PRESENT STATE OF THE SL/RN PROCESS AND ITS APPLICATION TO INDIAN RAW MATERIALS

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Abstract

The paper describes the present state of development of the SL/RN Process, discussing the reasons for using solid fuels as reductants and the application of a rotary kiln as reactor. Especially critical thought is given to the problem of economy of the direct reduction processes with regard to the prices of ore, coal and energy. In connection with the description of the SL/RN or Lurgi rotary kiln plants built so far, the special features and operating conditions of each plant are explained. Some of the most important initial difficulties **experienced** *with the plants erected up to now are discussed in detail and the measures taken to overcome these are stated. Reference is made to comprehensive studies and tests carried out with Indian ores and coals in the Frankfurt laboratories and also to the applicability of the SL/RN Process to the Indian Steel Industry.* **Some** *future aspests are mentioned which, in spite of the difficulties encountered so far, demonstrate that there are well-founded hopes for a favourable future development of the direct reduction process using solid fuels.*

I have the honour and pleasure to inform you today about the present state of development of the SL/RN Process and I wish to commence my talk quoting a sentence from the welcome address of your honourable Minister of Steel and Mines:

"So far as India is concerned, we would certainly benefit greatly from a break-through that can establish the utility of solid reductant for direct reduction."

This statement presents a challenge to the industry of your country and to those process and engineering firms such as Lurgi which are concerned with the problems of direct reduction. However, as an organization dealing with iron ore preparation on a world-wide basis, Lurgi is in any case confronted with a great number of problems which result from the varying composition of raw materials such as iron ores or fuels. Consequently, the SL/RN Process has to be as far as possible suitable for wide application for different raw materials and products.

I wish to break down my paper into the following sections:

1. Why solid fuels?
2. Why rotary kilns?
3. The question of economy.

4. Description of a few SL/RN and Lurgi. rotary kiln plants.
5. Discussion on some problems.
6. The future of the SL/RN Process and its application to Indian raw materials.

1. Why solid fuels ?

The question why coal and not gas; estimate reserves of coal and natural gas for the year 1970 as given in Fig. 1 should be considered. As can be seen, the amount of coal available is 30 times higher than that of natural gas. In other words, the energy resources are constituted only about 3% from gas, 4% from liquid fuels but 93% from coal. The estimates for consumptions and consequently diminishing reserves up to the year 2000 show opposite tendency. Up to that date, about 73% of the presently exploited gas, but only 2% of the coal resources will be consumed.

To demonstrate Fig. 2 it shows the forecasts on consumption and development of reserves or resources typical for a highly industrial country, such as the USA, up to the year 1990.

It can be seen that already in 1973 the consumption of gas can no longer be met by this country's own gas resources. After that date the deficit will be rising steadily in spite of all efforts to procure gas energy from other sources represented by curves 2 to 5. The question should thus be justified whether natural gas, speaking generally, is not a too valuable source of energy to be used for removal of oxygen from iron ores.

India, a typical land of coal, lacking however in sufficient supplies of good metallurgical coke, is ideally predestined for producing sponge iron utilizing solid reductants. Similar are the conditions in many other countries, such as South Africa and Brazil.

Fig. 3 shows the extent of the widely spread distribution of high-grade iron ores and of interesting coal deposits in India. It is therefore no wonder that Lurgi has already for a long time been associated with the problems of producing sponge iron from Indian ores and coals.

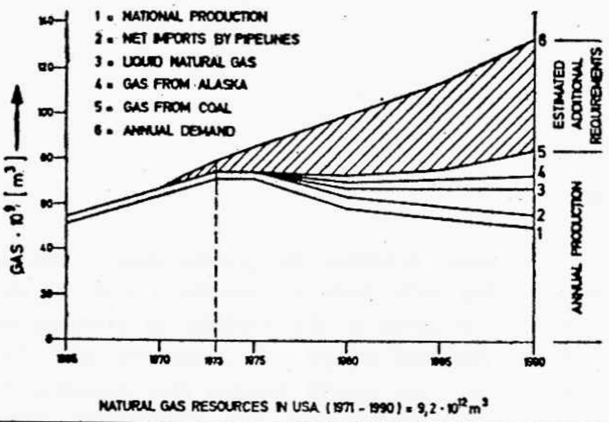
Although at present the gas reduction processes seem to have reached a more advanced stage of development, there are well-founded hopes that the still existing problems of solid reductant processes will soon be solved, and in the long run these processes will play an important role in view of the availability of large deposits of coal as an energy source.

2. Why rotary kilns ?

For direct reduction high-grade ores or rich concentrates in a size range up to 30 mm are of interest and suitable.

TYPE OF FUELS AND RESERVES	RESERVES 1970 10^9 t OF COAL EQUIVALENT	%	PERCENTAGE CONSUMPTION UP TO THE YEAR 2000 %
NATURAL GAS: PROVED AND PROBABLE RESERVES	233	3	73
COAL: PROVED, PROBABLE AND POSSIBLE RESERVES	7800	93	2

Fig. 1



GAS RESOURCES AND CONSUMPTION IN USA

Fig. 2

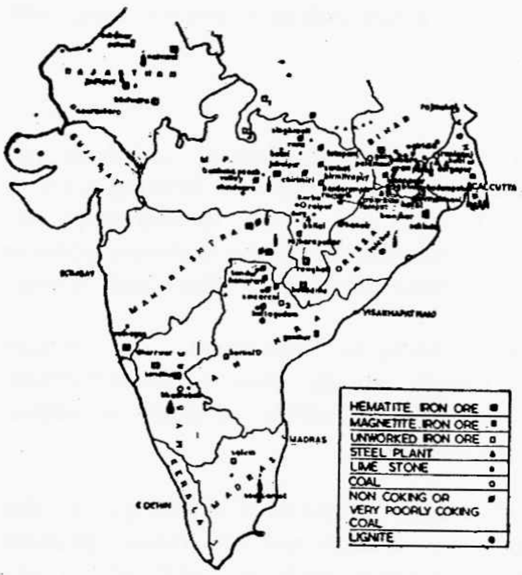


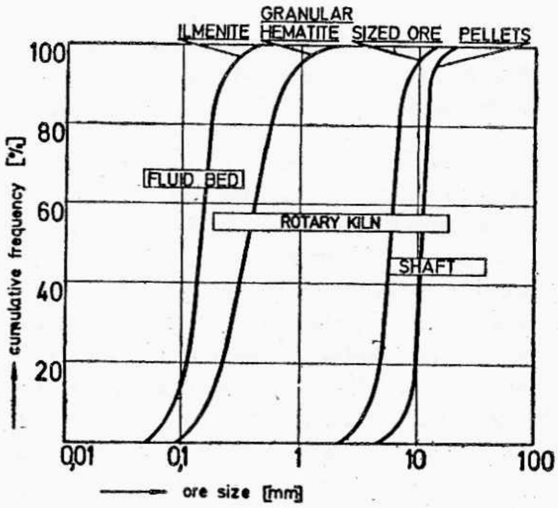
Fig. 3

Fig. 4 gives a survey of the applicability of the best known reduction processes with regard to physical characteristics of available iron ores. The coarse but controlled size range of 9-25 mm comprises most pellet types (9-18 mm) as well as sized ores. These are the typical feed materials for the shaft furnace processes. Fines in the size range of about -5mm, are used by processes based on fluid bed. Inbetween lies the wide range of materials suitable for the rotary kiln process. Thus, these processes find application in a range which is by far wider (e.g. spiral concentrates and lump ore with a size range up to 25 mm) than that of fluid bed and shaft furnace processes. This flexibility of the rotary kiln as compared with other reactors was one of the main reasons for our decision in favour of this device. I would like to mention that since 1930 Lurgi has been using this type of rotary kiln for the magnetizing roasting of haemetite iron ores, for the reduction of nickel ores, for the volatilization of non-ferrous metals, such as zinc (Waelz process), and for pyrite roasting. From that time on these kilns have also been equipped with several types of air pipes and shell burners.

3. The question of economy

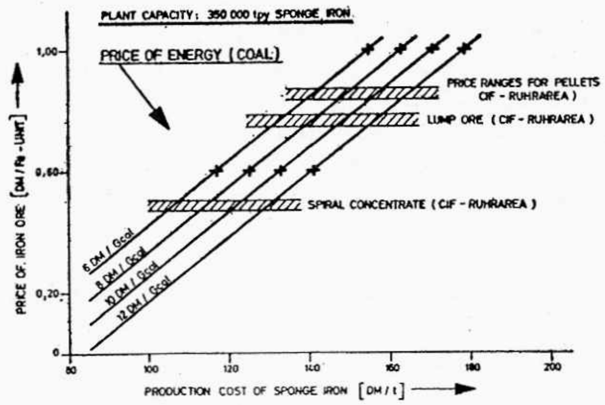
The question whether sponge iron is at all interesting economically requires consideration of a number of factors; besides the type of reductant and iron bearing material, the geography and further processing of the sponge iron have to be taken into account. In any case the sponge iron produced must compete in price with conventional metallurgical materials for steelmaking, namely pig iron and scrap. This applies in particular to highly industrialized countries. Neverthless, in developing countries also this confrontation cannot be set aside in the long run. It is important therefore to produce sponge iron at as low cost as possible. Experience has shown so far that about 60% of the production costs are attributable to the bearing material, and about 25% to the energy consumed. Capital and repair costs as well as labour constitute the remaining 15%. For this reason it is important to use an iron bearing material which is as cheap as possible. Fig. 5 shows the importance of this cost factor and of the coal price.

All figures refer to German conditions (i.e. prices in DM; 1 DM = Rs. 2.50). The ore prices have been entered on the ordinate. The different graphs correspond to the varying prices of heat energy (Gcal = 10 kcl). The hatched areas re-



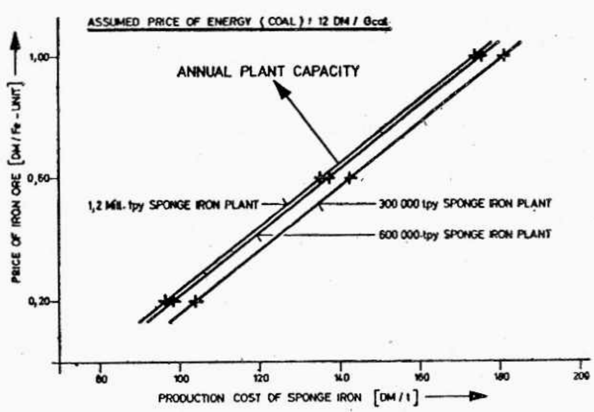
Ore sizes treatable in various reduction processes

Fig. 4



INFLUENCE OF ORE AND COAL PRICES
ON PRODUCTION COSTS OF SPONGE IRON

Fig. 5



INFLUENCE OF PLANT CAPACITY
AND ORE PRICE ON PRODUCTION
COSTS OF SPONGE IRON

Fig. 6

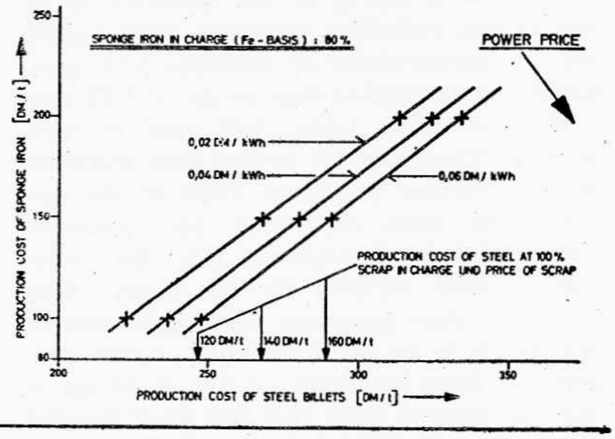
present the various size fractions of interest such as spiral concentrates, lump ores and pellets. The diagram shows the influence of the price of feed materials on the production costs (abscissa).

Besides the prices of the iron bearing material and coal, the size of the planned reduction plant is also of importance. In Fig. 6 several plant capacities in terms of production per year have been considered in connection with the price of the iron bearing materials. The annual productions chosen are 300,000, 600,000 and 1,200,000 tons of sponge iron. The great influence of the prices of iron bearing materials and the minor influence of the capital costs on production costs of sponge iron, as mentioned before, is clearly shown in this figure.

After the main factors constituting the sponge iron price have been represented in Figures 5 and 6, the influence of the sponge iron price together with the electric power costs on the production costs of steel billets is to be shown in Fig. 7. As an indication of the competitive price of scrap a few figures have been incorporated in this graph. In detail the figures are self-explanatory; under certain conditions sponge iron can actually compete with scrap for steelmaking.

4. Description of a few SL/RN and Lurgi Rotary Kiln Plants

The reduction plants based on natural gas built so far have in most cases been set up within



INFLUENCE OF SPONGE IRON AND POWER PRICES ON PRODUCTION COSTS OF STEEL BILLETS

Fig. 7

one group of firms (such as Midland Ross or Hojalatay Lamina) which within the group plans, constructs, operates and owns the plant itself. This structure of organization makes it possible to promptly eliminate any difficulties which may be faced and to pursue a uniform sales policy. Furthermore, the gas reduction plants are based on a uniform iron bearing material, namely indurated and screened pellets as well as reformed natural gas as reductant. Another advantage which should not be underestimated is that many of these plants were built in highly industrialized countries with long years of industrial tradition.

Company	Highveld Steel and Vanadium Corp. South Africa+	Inchon Ironworks South Korea	New Zealand Steel Ltd. New Zealand	Falconbridge Nickel Mines, Ontario, Canada	Western Titanium Corporation Australia	Acos Finos Piratini Brazil
Plant size	5 kilns 4 x 60 m	1 kiln 4 x 60 m with pre-hardening grate 14 sq.m.	1 kiln 4 x 75 m	1 kiln 5 x 50 m with pre-hardening grate 49 sq.m.	1 kiln 2.4 m x 30 m	1 kiln 3.6 x 50 m
Ore throughput	1,250,000 MTPY	230,000 MTPY	190,000 MTPY	425,000 MTPY	50 MTPY	95,000 MTPY
Raw materials	Lump ore	Lump ore and pellets	Iron sand concentrate Green pellets	Pyrrhotite calcine pellets	Ilmenite concentrate not pelletized	Lump ore
Ore	55 % Fe 1.6 % V_2O_5	Average 60 % Fe	60.0 % Fe 8 % TiO_2	66.5 % Fe 1 % Ni		67, % Fe
Coal	high-volatile coal	anthracite	hard brown coal	high-volatile coal	bituminous coal	high-volatile coal
Product and further processing	40 % pre-reduced ore electric furnace PIG IRON	75 % pre-reduced ore electric furnace PIG IRON	High-metallized pellets electric arc furnace STEEL	high-metallized pellets. sale to steel plants STEEL	high-metallized concentrate leaching ARTIFICIAL RUTILE	high-metallized ore electric arc furnace STEEL

Fig. 8 SL/RN plants and rotary kilns for pre-reduction to feed electric reduction furnaces (Plants built or under construction)

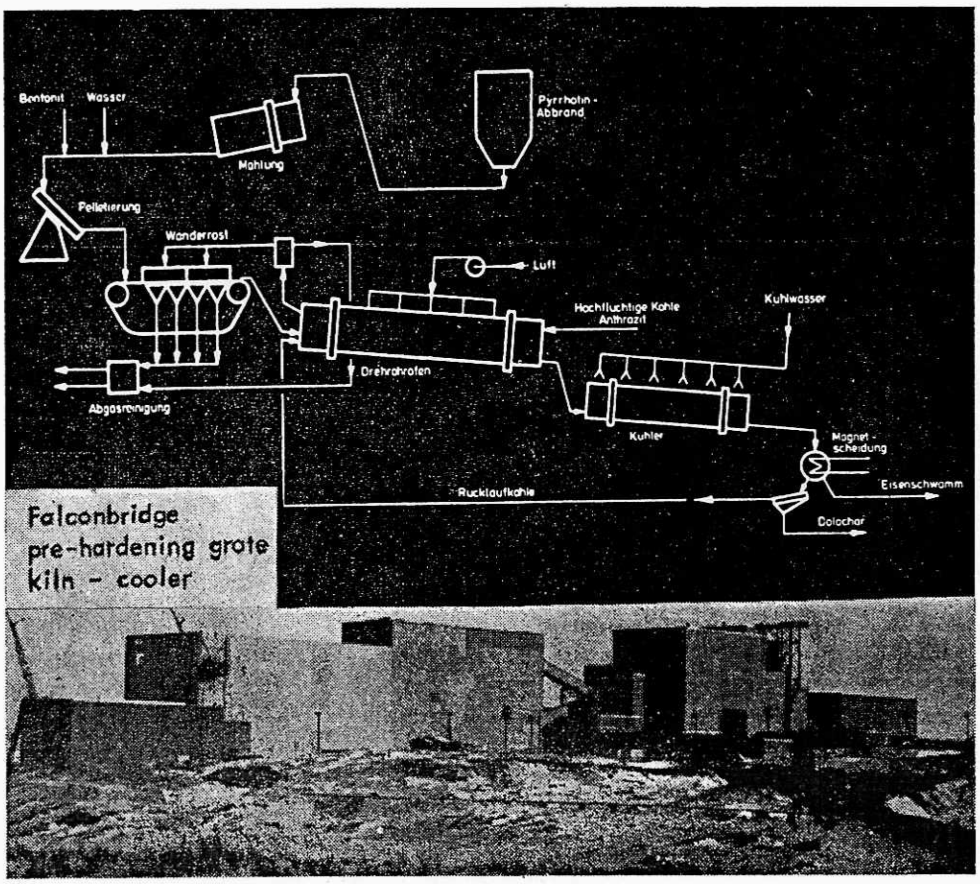

Bentonit
Wasser
Mahlung
Pyrrhotin-Abbrand
Pelletierung
Wanderrost
Luft
Hochfluchtige Kohle Anthrazit
Kuhlwasser
Drehrohrofen
Abgasreinigung
Kuhler
Magnet-scheidung
Eisenschwamm
Rucklaufkohle
Dolochar
Falconbridge
pre-hardening grate
kiln - cooler

Fig. 9

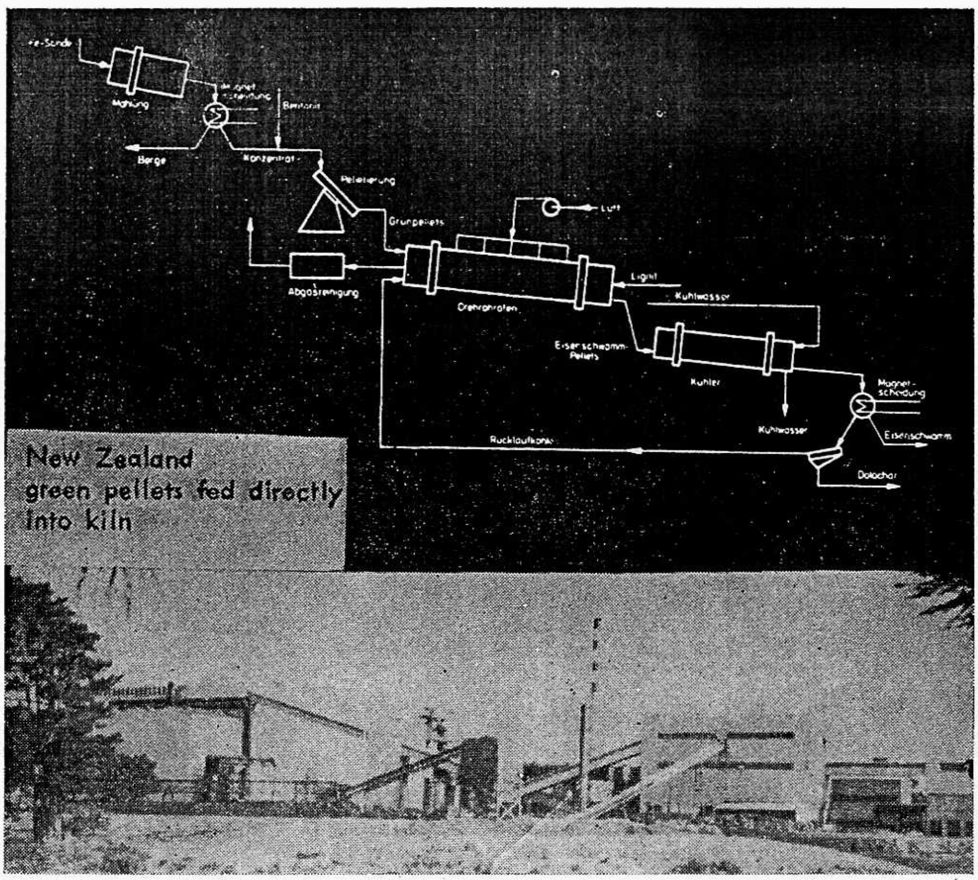

Mahlung
Bentonit
Berge
Pelletierung
Grunpellets
Luft
Abgasreinigung
Lignit
Kuhlwasser
Drehrohrofen
Eisenschwamm-Pellets
Kuhler
Kuhlwasser
Magnet-scheidung
Eisenschwamm
Rucklaufkohle
Dolochar
New Zealand
green pellets fed directly
into kiln

Fig. 10

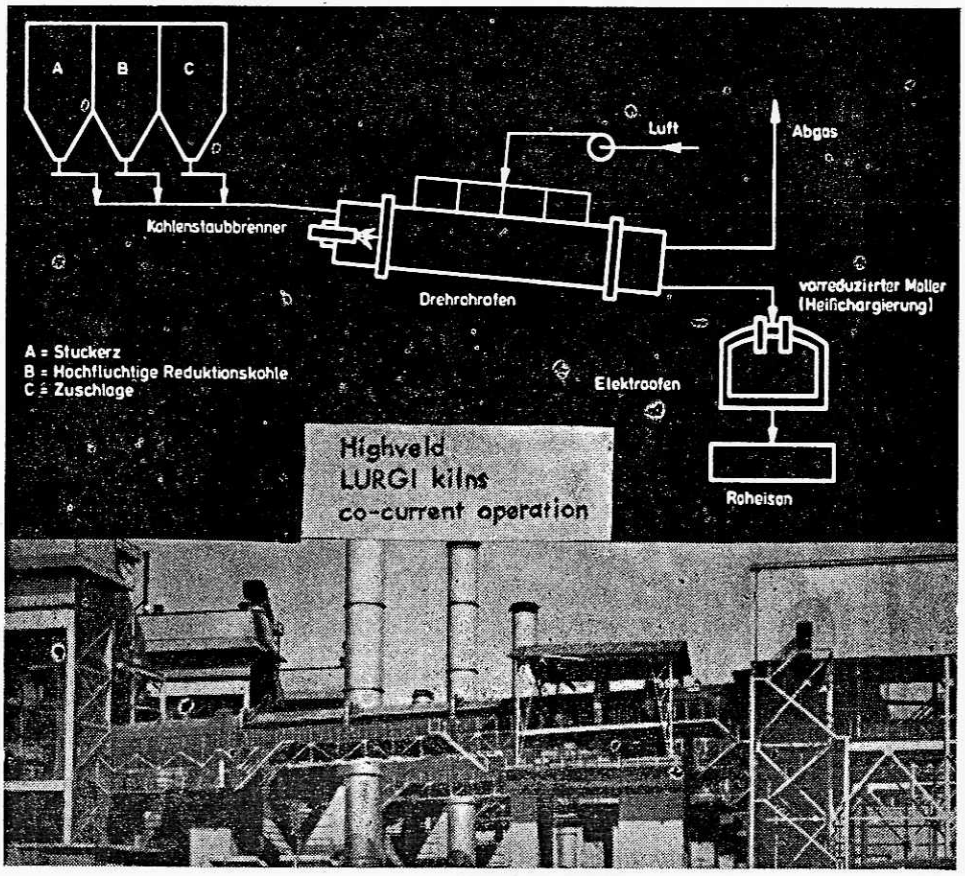


Fig. 11

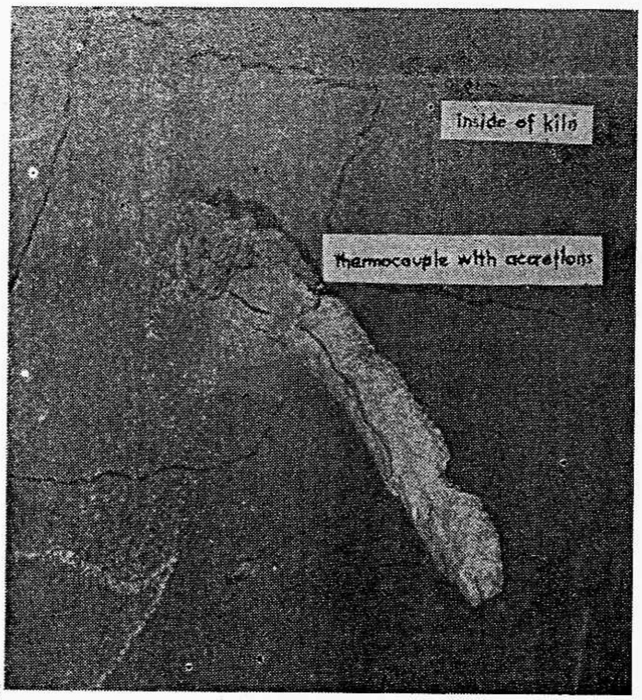


Fig. 12

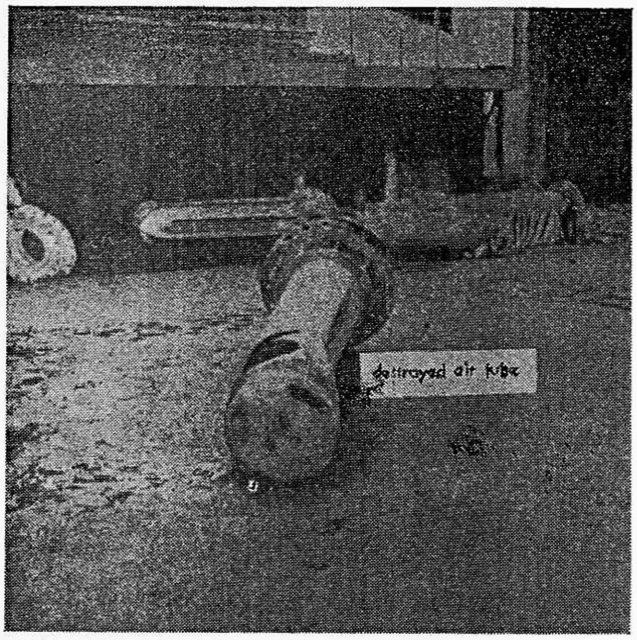


Fig. 13

The development of the SL/RN process took place in a completely different way. The first plants of this type were mostly set up in developing countries processing in each case raw materials of extremely varying characteristics. Thus, the possibility of applying the experience gained in one plant to the next one was very limited.

The rotary kiln or the SL/RN plants built by Lurgi are listed in the table shown in Fig. 8. Up to now 5 rotary kilns, having a throughput capacity of 1.25 million tons of ore per year, have been set up for Highveld Steel and Vanadium Corporation, South Africa. The process is to some extent based on an old technology of Elektrochemisk, Oslo; however, in this special case, it has been developed by Highveld Steel and Vanadium Corporation in its own research centre. Special features are: vanadiferous ore, coal with high volatiles content, degree of reduction 40-50% mode of kiln operation: gas—solids in parallel flow.

Lurgi plant for Inchon Iron Works, Korea: Throughput 230,000 tpy, lump ore and pellets with an average iron content of 60%; anthracite reductant, oil as fuel. The product with a degree of reduction of 75% was smelted in an electric furnace to pig iron. Due to economic reasons, this plant was not restarted after an accident. (This is a typical example how vitally important the question of economy for the success of a process is). The third plant, built for New Zealand Steel Limited, New Zealand, comprises a rotary kiln, having a throughput capacity of 190,000 tpy on the basis of beach-sand concentrates which were charged as green pellets together with lignite. The process is now being modified. Green pellets are no more used but instead the magnetic concentrate is reduced directly in the rotary kiln without any pre-treatment (size range 0.05—2 mm). Direct further utilization of the reduced sand to make steel in an electric arc furnace is an outstanding feature in spite of the high TiO_2 content. The plant has not yet reached its full capacity. prospects for reaching this aim are promising.

For Falconbridge Nickel Mines Ltd., Canada, a plant with a pre-hardening grate was erected, designed for a throughput capacity of 425,000 tons of ore per year. The raw material used is pyrrhotite calcine with a nickel content of about 1%. Coal with a high percentage of volatiles was used as reductant. This plant is also no more being operated since at the moment the economic conditions for marketing the nickel-containing pellets are unfavourable.

For Western Titanium in West Australia a kiln was supplied in which unpelletized ilmenite concentrate was reduced with bituminous coal, the aim being a high degree of metallization (throughput about 50,000 tpy).

Another plant for Acos Finos Piratini, Brazil will be commissioned shortly. In this plant 95,000 tons of high-grade lump ore (67% Fe) will be metallized to a high degree using a coal of high ash content and the product will be melted to steel in an electric furnace.

The Figures 9, 10 and 11 show flow sheets and views of the plants of Falconbridge, New Zealand Steel and Highveld.

5. Discussion on some Problems

A decisive factor for the success of the rotary kiln operation is the temperature control in the bed as well as in the gas phase. Both on laboratory as well as pilot plant scales it was possible to control the temperatures by means of installed thermocouples. However, when scaling up to industrial operation, unforeseen problems were encountered which led to considerable difficulties.

Fig. 12 shows the inside of a rotary kiln and a thermocouple which become unserviceable by accretions making an exact control of temperature no longer possible. This resulted in uncontrollable overheating which led to destruction of the air tubes (Fig. 13).

As a further consequence of the uncontrolled operating conditions in the rotary kiln, substantial accretions were forming as can be seen in Fig. 14.

Only after getting the temperature measurements under control was it possible to increase the service life of the air tubes (up to 12 months) and to practically avoid the formation of accretions.

Fig. 15, for example, shows two air tubes in good conditions as well as part of a coating in the kiln wall which is very important and desirable for the protection of the bricklining. This coating is about 15 to 20 cm thick in a kiln 5 m in diameter. In no rotary kiln, not even in cement kilns, is it possible to completely avoid the formation of accretions. On the contrary, a certain amount of accretions is desirable for protecting the brickwork.

In due course it has been found that the following points are important for kiln operation:

1. Exact metering of the raw materials to be fed (ores, coal).

2. Controlled coal feeding at the kiln discharge and together with ore in an optimum ratio.

3. Control of air volumes, total waste gas volume and temperature.

4. Charging of dust-free ore.

After several years of struggle with immense difficulties in various plants, Lurgi has been successful in solving most of the problems faced. There are justified hopes that the plants which are now in operation will soon be producing sponge iron more economically. New plants can now be planned, designed for reliable operation, using the valuable experience gained.

As mentioned in the beginning, India is not only endowed with good ores but also suitable coals are available. It was, therefore, quite natural that Lurgi started investigating Indian raw materials at a very early date and continues to do so. Fig. 16 gives a list of Indian iron ores and coals tested so far.

6. The future of the SL/RN Process and its application to Indian raw materials

Last but not least the question has to be answered: How does Lurgi today plan the SL/RN plants?

A simplified illustration of this procedure is given in Fig. 17. At first standard bench-scale tests are performed with the raw materials in

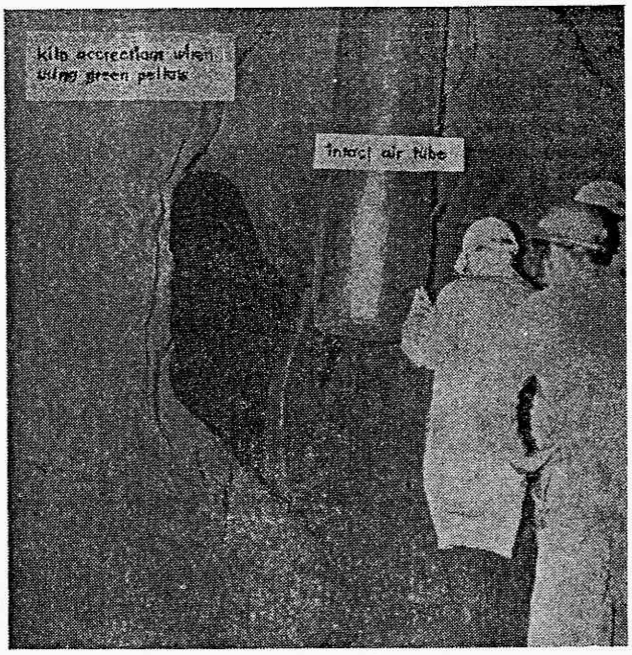


Fig. 14

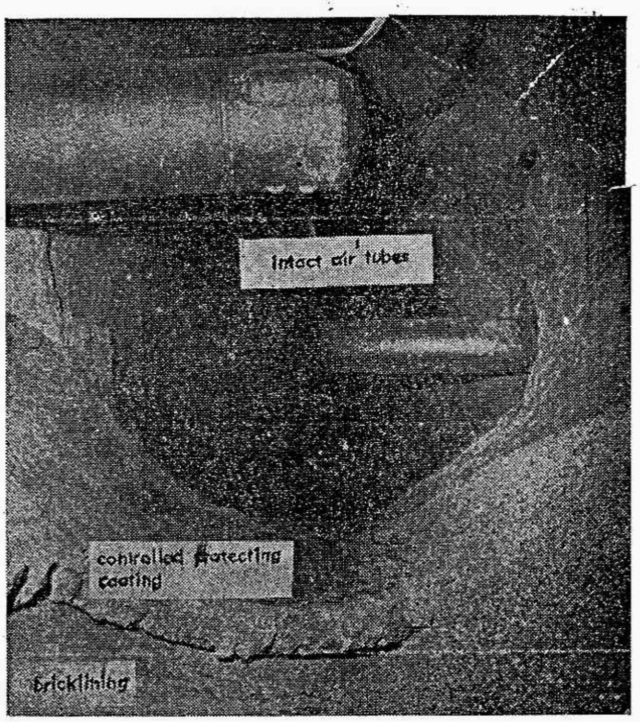


Fig. 15

IRON ORES	Fe tot %	COALS	Fixed Carbon %
Hospet	67,1	Singareni Andhra	43,0
Vengann Shetty	68,6	Porascile Ranigun	54,3
R. B. S. S. D.	67,0	Ghusik Muslia	44,9
Gangadarappa	69,5	Toposi	56,2
Vishnu Numbkar	69,7	Jambad	52,2
Allam Sumangaiamma	69,4	Kalibahad	61,6
P. B. S-Shetty	69,0	Lower Kanda	47,1
Gogga Brothers	69,7	Bala pur	54,7
M. Venkoba Rao	68,0	Hindustan	54,3
Karadikolla	67,0	Barmondia	53,5
Donimalai	6 ,6		

Fig. 16 Indian iron Ores and Coals tested in Lurgi's Direct Reduction Fascilities

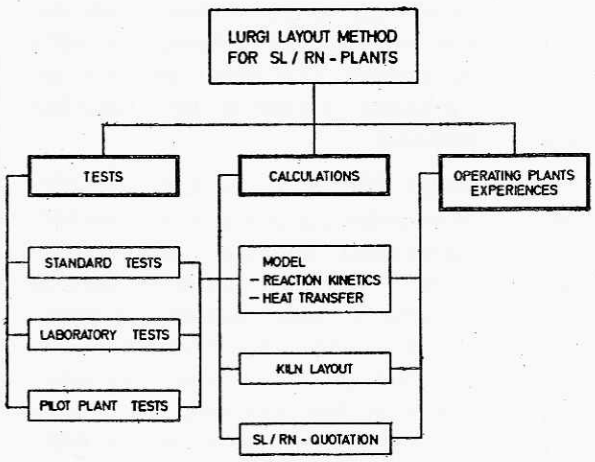


Fig. 17

question to study their suitability in general. After positive results of such tests, important parameters will be determined by specific laboratory scale tests and the results of these will form the basis for semi-commercial tests in the pilot plant. The most important results of pilot plant tests will then be fed to a computer in order to establish a model to determine the kinetics of reaction and the specific heat requirements and heat transfer. At the same time, the project planning work will be commenced taking into consideration, as a very important factor, knowledge fed back from plants in operation. The project study for the client is thus based on test result, calculations and operational experience. In this optimum manner the success of a plant under planning is ensured.

Coming finally to the question of future prospects for this process, it can be said that the process is not only suitable and viable for the production of different reduction products (see Fig. 9) but can also be considered as a welcome supplement to blast furnace plants when treating so-called "waste oxides" for the elimination of undesirable non-ferrous metal contaminations. Such a plant, based on the SL/RN process, is at present being built in Japan by an important steel mill, designed for a throughput of about 500,000 tpy. There are some other interesting projects some of which involve special cases but which will in any case be used for the production of high-grade furnace charge.

Discussion

Dr. Suresh Jha Ajit (Regional Institute of Technology, Jamshedpur).

1. What in your opinion should be the route to expansion of steel capacity in India viz. sponge iron—electric furnace or blast furnace-LD.

2. What should be the optimum side of sponge iron plant in India for low cost of production?

Dr. Kurt Meyer (Author).

1. In my opinion India's steel capacity should be increased in the near future by producing sponge iron as a charge material for the existing and planned mini steel plants. Additionally, this measure will counteract to dropping scrap quality and climbing scrap prices. For judging the route best suited for expansion in the distant future, the following specific Indian conditions must be recalled: (a) good iron ores spread over the country (b) non-coking coals available (c) coking coals concentrated in the North-East (d) large distances for transportation (e) capital shortage. These reasons advocate very strongly in favour of the direct reduction route.

2. As the optimum size depends on too many local factors, I have to generalize. I would suggest that the 'near future concept' should serve 3 to 10 Indian mini steel plants, each resulting in a capacity in the order of 50 to 100,000 tpy of sponge iron. Furthermore, I would assume that the 'distant future concept' will operate in the 200 to 500,000 tpy range.

Mr. B. S. Krishna Rao (Heavy Engineering Corporation Ltd., Ranchi).

(1) To what extent can sponge iron be charged into open hearth and other steel melting furnaces other than electric furnace? (2) Can sponge iron be charged into electric arc Furnace without using scrap? (3) What is in your opinion, the optimum scrap sponge ratios for charge into different smelting furnaces for economical operations?

Dr. Kurt Meyer (Author).

(1) Sponge Iron can most favourably be converted to steel in furnaces with a concentrated and high-temperature heat source like arc furnaces and BOFs. In most other steelmaking processes only small amounts of sponge iron are tolerable under economic aspects. Increasing percentages of sponge iron in charge tend to create accretions and agglomerates which can hardly be melted with the poor heat sources available.

(2) In arc furnaces about 20% of the tap weight is necessary in form of scrap for the initial hot heel into which the sponge iron is charged continuously. This scrap consumption can be reduced by retaining 20% of the tap weight back in the furnace to form the hot heel for the next heat. As this procedure can be repeated up to four times subsequently, the minimum scrap consumption totals only about 5% with this method. Only with transformer ratings above say 30 MVA a 100% sponge iron charge has proven successful so far.

(3) As to the optimum scrap/sponge iron ratio for arc furnaces, I refer to Mr. Post's paper (Paper No. 30). The most economical ratio for various smelting furnaces depends on so many parameters that a general answer does not seem possible without knowing details.

Mr. M. K. V. Chari (McNally Bharat Engg. Co. Ltd., Dhanbad).

(1) How was the problem of thermocouple solved? Can the author please give details of the new temperature sensing device which has been found successful?

(2) One of the reasons for the closure of Falconbridge Plant, it was mentioned, was the difficulty in reaching the rated capacity. What were the technical constraints?

Dr. Kurt Meyer (Author).

1. Our industrial experience has proven that the temperature profile in the rotary kiln can be controlled by merely adjusting the air addition through the various air inlet pipes on the shell. The measurement of the temperature is only necessary in the early start-up period and later on for controlling. For these purposes a self-cleaning device is used to avoid accretions on the shell of the thermocouples.

2. The main reason for the closure of the Falconbridge plant was the finding that at that time the plant could not work with profit even at rated capacity. This was due to a sharp increase in labour and coal cost and a sharp decrease in sulphur, nickel and scrap prices since placing the order (1968). About 70% of the rated capacity were reached at the time of closure. This value seems normal when taking into account that during most of the start-up period not enough oxide material was available to increase the throughput, because the SL/RN step was only one part of this integrated plant.

Mr. G. N. Mehta (Directorate of Industries, Ahmedabad). Could CO be used in the rotary kiln process. Large quantities of CO are available as by-product at Bhavnagar in Gujarat in the phosphorus plant.

Dr. Kurt Meyer (Author). In the rotary kiln processes the carbon being necessary for the mere reduction must be charged in form of coal. However. the energy for heating up the materials and for maintaining the temperature can well be covered by other fuels if there is not enough volatile matter in the coal. These fuels which may be natural gas, oil or CO are introduced into the kiln via shell burners.

Contribution

Prof. V. A. Altekar (National Metallurgical Laboratory, Jamshedpur)

I must compliment Dr. Kurt Meyer for the very candid presentation on the status of the rotary kiln process particularly the SL/RN Process. While trying to choose the rotary kiln, Dr. Meyer has given comparative benefits arising out of the rotary kiln approach. At the NML, we have developed rotary kiln process and that too on tonnage basis.

However, there are some reasons why I would prefer a shaft furnace to a rotary kiln. Firstly, for similar output capacity, the investment in rotary kiln is more than for a shaft furnace; secondly, irrespective of what care one exercises during the operation of the kiln some kind of decrepitation of the charge does take place and this leads to considerable dust and similar nuisance, and finally the thermal efficiency of the kiln although one may have very long kilns, is not as much as one can expect out of a shaft furnace. And of course there are operational difficulties like ring formations.

A comparison of the various processes would reveal that per cu. metre/day capacity of the shaft furnace can be much higher than what is obtainable in the kiln today. This may average around 0.6 to 0.8 tons per M^3 per days. As against this figure, the productivity of shaft furnace processes varies from two to five times the productivity of rotary kiln. An objective of the various processes would bring out these contrasts.

On the other hand, I would agree with Dr. Meyer that in the world as well as in India, we have to content with the solid reductant. We have to use solid reductants, the gas may not be available and there is plenty of widely distributed non-coking coal reserves all over the world as well as in India.

However, it may be desirable to gasify the coal and use the gas for gaseous reductant process than to use the coal directly as in rotary kiln or Icheveria type retort processes.

SESSION III – FUNDAMENTAL AND OPERATIONAL ASPECTS OF SPONGE IRON PRODUCTION IN ROTARY KILNS

Tuesday, 20 February, 1973

The Session was convened at 9.00 A. M. The Chairman was Mr. P. Anant, General Manager (Operations), Tata Iron & Steel Co. Ltd., Jamshedpur, the Co-Chairman was Mr. Walter Maschlanka, Korf-Stahl A. G., West Germany and the Rapporteur was Prof. S. L. Malhotra, Department of Metallurgical Engineering, Banaras Hindu University, Varanasi.