially distinguished by the introduction simultaneously through each tuyere of blast jets of different pressure and temperature, or even different oxygen content, with the aim of extending the oxidising zone. From the literature it is obvious that the oxidising zone in front of the tuyeres extends about 1 meter into the furnace independently of the hearth diameter and the means of introducing the blast equipment (Windführung). It has already been attempted to affect the oxidising zone by altering the quantity and temperature of blast and the cross section (Blasquerschnitt). The tests dealt with in the literature all show results which are in approximate agreement, i.e. that the oxidising zone with 1% CO_2 in front of the tuyeres extends roughly 1 meter into the hearth. Between the tuyeres and in the interior of the hearth there is a reducing zone in which the coke can only be burnt by the ore oxygen. The depth of penetration of the oxidising gases is independent of the blast quantity and pressure up to 0.9 atm. According to W. Lennings the 1 meter deep combustion zone increases proportionately with the hearth diameter, and the size of the combustion zone determines the output of the furnace. This 1 meter deep annular section (which cannot, however, be regarded as completely continuous, and in which coke can still be burned by atmospheric oxygen) should be regarded as the effective or operative hearth area, and is dependent on the depth of penetration of the oxidising tuyere gases into the hearth. Subsequent investigation of the output of different blast furnaces resulted likewise in the determination of a roughly linear relationship between the output and the effective hearth area.

When the average yearly output per m^2 of effective hearth surface is plotted against quantity of ore and flux mixture consumed, all furnaces show an approximately equal output per m^2 of hearth area of 1 m. depth for a given quantity of ore-flux mixture. If this relationship between output and effective hearth area, which was purely statistically determined, is correct, an increase of the effective area should of itself lead to an increase in output without an increase in the total diameter of the hearth. The increase in effective area means the ability to handle a correspondingly greater quantity of coke.

In the lower part of the furnace there is what is known as the "dead man", which impedes the progress of the reactions in the

blast furnace. This "dead man" increases with increasing hearth diameter and thus the effective part decreases in proportion. This is based on the fact that with the usual blast operation the depth of the oxidising zone is fixed for any given quantity and pressure of blast. Since the design of the combustion zone and the movement of material in the blast furnace are closely related, any alteration in this zone means a corresponding alteration in the material movement. The movement in the blast furnace is started off by the gasification of the fuel in front of the tuyeres. Thus the shape of the oxidising zone certainly affects the movement and with it the distribution of gas in the upper regions of the furnace. The combustion zone should be so designed that the charge can descend without arching and so that the gas distribution is uniform over the whole of the cross sectional area. With even gas distribution in the shaft, the speed of the ascending gases (in the furnace) is at a minimum and the duration of contact between CO and ore is consequently at a maximum. A most favorable indirect reduction and the minimum coke consumption per (metric) ton of pig iron is the result. This, however, also means an increase in output. In this connection it is worth mentioning the work of W. Looz, W. Feldman, and M. Paschke on the relationship between the hearth diameter, blower (tuyere?) cross section and shaft cross section with reference to the operation of the furnace.

To determine whether an extension of the oxidising zone and consequent extension of the effective hearth area was at all possible with a fixed hearth diameter, the blast pressure, the amount of blast, and the design of the tuyeres were all altered. The composition of the gas in the hearth was determined by samples taken in (through) the tuyere, beside the tuyere and above the tuyere by means of a water-cooled tube. The experimental furnace was charged with Thomas grade ore and had an available capacity of 818 m³, a hearth diameter of 6,5 m. and 10 tuyeres. Ore-flux mixture, height of charge and the charging interval remained unaltered throughout the duration of the experiment. Apart from the gas samples from the hearth and chamber, samples were taken from the shaft 2.5 m. below the charging level by means of a built-in sampling (arm) tube.

The first tests were for the purpose of determining the extent of the oxidising zone in normal furnace operation with the usual tuyeres of 210 mm. diam. and variable amount of blast. During the course of the tests the blast volume was 60 to 65,000 m³/hr. for short periods during each test. The blast temperature was the same for all tests, averaging 7300C.

The gas composition in the plane of the tuyeres and at right angles to them was determined from the composition of the test samples in (along) each measuring arrangement (Messgerade) and were represented (graphically) by areas.

The lines of equal O₂ content show that the already extensive O₂ zone becomes even more extensive as the amount of blast increases. The atmospheric O₂, which amounted to 21 volumes at the tip of the tuyere,

rapidly decreases towards the center of the furnace. The 1% O_2 line reaches a depth of 570 mm. with 38,000 m^3/hr ; i.e. 200 mm more with 85,500 m^3/hr . than with 38,000 m^3/hr . The depth of O_2 penetration is thus dependent on the amount of blast and consequently also on the blast pressure. The CO_2 contents increase at first to over 15%; they then decrease rapidly towards the furnace center. The maximum CO_2 value is reached when there is still about 1% of free O_2 in the gas phase. The 1% CO_2 line extends 990 mm into the furnace, from the tuyere tip, with 38,000 m^3/hr ., 1040 mm. with 62,000 m^3/hr . and 1120 mm. with 85,500 m^3/hr . Thus the CO_2 penetrates deeper with increased amounts of blast.

In Fig. 2 the lines of equal O_2 and CO_2 content are shown for 62,000 m^3/hr . The lines of equal CO_2 content in the plane of the tuyeres bend back towards the furnace wall. The considerable extension of the oxidising zone found by the investigations is likewise striking. There are still small quantities of CO_2 between the tuyeres so that a continuous annular oxidising zone is formed. Later tests did not show an equal extension. The reason for this is probably that, at the time the samples were taken, the furnace was (operating) densely packed, added to which the distance of 680 mm. from the furnace wall to the tuyere nozzles (tips) is considerable. Thus the tuyere gases could flow much more readily into the loosely packed zone between the tuyeres.

The zone boundaries (Schichtlinien) of the CO content were of the same contour as those of the O_2 content. The CO content increases constantly towards the center of the furnace from 0% at the tuyere tips. However, only after the disappearance of the O_2 from the gas phase, does a rapid increase of the CO content to over 34% take place. The areas of equal gas content were measured for 1% O_2 , 1% CO_2 and 30% CO. The extent of the oxidising area increases with increasing amount of blast, and the effective portion of the hearth area becomes greater. In Fig. 3a (not shown here) the 1% O_2 area, the 1% CO_2 area and the 30% CO area are plotted against the amount of blast supplied per tuyere. It is assumed for this purpose that each tuyere supplies the same proportion of the total blast. With increasing blast the O_2 area increases linearly, whilst the CO and CO_2 areas do not show this linear relationship. Since the output of a furnace increases linearly with amount of blast, assuming fixed coke and ore-flux mixture consumption, the magnitude of the O_2 area can be taken as a measure of the output.

In Fig. 3b (not shown) the depth of penetration of the tuyere gases is plotted against the amount of blast. The depth increases with increasing blast.

The gas composition 1070 mm. above the tuyeres was the same for all blast quantities. CO could only be detected in the gas phase with small amounts of CO_2 up to 5%. The lines of equal CO_2 content in the plane perpendicular to the plane of the tuyeres indicate a bending back towards the walls of the furnace (Ofenrand). The slope of the areas probably also indicates the direction of the gas flow.

The gas distribution in the upper region of the furnace, 2.5 m. below the charging level, is shown in Fig. 4a (not shown).

The operation of the furnace can be determined from the CO_2 content. Low CO_2 contents are found where there is a large quantity of ascending gas and the gas speed is great. The furnace thus operates peripherally, the main gas concentration forming at the periphery (along the walls?). The loose middle zone possibly also undergoes considerable saturation with gas corresponding to the low CO_2 content also found there. This area is not as large, however, as the larger gas saturated peripheral area.

The tests (Table 1 of original report) showed that in fact the depth of the oxidising zone is dependent on the amount and pressure of the blast. Accordingly it could be expected that by using a higher pressure the combustion zone would penetrate deeper into the hearth, thus enabling the operative hearth area to be enlarged. Accordingly it was decided to instal "Sieromal" nozzles in six (blast) tuyeres (Nos. 2, 3, 4, 7, 8 and 9) through which additional high pressure blast was blown into the furnace. Four tuyeres remained unaltered and supplied only low pressure blast. The nozzles had an outer diameter of 120 mm. and an internal diameter of 100 mm. (Fig. 5a -- not shown). The tip was designed as a Laval nozzle, having a minimum width of 50 mm. Three compressors were used to generate the high pressure blast, which was heated in a recuperator. The blast temperature in the high pressure annular (ring) duct was 400°C . for all the tests. The temperature of the low pressure blast varied between 700 and 750°C ., averaging 730°C . as in the previous tests.

The extent of the oxidising zone was investigated for various blast quantities and pressures. Since it was no longer possible to take samples through the tuyere, a sampling tube was introduced at the side of the tuyere at such an angle that the axis of the tuyere was cut 1100 mm. behind the tip. Furthermore, the tube was placed nearer to the tuyere. The sampling tube above the tuyere was placed lower, i.e. only 750 mm. above the plane of the tuyere. It cut the tuyere axis 820 mm. behind the tip. (The positions of the sampling tubes and the lines of equal gas content are shown in diagrams in the original paper). With $62,000 \text{ m}^3/\text{hr}$. low pressure blast of 68 cm. of mercury and $14,000 \text{ m}^3/\text{hr}$. high pressure blast of 1.75 atm. (test 4), the line for 1% O_2 reaches a depth of 900 mm. into the furnace, which is 160 mm. more than with the same amount of blast without nozzles. The O_2 contour (strata) lines produce a much smaller pattern than those for the tests without high pressure blast. The same applies to the CO_2 and CO lines.

In order to increase the depth of penetration of the O_2 the amount of low pressure blast was increased to $70,000 \text{ m}^3/\text{hr}$. and the high pressure quantity to $17,000 \text{ m}^3/\text{hr}$. During the taking of the sample the blast pressure in the low pressure annular duct was 76 cm. of Hg.

and in the high pressure duct 3.1 atm. The lines of equal O_2 and CO_2 are shown in Fig. 6. The line for 1% O_2 is also given. The lines of equal CO and CO_2 content likewise form smaller areas, which, however, extend considerably deeper into the furnace. The line for 1% CO_2 cuts the tuyere axis 1800 mm. behind the tip. Fig. 7 (also not shown here) gives the vertical section for the lines of equal CO_2 content. There is a slight bending back of these lines towards the peripheral region. It is remarkable that, after the installation of the high pressure nozzles, the blast pressure in the low pressure annular duct increases with the same (induced) blast quantity. Thus in test 4 the blowing had to be at a pressure of 68 cm. Hg. to induce 62,000 m^3 of low pressure blast per hour. In test 5 the pressure for supplying 70,000 $m^3/hr.$ increased to 76 cm. of Hg. Besides the effect of the reduced tuyere cross section (caused by the nozzles) there is also, however, a higher pressure in the hearth (caused by the high pressure blast) to overcome. After prolonged smelting with a high pressure blast of 1.75 atm. a completely different gas distribution was determined in the upper region of the furnace. The furnace became "centrally operative" after the installation of the six high pressure jets although the ore-flux mixture, height of charge and the charging interval remained exactly the same. On smelting with high pressure blast of 3.1 atm. the central operation became even more marked. (Fig. 4b).

The rechecking of the profile (side view?) at the opening of the sampling tube showed that an incrustation of a thickness of 400 mm. had formed in the hearth so that the distance from the tuyere tip to the internal furnace wall had decreased to 280 mm. A failing of both tests was that not all the tuyeres were provided with nozzles so that the blast quantity of each tuyere could not be accurately determined.

Consequently, in the next test 6) nine tuyeres were fitted with simple nozzles. Since tuyere number 10 could not be fitted with a nozzle because of the stop machine, it was put out of action for the duration of the test. The nozzles consisted of a Sicronal tube tapered at the front through a length of 300 mm. from an internal diameter of 100 to one of 50 mm. (Fig. 5b). The sum of the high and low pressure blast was to be equal to the total blast in test 5). In this test as well, on blowing with high pressure blast of 1.9 atm. and 23,000 $m^3/hr.$ the pressure of the low pressure blast increased to 76 cm. with 63,000 $m^3/hr.$ The results of these tests are given in Fig. 8. The course of the line for 1% O_2 is 1080 mm. from the tip of the tuyere, that for 1% CO_2 , 1280 mm. The O_2 area has become long and narrow. It is smaller than in test 4) where it was 9.9 cm^2 . Here it is only 8.7 cm^2 . It is larger, however, than in test 5) where it is only 4.4 cm^2 . The three tests with high pressure blast showed that the depth of penetration of the oxidising zone increases with increasing blast pressure. There is no clear relationship between the blast pressure and the cross sectional area of the oxidising zone. The area enclosed by the 1% O_2 line decreases with higher pressure whereas the 1% CO_2 area increases. The gas distribution in the upper region of the furnace during blowing with nine high pressure nozzles is shown in Fig. 4b) in which six nozzles had blown at a pressure of 3.1 atm.

In order to achieve a widening of the oxidising area with simultaneous deeper penetration, tests with the so-called conical bag tuyere were performed. The tuyere diameter was 230 mm. and widened out to 296 mm. (Fig. 5c). Since the object of these tests was to determine the development of the oxidising zone in front of the tuyeres, only one tuyere of this kind was constructed. The other nine tuyeres had a diameter of 210 mm. The extent of the oxidising zone in front of the conical tuyere is shown (Fig. 9). The line for 1% O_2 extends 760 mm. into the hearth, the one for 1% CO_2 1100 mm., i.e. about the same depth as with the usual tuyeres of 210 mm. diameter for the same blast quantities. With the conical tuyere the oxidising zone extends more in width than in depth; surprisingly, however, the area was not as great as in test 3) with 210 mm. tuyeres. It was to be expected that with the conical tuyere the oxidising zone would be wider than with the usual tuyeres. However, the ratio of blast volume to pressure in the test was very high. It amounted to 1700, the volume being 85,000 m³/hr. and the pressure 50 cm. The operation of the furnace was very good in comparison with test 3) at the time of the taking of this sample. It is probable that the oxidising zone varies in accordance with the operation of the furnace, i.e. probably with a loose furnace, that is to say, a high ratio of volume to pressure, the oxidising zone becomes smaller. After the conical tuyere had been in operation for two days, the incrustation in the hearth at the measuring points had already become 300 mm. smaller so that the distance from the tuyere tip to the internal furnace wall was again 580 mm.

For the next test (8) a high pressure nozzle (No. 33) was incorporated in the conical tuyere. Fig. 10 shows the oxidising zone extension on blowing with the conical tuyere and Siermal nozzle No. 33. The amount of low pressure blast was 85,000 m³/hr. at a pressure of 52 cm., the amount of high pressure blast was 3000 m³/hr. at a pressure of 3.2 atm. The effect of the high pressure blast can be seen quite clearly. The O_2 area becomes long and narrow. The depth of penetration is considerable amounting to 1330 mm. 1% CO_2 was still found 1550 mm. from the tuyere tip.

To achieve a greater extension of the oxidising zone, the external shape of the high pressure nozzle was made the same as that of the conical tuyere, thus acquiring a mushroom-like shape. (Fig. 5d). This mushroom nozzle caused the low pressure blast to flow still more obliquely out of the tuyere. The oxidation zone is thus still further extended. The internal measurements of the mushroom nozzles are the same as in nozzle No. 33. The blast quantities corresponded to those of test 8. The blast pressure of the low pressure blast was 50 cm., that of the high pressure blast 3.2 atm. In fig. 11 the shape of the oxidising zone is shown. The O_2 area enclosed by the 1% line is larger than the one without the mushroom nozzle and amounts to 16.4 cm². The 1% CO_2 area is also considerably enlarged, amounting to 63.9 cm² and takes up a tenth of the hearth area. The depth of penetration of the oxidising zone is 1120 mm. and that of the CO_2 is 1480 mm.

The tests with high pressure blast have shown clearly that the depth of penetration of the oxidising zone can be considerably increased. However, on installing high pressure nozzles in ordinary tuyeres, a certain narrowing results so that the operative hearth area is not increased by the use of high pressure nozzles.

This difficulty can be overcome by the construction of conical tuyeres and mushroom nozzles which enable a continuous annular oxidising zone with considerable depth of penetration to be obtained, thus increasing the operative hearth area.

No clear relationship can be worked out between the area of the oxidising zone and the amount of blast from the high pressure tests. But there is quite a clear relationship between the depth of penetration and the blast pressure. (Fig. 12). The depth of penetration of the oxidising tuyere gases increases linearly with increasing pressure.

The alteration of the oxidising zone also affects the gas distribution in the upper region of the furnace. Thus with the same charge, ore-flux mixture and charging interval, a peripherally operating furnace could only be made to work centrally by means of high pressure blast. Accordingly it should be possible to design the oxidizing zone in front of the tuyeres in such a way that the gas distribution in the shaft should be homogeneous over the whole cross section. According to W. Looz and W. Feldman and M. Paschke the gas distribution can be altered by other means, e.g. widening of the shaft and alteration of the charging.

By the incorporation of high pressure jets in the tuyere the air current in the hearth should be guided in such a way and the combustion zone so shaped that there should be an even descent of charge together with a homogeneous gas saturation of the upper region of the upper furnace. Especially with markedly peripherally operating furnaces the construction of high pressure nozzles (especially where there is a large hearth dia.) promises to be of advantage because in this way the depth of the combustion zone can be increased and the gas saturation of the center of the shaft can be improved. By means of the construction of suitably designed low pressure tuyeres and high pressure nozzles or the construction of a large number of tuyeres, it is possible so to shape the oxidising zone that coke is burnt over the maximum hearth area resulting in an even material movement. This would lead to even gas distribution in the shaft and the best indirect reduction, minimum coke consumption and maximum output.

The practical application of the newly gained knowledge led to a considerable increase in output. In order to obtain the widest possible oxidation zone, 8 conical tuyeres of 260/330 mm. and 8 mushroom nozzles of 50/165 mm. diam. were installed. Tuyeres 1 and 10 which were situated right and left of the tap hole, were ordinary tuyeres of 180 mm. diam. without any high pressure nozzles. The height of charge of 1.5 m. as well

as the ore-flux mixture were not altered during the test. The ore-flux mixture was of the following composition:

Kiruna ore	19.7%
Swedish ore	27.8%
Minette	17.4%
Normandy ore	3.8%
Haverlahwiese ore	0.7%
Kahlenberg ore	1.5%
Barbecke ore	5.0%
Bueltenor ore	0.8%
Rotary furnace sinter	9.3%
SM slag	10.5%
Slag iron	1.5%
Kaminbaeren	2.0%

The iron content per metric ton of ore-flux was 435 kg. i.e. 465 kg. pig iron per ton of ore-flux. The iron content in the furnace dust was about the same as that in the ore-flux, so that the furnace dust drawn off could be regarded as non-charged ore-flux mixture. The usable charge is thus equal to the actual charge apart from the drawn off quantity of dust. The ores had all to be smelted in the unprepared state. The rotary furnace sinter consisted in the main of charge-dust. The slag amounted to 20 kg./t. pig iron.

The theoretical coke consumption with normal furnace load would be 990 kg. per ton of pig iron, if, for a slag-free ore-flux, 700 kg. coke/t pig iron and for 1 ton of slag 400 kg. of coke are inserted. According to F. Wesemann there would likewise be a coke consumption of about 1000 kg/t of pig iron.

The test furnace has been in operation since 1934 and has already yielded 2,300,000 tons (metric) of pig iron. Since the furnace wall has already been subjected to considerable wear and tear and nearly all the cooling chambers project into the charge, the cooling losses and the radiation losses of the furnace are very high. However, the increase in shaft cross section brought about by the wear and tear is of advantage for increased output, in the light of the work of Loers, Feldman and Paschke, because the wider shaft favors the widening of the oxidising zone to a certain extent. The wet coke consumption of 1010 kg./t pig iron with normal furnace operation is to be regarded as quite good in view of the heavy burden and the unprepared ore-flux. On the average the coke contains 3% H₂O, 10% ash, and 86% c.

The results of the output tests are in table 2. In order to be able to compare the coke consumption in all the tests, it has been calculated for 46.5% ore-flux consumption and 700°C. hot blast temperature by adding or subtracting 15 kg. coke for each percent of ore-flux and 40 kg. for 100°.

With normal furnace operation (usual tuyeres) the coke consumption was over 1000 kg. per ton of pig iron. After installing the high-pressure

nozzles and the conical tuyeres of 260/330 mm. diam. the coke consumption per ton of pig iron sunk from 1005 to 945 kg. in the first week (with additional blowing with high pressure blast), a drop of 6%. The output increased from 35.1 tons to 41.4 tons per hour (18.0%). In the second week the pressure of the high-pressure blast was increased. There was an increase of output of 18.2%, however, without any appreciable coke saving. The furnace did not operate so evenly at 2.4 atm. as at 1.7 atm and arched occasionally. The third test week cannot be evaluated as the furnace was out of commission for a number of days as a result of a breakdown at the plant. In the 4th week, when blowing was resumed with high pressure blast of a lower pressure (1.6 atm), the coke consumption sank to 76 kg. (7.6%), together with an increase of output of 14.8%. Two high pressure nozzles burnt out in the fifth week as a result of a shortage of water so that with lower blast pressure in relation to the increased blast cross sectional area, the amount of high pressure blast increased. The operation of the furnace was quite satisfactory and the average daily production was 1100 tons; i.e. an increase in output of 30.4% with a reduction in coke consumption of 61 kg/t pig iron (6.1%). In order to be able to obtain a greater amount of high pressure blast with a pressure of 1.5 atm. the internal diameter of the high pressure nozzles was increased to 70 mm. In the sixth week the coke consumption was 943 kg. per ton of pig iron, i.e. 6.2% less, and the output went up by 18.8%. In the next two test weeks the furnace was to be so operated that with a good output the coke consumption should be at a minimum. Thus in the 7th week, with the same loading of the furnace as in the comparative test, with a coke consumption of 893 kg./t pig iron (11.1% less) there was an increase of output of 12%, whilst in the eighth week, with the same coke consumption, there was an increase in output of 8%, i.e. an average increase of 10% with a roughly equal coke saving of 11.1%. The oxidising zone was also investigated during these tests. For the conical tuyere of 260/300 mm. and the mushroom nozzle of 50/165 mm., the lines of equal CO₂ content in the plane of the tuyere and the line for 1% O₂ are shown in Fig. 13 (1.7 atm. high pressure blast). The depths of penetration of O₂ and CO₂ (plotted against the blast pressure in Fig. 12) agree with previous results. The oxidising zone again had a continuous annular form with high pressure blast of 1.7 and 1.6 atm. There was no reducing zone between the tuyeres. At 2.5 atm. the oxidising zone consists of a number of separate oxidising areas so that a reducing zone probably forms between the tuyeres. The gas distribution in the upper region of the furnace for 1.7 atm. is shown in Fig. 4d. The furnace operates in a peripherally central manner with lower pressures, whilst at 2.4 atm. the more strongly gas-saturated peripheral zone is no longer present. The complete saturation of the upper region of the furnace thus depends to a large degree on the pressure i.e. with higher pressure the furnace becomes more central in operation.

Summary

The effect of high pressure blast on the oxidising zone was first determined by a large number of tests. The depth of penetration of the oxidising tuyere gases is dependent on the blast pressure and increases linearly with it, so that with high pressure blast there is also a flow of

air to the interior of the hearth. By means of the use of high pressure blast and the installation of suitably designed low pressure tuyeres and high pressure nozzles, the oxidising zone can be considerably affected thereby also affording a means of regulation of the gas distribution in the upper region of the furnace. A continuous annular-shaped oxidizing area, penetrating deep into the interior of the hearth, is the best design for smooth furnace operation and maximum output with minimum coke consumption. The increase in output of 30.4% with a saving in coke of 6.1% is a good enough indication of the value of the new process. It is even probable that with a different design of the low pressure tuyeres and high pressure nozzles, e.g. larger conical tuyeres, there could be an even greater increase in output and saving in coke.

APPENDIX NO. 2

DESCRIPTION OF GRUNDHOFER, BRANDENBURG (KNOEPEL), AND FRIED. KRUPP PROCESSES FOR UPGRADING OPEN HEARTH STEEL

(Report furnished by Dr. Arno Ristow, Verein
Deutsche Eisenhüttenleute)

The increasing shortage of electric steel at the end of the war forcibly entailed the necessity to produce large quantities of certain steels, especially manganese steel with 2.2% Mn (Flieg 12.65), of open-hearth steel in order to lessen the strain on the electric furnaces. For this purpose three processes were adopted: The patented process of Herr Grundhöfer (DRP No. 748 C77) and the process of Stahlwerk Brandenburg (Dr. Knäppel). Both the processes are in some way similar to the production process of Fried. Krupp which for some years already had been treated as secret process.

I. Grundhöfer (Decxydation by calcium-silicon).

After the melting down as much as possible of the slag is pulled off by means of wood hooks in order to avoid that during the subsequent decxydation the phosphorous in the steel rises again. The tapping of the slag is very tiresome and is only applicable in furnaces of a maximum capacity of 60 ts. Nevertheless even the last traces of the phosphorous containing slag must be eliminated as otherwise too high a rephosphorization would result. Scrap with a low content of phosphorus was then not available in Germany, except at Fried. Krupp. After the slag had been taken off the FeMn 65% (0,4%P) silico-manganese (80% Mn, 15% Si) and manganese affinee (85%) were preheated in another furnace. The bath had to boil for some time. The combustion air was completely turned off and the coke oven gas too was cut by a third of the previous quantity, because the large quantities of heat set free after the adding of the calcium-silicon would have attacked the lining too severely. The calcium-silicon was distributed over the entire surface of the bath, the chimney damper sharply pressed so that the furnace blew out strongly. For the complete decxydation a quarter of an hour later granulated aluminum was distributed over the bath. Through this process the composition of the slag is changed for instance as follows:

Melt 6761 of August Thyssen-Hütte in May 1944

<u>Melt</u>	<u>6761</u>	<u>6761</u>	<u>6771</u>
Test	9	11	12
Time	10,15	11,12	11,37
Fe	16,7 %	1,2 %	0,9 %
Mn	4,9 %	1,5 %	0,4 %
P	0,86%	0,09%	0,03%
SiO ₂	12,9 %	27,8 %	18,8 %
Al ₂ O ₃	1,29%	1,38%	13,39%
CaO	48,8 %	55,3 %	57,6 %
MgO	5,0 %	5,96 %	5,51%
S	0,32%	0,45%	0,47%
F	0,49%	3,2 %	1,5 %

Between test 9 and 11 the slag was tapped and at 10⁵³ hours calcium-silicon was added. Before the adding of calcium-silicon as well as afterwards lime must be given in order to avoid a heavy increase of silica in the slag.

With the sampling it has to be observed that the slag which at first is dark or of a brown colour, after a successful decydatation becomes light-grey. After a short time in the air it turns into a light-grey powder like the electric furnace slag. This is the best proof of a successful decydatation. The tapping and the further treatment in the casting pit do not differ from normal melts. The steels so produced were successfully used instead of the aircraft material 12.65, formerly produced only in the electric furnace. Only the degree of purity regarding inclusions of sulphide and oxidizing non-metals was treated. The result of the examinations of Flieg 12.65 is shown in annex 1.

Analysis and test regarding inclusions and nitrogen in Fl.1013 (manganese steel containing 1,6 to 1,9% Mn) are shown in annex 2. The table also contains the prescriptions for the analysis. The microscopic test revealed a grade of steel not equal to the electric steel, but sufficient for the purposes of applications in the war.

A complete decydatation in the open-hearth furnace was not always reached as can be taken from the attached table 3. The FeC-content of the slag was over 2% in several melts. The melts were made for Mannesmann at the Oberbilker Stahlwerk, Düsseldorf. During the last months of the war mainly Fress-und Walzwerk, Reisholz, and Mannesmann-Grossenbaum operated according to this process. Some melts were also carried out at August Thyssen-Hütte, Hamborn.

These qualities were previously obtained exclusively from the electric furnace and, after introduction of the Grundhöfer process displaced to other steelworks. Thus dependable comparisons of the improvements to be obtained by adopting the Grundhöfer-process are not available from the same works. Nevertheless the results may be summarised as follows:

- a) All melts showed an improvement against the ordinary quality obtained from the open-hearth furnace due to the change of the slag. However, a degree of purity on a level with electric steel was not obtained.
- b) In furnaces of 40 to 60 tons the duration of the heat was 1 1/2 to 2 hours longer when working according to the Grundhöfer-process. Therefore this process is scarcely economical. The manual work for the pulling off of the slag is very heavy. On the long run the melters will scarcely be able to carry it out.
- c) By taking advantage of the decydising effect of calcium-silicon and aluminium more expensive or scarce alloys can be economized.

- d) Moreover a desulphurizing effect of the slag was observed.
- e) Special care is to be taken to avoid a rephosphorization. This will especially be observed in the case of high-phosphorous alloys, as used at the end of the war.
- f) The physical data were: Tensile strength 66 to 71 kg/mm², elongation 22 to 24%, yield point 55 to 60 kg/mm², impact strength (longitudinal) 18,5 to 23,9 mkg/cm². This means an improvement of 3 to 5 mkg in longitudinal direction against electric steel which generally has an impact strength of 16 mkg.

II. The Brandenburg-process (deoxydation by calcium-carbide and ferro-silicon) essential differs from the Grundhoffer process, according to its inventor Dr. H. Knüppel. For this reason two melts were made in the Press-und Walzwerk for the sake of comparison. Data on the melts no. 25964 and 25965, made simultaneously in two 60-ton furnaces with Radex roofs under exactly the same conditions, can be taken from annexes 4a and 4 b. (Not reproduced; forms part of Exhibit No. 8 in Auxiliary File). Owing to the bad quality of the merchant scrap used there, a large tapping of the slag was necessary, in order to lower the content of phosphorus in the steel before the deoxydation to the required 0.01% P. In a 3.5% charge of burnt lime 60 tons of steel entail 7.5 tons of slag of which 6.5 tons have to be removed. The melting diagrammes on the progress of these two experimental melts are attached as annexes 5a and 5b.

In the opinion of the undersigned, who was present during the melting, there is no essential difference in the way the melts were carried out. Really, the only difference lies in the addition for deoxydation, Grundhoffer using almost exclusively calcium-silicon, Brandenburg calcium-carbide and ferro-silicon. As calcium-carbide has a very high melting point, the slag easily gets thicker in the Brandenburg process.

III. Fried. Krupp-process (deoxydation by granulated aluminium). The process adopted since many years by Krupp differs from I and II insofar as exclusively aluminium granulated are used. The result is a very good desulphurization, as had to be expected according to the well-known metallurgical reaction. Process see no. I.

IV. In view of the most favourable lowest melting slag a combination of calcium-silicon and aluminium might be adopted. At any rate, experiments at the August Thyssen-Hütte took a very satisfactory course.

Unfortunately during the last months of the war no comparative experiments could be carried out in the laboratories, nor were there analyses of oxygen.

On request of Mr. Myers, London, we have had made oxygen analyses of the still existing melts of Grundhoffer-process according to the method of vacuum hot extraction.

No.	% oxygen
25 929	0,003
26 037	0,005
26 042	0,004
26 050	0,003
26 052	0,005

Thus the contents of oxygen are equal to those of good acid open-hearth steel. A remarkable improvement has been obtained indeed.

Chances for these processes in peacetime

It is not sure whether these processes are economical under normal conditions.

1. Decrease of the output of open hearth furnaces of about 20% (economy).
2. At peacetime the customers will require real electric steel, no open hearth steel with similar properties.
3. A different position with regard to the necessity of saving ferro-alloys.
4. The troublesome tapping of slag brought on a refuse by the open hearth melting. They are too weak to perform this arduous task.
5. The higher temperature and longer heat (10 to 15%) cause excessive attack on a silica roof. Therefore the condition for these processes is the use of chrome-magnesite roofs (Radex-E).
6. The consumption of ferro-silicon, calcium-silicon or aluminium for these processes is very high, and in these ferro-alloys is also bound a lot of electric power so that at normal time it is perhaps the same whether this electric power is used in ferro-alloy furnaces or in electric steel furnaces.
7. These processes were used especially for two aircraft steels (F 1265 and 13.10). We doubt whether these steels in some measure will be used in peacetime, further it is probable that the manufacturing of such steels in surplus available large electric steel furnaces is more economical.

/s/ Arno Ristow

ANNEX 1

smelting of Fl. 12.65 Steel analyse in % Mannesmann, Grossenbaum

	C	Si	Mn	P	S	N ₂	Grade of purity	
							Sulphites	Oxides
smelting analyse 4389	0,19	0,47	2,07	0,039	0,025	--		
" control	0,21	0,40	2,10	0,035	0,024	0,008		
	0,20	0,41	2,10	0,037	0,019	0,008	1-2a	1-2b test ingot
	0,21	0,41	2,12	0,036	0,023	0,012	1-2a	1-2b rolling mat.
smelting analyse 4448	0,16	0,48	2,18	0,032	0,029	--		
" control	0,20	0,46	2,38	0,038	0,031	0,010	1-2a	1-2b rolling mat.
	0,18	0,44	2,34	0,032	0,029	0,004	1-2a	1-2b test ingot
smelting analyse 4409	0,19	0,47	1,95	0,038	0,035	--		
" control	0,20	0,47	2,05	0,036	0,028	0,011	1-2a	1-2b test ingot
	0,19	0,43	1,06	0,036	0,032	0,008	1-2a	1-2b rolling mat.
	0,21	0,45	2,00	0,038	0,037	0,010		

Analyse of the finished slag

	Fe	Mn	SiO ₂	Al ₂ O ₃	FeO	CaO	MgO	P ₂ O ₅	MnO
smelting									
4389	2,30	0,90	16,96	11,0	2,82	53,50	13,16	0,22	1,16

- 100 a -

Grundhofer

Allex 2

Wannesmann, Grossenbaum

Steel Analyse in %

Smelting of steel 13.10

analyse required	C	Si	Mn	P	S	V	N ₂	Grade of Purity Sulphides	Oxides
smelting analyse	0,38-0,45	0,40	1,6-1,90	0,035	0,035	0,88-0,15			
control analyse	0,43	0,39	1,62	0,040	0,020	0,11			
"	0,40	0,34	1,70	0,037	0,014	0,13	0,10	1-2a	1b
"	0,42	0,36	1,70	0,038	0,014	0,13			
smelting analyse	0,42	0,34	0,52	0,042	0,019	0,09			
control	0,41	0,30	1,64	0,050	0,020	0,12	0,10	1-2a	1b
"	0,40	0,30	1,65	0,048	0,020	0,12			
smelting analyse	0,53	0,44	1,52	0,040	0,018	0,12			
control	0,55	0,38	1,62	0,030	0,020	0,13	0,12	1-2a	1b
"	0,55	0,40	1,69	0,034	0,020	0,12			
smelting analyse	0,42	0,32	1,59	0,031	0,026	0,14			
control	0,44	0,29	1,69	0,028	0,028	0,12	0,10	1-2a	1-2 b
"	0,42	0,28	1,73	0,034	0,024	0,13			
smelting analyse	0,40	0,50	1,70	0,025	0,028	0,12			
control	0,40	0,44	1,82	0,034	0,020	0,14	0,10	1-2a	1b
"	0,40	0,45	1,82	0,034	0,020	0,12			
smelting analyse	0,38	0,50	1,88	0,032	0,010	0,12			
control	0,37	0,47	2,04	0,035	0,015	0,13	0,11	1-2a	1-2b
"	0,36	0,45	2,05	0,031	0,013	0,13			

Analyse of the finished slag
in %

smelting	Fe	Mn	SiO ₂	Al ₂ O ₃	CaO	MgO	P ₂ O ₅
4629	8,84	3,48	28,38	5,13	47,57	18,34	0,20
4720	1,81	0,72	13,56	5,95	47,12	13,46	0,25
4756	3,70	1,94	20,44	13,58	58,27	10,58	0,25
4758	1,52	1,42	20,40	4,34	48,93	19,70	0,16
4790	3,36	1,40	16,20	4,65	59,43	11,33	0,15
				4,31	53,20	19,90	

Schmelze Nr.	C	Si	Mn	P	S	FeO-Gehalt der Schl.
25929	.18	.45	2,28	.024	.020	<u>2,20</u>
25930	.16	.30	1,80	.045	.023	<u>2,20</u>
25964	.17	.40	2,28	.027	.016	1,19
25965	.17	.57	2,22	.029	.017	2,59
25976	.18	.42	1,88	.029	.022	1,94
25977	.17	.51	2,04	.027	.023	<u>2,17</u>
26005	.19	.21	1,58	.040	.019	2,14
26006	.19	.54	2,24	.045	.026	1,74
26013	.21	.38	2,24	.028	.015	2,08
26014	.19	.21	1,92	.035	.014	2,59
26037	.18	.35	2,10	.043	.031	0,95
26042	.18	.43	2,08	.035	.019	<u>2,34</u>
26050	.17	.67	2,29	.037	.034	1,86
26052	.16	.43	2,08	.033	.017	<u>2,92</u>
26054	.18	.51	2,06	.030	.022	1,50
26056	.16	.66	2,10	.037	.028	1,94
26062	.19	.54	2,20	.031	.016	2,68
26064	.23	.69	1,74	.040	.032	1,52
26066	.24	.68	1,74	.033	.027	1,39
26115	.20	.37	1,60	.039	.040	0,97
26117	.22	.52	1,63	.037	.027	0,97
26124	.21	.52	1,66	.035	.038	<u>2,70</u>
26126	.22	.35	1,56	.032	.036	1,77
26142	.22	.44	1,78	.033	.032	1,94

ANNEX 5a

Oberbilker StahlwerkMelt 25064, Process Grundhöfer

Report on melting and casting. Flieg 1265
Data on charging and melting see
annex

The charge was well molten and entered with a convenient carbon content. It could be ored several times. Boiling started with the first sample. Then the bath continued to boil well until the manganese was added. The pulling off of the slag started immediately after the first sample, 3 cases of slag = 7 ts of slag were tapped so that only a small quantity of slag remained on the bath. The slag was always kept liquid without difficulty, owing to the continuous quantity of melting gas. The perfect condition of the oxidizing slag is revealed by the fine dephosphoration of 0.40 to 0.008 %. In spite of the heavy slagging, however, the content of manganese in the bath could be maintained. The last preliminary test had a temperature of 1680°C (Biopitix). The finishing started with the adding of the different manganese alloys. At first the FeMn 65% (0.39 P) was added slightly preheated, then silicomanganese and FeMn-affine also slightly preheated in another open-hearth furnace. Then the bath just slightly boiled. With the addition of the slightly preheated CaSi the deoxydation period was initiated. Previous to that the combustion air and brown coal dust were completely turned off, long distance gas to 2/3 of the previous quantity. The CaSi was distributed over the whole surface of the bath, the chimney damper sharply throttled so that the furnace blew out strongly. After a quarter of an hour granulated aluminium was distributed over the bath, then the slag was well mixed with rods. It was liquid without being thin, and stringy on the rods. The subsequently taken slag sample was still brown under water, but disintegrated into an almost white powder in the air. The second slag sample taken after a further addition of aluminium was lighter under water but did not disintegrate. The third slag sample taken shortly afterwards after a further little addition of aluminium was also liquid and completely white under water. In the air it disintegrated into a light-grey powder. Then normal tapping.

At a temperature of 1590/160°C (Biopitix) the melt was well cast in group teeming of four ingots with 40 mm magnesite nozzle. The nozzle had to be burnt several times; the jet slurred slightly at the nozzle, was, however, liquid in the mould. It was rather clear with much ingot foam.