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Second Interregional Symposium
on the Iron and Steel Industry

Moscow, USSR, 19 September - 9 October 1968

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SL/RN DIRECT REDUCTION PROCESS FOR THE PRODUCTION OF SPONGE IRON AND ITS MELTING TO STEEL [1]

by

Horst Garbe and Wolfgang Janke
Federal Republic of Germany

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SL/RN DIRECT REDUCTION PROCESS FOR THE PRODUCTION OF SPONGE IRON AND ITS MELTING TO STEEL[1]

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Federal Republic of Germany

SUMMARY

The SL/RN process for the reduction of iron ores with solid carbonaceous reductants in a rotary kiln has been developed over the last years to a stage of commercial exploitation in various pilot plants. The largest existing pilot plant unit for the process is capable of producing 100 tons of sponge iron per day. Several commercial plants having a total annual throughput capacity of 2 million tons ore are under construction or already in operation. The largest plant has been designed for an annual production of 300,000 tons of sponge iron. It will go on stream in Canada at the end of next year and will be the largest production unit yet built in the world.

The process is distinguished by its simple and clear arrangement, by the use of units approved in practice and by its flexibility with regard to requirements concerning the quality of raw materials.

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* This is a summary of a paper issued under the same title as ID/WG.14/19.

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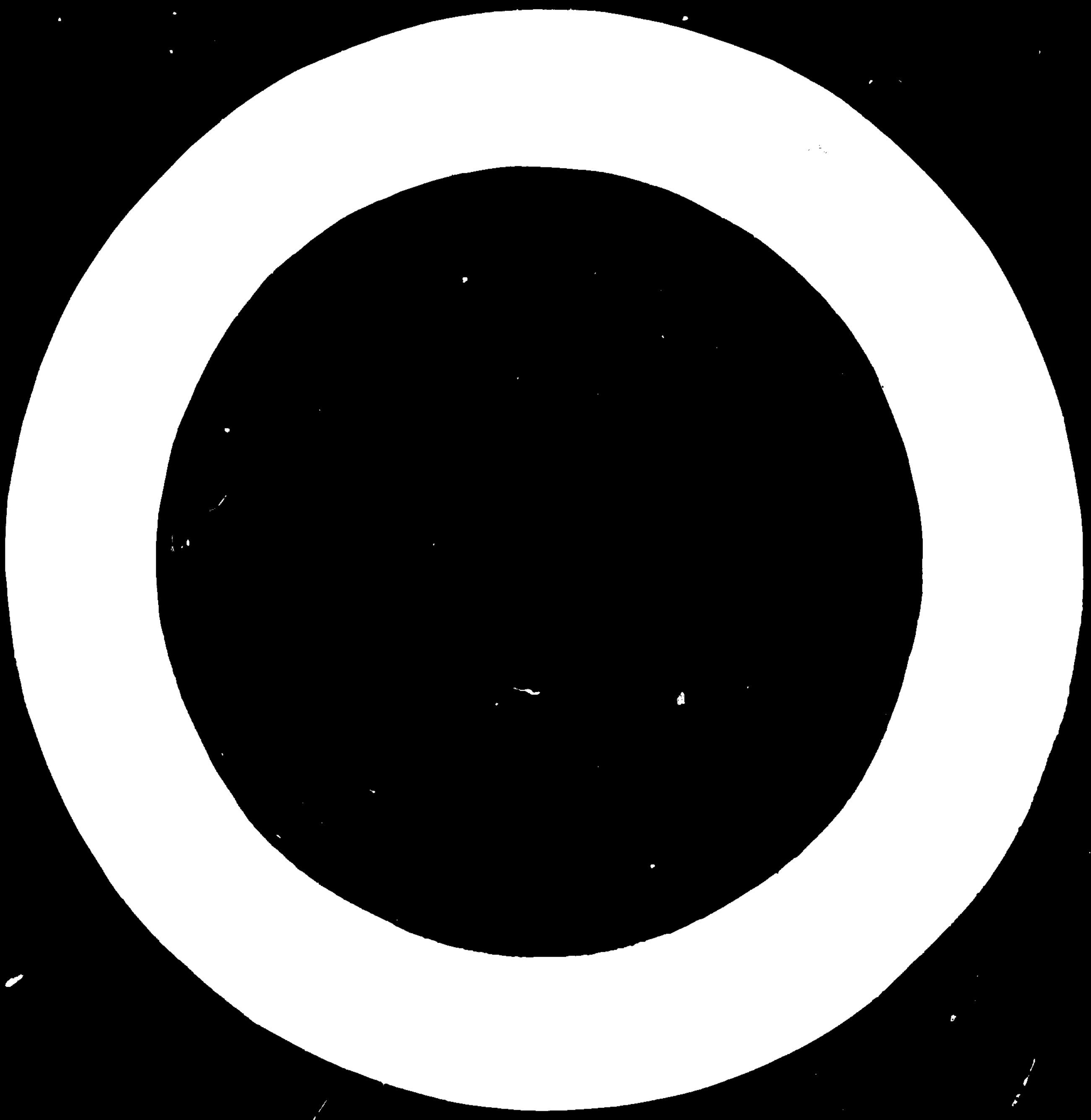


The quality of iron ores is exclusively determined by the kind of further treatment of the reduced ore. For the direct steel production in the electric arc furnace a low content of gangue - approximately 5% at the maximum - is required, whereas as a blast furnace or electric reduction furnace charge for the reduction of pig iron within the limits of economy the gangue is not subject to any limitation.

The ores can be charged both as lump ores - 5-15 mm grain size preferably - and fine ores. The latter ores must, however, be agglomerated prior to being fed to the rotary kiln. In this case, it is advantageous to pelletize the fine ore, possibly after grinding, and to preharden the green pellets and heat them to reduction temperature on the grate preceding the rotary kiln by using the heat content of the kiln waste gases. By this measure, the rotary kiln is relieved to a great extent from heating the feed materials to reduction temperature and is essentially used for its main task, that of reduction. Thus the specific capacity of the rotary kiln, particularly that of large units, is more than doubled and by a consequent reduction in size of the kiln the additional cost of the grate is practically compensated.

With certain limitations any coal can be used as a reductant if the ash-softening temperature ranges approximately 100°C above the desired reduction temperature, that is at approximately 1200°C. Non-caking, high volatile coals are preferred. These coals are distinguished particularly by their high reactivity that exercises a decisive influence on the specific reduction capacity. A further advantage is that, contrary to low volatile coals such as anthracite or coke breeze, additional heating of rotary kiln by gas or oil is not required. By means of a special technique the coal is pneumatically charged at the kiln discharge end and the volatile components expelled in the kiln are burnt on their way to the feed end.

With the exception of the reduction degree, the composition of sponge iron depends exclusively on the analysis of the ore fed. The degree of reduction can be adapted to correspond to the requirements of the following process. For steel production in the electric arc furnace a sponge iron with a metallization of more than 95% and a sulphur content of less than 0.02% is desirable. This can be produced without any difficulties by the SL/RN process.

The investment cost will, in particular, depend on plant size, arrangement of plant, conditions prevailing at site, and prices of machinery and civil engineering work in the country concerned. A turn-key plant of medium size, approximately 300,000 tons of sponge iron per year, based on German conditions, will cost approximately DM 30 million or DM 100 per ton of sponge iron per year. The specific plant cost of a 100,000-ton plant will increase to approximately DM 150 per ton of sponge iron per year and that of a 500,000-ton plant will decrease to approximately DM 80-90 per ton of sponge iron per year, the above-stated costs being based on one production unit.

The operating costs are mainly determined by the costs of ore and coal, upon which fall as much as 75-80% of the total cost. The selection of raw materials will therefore not only be influenced by the quality of raw materials but also by their prices.

In principle, sponge iron can be charged into all known metallurgical furnaces for pig-iron, foundry-iron and steel production. By a consequent utilization of the sponge iron properties in chemical and physical respects, advantageous effects on productivity, product quality and process economy could be shown by the respective examinations.

The positive influence exercised by the use of prereduced material in blast furnaces and electric reduction furnaces on their operating figures is known from the literature of the last years: the consumption of reducing agents and of energy decreases and the productivity increases with the percentage of the sponge iron in the burden.

If, however, ores poor in gangue are available for direct reduction, the indirect way via pig iron will no longer be economically justifiable for steel production. Intensive investigations during the production of steel from sponge iron in electric arc furnaces lead to a new process by which the free-flowing sponge iron can be continuously fed directly into the bath of molten steel. The melting and refining operations run, to a great extent, parallel whereby, compared with steel production from scrap, capacity increases up to as much as 45% can be attained. Some further advantages, such as improvement of quality, better utilization of transformer units and uniform heat times, were observed. The process is, from a technical point of view, fully developed and the results could be confirmed with sponge iron rates of 20-100% in electric arc furnaces of different sizes in the United States of America and in Canada.

By a combination of direct reduction plants with modern electric steel works it will be possible for smaller plants also to produce steel at competitive prices. When planning the SL/RN reduction plant and the steel works it will be advantageous to integrate them. The arrangement of steel works should be adapted to the properties of the new iron-bearing material. The sponge iron is transported via belt conveyors and bins to the continuous furnace charging equipment that can also be used for other additives, such as slag-forming constituents.

A comparison of investment costs of integrated steel works clearly shows, for all the cases involved, lower investment costs per ton of raw steel for integrated SL/RN plants and electric arc furnaces than for conventional combinations of blast furnace and basic oxygen furnace plants. The cost advantage is particularly pronounced at small capacities of up to 0.5 million tons of raw steel per year, but it is still considerable at high capacities of up to 3 million tons of raw steel per year. The difference in cost will increase if plants for coke production and burden preparation (sintering or pelletizing plants) are to be provided for the blast furnace.

The comparison of production costs per ton of raw steel is to be calculated anew for each individual case because the local fluctuations in raw material and power costs are to be considered. In normal cases, however, the treatment costs of an electric steel works combined with an SL/RN reduction plant range below those of the conventional blast furnace/blast oxygen furnace combination. Due to the development of atomic power it is to be expected that the trend of falling costs of electric power will continue. The electric steel production will profit from this development in future too.

Besides the cost advantages, the process described above offers, in certain instances, a possibility of producing steel from ores that are unsuited for the blast furnace. A typical example is the steel plant of New Zealand Steel where sponge iron produced of TiO_2-bearing sea sands by the SL/RN process will be directly converted to steel in electric arc furnaces. This plant will go into operation at the beginning of 1969.

The method of continuous charging of SL/RN sponge iron to electric furnaces enables on a suitable ore basis a possibility of building and operating smaller plants competitively and of using in many cases a raw material basis that is not utilizable for the conventional blast furnace process. Moreover, it is likely that sponge iron produced in large plants in countries where especially favourable conditions of raw material prevail will become available to a limited extent in the world market. For the time being, however, no definite predictions can be made. With one single exception, all the SL/RN plants have hitherto been built by the consumer and are integral components of steel works.

Contents

1. Introduction

Particularly during the past 10 years, systematic improvements of the blast furnace process, new steelmaking processes and the continuous casting technique have changed considerably the appearance of iron and steel works. Blast furnaces of small capacity have been replaced by large units with an annual production exceeding 1 million tons of pig iron and the BOF process and electric arc furnace are being substituted for the Thomas process and open hearth furnace. Although this development is not yet complete, the steel industry must now consider a new process combination, namely, the production of sponge iron with subsequent melting in the electric arc furnace. Consequently, the direct reduction processes in which the iron ore is reduced in the solid stage have taken on new importance.

According to a study made by the Batelle Institute (1), the production of reduced iron ore will amount to 10 million tpy in 1975 and to 29 million tpy in 1980. For the moment it is difficult to predict to what extent the aforesaid production figures will be realised. It will depend, among other things, on whether the higher production costs of the electric arc furnace compared with the blast furnace can be compensated for by the lower production costs of the sponge iron. The outlook is favourable since the reducing agents used in the direct reduction process (non-coking coals, natural gas and oil) are cheaper than coke and since in future the price of current will tend to decrease. Added to this is the increasing availability of high-grade concentrates, pellets and lump ores as well as lower capital investment for steel plants based on sponge iron production and electric arc furnace. In this connection, it is remarkable that at this very moment plants with a total production of more than 3 million tpy reduced iron ore based on different direct reduction processes are in operation or under construction, approximately 1.6 million tpy thereof being produced by the SL/RN process.

Actually, the greatest interest in the direct reduction is shown in countries which do not have a sufficient quantity of suitable raw materials for the blast furnace. These countries hope to be able to use their own raw material and energy sources with the aid of the direct reduction process. Typical examples are the Monterry steel plant in which natural gas is utilised for the reduction of iron ores and the steel plant under construction in New Zealand. In this plant sponge iron is to be produced from a TiO_2-containing magnetite concentrate by using lignite as reducing agent for processing in the electric arc furnace.

2. SL/RN Process

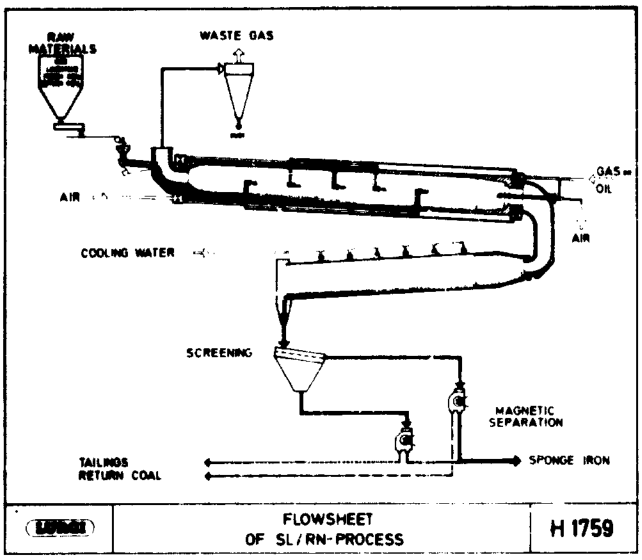
Iron ores can be reduced with gaseous or solid-reducing agents. However, the advantages and disadvantages of the different processes are not under discussion in this paper as extensive literature is already available on this subject. In this connection, the meeting held at Evian in 1967 (2) is particularly referred to. This paper only covers the SL/RN process and in particular variants, raw materials and relevant costs.

2.1 Process flow sheet

The SL/RN process was developed separately by two groups of companies - Steel Company of Canada (S), Lurgi Gesellschaft für Chemie und Hüttenwesen mbH (L), and Republic Steel Corp (R) and National Lead Company (N). Both processes are based on the use of a rotary kiln as reactor and solid carbon as reducing agent.

In the RN process (3), the development has been concentrated on the reduction of low-grade iron ores with subsequent beneficiation, and in the SL process (4, 5, 6, 7) on the reduction of high-grade iron ores into sponge iron which can be directly utilised for steelmaking.

Figure 1 shows the flow sheet of the process variant using pellets or lump ores and low-volatile reduction coal. The raw materials - ore, fresh reduction coal, return coal and limestone or dolomite - are charged into the rotary kiln and preheated to the reduction temperature of approximately 1100°C. The reduction time at this temperature depends on the desired reduction degree.

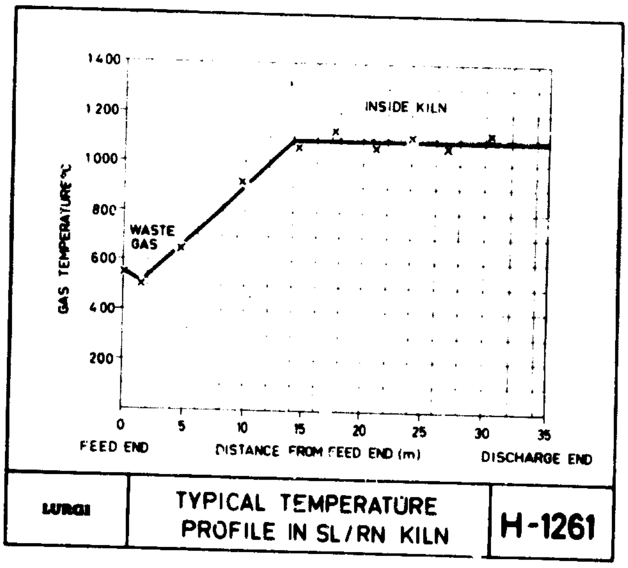


(1)

The kiln product passes through a gas-tight sluice into a directly water-cooled cooling drum and is cooled down to a temperature below 100^{o}C to avoid a reoxidation of sponge iron. The cooler discharge consisting of coarse-grained and fine-grained sponge iron, return coal, coal ash and desulphurisation agent is separated by screening and magnetic separation into the various constituents. The grain size of the kiln feed is so adjusted that the major part of the sponge iron can be separated by ordinary screening. The fine-grained sponge iron is removed by low intensity magnetic separators. The return coal can also be separated from the coal ash and the desulphurisation agent by screening to remove the - 1 mm fraction. This fraction comprises the desulphurisation agent which is fed in a grain size of - 1 mm and the major part of the coal ash.

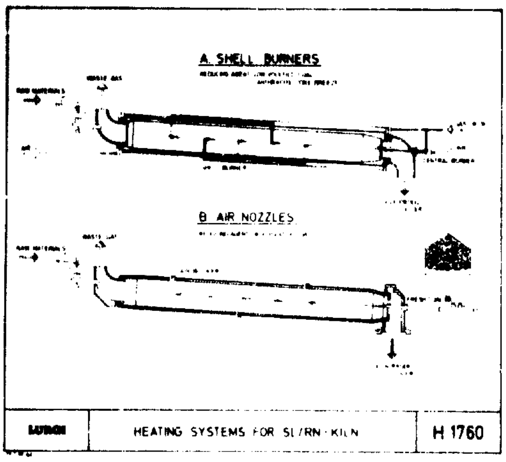
2.2 Kiln heating

The optimum reduction temperature depends upon the fusion temperature of the raw materials. To achieve a high throughput, it is necessary to operate the kiln at temperatures just under the fusion temperature of the raw matérials charged. In this connection, close checking of the kiln temperature is important. Figure 2 shows the temperature gradient which was measured in the semi-commercial plant of the Steel Company of Canada. It was possible to maintain a constant temperature of 1100°C over a length of 21 m. from the total kiln length of 35 m - which corresponds to 60 % of the kiln length.



(2)

Figure 3 illustrates two heating systems which best meet the above requirements. When using <u>low volatile coals</u>, the kiln is heated by a central burner situated at the kiln discharge end and by shell burners distributed over the whole kiln length, the discharge opening of which is located at the kiln centre. Combustion air and gas or oil are supplied separately through both kiln head seals to the shell burners. The kiln heating can be simplified by using <u>high volatile coals</u> as reducing agent since, in this case, an additional heating by gas or oil can be avoided. Fresh coal is injected into the rotary kiln at the discharge end and is instantly degasified as soon as it comes into contact with the hot kiln charge. The gases escape from the coal and burn on their way to the kiln feed end by the injection of air through air nozzles which are distributed in the same way as the shell burners over the kiln length. The combustion air is conveyed to the air nozzles by means of fans mounted on the kiln shell.

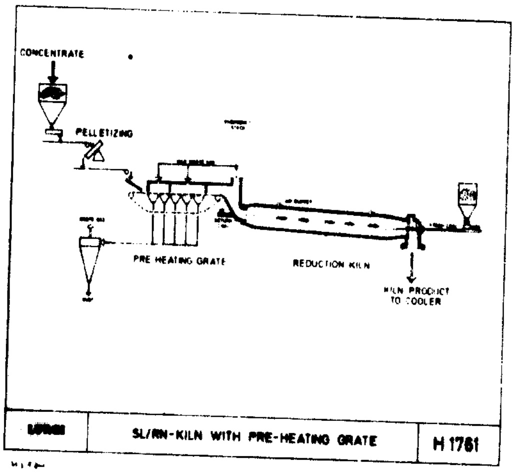


(3)

2.3 Combination: Preheating unit - rotary kiln

Ores with a low gangue content are preferable for the production of sponge iron to be processed in the electric arc furnace. Such ores are only available in a small number of deposits. It is thus to be expected that mainly fine-grained concentrates are utilised for the sponge iron production instead of lump ores. These concentrates, with the exception of a few types such as, for example, spiral concentrates, have to be pelletised before they are fed into the rotary kiln. Under certain conditions, green pellets (7) can be directly charged into the rotary kiln. However, in most cases, a thermal pre-treatment of green pellets is recommended. For this purpose, a great variety of systems such as travelling grates, shaft furnaces etc. can be applied.

Figure 4 shows the flow sheet based on a travelling grate. The pellets are pre-hardened and pre-heated by the waste gases leaving the rotary kiln. This process variant enables an economic combination of reduction and agglomeration of fine ores. Moreover, the throughput can be raised considerably as the rotary kiln is to a great extent freed from the task of pellet pre-heating and can thus be utilised more efficiently for the reduction. It is obvious that the capacity per kiln unit can be increased thereby. Actually the biggest units being designed are kilns with an annual production of 500,000 to 600,000 tons sponge iron. The kilns required for this capacity will have a diameter of 6 m and a length of 60 - 70 m.



LURGI SL/RN-KILN WITH PRE-HEATING GRATE H 1761

(4)

2.4 Raw materials

When the SL/RN process was developed great importance was attached to the use of a great variety of ore types and reducing agents (Fig. 5). The selection of ore type is limited only by the method of processing the reduced ore. If sponge iron is used in the electric arc furnace, the gangue content of the ore should not exceed 5 %. However, when the reduced ore is treated in a blast furnace or in an electric ironmaking furnace, the gangue content is not confined within economic limits. The grain size of the ore feed depends on its reducibility. In the case of lump ores, the grain size is between 5 and 20 mm and in the case of pellets between 10 and 15 mm.

RAW MATERIAL	GRAIN SIZE	ANALYSIS	REMARKS
IRON ORE	depending on Reducibility	no Limitation	
LUMP ORE	abt 5 - 20 mm	depending only on Product processing	———
GREEN PELLETS HARDENED PELLETS	10 - 15		
FINE ORE	dust - free		
COAL	minus 10 mm	no Limitation	Ash Fusion Temperature above 1200 °C non - caking
LIMESTONE DOLOMITE	minus 1 mm dust - free	no Limitation	amorphous type

LURGI CHARACTERISTIC DATA OF RAW MATERIALS H 1758

(5)

Practically all solid carboniferous agents except highly caking coals can be used as reducing agents. The most important prerequisite is that the ash fusion temperature is about 100°C above the working temperature i.e. 1200°C. The preferable grain size of coals is below 10 mm.

From a technological viewpoint, the ash and sulphur contents are unlimited. However, for economic reasons, coals with a low ash and sulphur content are preferred.

A very important factor in the coal evaluation is its reactivity. It is a criterion for the rate of conversion of the CO_2 formed during reduction into CO. The faster this reaction takes place, the higher will be the CO concentration in the charge and also the rate of oxygen removal from the ore. Consequently, the reactivity of the coal has a decisive influence on the kiln throughput. High volatile coals, in particular lignites in which the optimum reactivities were observed, are thus especially suitable as reducing agents.

Dolomite or limestone of 0.1 - 1 mm grain size are employed as desulphurisation agent. This agent should have a high mechanical strength to keep as low as possible the fines portion caused by degradation.

2.5 Final product

Table 6 gives some typical sponge iron analyses. The composition of sponge iron depends on the ore analysis and on the reduction degree. The oxygen combined with iron and with the more positive metals as well as the metals to be volatilised (zinc, lead etc.) are removed at a reduction temperature of approximately 1100°C. It is possible to attain reduction degrees exceeding 95% with reference to iron oxide.

TYPE OF ORE		LUMP ORE HEMATITE	PREHARDENED PELLETS HEMATITE	GREEN PELLETS MAGNETITE
SIZE	mm	6 - 15	10 - 15	10 - 15
Fe	%	68,4	65,8	68,0
S	%	0,01	0,01	0,05
SPONGE IRON				
Fe - TOT	%	96,7	91,9	95,5
Fe - MET	%	94,1	88,4	94,0
METALLIZATION	%	97,3	96,0	98,4
S	%	0,015	0,013	0,008
C	%	0,14	0,24	0,19

LURGI | TYPICAL CHEMICAL ANALYSES OF SPONGE IRON | H 1755

(6)

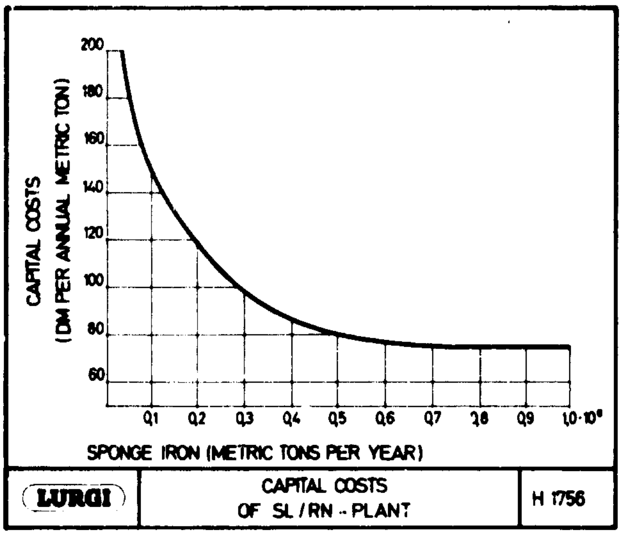
The absorption of sulphur is largely prevented by the addition of dolomite or limestone. According to the nature of sulphur present in the ore, desulphurisation is to a certain extent possible.

The low carbon content of sponge iron primarily consists of deposited carbon. The carbon content depends on the quality of reduction coal. In the case of high volatile coals which mainly form soot maximum carbon contents of about 0.5% in the sponge iron were measured.

2.6 Capital and production costs

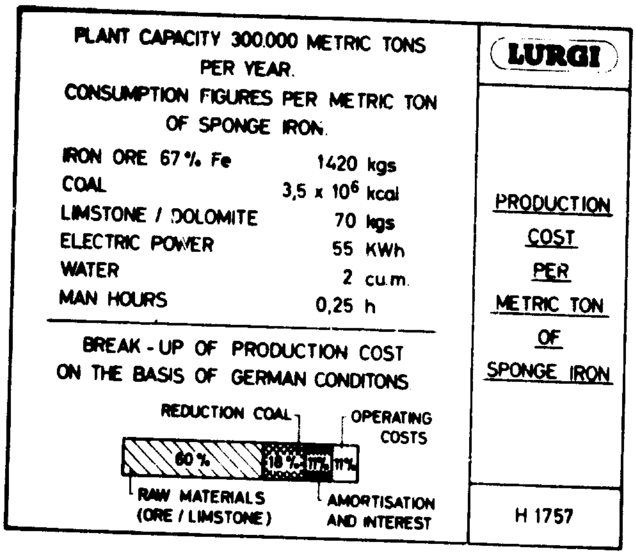
The capital costs depend not only on the plant size, but also on the plant layout necessitated by the type of raw materials to be used and by the method of processing the reduced ore, local conditions and prices for machinery, electrical equipment and civil engineering work valid in the country in question. It is therefore impossible to give particulars which have general validity.

Guide figures on the capital investment can be seen in diagram 7. The capital costs, calculated on a German basis, only cover the plant items within battery limits. Storage yards, railway tracks, roadways, land etc. are excluded. Furthermore, it has been assumed that a highly reduced sponge iron is produced in the plant and that all raw materials are available in the desired grain size.



(7)

Table 8 contains the consumption figures for a plant with an annual production of approximately 300,000 tons of sponge iron. These consumption figures are offered merely as a guide and may vary according to the ore and coal quality, plant size and plant layout. The production costs per ton sponge iron and the percentage of the various cost factors greatly depend on the local conditions and have to be separately evaluated for every particular case. The break-up of costs given in Table 8 for ore, reducing agents, operating costs, amortisation and interest is based on German conditions and on the use of Screened ~~classified~~ lump ore with 67% Fe and lignite as reducing agent. In this particular case, the production costs amount to approximately 130 to 135 DM per ton of sponge iron.



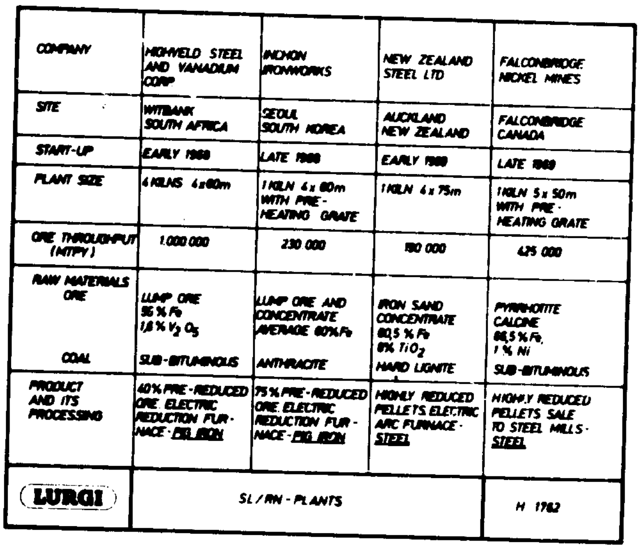
PLANT CAPACITY 300.000 METRIC TONS PER YEAR.
CONSUMPTION FIGURES PER METRIC TON OF SPONGE IRON.

IRON ORE 67 % Fe	1420 kgs
COAL	3,5 x 10^6 kcal
LIMSTONE / DOLOMITE	70 kgs
ELECTRIC POWER	55 KWh
WATER	2 cu.m.
MAN HOURS	0,25 h

BREAK-UP OF PRODUCTION COST ON THE BASIS OF GERMAN CONDITONS

(8)

As ore and coal represent the two main cost factors - in the present case they represent more than 75 % of the total costs - the plant site is of overriding importance. It may be that in the near future sponge iron will be produced primarily in countries with very favourable raw material conditions and will be transported to the steel producers (electric steel plants). However, at this juncture, no definite particulars can be given in this respect. As can be seen from Diagram 9, all SL/RN plants, with one exception, form an integral part of steel plants.



COMPANY	HIGHVELD STEEL AND VANADIUM CORP	INCHON IRONWORKS	NEW ZEALAND STEEL LTD	FALCONBRIDGE NICKEL MINES
SITE	WITBANK SOUTH AFRICA	SEOUL SOUTH KOREA	AUCKLAND NEW ZEALAND	FALCONBRIDGE CANADA
START-UP	EARLY 1969	LATE 1969	EARLY 1969	LATE 1969
PLANT SIZE	4 KILNS 4 x 60m	1 KILN 4 x 60m WITH PRE-HEATING GRATE	1 KILN 4 x 75m	1 KILN 5 x 50m WITH PRE-HEATING GRATE
ORE THROUGHPUT (MTPY)	1.000.000	230.000	150 000	425 000
RAW MATERIALS ORE	LUMP ORE 56 % Fe 1,8 % V_2O_5	LUMP ORE AND CONCENTRATE AVERAGE 60% Fe	IRON SAND CONCENTRATE 60,5 % Fe 8% TiO_2	PYRRHOTITE CALCINE 66,5 % Fe, 1 % Ni
COAL	SUB-BITUMINOUS	ANTHRACITE	HARD LIGNITE	SUB-BITUMINOUS
PRODUCT AND ITS PROCESSING	40% PRE-REDUCED ORE. ELECTRIC REDUCTION FURNACE - **PIG IRON**	75% PRE-REDUCED ORE. ELECTRIC REDUCTION FURNACE - **PIG IRON**	HIGHLY REDUCED PELLETS. ELECTRIC ARC FURNACE - **STEEL**	HIGHLY REDUCED PELLETS SALE TO STEEL MILLS - **STEEL**
LURGI	SL/RN - PLANTS			H 1762

(9)

2.7 Commercial plants

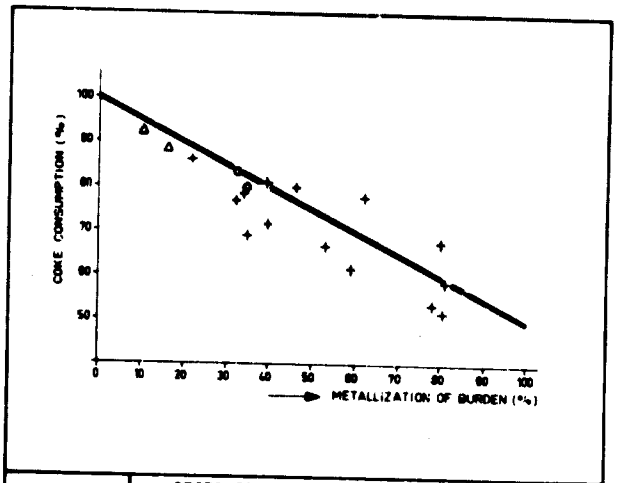
By the end of 1969 more than 1.8 million tons of iron ore will have been processed in 4 plants comprising altogether 7 kiln units. Further commercial plants are under design. The characteristics of these plants which are compiled under figure 9 illustrate the great flexibility of the process with regard to iron-containing raw materials, reduction coals and the reduction degree required for the treatment of the reduced ore. Details of the plant layout have already been specified in other papers (6, 8).

3. Processing of sponge iron

Although sponge iron has been produced and processed for some decades now, a series of detailed tests have been carried out during recent years with the aim of investigating the technology and economy of sponge iron processing. Basically, sponge iron can be employed in all known metallurgical furnaces for the production of pig iron, foundry iron, and steel.

3.1 Blast furnace

The blast furnace test results (9 -16) with pre-reduced material in the burden available so far are indicated in diagrams 10 and 11.



LURGI | DECREASE OF COKE CONSUMPTION BY CHARGING PREREDUCED BURDEN INTO THE BLAST FURNACE | H 1594 E

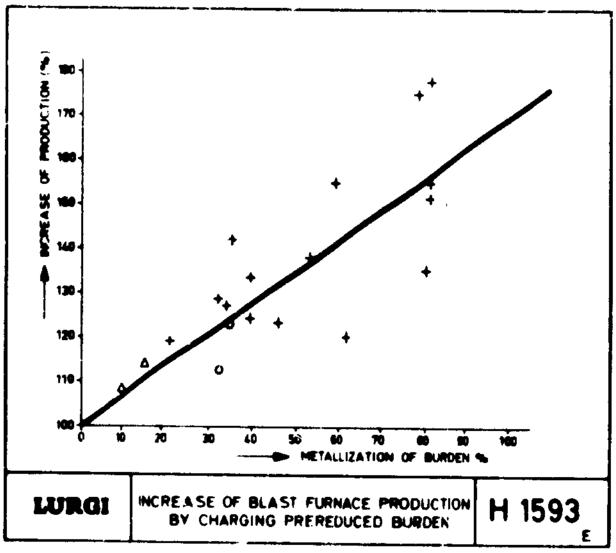
(10)

The degree of metallization (Fe_{met}/Fe_{tot}) is the abscissa on both diagrams. The degree of reduction, indicating the percentage of oxygen removed, is unsuitable as the base of reference. A pre-reduction, from hematite to wustite, for instance, would hardly affect the productivity and the coke consumption. For this reason, the question regarding the use of pre-reduced or pre-metallised material in the blast furnace is not at all irrelevant, since it is significant whether merely a certain part of the oxygen from the total burden is removed by partial reduction or by a complete metallization of a part of the burden.

Diagram 10 shows the percentage decrease of the coke consumption in relationship to the degree of metallization of the total burden.

The coke consumption with conventional oxide burden in various blast furnaces was taken as 100% and has been used in each instance as a starting point for the test series summarized here. Other parameters such as furnace size, iron yield of burden, substitute fuels, blast temperature, etc. were disregarded in the test evaluation. Despite the anticipated scattering, the values readily arranged themselves around a straight line representing a decrease in coke consumption of 0.5% per percent of burden metallized.

The evaluation of the percent production increase as a function of the degree of metallization (diagram 11) indicates an increased blast furnace productivity of about 0.7% per percent burden metallized.



LURGI | INCREASE OF BLAST FURNACE PRODUCTION BY CHARGING PREREDUCED BURDEN | H 1593 E

(11)

From results available it is now possible to reliably predict the anticipated production increase for degrees of up to 50% burden metallization. The few data available for metallization degrees of 50 - 100% require further verification by additional tests.

Under certain conditions, the use of pre-reduced material could prove to be an economical measure for the increased output of existing blast furnace plants. For very high degrees of pre-reduction it is doubtful whether the blast furnace is still the most economical aggregate or whether it would not be better to consider the use of low shaft furnaces or hot blast cupola furnaces instead.

3.2 Electric iron-making furnace

The advantages of burden pre-reduction are still more evident for low shaft furnaces - in particular electric iron-making furnaces - than for blast furnaces. The electric iron-making furnace has practically no shaft. Hence, there is very little of the shaft pre-heating and pre-reduction which takes place in a blast furnace. Each measure which performs these process steps in advance must be of direct consequence to capacity, coke and power consumption. Therefore, a complete metallization is no pre-requisite in this case.

A coke consumption of 350 kg and an energy consumption of 2000-2400 kWh per ton of pig iron ore are normal figures for a cold high-grade oxide burden. According to the calculations of Astier (17) it is feasible by the use of 87% pre-reduced burden - equivalent to 80% degree of metallization - to achieve a coke consumption of less than 100 kg and an energy consumption of 800 kWh per ton of pig iron. Furthermore, a production increase of up to twice the initial figure can be expected.

Combined pre-reduction and electric iron-making furnace plants are, for example, under construction or in operation in Skopje - Yugoslavia, in Highveld - South Africa and also in Korea.

3.3 Cupola Furnace

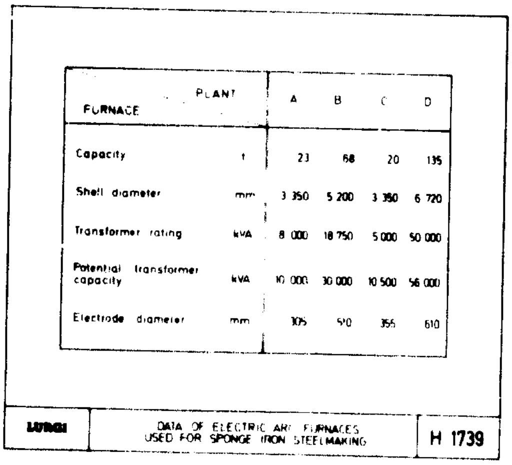
The use of highly reduced sponge iron in Cupola furnaces has been variously investigated (18). The chemical purity of the sponge resulted in the expected high quality of the products. Sponge iron in particular is extremely well suited for the melting of foundry pig iron with nodular graphite and of hot metal for the production of high grade steels in basic oxygen furnaces. Additional investigations are, however, necessary in this field, as the charge of relatively small-sized material in the form of sponge pellets or small sponge iron briquettes has led to segregations in the cupola furnace. An improvement should be quite possible with the aid of larger-sized briquettes.

3.4 Electric arc furnace

In spite of the successful results achieved and established in the use of sponge iron for the melting of pig and foundry pig iron, it remains to be seen whether the detour over pig iron to steel is at all justifiable with a low-gangue containing ore. Lump ores and pellets with iron contents of 65 to 69%, being no longer rare, can, by direct reduction, be converted into a material with more than 93% total iron content which, unlike pig iron, does not contain impurities like carbon, silicon, manganese and other elements. According to the purity of the ores used, the gangue content of such sponge iron is quite low. It can be used in place of scrap with good results for all conventional steel production processes. The results of tests made in this regard in the basic oxygen furnace and electric arc furnace are, although partly still unpublished, already available.

The use of sponge iron of various origins in electric arc furnaces is well-known. A special advantage for the melting of high grade steels is the purity of the material which, if the appropriate ores are used, contains virtually no copper, zinc, and chrome apart from low sulphur and phosphorus contents. This particular property of the sponge iron has been used deliberately for many years, especially in Sweden. The high production costs of the conventional sponge iron producing methods, for instance the Höganäs process, have, however, prevented a more extensive application. Also, a slow melting rate was often observed when sponge was used in an electric arc furnace when using standard bucket charging. This has led to longer cycle times and to an increased energy consumption. For this reason, a research group of Lurgi G.m.b.H., Germany, Steel Company of Canada, and Pickands Mather - USA, has extensively studied the suitability of SL/RN sponge iron pellets, in particular as a charge for electric arc furnaces. By the use of new methods, especially of the continuous charging of sponge iron into electric arc steel making furnaces, it has been possible to achieve productivity increases of up to 45% as compared with the standard scrap process. Here again the chemical purity and the homogeneity of the sponge, which is continuously added to a carburized molten pool until the specified steel analysis is reached, are of decisive importance. This new process has been developed in an electric steel plant in Edmonton, Canada, and is reported in the publications of J. G. Sibakin (19). Therefore, a detailed description is not required here. In the meantime, these surprising results have been confirmed by further tests carried out in other steel plants by interested firms, using electric furnaces of up to 135 metric tons capacity.

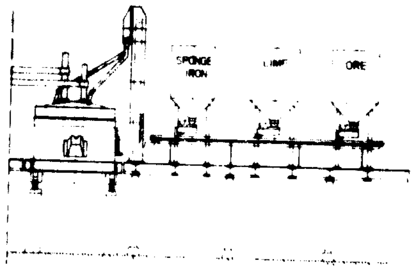
(12)



FURNACE / PLANT		A	B	C	D
Capacity	t	23	68	20	135
Shell diameter	mm	3 350	5 200	3 350	6 720
Transformer rating	kVA	8 000	18 750	5 000	50 000
Potential transformer capacity	kVA	10 000	30 000	10 500	56 000
Electrode diameter	mm	305	510	355	610

LURGI — DATA OF ELECTRIC ARC FURNACES USED FOR SPONGE IRON STEELMAKING — H 1739

Diagram 12 gives the technical data of the furnaces used so far and diagram 13 shows the arrangement of the continuous charging equipment for sponge iron to an electric arc furnace. This charging system can also be used for other additives, for instance lime or ore.



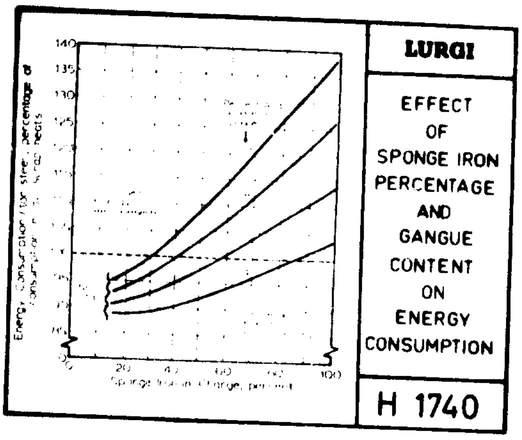
LURGI | CONTINUOUS FEEDING SYSTEM FOR AN ELECTRIC ARC STEELMAKING FURNACE | H 1735

(13)

The high increase of production rates obtained with this process as compared with the normal scrap practice is to be attributed to the reduction or elimination of the conventional refining period which proceeds concurrently with the period of continuous sponge charging. It depends upon the chemical analyses of scrap and sponge iron and on the steel specification as to what percentages of sponge iron are needed to achieve this productivity increase. In many cases, minimum percentages of sponge iron of 20% to 25% in the charge are sufficient. On the other hand, it is quite possible to operate electric steel furnaces, for instance, with a mixture of approximately 75% sponge and 25% in-plant return scrap if commercial scrap is too expensive or too difficult to procure. This offers an extensive flexibility in the sponge iron/scrap ratio, thus permitting the use of the cheapest raw materials available.

A comparison between the heat balance of the conventional scrap practice and the sponge iron practice shows that two different effects appear:

- the heat losses per ton of steel are diminished by decreasing tap-to-tap time;
- the energy consumption per ton of steel is increased due to the amount of heat required for gangue melting and slagging.

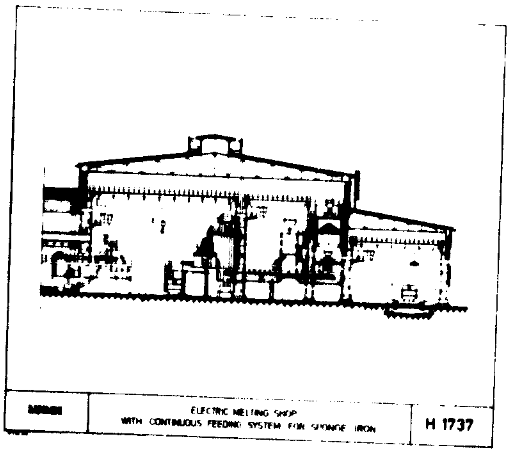


(14)

According to Sibakin (19), diagram 14 demonstrates that a decrease or increase of the energy consumption, as compared with all scrap heats, can be anticipated depending upon the percentage of sponge iron used and gangue content of the material.

Integrated reduction and steel making plant

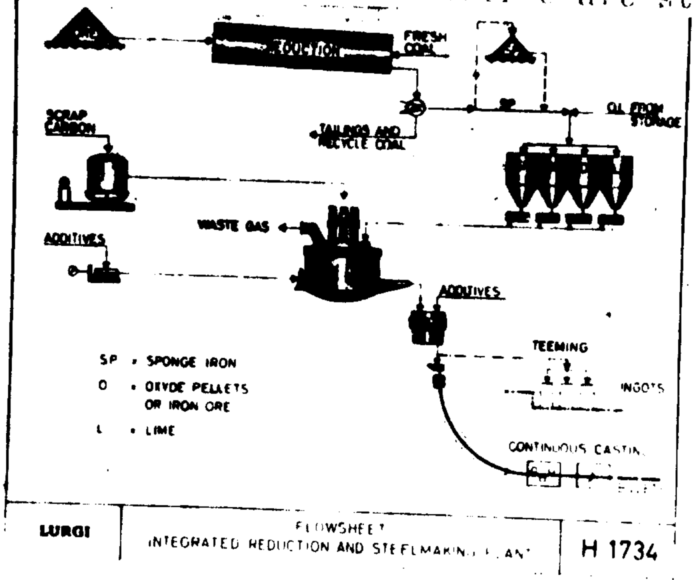
The additional equipment required for the continuous charging of sponge iron into the electric furnaces according to the new process can be incorporated in existing steel works without any particular difficulties. In the layout of new plants projected for sponge iron processing, the characteristics of the new material and the requirements of the new process should be taken into consideration right from the start.



(15)

Diagram 15 shows a sectional view of a steel shop of this type. The transportation of the material from the unloading point or stockpile and within the furnace building up to the electric furnace charging is carried out by belt conveyors or other continuously working devices. Weighing and control machines should be provided for the exact material proportioning which is an important factor in the process. From the storage bins for sponge iron, ore and fluxes, the materials are discharged in the required quantities and continuously fed into the electric furnace.

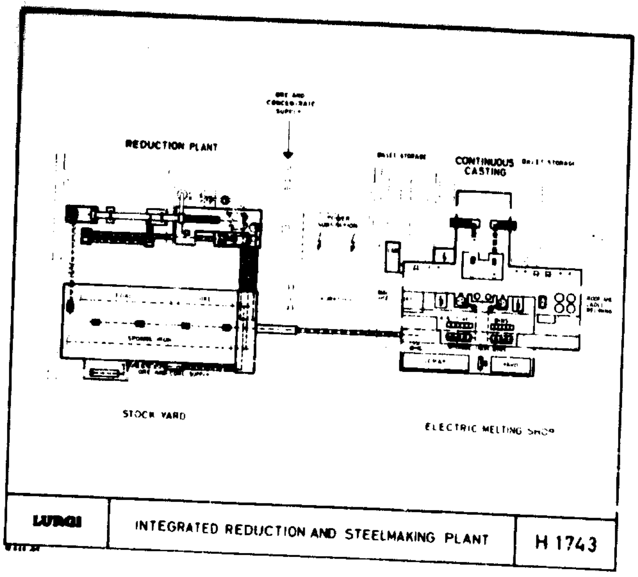
Diagram 16 shows the schematic flow sheet of an integrated SL/RN reduction plant and an electric arc steel-making unit.



(16)

The sponge iron produced in the reduction plant is conveyed directly to the stock bins of the steel shop. A covered sponge storage area is provided as a by-pass to adjust and synchronize the production of both plants.

To avoid reoxidation, the sponge iron should always be protected from direct influence of rain and moisture by providing covered storage areas or bins.



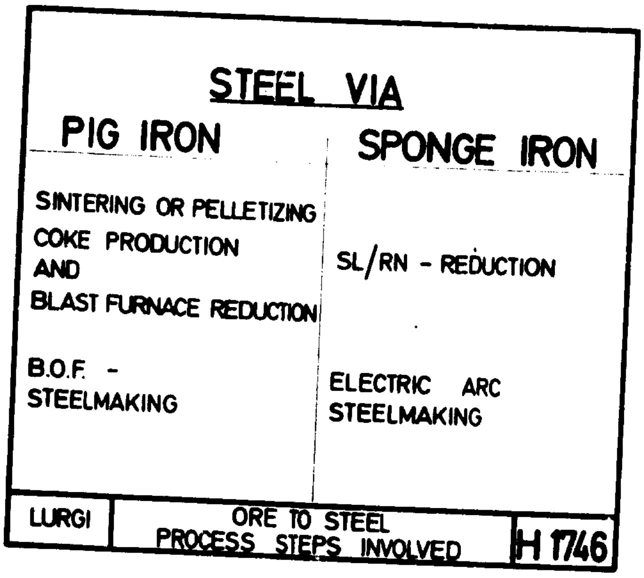
LURGI | INTEGRATED REDUCTION AND STEELMAKING PLANT | H 1743

(17)

Diagram 17 shows the plan of a combined SL/RN steel works equipped with one reduction kiln and two electric furnaces.

With a reduction plant of an appropriately large capacity and, for instance, electric furnaces each with a capacity of 200 tons, a plant of this type can produce up to 1.2 million tons of raw steel per year.

The layout of such an integrated SL/RN steel plant is relatively simple in comparison with a conventional steel works. The necessary process steps of both methods from the raw material to the raw steel are briefly compared in the diagram 18.



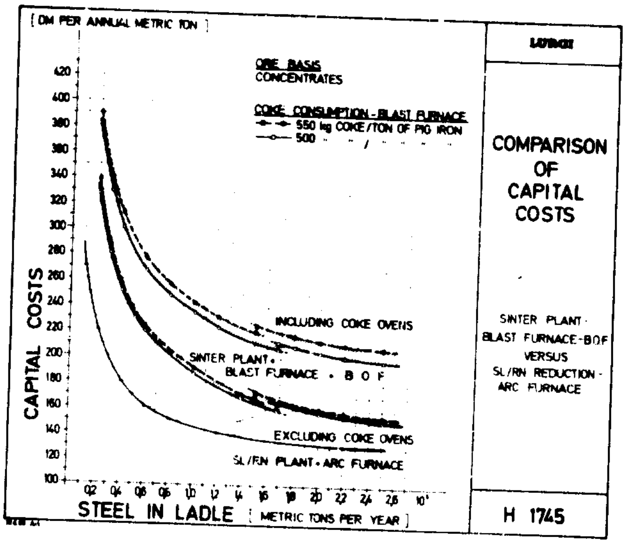
STEEL VIA

PIG IRON	SPONGE IRON
SINTERING OR PELLETIZING COKE PRODUCTION AND BLAST FURNACE REDUCTION	SL/RN - REDUCTION
B.O.F. - STEELMAKING	ELECTRIC ARC STEELMAKING

LURGI | ORE TO STEEL PROCESS STEPS INVOLVED | H 1746

(18)

Diagram 19 shows a comparison of specific investment costs between the usual steel-making method via blast furnaces and basic oxygen furnaces and the new method of direct reduction combined with electric arc steel-making. The costs are related to the annual production of the respective plants and are based on conditions prevailing in Germany.

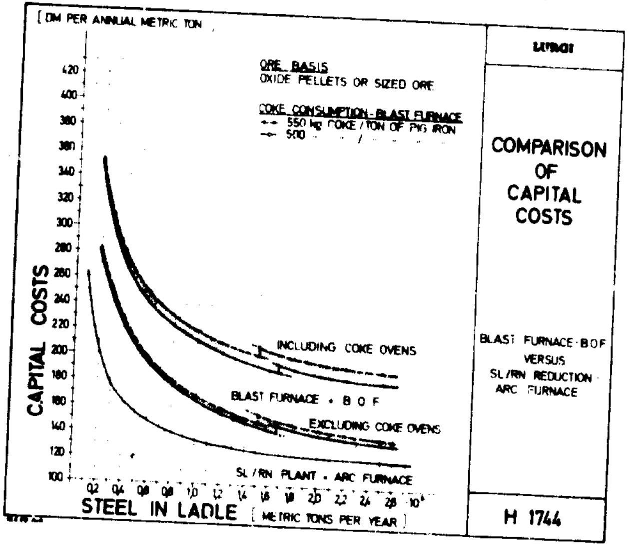


(19)

For example, at an annual production of 0.5 million tons of steel, the required investment costs of an SL/RN steel plant amount to only 60% of those for a plant based on blast furnaces. Even if it is assumed that the iron-making plant with blast furnaces does not produce its own metallurgical coke or, in other words, that part of capital foreseen for the coking plant is not required, the investment costs for a steel plant based on the SL/RN-direct reduction process would still be 25% lower than for one using pig iron. In this evaluation, only those plant sections within battery limits are compared which are basically different in both processes. Certain requirements necessary for both cases, such as land, roads, railway tracks, storage areas, and subsequent processing plants are not included in these considerations. It is assumed that ore fines or concentrates with an iron content of more than 65% are available and that 30% scrap will be used in the steelmaking furnace for both processes.

The shaded area of the blast furnace reduction curves represents a certain variation of the specific pig iron output for a blast furnace with a given hearth diameter. The specific coke consumption per ton of pig iron has been used as an indicator for productivity. The upper curve represents a coke consumption of 550 kg per ton of pig iron, the lower curve a coke consumption of 500 kg.

For an annual production of approximately 1.6 million tons of raw steel, the investment cost curves for blast furnaces show a step because it has been assumed in the calculations that one unit is capable of producing a maximum of approximately 1.2 million tons of pig iron per annum.



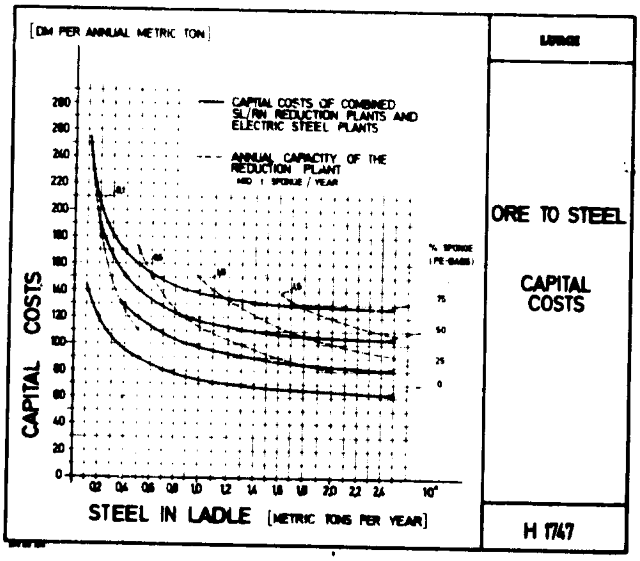
(20)

Diagram 20 shows similar curves which are based on sized ore burden for both processes. The costs for the agglomeration plant have been excluded in the case of blast furnace reduction and the investment costs for the SL/RN plant are also lower as no concentrate grinding and green balling equipment is needed.

The above diagrams indicate clearly that the direct steel production requires considerably less capital investment for all practicable production capacities - an advantage which, through amortisation, also directly influences the production costs.

The scrap consumption of 30% - based on the Fe-content - as used in the cost calculations already presents the upper limit for BOF-steelmaking and is only appropriate for vessels with a large holding capacity. The investment costs will rise if the pig iron percentage is increased in the case of small-sized vessels.

The direct steel production, however, allows the choice of any desired sponge iron/scrap ratio, the practical range being between 25 and 75% sponge iron in the steel-making charge. The lower limit of the sponge iron percentage is set by the minimum necessary to increase the productivity, while the lower limit of the scrap charge is determined by the given percentage of in-plant return scrap.

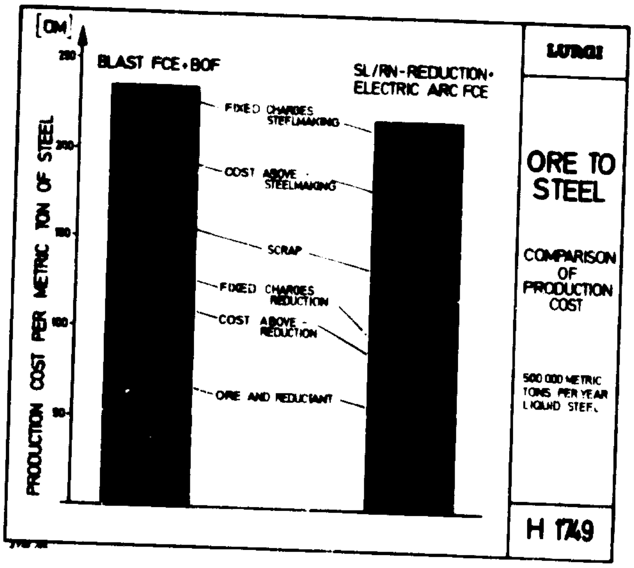


(21)

Diagram 21 shows how the specific capital investments for integrated SL/RN electric steel plants tend to decline when the percentage of scrap in the charge is increased. Higher scrap percentages should be considered in all instances where a reliable source of reasonably priced scrap of satisfactory quality is available.

A comparison of the production costs per ton of steel of both processes can have no general validity as the costs for raw materials, energy, and wages vary according to the local conditions.

Diagram 22 shows the result of cost calculation for an example worked out under German conditions.

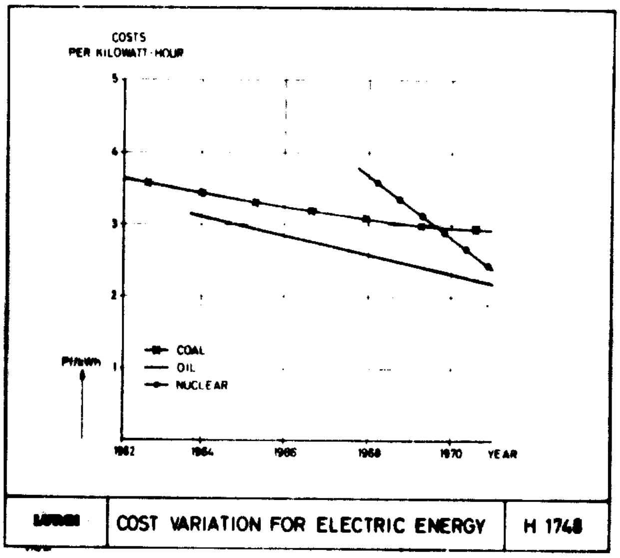


(22)

The production costs for directly produced steel are about 8% (18.75 DM/t.) lower than the comparable costs for steel produced from pig iron in basic oxygen furnaces. Both figures are based on the use of lump ore with 65% iron (0.85 DM/Fe-unit) and on 30% scrap (Fe-basis) in the steelmaking charge at a price of DM 130.- per ton of scrap. The calculations are for an annual capacity of 500,000 tons of liquid steel with an amortisation and interest rate of 15% for all plant sections.

A comparison of the costs reveals that the difference in the reduction costs is mainly influenced by the additional costs for metallurgical coke when compared with the cost of coal for direct reduction. This difference in costs will be evident in all cases, regardless of certain variations due to local conditions.

The conversion costs in the electric steel works are essentially influenced by energy consumption and energy price. The present example is based on 520 kWh per ton of steel at an energy price of DM 0.035 per kWh. This accounts for more than 30% of the total conversion costs. In future, a reduction of the unit energy costs may be anticipated, especially in view of the decreasing production costs of nuclear energy.



COST VARIATION FOR ELECTRIC ENERGY H 1748

(23)

Diagram 23 indicates the declining tendency of the production costs for power from various energy sources in Europe (20); the steep drop in the instance of nuclear energy may be attributed almost exclusively to the decrease of the capital costs for nuclear power plants achieved by the technical progress during recent years.

Apart from the obvious cost advantages offered by the direct production of steel from sponge iron, it is often possible to make use of raw materials which would be unsuitable for the blast furnace process. In many regions there is, for instance, a shortage of coking coal although non-coking coals suitable for the SL/RN process are readily available at favourable prices.

In special cases, it is often possible in the SL/RN process to utilise ores unsuited for use in the blast furnace. These are mainly iron ores, containing titanium dioxide, which produces a highly viscous slag in the blast furnace. A typical example of the processing of such material is the steel plant of New Zealand Steel presently under construction, where beach sands containing titanium dioxide will be up-graded, pelletized, and converted to sponge with 76 - 77% total Fe-content in an SL/RN plant. A lignite with a fixed-carbon content of approximately 50% is employed as reducing agent. The sponge iron will contain 10 - 12% TiO_2 and up to 20% total gangue. During the subsequent processing in the electric steel plant the slag resulting from the gangue will be removed without difficulties.

The plant will start production in early 1969 and is designed for an annual capacity of 140,000 tons of raw steel in the initial stage.

Summary

The SL/RN reduction process combined with the direct conversion of sponge iron to steel in electric arc furnaces opens up new possibilities with the following advantages to steelmakers :

- exploitation of domestic raw materials not usable for conventional iron and steelmaking processes
- use of scrap in any desired proportions
- possibility of using lower grades of scrap in combination with sponge iron free of tramp elements
- reduction of capital investment by as much as 40%
- reduction of production costs by 5 to 10%
- competitive production costs even for small-sized production units.

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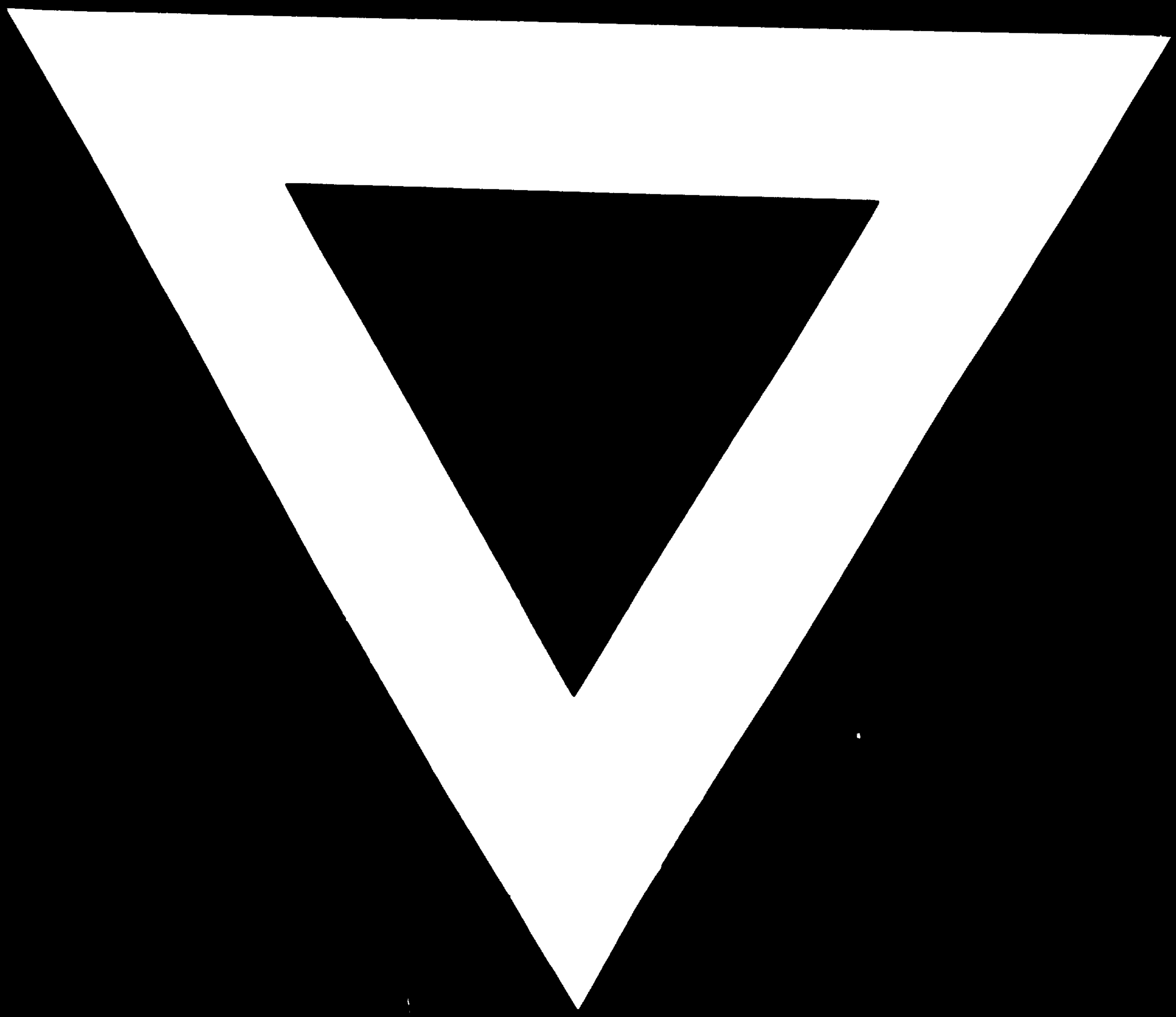

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