

THE KRUPP SPONGE IRON PROCESS PRODUCTION AND UTILISATION OF METALLIZED MATERIALS

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Introduction

NEXT to ore, fuel is the most important factor governing the cost of producing primary iron.

In the blast furnace process, coke with special metallurgical properties is the basic source of heat. Its production requires the availability of coking coal. The direct reduction processes, conducted in rotary kilns, permit, however, the use of non-coking bituminous coal and anthracite and are capable of being fired with gas or oil if this appears to be appropriate.

Table 1 shows the world reserves of fossil fuels (1). In spite of the inherent uncertainty, —additional deposits will presumably be discovered and long-term consumption is difficult to predict —, this Table furnishes a source of reference.

The world reserves of coal, compared with those of other fuels suitable as reducing agents, are immense, amounting to 7.600 billion tonnes as against 350 billion tonnes of coal equivalent in the case of crude petroleum and 233 in the case of gas. The major portion of the world reserves of crude petroleum and natural gas can be expected to be exhausted by the turn of these reserves will no doubt be preceded by shortages and rising prices.

The reserves of coking coal as against the reserves of non-coking coal amount to only about

357 billion tonnes of coal equivalent which is close to 5% of the total coal reserves.

Although, in view of the known world reserves of coking coal, no unsurmountable difficulties in obtaining supplies need be feared in the foreseeable future, local shortages and a continued rise in price must nevertheless be anticipated. Up to now, there are only a few countries capable of exporting coking coal. The exploration and development of further deposits

Table 1

Type of Fuels and Reserves	Reserves (1970) 10 ⁹ t of coal equivalent	Percentage consumption up to the year 2000 %	Percentage consumption up to the year 2000 %
Petroleum: Proved Proved and possible reserves, excl. sea Bottom	350	4	87
Natural Gas: Proved and Probable Reserves	233	3	73
Coal : Proved, Probable and Possible Reserves	7600	93	2

World reserves of different fuels and estimated consumption up to the year 2000

(After "Economic Survey of Europe in 1971," ECE, Geneva, 1972).

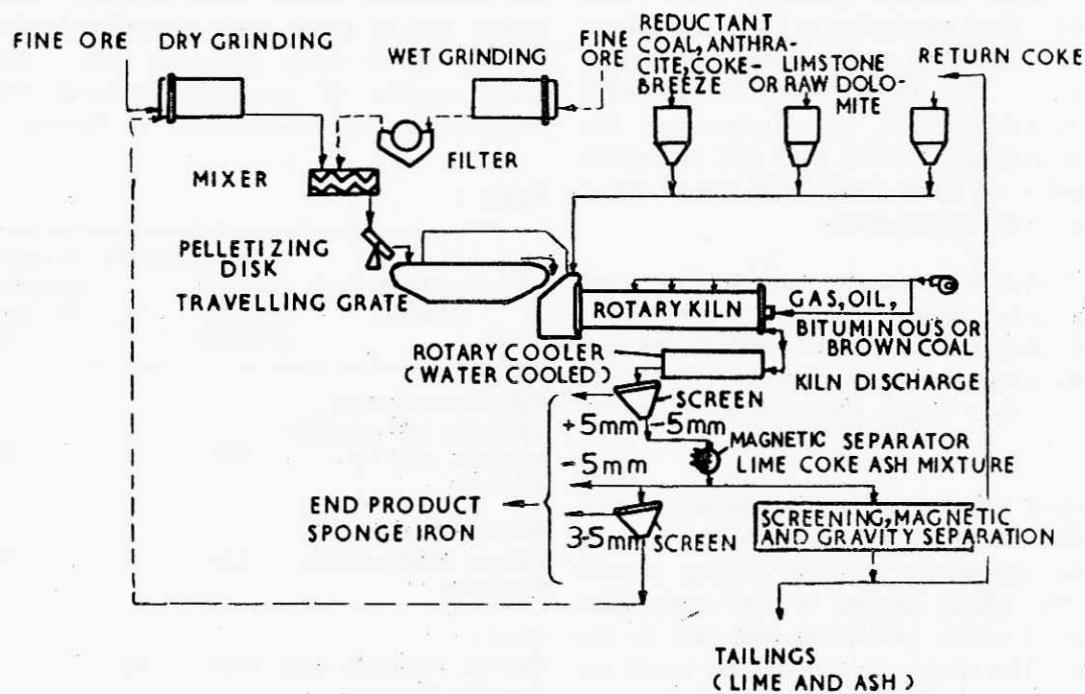
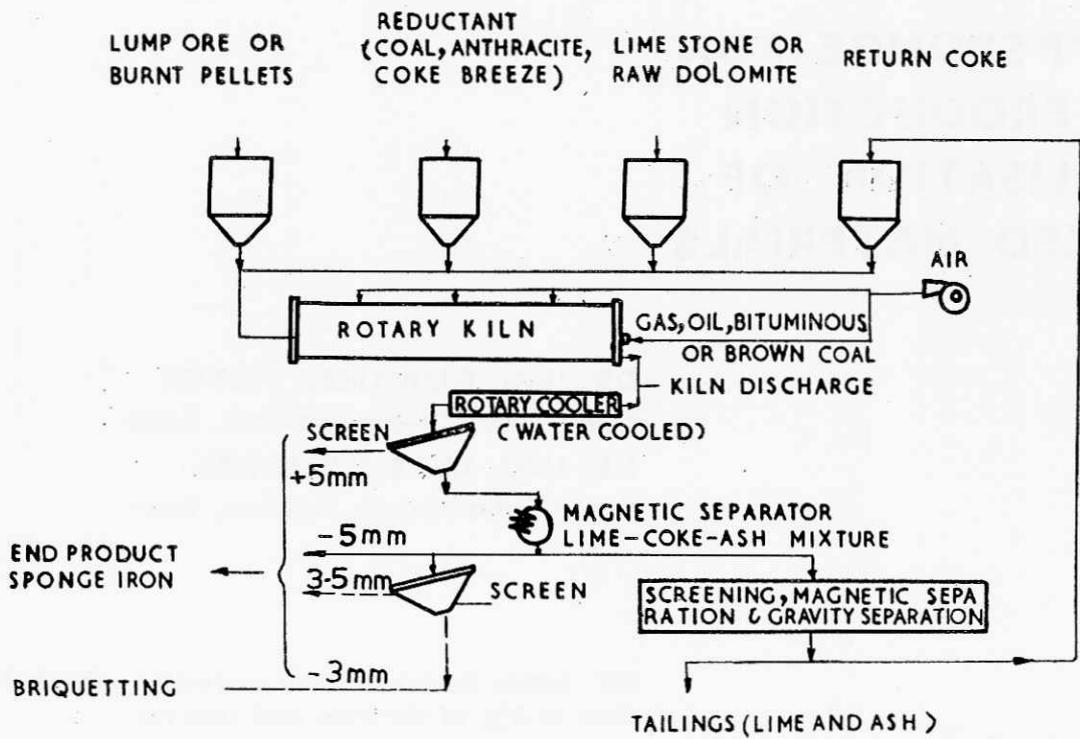


FIG.1. FLOWSHEETS OF COMMERCIAL KRUPP SPONGE IRON PLANTS FOR PROCESSING LUMP OR FINE IRON ORES.

(e.g. in Canada and the USSR) will involve immense capital expenditure. Owing to the recent decline of the steel market and the resultant severe cutbacks in the production plans of the Japanese steel industry, these projects will probably be postponed for the time being. The world market for coking coal will, however, relax only temporarily, and a further rise in the price of coking coal is to be expected. Since 1968, there have been progressive increases in price.

This trend has, among other things, been the main reason for the increasing attention paid in recent years to the potentialities of the direct reduction processes. This led to the inevitable conclusion that the blast furnace process should be supplemented by direct reduction processes in order to relieve the market for coking coal. The construction of mini-steelworks, using a direct-reduction product as melting stock, would make this possible.

Recent experience has shown that such a combination, i.e. the production of sponge iron and its use as melting stock in an electric arc furnace, is economical, provided the plant is sited in a region providing the requisite conditions.

The present output of primary iron produced by direct reduction processes constitutes only a small proportion of the total output of iron. While the blast furnace will, for the foreseeable future, retain its lead as a producer of primary iron, direct reduction will strengthen its foothold in the years to come. Prospects are good for those direct reduction processes which employ solid fuels as reductant, because the overall world coal reserves are, to all intents and purposes, inexhaustible. Moreover, these processes permit the use of a wide variety of fuels.

Backed by long years of experience gained with reduction processes, such as the KRUPP Renn Process as well as the Waelz Process for reducing zinciferous raw materials, KRUPP has developed the KRUPP Sponge Iron Process which is capable of reducing high-Fe lump ore as well as fine ore and concentrates into metallized products, using in the main solid fuels (2-9).

Essential features of the process

Fig. 1 shows the two variants of the process, one using lump ore and the other fine ore or concentrates. Lump ore is charged together with the reductant and a desulphurizing agent into an

inclined rotary kiln, where it is heated by a countercurrent flow of hot gas and reduced to sponge iron. Depending on the content of volatiles, the fuel is either blown into the kiln from the discharge end or introduced from the feed end together with the ore. The material discharged from the kiln consists of a mixture of sponge iron, surplus fuel, desulphurizing agent and ash, and is cooled down in a rotary cooler, mainly by direct spraying with water. Further treatment of the mixture consists of a combination of screening, magnetic and gravity separation.

The kiln is fired from the discharge end with a deficiency of air. It is provided with nozzles over the entire length of its shell for blowing air into the kiln. In contrast with other processes, the air supply is in the direction of the flow of waste gas. It serves to oxidize the carbon monoxide evolved during the reaction of the coal with the iron oxide, the volatiles contained in the coal, and the coal fines carried away in the stream of waste gas. In this way it is possible to keep the charge at a uniform temperature profile from 950 to 1050 deg. C over about 3/4 of the length of the kiln. When processing high-Fe fine ore or concentrates in the form of pellets, it proved necessary in all cases investigated so far to combine the rotary kiln with a travelling grate as preheating unit. The green pellets coming from a balling drum are dried with the hot waste gas leaving the rotary kiln and prehardened to a compressive strength of at least 10 kgf/pellet. This strength is necessary for subsequent treatment in the rotary kiln.

Experience with different raw materials

In the past, a number of different ores and fuels have been tested for their amenability to treatment by the KRUPP Sponge Iron Process. Small-scale tests have been carried out in laboratory-scale rotary kilns in order to assess the quality of the raw materials and to make a preliminary choice of ores and coals.

Fig. 2 shows the three laboratory-type rotary kilns. Ores are tested for their reducibility and degradation as the degree of metallization increases. Laboratory tests made with different types of coal furnish information on reactivity, degradation, softening behaviour of the coal and fusion of its mineral matter. By comparison with those obtained from materials already subjected to laboratory and semi-commercial tests, such laboratory-scale test results enable a qualitative assessment of the samples to be made.

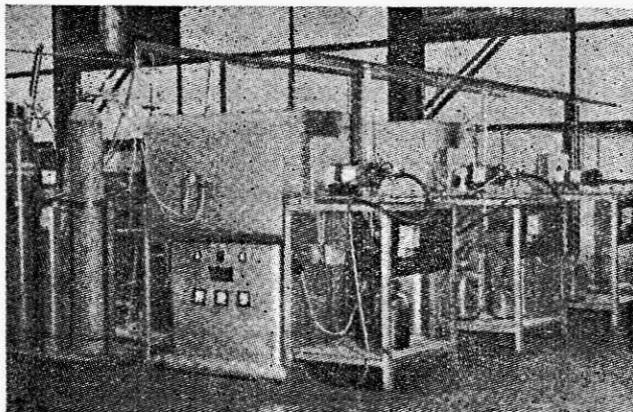


Fig. 2 : Krupp Laboratory Rotary Kilns

In order to obtain design data for the planning of commercial facilities, semi-commercial tests are carried out over a period ranging from 20 to 30 days with those raw materials which did not exhibit any negative properties during the laboratory tests. During such semi-commercial tests, the course of the process is optimized and the following parameters are determined:

Slope and speed of kiln, degree of metallization, sulphur content, ore throughput and heat consumption.

In addition, information is obtained as to ring formation in the kiln and disintegration of the ore or pellets.

The present pilot plant had originally been built for the purpose of carrying out semi-commercial tests by the KRUPP Renn Process and the Waelz Process. The data derived from such tests were used for the design and layout of commercial Renn and Waelz plants. It was found that a rotary kiln 14 m long and with a shell diameter of 1.2 m (= 0.9 m ID) was large enough to furnish representative results capable of being upscaled to a commercial operation. This requires, however, a great deal of experience since the results derived from semi-commercial tests, in terms of absolute values, cannot be applied direct to a commercial operation.

On the basis of tests carried out in the above-mentioned semi-commercial pilot plant, a considerable number of full-scale rotary kiln installations have been successfully delivered in the

past (4 kilns, 4.2 m dia., 110 m long, for the Essen-Borbeck Renn plant; 2 kilns, 4.2 m dia., 90 m long and 1 kiln, 5.2 m dia., 90 m long, for the pre-reduction of nickel ores at Larymna, Greece; 1 kiln, 4.2 m dia., 60 m long, for a Waelz plant at Iglesias, Sardinia).

Although experience suggested that the results derived from tests based on the KRUPP Sponge Iron process might well be scaled up to a commercial operation, a full-scale test was carried out in a production kiln of 4.6 m diameter and 110 m length, which had been modified to suit the conditions encountered in processing rich iron ores. This test furnished proof that the test results are reproducible on a production scale. These tests, which have been extensively covered in literature (4-6), extended over a two-month period during which sponge iron was continuously produced on a commercial scale. The tests again confirmed that semi-commercial tests carried out in the existing rotary kiln pilot plant furnish reliable design data as well as process characteristics for treating the raw materials in a commercial operation. The pilot plant today consists of a rotary kiln shortened to 13 m, a travelling grate, a shaft-type preheater and all the necessary equipment for the crushing, grinding and screening of the raw materials and for the magnetic separation, pelletization and dressing of the material discharged for the kiln. As a result of steady expansion that is still going on, the whole plant has been adapted to meet current requirements.

Fig. 3 is a typical example of how a semi-commercial test is performed in the pilot plant. Temperature, metallization, sulphur content and compressive strength of iron ore pellets are plotted against the length of the travelling grate/rotary kiln combination. The green pellets are first dried on the travelling grate by the stream of hot waste gas leaving the rotary kiln and then hardened to a strength of approximately 18 kgf/pellet. Consisting in the present case of hematitic concentrate, the pellets are then charged at a temperature of about 1000 deg. C into the rotary kiln together with low-volatile coal as reductant and the desulphurizing agent. After a slight drop as reduction starts, the strength of the pellets increases to almost about 200 kgf/pellet. In the present example the degree of metallization amounts to about 95%. From the discharge end of the kiln, high-volatile coal is blown in as a source of heat and as reducing agent. The temporary increase in the sulphur content of the

- 1 PELLETIZING DISC
- 2 TRAVELLING GRATE
- 3 FANS
- 4 CYCLONE
- 5 STACK
- 6 FEEDER FOR REDUCTANT AND DESULFURIZER
- 7 KILN FEED END
- 8 KILN DISCHARGE END
- 9 BURNER (GAS, FUEL OIL, COAL)
- 10 COOLING DRUM
- 11 ROTARY KILN
- D AIR TUBES
- T TEMPERATURE MEASURING POINTS

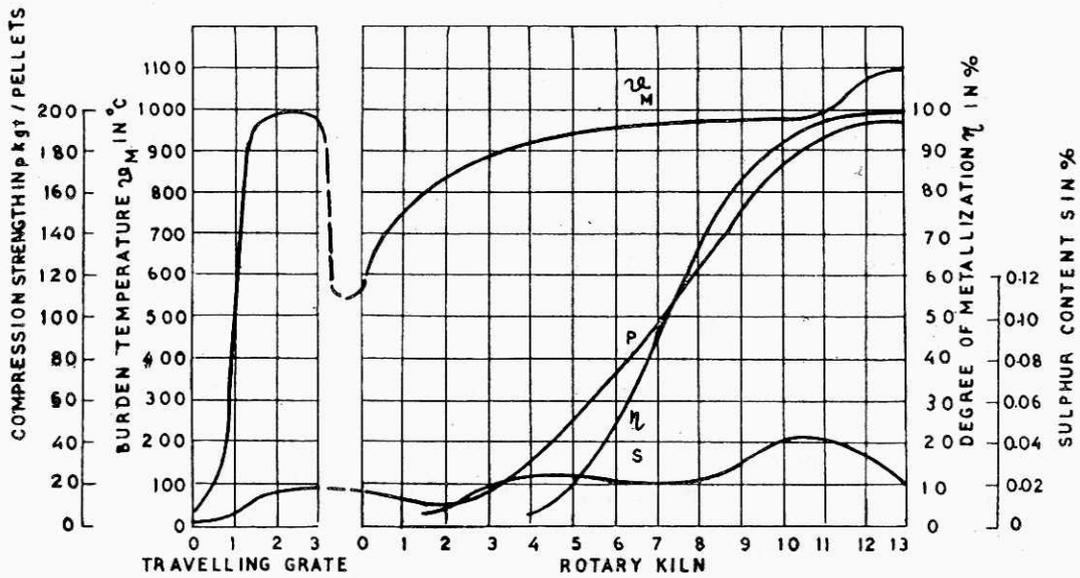
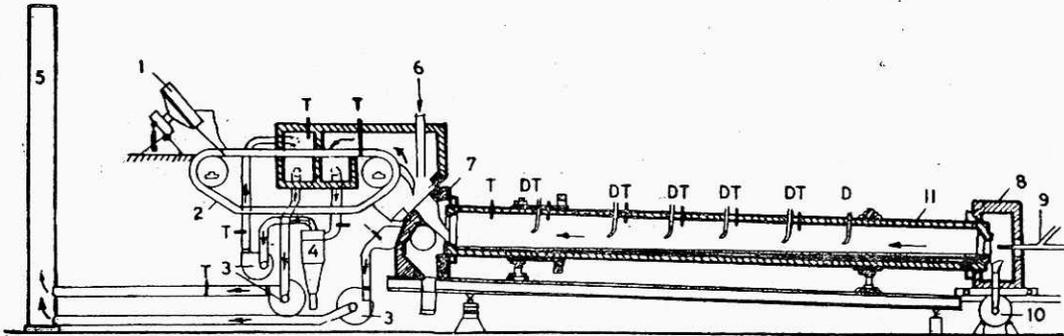


FIG.3. VARIATION OF CHARACTERISTICS WHILE PROCESSING IRON ORE CONCENTRATE IN THE KRUPP PILOT PLANT

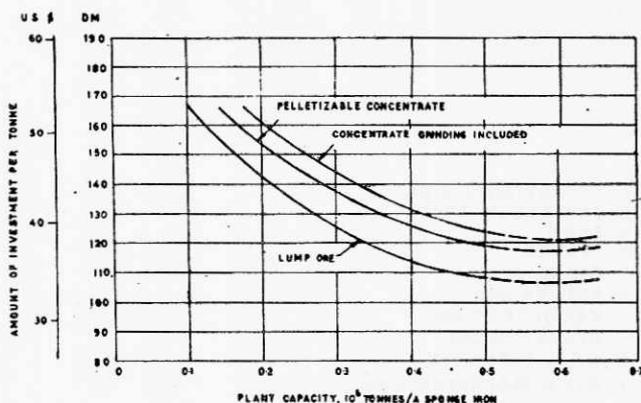


FIG. 4. EFFECT OF PLANT CAPACITY ON THE SPECIFIC AMOUNT OF INVESTMENT (PLANT IN BATTERY LIMITS, GERMAN CONDITIONS)

sponge iron near the discharge end of the kiln is due to the sulphur introduced by the coal blown into the kiln. The use of raw dolomite in sizes from 0.5 to 2 mm easily made it possible to achieve a final sulphur content of 0.02% in the metallized pellets. A sulphur content of less than 0.05%, as required of sponge iron used as melting-stock in arc furnaces, can be achieved in most cases.

The temperature of the feed in the kiln of more than 900 deg. C, at which reduction takes place, is maintained over the major portion of the kiln length. Near the kiln discharge end, the temperature of the feed was adjusted to about 1100 deg. C in order to give the pellets the desired degree of metallization. The temperature is limited by the softening point of the materials charged. The heat input required to increase metallization by 1%, for instance, is comparatively high.

In many cases, it was found advisable not to exceed a metallization of 95% in order to keep the thermal load on the kiln at the discharge end within tolerable limits. In this way such irregularities as ring-forming as a result of over-heating of the charge and of the lining, can be avoided.

Degrees of metallization higher than 95% can also be achieved by other means, but this would require a much longer retention time of the ore in the kiln and, as a consequence, a kiln of greater length. Once a high degree of metallization is reached, the reaction proceeds at a relatively slow rate so that only small concentrations of CO₂ are available for the carbon to react by the Boudouard reaction. In view of these facts we believe that it is not justifiable to drive the metallization beyond 95%.

Moreover, the present example shows that the pellets reach the maximum degree of metallization some time before they actually discharge from the kiln. This would appear to indicate that the kiln could have been shorter for attaining the same degree of metallization. We know from experience, however, that the rotary kiln will not always discharge products absolutely uniform in chemical composition and physical properties because separation of the feed components may occur within the kiln owing to their differing in specific gravity and in particle size. We, therefore, think that a sufficient length of kiln must be provided near the discharge end to serve as an equalizing zone.

The requirements to be met by the ore and fuel in the sponge iron process are discussed in the following.

Requirements to be met by the ore

The following characteristics are of importance for ores to be used in producing melting stock for steel-making furnaces:

- Chemical composition (total Fe, gangue, S, P)
- Size distribution
- Behavior under reducing conditions (such as reducibility, decrepitation and swelling)

The Fe-content of hematite should not be less than 65% and that of magnetite not less than 67.5%, ignition losses being taken duly into account. The processing of super-concentrates containing more than 69% Fe is not necessarily of advantage because the extremely small proportion of gangue may entail abrasion, an undesired increase in volume during reduction and, as a consequence, a distintegration of the pellets.

The ores should be charged into the kiln in as narrow a size range as possible. In the case of pellets, a size range of 5-15 mm has proved advisable, while in the case of lump ores, a size range from 5-25 mm is considered desirable since the comminution of run-of-mine ores to this size range, for instance, produces about 30-35% under-size.

While a narrower size range would offer certain advantages in respect of the kiln throughput rate, this would substantially increase the amount of fines produced in comminution and screening.

Assessing the pelletizing behaviour of ground fine ore and concentrates is based primarily on their specific surface after Blaine, which was bet-

ween 1 500 and 1 800 cm²/g in the cases investigated by us. With ores containing little gangue and very little alumina, this corresponds to a proportion of about 85% of minus 0,043 mm particles. Apart from the reactivity of the fuel, the reducibility of the ores exerts a significant influence upon the throughput rate of the rotary kiln. We know from experience and cost considerations that the R₄₀-value should not be less than 0,3% O/min. (R₄₀-value determined as per Stahl-Eisen-Prüfblatt 1770-64). With lower R -values, a satisfactory throughput rate can be achieved by reducing the particle size of the ore.

If pelletized concentrates are used for making sponge iron, undesired increases in pellet volume may occur during the reduction process (7). In a sponge iron process using a rotary kiln, such volume increases are undesirable because they may lead to increased degradation and consequently, to ring-forming. This can be kept within limits by thermal pretreatment of the green pellets under oxidizing conditions or by an addition of substances changing the composition of the gangue. The use of green pellets is not justifiable in full-scale commercial plants because disintegration and abrasion of the pellets will involve irregularities in kiln operation and difficulties in the waste gas cleaning system. The use of a traveling grate was found to be absolutely necessary in all cases investigated by us.

Table 2 shows a selection of lump ores, concentrates and pellets which we have used for the production of sponge iron in a rotary kiln. In each case, a highly metallized sponge iron was produced. As can be seen from the Table, the sulphur percentages were low enough. Even when the ore contained from 0,1 to 0,2% S and the gangue was mainly siliceous, a sponge iron could be produced with a sulphur content of less than 0,05%.

Requirements to be met by the fuel

The following characteristics are of importance in selecting the fuel for the process:

- Reactivity
- Volatile matter
- Sulphur content
- Ash content
- Ash softening point.

Further factors of importance are the bulk density, the size distribution and the properties of the low-temperature coke discharged as surplus fuel from the rotary kiln.

With increasing reactivity of the fuel, the throughput rate of the rotary kiln can be increased within certain limits. This is due to the fact that the rate of the Boudouard reaction determines the reduction potential. In selecting natural

Table 2

		CHEMICAL ANALYSIS									
		ORE							SPONGE IRON		
		Fe _{tot}	Fe ⁺⁺	S	P	SiO ₂	Al ₂ O ₃	CaO	Fe _{tot}	S	μ
Lump Ore											
Feijao	Brazil	67.5	0.1	0.01	0.06	0.77	1.2	0.1	94.6	0.010	96.5
Itabira	Brazil	68.4	1.0	0.01	0.06	0.8	0.3	0.1	91.5	0.028	95.0
Venezuela	Venezuela	65.3	1.5	0.02	0.10	1.3	1.4	0.4	93.5	0.030	95.6
Kromdrai	South Africa	67.3	0.5	0.14	0.04	0.6	0.3	0.5	93.3	0.030	95.2
Tazadit	Mauretania	65.1	0.3	0.01	0.05	4.4	0.9	0.4	89.0	0.035	95.0
Kiruna-C ₂	Sweden	67.0	22.0	0.02	0.30	2.8	1.0	1.8	89.1	0.030	93.2
Bomi Hill	Liberia	64.0	13.4	0.05	0.05	6.3	1.8	0.3	88.5	0.030	93.5
Concentrate											
Pellet Concentrate	Brazil	68.3	0.1	0.02	0.02	1.6	0.2	0.1	94.1	0.020	96.2
Sydvaranger	Norway	67.6	22.5	0.05	0.02	4.5	0.2	0.6	89.6	0.020	95.2
Pellet Concentrate	South Africa	66.8	21.6	0.03	0.04	0.4	0.4	0.3	87.5	0.030	96.2
Pellets											
Marcona	Peru	66.4	0.7	0.02	0.05	2.8	0.66	0.8	90.8	0.020	96.8
Carol Lake	Canada	63.8	0.1	0.01	0.04	5.3	0.4	1.4	88.6	0.020	94.8
Malmberget	Sweden	67.4	0.2	0.01	0.055	0.6	0.6	0.2	93.5	0.020	94.7

Chemical Composition of some ores and of sponge iron produced therefrom

carbonaceous materials for use as reductants, the fact that the content of volatile matter generally increases with the reactivity of the fuel should be duly considered. The exclusive use of high-volatile coal is not necessarily of advantage for economic and technological reasons, since such coal will evolve more gas than can be utilized in the process for reduction and heating of the charge. For reasons of heat economy it would as a rule be necessary to recover the heat contained in the waste gas. In order to reduce the total heat requirement as much as possible without making use of the waste gas heat it will be of advantage to employ a combination of high and low-volatile coal. If high-volatile coal is available at a low price, however, it may be justified to do without any recovery and utilization of the waste heat.

Table 3 indicates, as examples, a number of fuels which we used as reductants and for heating in the production of sponge iron. These selected fuels show a wide spectrum of volatile matter, ranging from 0,6% in the case of coke breeze to about 50% in the case of German lignite. Test runs with these coals have shown that it is possible to obtain sponge iron with a sufficiently low sulphur content even if the fuel contains up to 1,5% sulphur.

Higher sulphur percentages are tolerable if

the mineral matter contained in the fuel is basic. A low-temperature lignite coke containing about 4% sulphur, for instance, was used without this having any adverse effect on the composition of the sponge iron.

Coal containing more than 20% ash is not commendable even if the ash softening point is sufficiently high. Moreover, the fine particles are susceptible to over-heating resulting in ring-forming in the kiln and sintering together with the sponge iron. In this way the Fe-content of the sponge iron is per force reduced and the sulphur content increased. The Spanish anthracite listed in the Table and containing about 22,1% ash, for instance, should only be used together with a high-volatile coal containing less ash.

The ash softening point of the coal to be used is of particular importance and, as experience has shown, should be at least 100 deg. C above the maximum temperature of the material in the kiln. If it is below this value, considerable operational irregularities may occur as a result of ring-forming and sintering together of different constituents.

Processing of sponge iron

In the past, several papers have been published (10-14) about the experience gained at KRUPP's

Table 3

		CHEMICAL ANALYSIS					
		C _{fix}	Volatiles	Ash	S	Moisture	Net C.V.
		%	%	%	%	%	kcal/kg
Natural Fuels							
<i>Low Volatile :</i>							
Diergart-Mevissen	Germany	85.7	8.5	5.8	0.87	8.2	7392
Canmore-Mines	Canada	83.3	11.9	4.8	0.77	0.7	8093
Duff	South Africa	80.4	10.3	9.3	0.75	9.4	6743
Garcia-Monte	Spain	73.3	4.6	22.1	0.61	8.4	5622
<i>High Volatile :</i>							
Duff	South Africa	62.5	25.1	12.4	0.73	6.6	6322
Zonguldak	Turkey	61.1	26.9	12.0	0.41	2.6	7140
Wyvern-Seam	Australia	60.6	36.7	2.7	0.26	19.0	5305
Pea-Size	South Africa	60.3	24.9	4.8	0.74	4.2	6318
Furst Leopold	Germany	56.8	37.9	5.7	1.32	9.3	6920
Luscar	Canada	54.6	35.4	10.0	0.34	1.9	6415
Naricual	Venezuela	56.8	41.4	1.8	0.86	3.0	7420
Pozo San Vicente	Spain	54.0	33.6	12.4	1.58	7.1	6384
Spitzbergen	Norway	52.6	40.9	6.5	1.20	5.9	7220
Lignite	Germany	46.1	49.3	4.6	0.44	19.2	4640
Carbonized Fuels							
Coke-Breeze	Germany	90.6	0.6	8.8	0.74	8.3	7200
Petrolcoke	Germany	89.66	10.0	0.34	1.56	24.3	5935
Lt-Coke (Bituminous Coal)	Germany	76.4	12.8	10.7	0.66	24.1	5340
Lt-Coke (Lignite)	Germany	67.6	14.2	18.2	4.04	20.0	n. e.

Characteristic Fuel Data

in the use of sponge iron in different steelmaking processes. These investigations were mainly concerned with the use of sponge iron as melting stock in electric arc furnaces and LD-converters.

Although in recent years the use of sponge iron as melting stock has frequently led operators to expect too much in the way of an improvement in the operational and performance data of electric arc furnaces, it may be regarded as being generally accepted today that its use as melting stock is of benefit. Increases in output are mainly possible as a result of the shorter refining period. Observations of sponge-iron-bearing heats during the melt-down period showed that, in comparison with straight scrap charges, the arcs were extremely stable and the power input very uniform. It was possible in all heats to operate the furnace from the start at full power. Undesired effects on the power supply system were substantially reduced. These advantages should make it possible in the future to reduce the cost of electric power.

As already mentioned, sponge iron contains, apart from a certain amount of gangue, residual oxygen that is combined with the iron. Both the melting of the gangue as well as the reduction of the residual iron oxide require an additional input of electric power. With a furnace efficiency of 85%, power consumption, as theoretical calculations have shown, can be expected to increase by

0,67 kWh per kg of slag, or
0,91 kWh per kg of Fe (from FeO) (10).

Compared with straight scrap charges there was no or only a slight additional power consumption when the addition of sponge iron amounted up to about 30%. This was due to the uniform power input observed, particularly at the beginning of the melt-down period, which compensated for the extra subsequent consumption. Whether this effect makes itself fully felt, however, depends largely on the method of charging and the quality of the sponge iron.

If sponge iron makes up more than 30% of the charge, the energy required for reducing the residual FeO and the melting of the gangue generally results in a higher power consumption during melt-down.

High proportions of sponge iron must be expected to prolong the melt-down period. But the refining period can, as a rule, be shortened. After the melting down of the charge, it is, in general, merely necessary to correct the carbon content and temperature. Special investigations conducted by us have shown that even hard steels can be produced if low-carbon sponge iron is charged

continuously together with such carbonaceous material as anthracite, for instance (14).

Owing to the strong exothermic reaction, coolants must be added in refining high as well as low-phosphorus hot metal in an oxygen-blowing converter in order that the steel can be teemed at the desired temperature. In any case, the additions of coolants should be as large as possible for reasons of cost. Scrap as well as sponge iron can be used for cooling. We carried out several investigations into the use of sponge iron for this purpose (11, 12, 13) and used sponge iron in different test runs, both in a 3-tonne pilot converter and in production converters of 35 and 100 tonnes capacity. The sponge iron used for the tests in the 35-tonne converter had the following composition:

Total iron	94%
Metallic iron	87,5%
Metallization	93%
Sulphur	0,03 — 0,05%
Phosphorus	0,04%

The sponge iron was added in sizes of minus 25 mm, the proportion of minus 3 mm sizes amounting to about 25%. Blowing proceeded without slopping and the target analysis of the steel was achieved without any difficulty. The temperature of the metal bath could be controlled within narrow limits.

The quantity of sponge iron was increased from 17% to 25% of the hot metal charge during tests in the 3-tonne converter. This gave final temperatures of 1 650 deg. C.

The addition of carbon made it possible to increase the amount of sponge iron to more than 27% of the hot metal charge (15).

A continuous charging of the sponge iron results in preheating the sponge iron as it passes through the hot converter gases and the slag. The cooling effect depends mainly on the degree of metallization and on the type and quantity of gangue contained in the sponge iron. Highly metallized sponge iron containing little gangue generally gives roughly the same cooling effect as scrap.

The questions of charging hot sponge iron in steel-making practice has often been considered in order to utilize the sensible heat for melt-down and thus to reduce power consumption. This idea is, however, difficult to put into practice because the material leaving the rotary kiln at a temperature of about 1 100 deg. C. is a mixture consisting of sponge iron, coal ash, desulphurizing agent and surplus fuel. Hot screening of large

quantities of material continuously discharged from a rotary kiln cannot yet be carried out satisfactorily. Moreover, intermediate storage of the hot sponge iron under a blanket of protective gas in heat-insulated receivers will entail considerable investment costs, which might offset the advantages to be gained from hot charging. At the present stage, the capital expenditure involved in the hot charging of sponge iron does not appear to be justified.

Reoxidation of sponge iron is a question of prime interest. In the past, a number of investigations have been carried out on the subject; the findings have been published elsewhere (4, 6, 14). It was found that it is possible in most cases to produce a sponge iron that can be transported over considerable distances without any risk of reoxidation provided that specific precautions are taken. As a rule, protecting the sponge iron from direct contact with water is sufficient.

DATA ON ECONOMY

Investment cost

The specific investment costs of sponge iron plants with different plant capacities are indicated in Fig. 4. They always depend on the conditions prevailing at the site and are therefore subject to change. The specific investment costs are known to decrease with an increase in plant capacity.

Plants intended for processing fine ores or concentrates involve more investment costs than plants intended for lump ores because they require such additional equipment as grinding mills, pelletizing and prehardening facilities. This is the reason for the difference in the investment costs involved in the two alternative routes. For a 300 000 tonnes/year sponge iron plant processing lump ore, the investment costs can be expected to amount to about DM 125, per tonne of installed annual capacity. The use of pelletizable concentrates can be expected to increase the investment cost by about 8% and, if ore grinding is included, by about 13%.

Multi-kiln plants of the extent under consideration (i.e. in battery limits: starting from the raw material bins and ending with the products bins) can be expected to give only a minor reduction in the specific investment costs because of equipment duplication within the battery limits. However, substantial savings are possible if such multi-kiln plants include the necessary unloading, storage and dressing facilities.

The curve relating to the use of lump ore begins at a plant capacity of 100 000 tonnes/year. From the standpoint of economy, we think that

this constitutes the minimum size of such plant in most cases.

The curves applying to concentrate end at a plant size of about 150 000 and 180 000 tonnes/year. This is intended to show that we can normally recommend the use of the sponge iron process for the reduction of iron ore concentrates only for a plant capacity of more than 200 000 tonnes/year. The economic plant sizes given in Fig. 5 are, of course, rough estimates and emphasize the need for thorough testing of the raw materials to be used in order that an optimum plant capacity can be determined for any specific combination of raw materials.

Production cost of sponge iron

Before a project can be assessed for its feasibility, the production cost must be estimated. Since the production cost represent the cost of raw materials and the cost of conversion or processing, the unit costs must, of necessity, be determined as reliably as possible. The materials balance, incorporating the results of semi-commercial tests, serves in each case as the basis for such a calculation.

Indicating the production cost of sponge iron is always somewhat problematical because the figures arrived at are never universally applicable. It is particularly difficult to predict future developments in the costs. Presenting the materials balance for a commercial plant in the way as shown in Table 4 therefore appears to be preferable; the potential customer himself enters the costs applying in his particular case and then determines the production costs. This will give a general idea of the magnitude of the cost to be anticipated. The data given are based on the results of extensive tests and on the experience gained in the construction of reduction plants for different applications (16).

Table 4 gives the specific data per tonne of sponge iron for a 300 000 tonnes/year KRUPP Sponge Iron Plant, both for lump ore as well as for concentrate, assuming that sponge iron with a degree of metallization of 93 — 94% will be produced and that all raw materials will be supplied in a size suitable for treatment.

The costs of the ore and fuels are the main factors governing the production cost of the sponge iron. This clearly means that plant sites close to the ore or fuel deposits are particularly attractive.

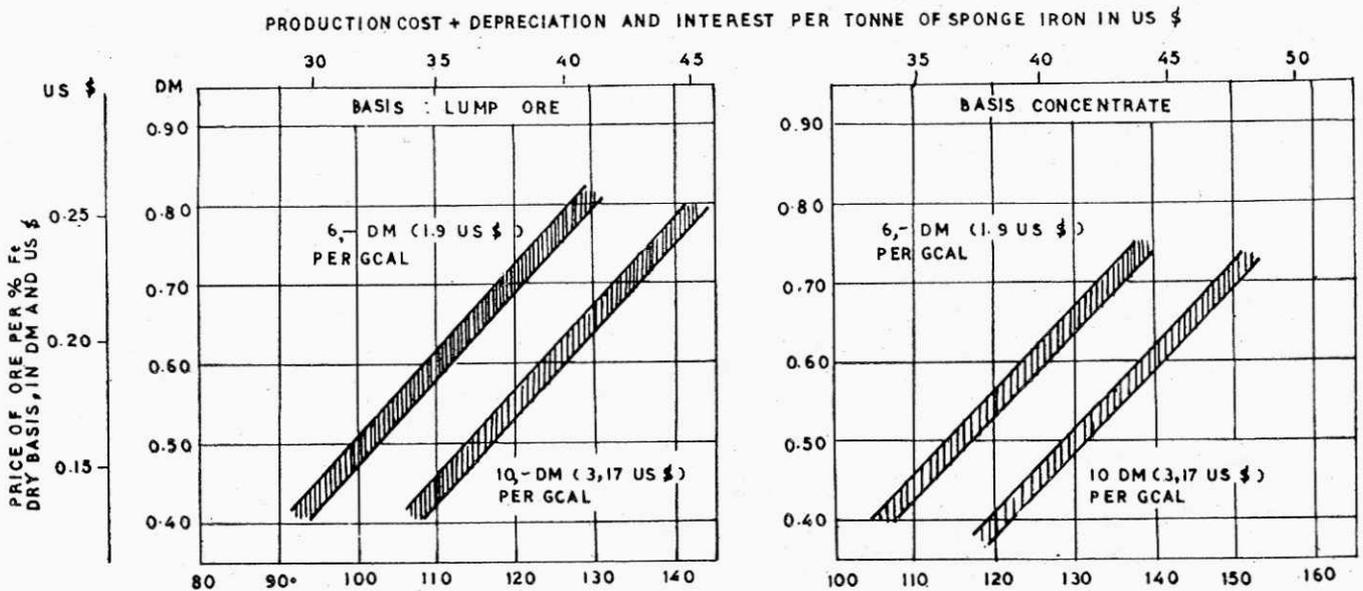
Fig. 5 shows the influence, already mentioned above, of the cost of the raw materials upon the

Table 4

Data per tonne of Sponge Iron		Lump Ores	Concentrates ^{*)}
Raw materials			
Iron Ore, 67% Fe, dry	kg	1430	1430
Bentonite	kg	—	1
Fuels for heating and reduction	kcal	3.5×10^6	3.5×10^6
Limestone/Raw dolomite	kg	60	60
Processing data			
Labor	h	0.40	0.45
Maintenance	DM	3.75	4.40
Refractories	kg	3.0	3.0
Power	kWh	5.0	65
Water	m ³	1.5	1.0
Consumables	DM	1.50	1.65

*) grinding not included

Specific data of a Krupp Sponge Iron plant with a capacity of 300.000 Tonnes/a of Sponge Iron (plant in battery limits, German conditions)



PRODUCTION COST+DEPRECIATION AND INTEREST PER TONNE OF SPONGE IRON IN DM

BASIC FACTORS PLANT CAPACITY OF 300.000 TONNES/YEAR OF SPONGE IRON
DEPRECIATION AND INTEREST 12 %; PLANT IN BATTERY LIMITS
TOTAL HEAT CONSUMPTION 35×10^6 Kcal PER TONNE OF SPONGE IRON
1 US \$ \approx 3.15 DM

FIG. 5. RAW MATERIAL COSTS VS PRODUCTION COST+DEPRECIATION & INTEREST IN THE PRODUCTION OF SPONGE IRON USING THE KRUPP SPONGE IRON PROCESS

production cost with a plant capable of producing 300 000 tonnes of sponge iron per year from lump ore (left-hand side) and fine ore or concentrate (right-hand side). In either graph, fuel costs of DM 6,—and DM 10,—per Gcal (1.9 and 3.17 US \$ per Gcal) respectively were assumed.

Reducing the price of lump ore from DM 0,75 to DM 0,65 per Fe-unit decreases the production cost of sponge iron from about DM 125,—to DM 115,—per tonne. With a fuel price of DM 10,—per Gcal and assuming the same conditions, the production cost of sponge iron decreases from about DM 140,—to DM 130,—per tonne.

The question is frequently asked what difference there must be in the price per Fe-unit between concentrate and lump ore if both variants of the process are to give sponge iron at equal costs. By combining the two graphs in Fig. 6, the conclusion can be drawn that production costs will be equal with a plant of the above capacity if there is a difference in price from about DM 0,15 per Fe-unit of the ore. This means to say that if this difference is greater, it will be more attractive to produce sponge iron from fine ore or concentrates; if it is smaller, the use of lump ore will involve less cost. It should be noted, however, that a lump ore plant is less complex and easier to operate. At that, it should be realized that the difference between the prices of lump ore and fine ore has decreased in recent years owing to a fairly strong demand for fine ores for use in sinter plants. The data presented

here refer to conditions prevailing at present in the Federal Republic of Germany.

First commercial plant under construction

KRUPP is at present engaged in building a commercial plant for the Dunswart Iron and Steelworks in Benoni, South Africa, which is scheduled to be commissioned early in 1973. Fig. 6 shows the layout of this 150 000 tonnes/year sponge iron plant.

The raw materials to be used are South African lump ore containing 65—67% Fe, which will be charged in sizes from 5—25 mm, and indigenous anthracite and bituminous coal (Duff). The anthracite contains about 79% fixed carbon and 11—12% ash. The Duff coal contains about 57% of fixed carbon, 26.5% of volatile matter, and about 16.5% ash. Anthracite and Duff coal will be used in a specific ratio for reducing and heating.

The sponge iron plant will be integrated in an existing steelmaking plant. For the time being, it is proposed to feed sponge iron in amounts of 35—50% of the arc furnace charge.

The storage yards are large enough to permit the plant to accommodate another rotary kiln.

In view of the country's extensive resources of raw materials, South Africa offers excellent conditions for the production of sponge iron, and once marine terminals have been constructed and expanded, the export of sponge iron might become a significant business.

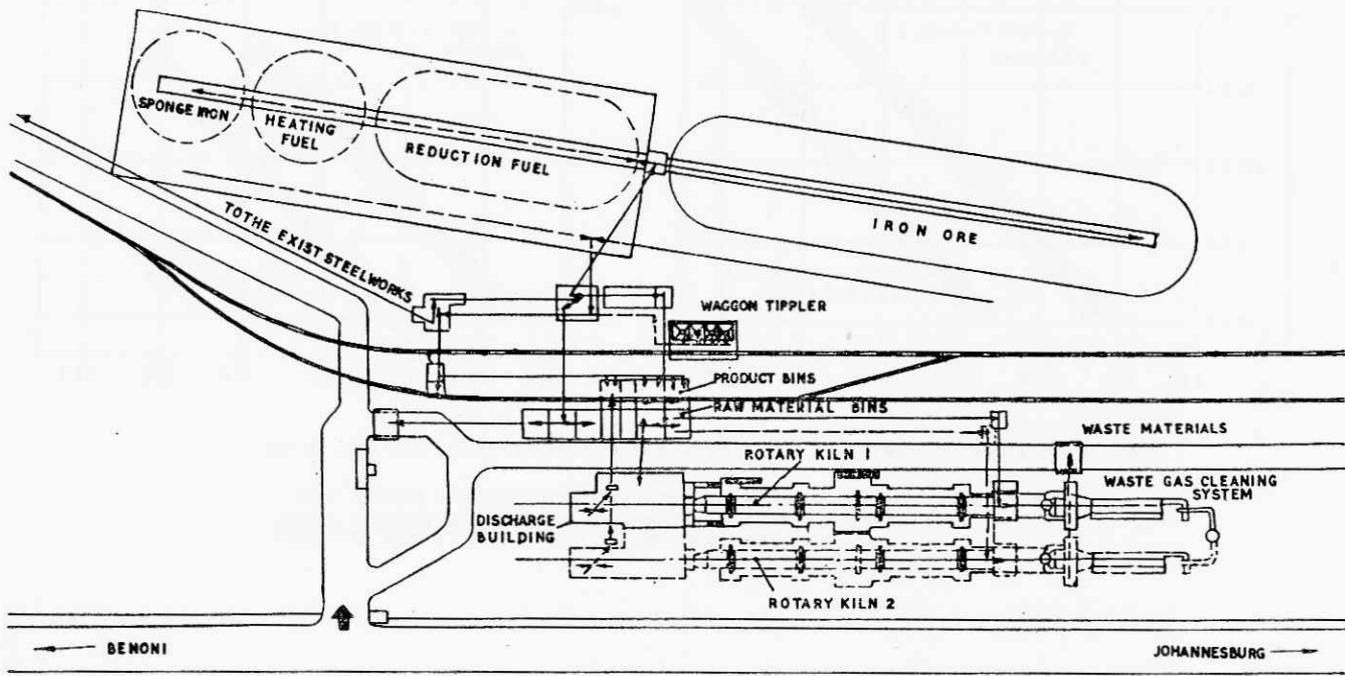


FIG. 6. KRUPP SPONGE IRON PLANT CAPACITY 150.000 TONNES/YR FOR DUNSWART IRON & STEEL WORKS LTD..BENONI, SOUTH AFRICA

Conclusion

Interest in direct reduction processes is constantly increasing as a result of the rising cost of coking coal and the shortage of scrap in many parts of the world. The reduction processes using solid reductants hold good promise for the future since world reserves of coal may be regarded as being practically inexhaustible. Moreover, these processes also permit the use of a wide variety of carbonaceous materials.

The essential features of the KRUPP Sponge Iron Process based on lump ores, fine ores and concentrates, are described. KRUPP's laboratory facilities as well as the semi-commercial pilot plant, consisting of a combination of travelling grate and rotary kiln, are described and its operation explained. The question is discussed what capacity such a pilot plant should have if the results obtained in semi-commercial tests are to reflect the conditions to be anticipated in an upscaled commercial plant.

An assessment is made of the special requirements that must be met by the feed ore and coal. While the main characteristics of the feed ore are chemical composition, size and behaviour under reducing conditions, the coals are characterized by reactivity, volatiles, sulphur, ash and ash softening point. The limiting values for these characteristics are discussed in detail.

Information on the economy of sponge iron production is given in the form of a materials balance, as well as investment cost data. For a plant designed to produce 300 000 tpy of sponge iron from high-Fe lump ore, the investment cost can be expected to be in the order of DM 125,— per ton of installed annual capacity.

When processing pelletizable concentrates, investment costs are likely to be higher by 8%, or 13% when including the cost of grinding. Mention is made of the minimum economic sizes of sponge iron plants.

The first KRUPP Sponge Iron Plant, now under construction in South Africa, is described.

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