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Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

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Third Interregional Symposium
on the Iron and Steel Industry

Brasilia, Brazil, 14 - 21 October 1973

Agenda item 5

DIRECT REDUCTION OF IRON ORE : TECHNICAL AND ECONOMIC ASPECTS[1/]

Report of a seminar
organized by the
United Nations Economic Commission for Europe
held at
Bucharest, Romania
18 - 23 September 1972

1/ The views and opinions expressed in this paper do not necessarily reflect the views of the secretariat of UNIDO.

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STEEL COMMITTEE

(Item 7 (a) of the provisional agenda for the fortieth session)

REPORT ON THE SEMINAR ON DIRECT REDUCTION OF IRON ORE: TECHNICAL AND ECONOMIC ASPECTS

Introduction

1. The Seminar on Direct Reduction of Iron Ore - Technical and Economic Aspects was held in Bucharest (Romania) and Galatz from 18 to 23 September 1972. More than 300 experts from 33 countries participated in the Seminar; there were 142 speakers in the discussions. A list of participants was circulated at the meeting (STEEL/Sem.Dir.Red./Gen./Conf. Room Doc. No.2).

The programme of the Seminar was the one established by the Steel Committee's Preparatory Group for this Seminar (STEEL/248), and a list of the papers presented is reproduced in Annex I of the present report.

3. Mr. D. Nita (Romania) and Mr. A.T. Barnaba (Italy) were Chairman and Vice-Chairman, respectively.

Opening session

4. The participants were addressed by Mr. N. Agachi, Minister of the Metallurgical Industry of the Socialist Republic of Romania, who stressed the importance of an exchange of technical and economic experience within the framework of international seminars. He also provided a survey of the development of the Romanian iron and steel industry, outlining the future changes and planned improvements of the host country's iron and steel industry and expressing the great interest displayed by Romanian metallurgists for the future development of direct reduction. Participants were also greeted by Mr. D. Joita, Deputy General Mayor of the City of Bucharest, and by Mr. E. Conrot (Luxembourg), Chairman of the Steel Committee of the Economic Commission for Europe. The Secretariat conveyed the greetings of the Executive Secretary of the Economic Commission for Europe, Mr. J. Stanovnik.

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Summary of the Working Sessions

The different technical and economic aspects of direct reduction were discussed in three separate sessions.

Session I - Scientific and economic aspects of direct reduction processes

5. The discussion leaders for this session were Mr. J. Astier (France), Mr. K. Meyer (Federal Republic of Germany) and Mr. B. Trentini (France). A discussion paper summarizing the various contributions for this session was presented (STEEL/Sem.Dir.Red./Disc.I).

6. To facilitate discussions the eighteen papers of this session were presented in three groups:

(a) gaseous reduction in shaft furnaces and in fluidized beds;

(b) reduction in rotary kilns and in the Lubatti furnace;

(c) other processes and general aspects.

(a) Gaseous reduction in shaft furnaces and in fluidized beds

7. Of the eight papers in this group, four dealt with the shaft furnace, three with fluidized beds, and one had a more general character. The first paper described the MIDDLAND-ROSS process (paper I - 2) and provided information on the experience gained in the most recent installation of this type, i.e. at the Hamburger Stahlwerke G.M.b.H, Hamburg, Federal Republic of Germany. The second paper dealt with the ARMCO metallizing process (I - 7) and presented the installation under construction in Houston, Texas. This paper was followed by a description of the PUROFER process and the results obtained in the pilot plant of 500 tons per day at Oberhausen, Federal Republic of Germany. A paper on the ICEM process (III - 2) provided the results obtained in a Romanian experimental installation; this process had been mentioned by Mr. Agachi, Minister of the Metallurgical Industry of Romania as being of particular interest for the further development of the country's iron and steel industry. The last paper (I - 11) in this group gave the results of industrial operation of the HyL process and described the further developments which are under way.

8. Among the papers dealing with gaseous reduction in fluidized beds, there was one describing the NOVALFER process (I - 5), providing a detailed economic outlook for this type of process. Paper III - 16 dealt with the FIOR process, and paper I - 15 gives consideration to a number of basic aspects of blended ores in fluidized beds.

9. This first group of papers was received with great interest by the participants, as was also brought out by the number of questions asked in the course of the discussion. The questions concerned mainly the different technical, technological and economic aspects of the individual processes described, but in particular the actual production volume reached, difficulties of operation encountered and the corresponding economic data.

(b) Reduction in rotary kilns and in the Lubatti furnace

10. Paper I - 14, on the SL-RN process, gives a survey of the installations which have been built in the different regions of the world, giving explanations for difficulties encountered and taking stock of the progress achieved. The Krupp Sponge Iron Process is the subject of paper I - 16; it provides a description of results achieved at the pilot plant scale and gives information on the plant under construction in South Africa.

11. The ensuing discussion dealt in particular with the characteristics of each process with the possibilities of extension from pilot plant stage to industrial scale, with the characteristics of raw materials, energy and fuels, with refractories, and with the scale and maximum possible production per unit. Referring to the difficulties encountered in several installations which had been constructed in developing countries, the representative of the United Nations Industrial Development Organization (UNIDO) stressed the importance of obtaining sufficiently reliable data on individual processes, in order to diminish the risk of failure; mention was made in this context of the construction in India, under the auspices of UNIDO, of a rotary kiln for testing different raw materials. The discussion of the paper on the Lubatti process (II - 7), which had been used in Italy during the 1950s, centred mainly on the principles of heat transfer.

(c) Other processes and general aspects

12. In this group there were three papers describing research work undertaken in the USSR: Paper I - 3, making an evaluation of direct reduction for the blast-furnace charge, for steel making and for the production of iron powder; paper I - 10, comparing the different direct reduction processes, pointing to the possible economies for production of high quality steels, and predicting that in the USSR the further development of direct reduction would be for high-quality steels rather than for current steels; paper I - 1, describing a pilot installation with a rotary grate kiln, using methane injection through tuyeres into the ore bed, and providing information on an industrial scale plant under construction in Krivoirog. The discussion on these papers was mainly on future production of pre-reduced material in the USSR as well as on a number of technical subjects, concerning particularly the method of reduction on a grate.

13. Paper I - 9 presents results of laboratory work and small pilot installations for reduction of a blend of ore and coal, using outside heating. The discussion of this paper was mainly devoted to the problem of difficulties of heat-exchange. Paper I - 4 raised a number of problems from the viewpoint of physical metallurgy and suggested various orientations for research work, particularly for use of pre-reduced material for alloy steels; the ensuing discussion turned around the physio-chemical aspects of controlled reduction of the different oxides. Finally, a paper was presented (I - 13) giving a survey of the increasing production and use of pre-reduced material, and an outlook until 1985.

14. Session I ended with a general discussion on all papers presented, thus permitting a comparison of the principal characteristics of the different direct reduction processes

Session II - Raw material and energy situation for direct reduction

15. The discussion leaders for this session were Mr. J.W. Shea (United States) and Mr. H.A. Janson (United States). A discussion paper summarizing the various contributions for this session was presented (STEEL/Sem.Dir.Red./Disc.II).

16. To facilitate discussions the eleven papers were presented in four groups: Group (a), dealing with energy requirements, taking into account the world energy situation and expected trends; Group (b), dealing with the principles of gaseous reduction and the various methods of manufacturing reducing gases; Group (c), dealing with the relationships between available iron ores and suitable direct reduction processes for their use, and Group (d), dealing with the solution of the possible problems arising from reoxidation of metallized ore materials. This system proved effective, since some questions raised by one paper were answered by another in the same group and the very active discussions contributed substantially to the subjects covered in this session.

17. In the first group of papers the metallurgical route of direct reduction and steelmaking in electric arc furnaces was compared with the conventional method of blast-furnaces and oxygen converters, against the background of the world energy supply situation and the shortage and increasing prices of coking coals. While energy consumption for the conventional process is approaching the theoretical minimum, energy requirements for the direct reduction/electric arc furnace systems are now only very slightly higher and are expected to be reduced through further developments (paper II-1) Recent reports already indicate that, when actual prices are applied to the types of energy used, present energy costs for the latter system are lower than for the conventional plant.

18. Because of the increasing demands for all kinds of energy, the application of nuclear heat for industrial processes is being actively explored, including its use in the steel industry. Such a system would use the process heat of a nuclear reactor to produce a reducing gas for the direct reduction process, and, at the same time, generate the electric power to make steel from the reduced iron products.

19. Two concepts were described, on-site employment of a nuclear reactor in an integrated steel plant, with all of the energy produced consumed within the plant (paper II-3), and a centralized energy station, supplying both reducing gas and electric power to satellite steel plants, with the second concept apparently offering more flexibility (paper II-2). Present technology dictates that a steel plant with an on-site nuclear reactor would have to be of 3 to 4 million tons annual capacity, producing steel in 6 UHP electric arc furnaces at 75 tons per hour each. While the necesary size of such a plant could impose certain limitations such as size of markets, return on investment, etc., these would be the same as for a conventional plant, but costs should be lower. Also, while these nuclear concepts envisage about the same energy consumption as the conventional processes, energy cost would be cheaper, and the opinion was expressed that suitable high temperature nuclear reactors may be available by 1980, and a small-scale steel plant based on the nuclear concept could be installed by 1985.

20. The second group of papers dealt with reducing gas generation and energy requirements. While the technology of direct reduction processes is still developing, technically and economically feasible processes are available, with the metallized ore produced being used for steel production in electric arc furnaces. Various fossil fuels serve as reducing agents for iron ores - rotating kilns using various types of solid carbon materials; shaft-furnaces, retort processes and fluidized bed reactors employing converted natural gas. Energy requirements vary between 3.5 and 4.5 Gcal/ton of sponge iron for a highly metallized product which can be directly used for steel production (paper II-11).

21. Reliable technologies are available for the economical production, from various source materials, of reducing gases which always contain mainly hydrogen and carbon monoxide (paper I-12). Gas recycling and the re-use of top gas for reduction gas production improves the economics of all gas-based direct reduction processes, especiall in the shaft furnace concept. Because of the presence of high-quality natural gas in Romania, a considerable amount of work has resulted in the development of industrial scale direct reduction processes, the products of which also include iron powder for application in sinter metallurgy (papers II-3, II-9).

22. The third group of papers focused on the suitable types of iron ores, by process and in relation to local conditions. The physical shape of the ore to be chosen is process-dependent. The rotary kiln seems to be flexible in this regard, the shaft furnace and the retort can reduce lump ore and pellets, while the fluidized bed reactor needs fine ores of exactly defined grain size. The use of fine ores may have economical advantages over lump ores; however, pelletization often has then to be considered as another cost factor (paper II-5).

23. The iron content of the ores is very important, with low grade ores being only economical in certain geographic areas, although the reduction of iron-containing waste products may be justified in certain cases. Generally, high-grade ores are the most desirable, because of their reductibility as well as reduction behaviour, and it may be more economical to import these instead of using low-grade local ores.

24. Since the removal of gangue is not possible in direct reduction, and since this must be done through the slag phase of the arc furnace steelmaking process, the gangue content of the ore normally should not exceed 5.5 per cent. A high gangue content will increase power consumption, although this may be partly compensated by continuous hot-charging of the sponge iron to the melting furnace (paper II-5).

25. The introduction of direct reduction is of special interest for the Arab countries, which are rich in iron ores, but fully dependent on imported coke for the use of the blast furnace process. Since these countries are also rich in petroleum and natural gas, gaseous reductants are available at very low prices. Process development, which has been under study for a considerable period, is continuing with the possibility of establishing an Inter-Arab integrated steelplant, based on direct reduction, to produce one million tons annually. Major problems still exist in the concentration and upgrading of domestic ores (paper I-17).

26. The papers and contributions of the fourth group discussed the chemistry and reoxidation of metallized ore products and protective measures against it. Sensitivity depends mainly on the technological conditions of the reduction process and the physical nature of the product, with some having almost no tendency to reoxidize, while others can be protected by passivation or by briquetting (papers II-10, II-6). Various other methods are suggested for protection, including plastic materials, either as individual shells around sized ore or as foam cover on piles of sponge iron. Protection with plastic materials can be applied with inexpensive equipment and at economical costs. All direct reduction companies were confident that reoxidation does not create problems in the use, shipping and storing of metallized ore, as long as the necessary precautions are taken.

Session III - The place of direct reduction in iron and steelmaking

27. The discussion leaders for this session were Mr. A.T. Barnaba (Italy) and Mr. I. Tripsa (Romania). A discussion paper summarizing the various contributions for this session was presented (STEEL/Sem.Dir.Red./Disc.III).

28. Although this final session was intended for dealing entirely with the use of prereduced material for pig iron and crude steel production, there was also a number of papers of a more general character: one contribution (III-15) voiced certain doubts on the further rapid development of direct reduction; it remained, however, the only one not sharing the general optimism for direct reduction. There was also a paper (III-10) describing the activities of the United Nations Industrial Development Organization (UNIDO) in the field of the iron and steel industry, with particular reference to assistance provided to developing countries which install or operate direct reduction plants.

29. Among the main papers presented the importance of two contributions should be particularly stressed; one dealing with the possibility of using the blast-furnace itself for achieving reactions of direct reduction, with a view to reducing coke consumption to the minimum (paper III-1): the other, describing the present state of development of the ELKEM process, which utilizes the gas arising from the electric reduction furnace for achieving a pre-reduction and a pre-heating of the ore, immediately before it is charged into the electric reduction furnace itself (paper III-14).

30. As far as the treatment of the session's principal subject is concerned, it can be said that the expectations of participants and their specific interests were fully satisfied. The aim was to be informed on the practice of plants using sponge iron in the charge of blast furnaces and of electric reduction furnaces for the production of pig iron, and in electric arc furnaces for the production of crude steel.

31. The papers presented and the exchange of views have shown that the use of sponge iron in blast furnaces and in electric reduction furnaces is economical in particular cases. There was general agreement that, when pre-reduced material is used for the production of pig iron, a sponge iron of high degree of metallization should be used; the reason being that the cost of reduction increases noticeably for each percentage point above 80 to 85 per cent of reduction.

32. The information provided by actual results from the use of sponge iron in electric arc furnaces was particularly satisfactory. As far as the charging of these furnaces with pre-reduced material are concerned, it appeared from the discussion that the most rational way is continuous charging; the efficiency and simplicity of [illegible] through [illegible] in the arc furnace roof was stressed. [illegible] technology [illegible] the formation of "iceberg" and to protect the refractories in the furnace linings: the latter have now in many cases the same or even a longer life-time than in furnaces charged with scrap.

33. It would also seem that a definite answer can now be given to all those who have doubted the possibility of charging electric furnaces with a high proportion (up to 100 per cent) of sponge iron. It is true that an increase of the proportion of sponge iron in the charge will result in an increase of electric power consumption, due to the quantity of gangue and, hence, of slag. However, this does not lead to an extension of the tap-to-tap time, since the subsequent refining operation is shortened, due to the purity of the charge. It is at any rate hardly necessary to use a 100 per cent scrap charge since steel plants have always a certain quantity of circulating scrap at their disposal.

34. There was general agreement that considerable improvements in steel quality are derived from the use of sponge iron; there are steelmakers who claim that very high quality steels can only be produced starting from sponge iron.

35. As far as the economic aspects are concerned, it was once more brought out that production and use of sponge iron in integrated plants are economic at output levels up to two million tons per year.

36. During the session an interesting study of the factors which determine the characteristics of pre-reduced pellets was also presented. There were also papers illustrating the interest which exists in Spain, Romania and in the Arab countries for using direct reduction processes; particular attention was given in these papers to problems which are common for countries which do not have domestic coking coal reserves.

37. In conclusion, it can be said that the third session was very well documented, and that it has thrown light on a number of interesting questions, particularly on those which may arise in the use of pre-reduced material in steel-melting shops.

Main findings of the seminar

38. Two of the most important elements involved in all iron and steelmaking processes are raw materials and energy, and their availability and price are of paramount importance. These factors are, in turn, influenced by the rapid growth of world steel consumption and production: while world population has slightly more than doubled since the beginning of the century, world steel consumption has multiplied sixteen times. In the course of this rapid growth of the industry, its structure and geographical distribution as well as the technology used have been subject to important changes, and one of the most recent changes involves the direct reduction of iron ore.

39. The seminar has provided a very useful framework for a review of the state of development of direct reduction processes, for an exchange of experiences gained in different countries and locations, under differing circumstances of raw materials and energy input, and of requirements on the finished product.

40. Among the processes examined at the outset of the seminar, several proved to have become operational; they are mainly those using – on an industrial scale – gaseous reduction in shaft furnaces, with either discontinuous charging and decharging, or fully continuous processes. The seminar has also shown that important efforts are being made to achieve industrial, large-scale production by using gaseous reduction in fluidized beds, and by reduction in rotary kilns with coal and/or gas, or with other hydrocarbons. It was also noted that research is underway to develop other methods which could, in the longer run, gain in significance.

41. The various aspects of the availability and use of energy were also examined; it was shown that in many regions the use of energy sources other than coking coal can be envisaged. In this context it should be noted that it was possible during the seminar to compare with a relatively high degree of precision, the respective energy balances of

- the so-called classical route, comprising the refining with oxygen of blast-furnace pig iron, in certain cases making use of a pre-reduced blast-furnace charge;

- the route based on the direct use of pre-reduced material in electric arc furnaces.

While the total energy consumption in each of these routes is rather similar, the proportions held by solid, liquid or gaseous fuels are very different from one to another

42. Among the various sources of energy which come into consideration for use in direct reduction, an increasingly prominent place may be held in future by the process heat of high-temperature nuclear reactors; their logical function could be to generate a reducing gas as well as electrical energy.

43. The seminar has permitted the review of various uses of pre-reduced materials, and it was shown that the electric arc furnace is their most important outlet. The application of continuous charging is rapidly expanding, and its advantages appeared to have been proven.

44. The use of pre-reduced material in blast furnaces is less widespread; this problem has, however, been studied in great detail, by making tests in both experimental blast furnaces or in furnaces of small capacity. The advantages of pre-reducing the charge of electric pig-iron furnaces were also stressed, a practice which is already used in some iron and steel plants.

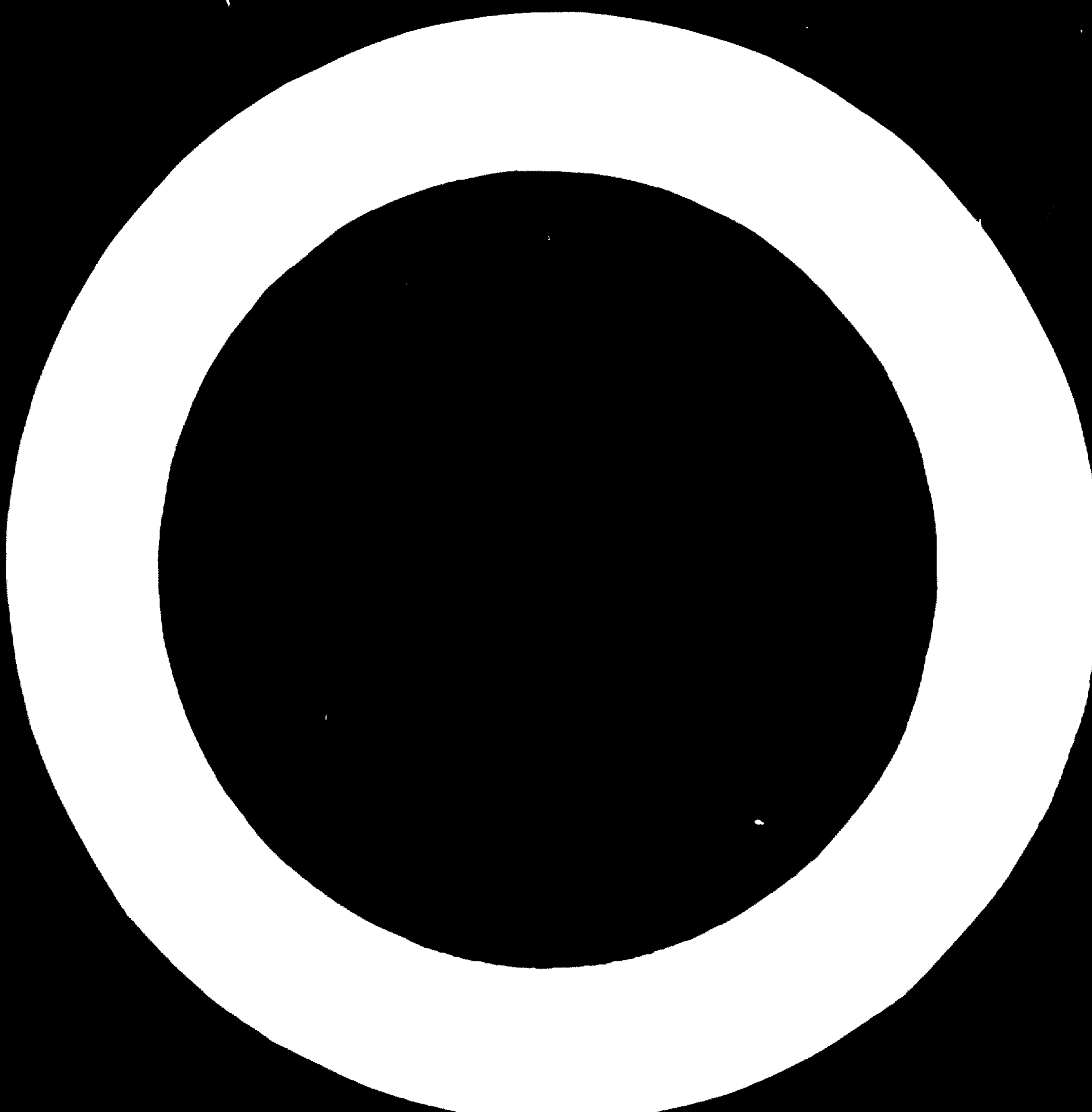
45. In their entirety, the papers presented gave rise to animated discussions, not only on the subject of direct reduction in general, but also on the production routes which may be used in future for steel production.

46. One of the important features of the seminar was the provision of information on direct reduction plants which had been operating on an industrial scale. In this way, the rather more theoretical data available from pilot plants or from laboratory work could be reviewed against the background of actual experience. It was found that - as is the case for any technological innovation - the transition from pilot installation to industrial scale operations still presented certain problems; there is, however, an increasing number of examples of installations working economically, each being adapted to local conditions (e.g. availability of natural gas, fuel oil, good quality iron ore, as opposed to coking coal, coke and scrap; specific investment cost; quality and type of steel products to be produced; relationship between scale of production and market size). For this reason, it would seem that the efforts of the industry to provide more universally applicable solutions should be continued.

47. The documentation presented and discussed at the seminar had been prepared by eminent experts from many countries; it was regarded as an important contribution to the literature on the subject of direct reduction. In order to make this information available to a wider circle of interested persons, the Steel Committee may wish to derestrict the papers presented at the seminar.

48. It was also suggested that the Steel Committee should consider the possibility of including in its programme of future work an item dealing with the further evolution of direct reduction. Given, furthermore, the close relationship between the products of direct reduction and the electric arc furnace, the Committee may also wish to undertake a project devoted to electric steelmaking.

49. Unanimous appreciation was expressed to the authorities of Romania for the excellent arrangements made for holding the seminar in Bucharest and for the visit to the Galatz iron and steel plant, for the efficient organization of the meetings and for the generous hospitality offered.



ANNEX I

LIST OF PAPERS PRESENTED AT THE SEMINAR 1/

SESSION I - SCIENTIFIC AND ECONOMIC ASPECTS OF DIRECT REDUCTION PROCESSES

Symbol	Title
STEEL/Sem.Dir.Red./Disc./I	Scientific and economic aspects of direct reduction processes. By: Mr. J. ASTIER, France.
STEEL/Sem.Dir.Red./I-2	The use of the Midland-Ross direct reduction process in small or medium scale iron and steel plant. By: Mr. W. MASCHLANKA *et al.*, Federal Republic of Germany.
STEEL/Sem.Dir.Red./I-7	ARMCO's Metallizing Process. By: Mr. W.E. MARSHALL, United States of America.
STEEL/Sem.Dir.Red./I-6	The PUROFER Process - Description, first industrial results, heat balance. By: Messrs. H.D. PANTKE and G.H. LANGE, Federal Republic of Germany.
STEEL/Sem.Dir.Red./I-5	The NOVALFER process - economic aspects. By: Mr. G. IGOUMENC, France.
STEEL/Sem.Dir.Red./III-16	The FIOR process for the direct reduction of iron ore. By: Mr. R.J. OEHLBERG United States of America.
STEEL/Sem.Dir.Red./I-11	The Hyl direct reduction process - past, present and future. By: Mr. R. LAWRENCE, Jr., United States of America.
STEEL/Sem.Dir.Red./I-15	Some considerations on the reduction of blended iron ores in fluidized beds and the utilization of high density briquets of prereduced materials. By: Messrs. A. DI CANDIA and C.LITIGIO, Italy.

1/ The papers are listed in the order of presentation.

Symbol	Title
STEEL/Sem.Dir.Red./III-2	Direct reduction of iron ores in a shaft furnace-ICEM process. By: Mr. C. MATARASCU *et al.*, Romania
STEEL/Sem.Dir.Red./I-14	SL/RN process: production of sponge iron using solid reductants. By: Messrs. H. SERBENT and W. JANKE, Federal Republic of Germany.
STEEL/Sem.Dir.Red./I-16	The Krupp Sponge iron process - its products and applications. By: Messrs. G. MEYER *et al.*, Federal Republic of Germany.
STEEL/Sem.Dir.Red./II-7	Directly from iron ore to steel with Lubatti's process. By: Mr. A.T. BARNABA, Italy.
STEEL/Sem.Dir.Red./II-12	Influence of various types of raw materials on the costs for production of sponge iron, applying the SL/RN process. By: Mr. G. REUTER, Federal Republic of Germany.
STEEL/Sem.Dir.Red./I-3	Research on processes of direct reduction of iron from ores. By: Mr. N.I. SAVELOV *et al.*, USSR
STEEL/Sem.Dir.Red./I-4	Some observations on the future of direct reduction from the standpoint of physical metallurgy. By: Mr. P.M. GIELEN, submitted at the invitation of the host-government.
STEEL/Sem.Dir.Red./I-8	Carbo-thermic process for the reduction of iron ores. By: Mr. L. VISNYOUSKY *et al.*, Hungary.
STEEL/Sem.Dir.Red./I-10	Evaluation of processes of direct reduction of iron ores, trends in their developments and future prospects. By: Mr. A. GIMMELFARB and Mr. A.M. NEMENOV, USSR.

Symbol	Title
STEEL/Sem.Dir.Red./I-1	Study of the process of metallization of iron ore pellets with complete or partial use of natural gas as the reductant. By: Mr. G.V. [illegible] et al., USSR
STEEL/Sem.Dir.Red./I-13	The increasing production and use of directly-reduced iron ore. Forecasts for 1975 to 1985. By: Mr. J.R. MILLER, submitted at the invitation of the host-government.

SESSION II - RAW MATERIAL AND ENERGY SITUATION FOR DIRECT REDUCTION

Symbol	Title
STEEL/Sem.Dir.Red./Disc.II	Raw Material and energy situation for direct reduction. By: Mr. SHEA, United States of America.
STEEL/Sem.Dir.Red./II-1	Energy in prereduction processes and various routes in steel-making. By: Mr. J. ASTIER et al., France.
STEEL/Sem.Dir.Red./II-3	Diversification of energy sources for the iron and steel industry. By: Mr. A. [illegible], Italy.
STEEL/Sem.Dir.Red./II-2	Long term trends in the process technologic application of nuclear heat to ironmaking. By: Messrs. W. WENZEL and F.R. BLOCK, Federal Republic of Germany.
STEEL/Sem.Dir.Red./II-11	Requirements governing the composition of reducing gas for iron ore reduction. By: Messrs. H.D. [illegible] and G.H. LANGE, Federal Republic of Germany.
STEEL/Sem.Dir.Red./I-12	Generation of metallurgical reducing gas. By: Mr. [illegible], Italy.
STEEL/Sem.Dir.Red./II-8	The use of methane in the reduction of iron oxides. By: Mr. Z. SĂRĂCHEZ et al., Romania.

Symbol	Title
STEEL/Sem.Dir.Red./II-9	Study of iron ore reduction by gases derived from conversion of methane with CO_2. By: Mr. Gv. HATARASCU, Romania.
STEEL/Sem.Dir.Red./II-5	Process for the direct reduction of iron ores in relation to ores supplies. By: Mr. U. KALLA et al., Federal Republic of Germany.
STEEL/Sem.Dir.Red./I-17	Gaseous reduction as the future basis of iron and steel manufacture in the Arab countries. By: Mr. S.Y. EZZ, Arab Republic of Egypt.
STEEL/Sem.Dir.Red./II-10	Reoxidation in connexion with the storage and transportation of metallized ore. By: Mr. KNOP et al., Federal Republic of Germany.
STEEL/Sem.Dir.Red./II-6	Protection of sponge iron from reoxidation. By: Mr. H.W. GUDENAU, Federal Republic of Germany.

SESSION III - THE PLACE OF DIRECT REDUCTION IN IRON AND STEELMAKING

Discussion leaders: Mr. A.T. BARNABA Italy
Mr. M. TRIPSA Romania

STEEL/Sem.Dir.Red./Disc.III	The Place of Direct Reduction in Iron and Steelmaking. By: Mr. A.T. BARNABA, Italy.
STEEL/Sem.Dir.Red./III-15	Direct or indirect iron? By: Mr. D.H. JURDEN, Canada.
STEEL/Sem.Dir.Red./III-10	UNIDO's technical assistance activities in the field of the iron and steel industry, including direct reduction processes. By: Mr. B.R. NIJHAWAN, UNIDO.

Symbol	Title
STEEL/Sem.Dir.Red./II-4	Investigation of factors conditioning the quality of metallized pellets in pilot kilns. By: Mr. E. MAZANEK, Poland.
STEEL/Sem.Dir.Red./III-1	Direct reduction in the blast-furnace. By: Mr. A. POOS *et al.*, Belgium.
STEEL/Sem.Dir.Red./III-4	Improving blast-furnace performance with HIB-experimental-blast-furnace results. Mr. D.G. WHITE *et al.*, United States of Ameri[ca]
STEEL/Sem.Dir.Red./III-3	Results of and remarks on the use of directly-reduced material in conventional electric reduction furnaces. By: Mr. H. KÖNIG, Federal Republic of Germany.
STEEL/Sem.Dir.Red./III-14	Present status of the ELKEM pretreatment processes and hot feed to electric smelting furnaces. By: Mr. H.C. ANDERSEN, Norway.
STEEL/Sem.Dir.Red./III-11	Theory and practice of the melting of sponge iron in arc furnaces. By: Mr. H. POST, Federal Republic of Germany
STEEL/Sem.Dir.Red./III-12	Experiences on the UHP - arc furnace operation. By: Mr. H. NODA *et al.*, Japan.
STEEL/Sem.Dir.Red./III-5	The use of metallized pellets in electric-arc furnace steelmaking processes. By: Messrs. P. KEHL and H. VOSS, Federal Republic of Germany.
STEEL/Sem.Dir.Red./III-9	Use of sponge iron in electric furnace steel-making. By: Mr. G. MORELLI *et al.*, Italy.

Symbol	Title
STEEL/Sem.Dir.Red./III-7	Continuous smelting of hot metallized pellets in an electric furnace. By: Mr. V.S. KUDRYAVTSEV and Mr. S.A. PCHELKIN, USSR.
STEEL/Sem.Dir.Red./III-8	Review of the situation of prereduction in Spain. By: Mr. ROGUERO, et al., Spain
STEEL/Sem.Dir.Red./III-6	Present and future aspects of the use of sponge iron in Romania. By: Mr. D. COSMA et al., Romania.

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FIRST MEETING - SCIENTIFIC AND ECONOMIC ASPECTS OF DIRECT REDUCTION PROCESSES

INTRODUCTION OF PAPERS AND SUMMARY OF TOPICS FOR DISCUSSION

Prepared by Mr. Jacques Astier, Director of IRSID (France)

INTRODUCTION

1. The purpose of this first meeting is to consider the scientific and economic aspects of direct reduction processes, and it should be borne in mind, from the outset, that as the various papers will show, prereduction is already effectively in existence and accounts for a by no means negligible output.

2. This paper is in two sections corresponding to the two following topics:

- developments in each of the various prereduction processes;
- comparison of these processes, especially their economic aspects.

I. Description of and developments in the chief prereduction processes

3. It should be recalled that there are many possible methods for prereducing iron ore. They may be classified according to a number of differing criteria, such as:

- the nature of the ore used in the plant;
- the properties of the corresponding prereduced ores (degree of reduction, particle size);
- the sources of energy used;
- the type of furnace;
- other.

4. The last two criteria mentioned above are thought to be the most important, and in table 1 a specification is given of the principal methods of prereducing iron ore according to the form of energy and type of furnace used.

5. This seminar is not primarily concerned with the methods that might be used, nor with scientific comparisons, but rather with the processes that are already industrially practicable. Virtually only "operational" processes or processes on the verge of becoming operational will be taken into consideration.

6. In this connexion, table 2 shows that:

- already more than 600,000 t Fe/y is being produced by the HyL process and the installed annual capacity will reach 1,200,000 t by the end of 197
- MIDREX plant capacity is already about 1,000,000 t Fe/y and should reach 1,400,000 t in 1973;
- a fluidization plant with a capacity of about 1,000,000 t Fe/y is being developed to the industrial stage;
- a whole series of plants using rotary kilns is in operation or being developed.

The papers which have been prepared for this meeting are:

Table 1: Principal methods of prereducing iron ores

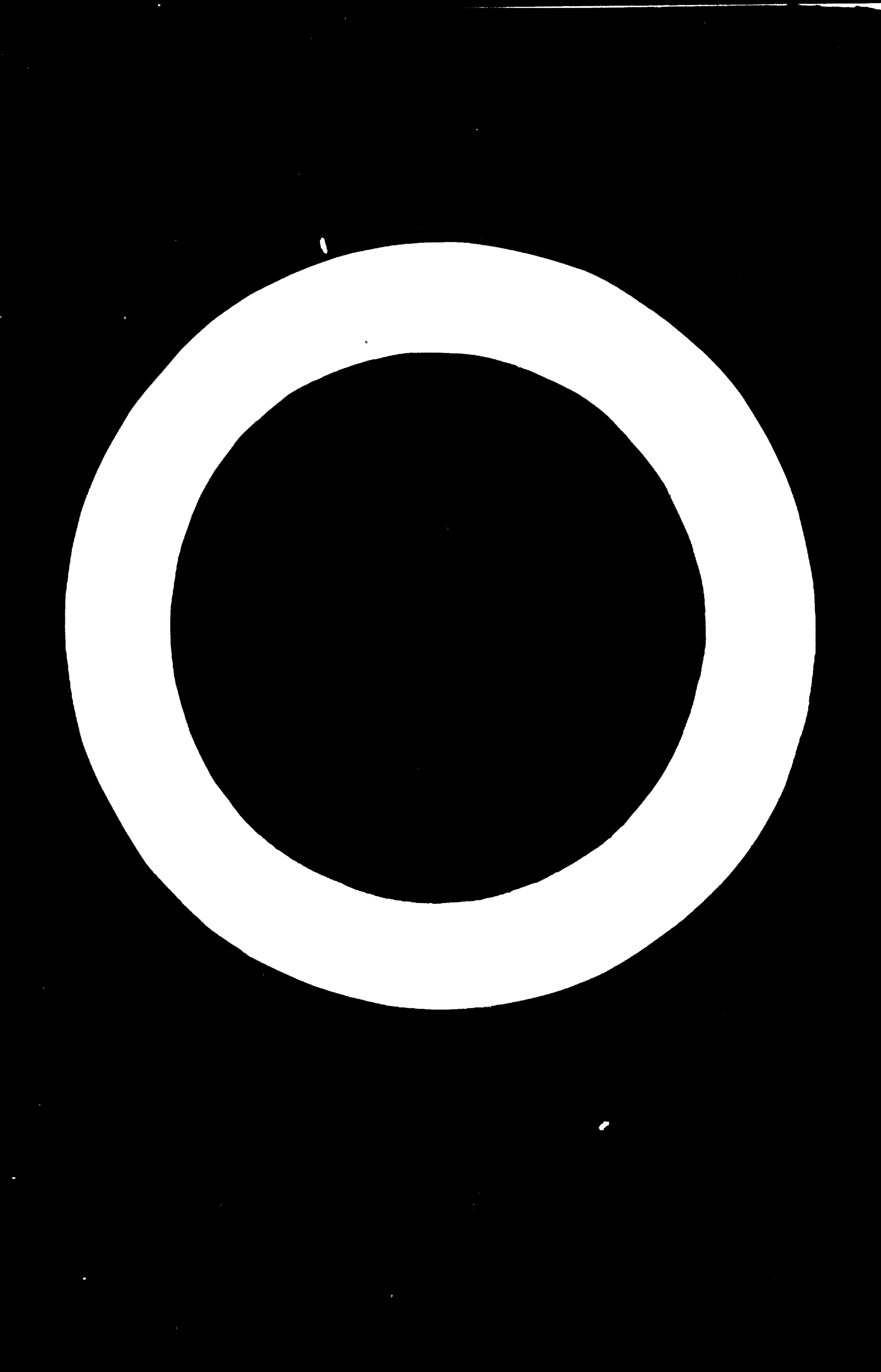
Reducing agent	Reducing furnace	Remarks
Reducing gas produced from: - natural gas, - possibly from naphtha, etc.	Retort	discontinuous: HyL process
		continuous: MIDREX, ARMCO, PUROFER, ICEM, etc., processes
	Fluidization	NOVALFER, HIB, H-IRON, FIOR, e
Solid and/or liquid or gaseous fuels	Rotary kiln	SLRN, KRUPP, etc., MEKHANOBRTCHERMET, etc.
	Retort	ECHEVERRIA
	Crucibles (containers)	HOGANAS

Table 2: ESTIMATE OF WORLD CAPACITY FOR PRE-REDUCTION OF IRON ORES

(Capacities in millions of metric tons iron/year)

rocess	Country and place		Operating	Starting up or under test	under construction (and year of starting)	Remarks
yl	Mexico		1 x 0.065		1 x 0.360 (in 1973)	Increase of 0.132 in capacity projected
	Monterrey	Monterrey	1 x 0.165			
	Vera Cruz	Vera Cruz	1 x 0.165			
	Puebla	Puebla	1 x 0.200		1 x 0.200 (in 1973)	
	Brazil	Bahia				
IDREX	United States	Portland	1 x 0.350			
		Georgetown	1 x 0.350			
	Fed. Rep. Germany	Hamburg	1 x 0.350		1 x 0.350 (in 1972)	
	Canada	Contrecoeur				
	United States	Louisiana			1 x 0.350 (in 1972)	
RMCO	United States	Houston				
UROFER	Fed. Rep. Germany	Oberhausen		1 x 0.150		
IB	Venezuela	Puerto Ordaz		1 x 1.000		
LRN	New Zealand	Glenbrook	1 x 0.150			
	Rep. of Korea	Inchon		(1 x 0.150) 1/ (stopped at present)		
	Canada	Sudbury	1 x 0.300		1 x 0.060 (in 1973)	
	Brazil	Piratini				
RUPP	Greece	Larymna	2 x 0.090 1/ (nickel-bearing laterites)		1 x 0.100 1/ (nickel-bearing laterites)	
	South Africa	Dunswart			1 x 0.100	
Miscellaneous rotary kilns						
midth-Kiln	Yugoslavia	Skopje		(5 x 0.100) 1/ (stopped at present)		
urgi	South Africa	Witbank	4 x 0.080 1/		1 x 0.080 1/	
OTAL	(a) not including partial pre-reduction for electric furnaces		2.095	1.150	1.420	
OTAL	(b) partial pre-reduction for electric furnaces		0.500	(0.650)	0.175	
ENERAL TOTAL			2.595	1.150	1.595	

1/ These plants which are intended to supply electric reduction furnaces, are usually designed for a fairly low degree of metallization.



(a) Prereduction - gas/retort process:

7. The paper on the HyL process (I-11) points out the substantial quantities produced by this process - more than 4,000,000 t since the first plant at Monterrey was started and 747,500 t of prereduced ore produced in 1971. The paper gives a great deal of information on the operating of the process and the method of working at the Peubla plant, and concludes with some economic data on the method.

8. Continuous working retort processes are now expanding very rapidly, and there are two papers on this subject:

- a paper describing the MIDREX process (I-2);

- a paper describing the ICEM process now being developed in Romania (III-2).

9. It would be worthwhile asking the authors what metallurgical/economic prospects these methods hold out. The discussion might be widened to seek information on other retort processes, such as ARMCO or PUROFER, if representatives of these groups attend the Seminar.

(b) Reduction by gases in fluidized beds:

10. The very interesting paper on the NOVALFER process (I-5) describes the general principles of these methods and especially the method chosen for both the 60 t/day pilot plant and the industrial projects of 720 t/day and 1,950 t/day capacities. It would be interesting if possible, to enlarge the scope of the discussion to cover similar processes such as HIB, FIOR, H-IRON, etc.

11. It should be pointed out that the economic estimates submitted in paper I-5 are of the highest interest and very promising. It seems that very attractive net costs might be achieved with large-capacity fluidization units operation under pressure.

(c) Rotary-kiln prereduction with solid and/or gaseous fuel:

12. Under this heading the trials undertaken by the MEKHANOBRTCHERMET Institute (I-1) and the Polish studies (II-4) will be discussed. Here again, in the course of discussion it may be possible to widen the scope and consider the position in regard to the SLRN, KRUPP, etc. processes. It would be helpful, as in the case of other processes, to get some economic estimates, in order to compare the value of these methods with that of the gas reduction retort or fluidization processes.

(d) Solid fuel prereduction processes in various types of furnace:

13. These studies, submitted by the Government of Hungary (I-8) and by the USSR (I-9), will be considered together. These processes seem to offer some interesting possibilities and to be related to well-known processes such as reduction in crucibles (HOGANAS process) and the ECHEVERRIA retort process. It would be useful, to keep the Seminar to its main purpose, to invite the authors to say what economic prospects they consider these methods might offer.

II. Technical/economic comparison of prereduction processes

14. It is suggested that the following papers should be discussed together:

- The study submitted by the USSR Government (I-3);

- Another study, also submitted by the USSR Government (I-10).

To which might be added:

- The study by Mr. Gielen (I-4), unless it is preferred to take this at the third meeting, since it refers particularly to the utility of the layouts based on prereduction for the production of high-resistance welding steel.

9 - The paper by Mr. Nijhawan of UNIDO (III-10), which might be placed first of these papers, unless it is preferred to leave it to the third session, where it might be of use as an introduction to the papers on the use of prereduction processes and the applications of prereduction in general.

The discussion on these papers might follow these lines:

(a) Metallurgical and technical aspects:

15. Under this heading the following in particular should be discussed:

- The comparative requirements of the various processes, as regards the ore, particle size, for instance, and any advantages in using pellets;

- The nature and form of the prereduced ores, which may of course be in the form of powder, pellets, lumps, etc., and which may sometimes necessitate a further operation in briquetting.

(b) Capital investment:

16. It would be useful to begin the discussions on the economic aspects with a comparison of investment costs, to see, for instance, how the relation between investment and annual tonnage output is reduced with increasing plant capacity. On this subject, there are some interesting data on the fluidization process in the paper on the NOVALFER process (I-5).

(c) Production costs:

17. It is difficult to compare all the factors in the course of a seminar meeting. It is suggested that two major points might not be discussed in too much detail:

- the ore, since the position varies greatly between one location and another, and as has been pointed out above (paragraph 2/1.), the requirements for the various processes may be very different;

- power, since that will be dealt with at the second meeting. One of the papers for that meeting (II-1) is entirely devoted to this subject.

18. In other words, it would be much better to aim at an exchange of views on the order of magnitude of production costs such as labour, maintenance, miscellaneous supplies, etc.

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STUDY OF THE PROCESS OF METALLIZATION OF IRON-ORE PELLETS WITH COMPLETE OR PARTIAL USE OF NATURAL GAS AS THE REDUCTANT

Paper submitted by the USSR

Authors: G.V. Gubin, Doctor of Technical Sciences
V.F. Bernado, Metallurgical Engineer
N.N. Berezhnoy, Master of Technical Sciences
L.A. Drozhilov, Metallurgical Engineer
(Institute for the Mechanical Conversion of Ferrous Metals)

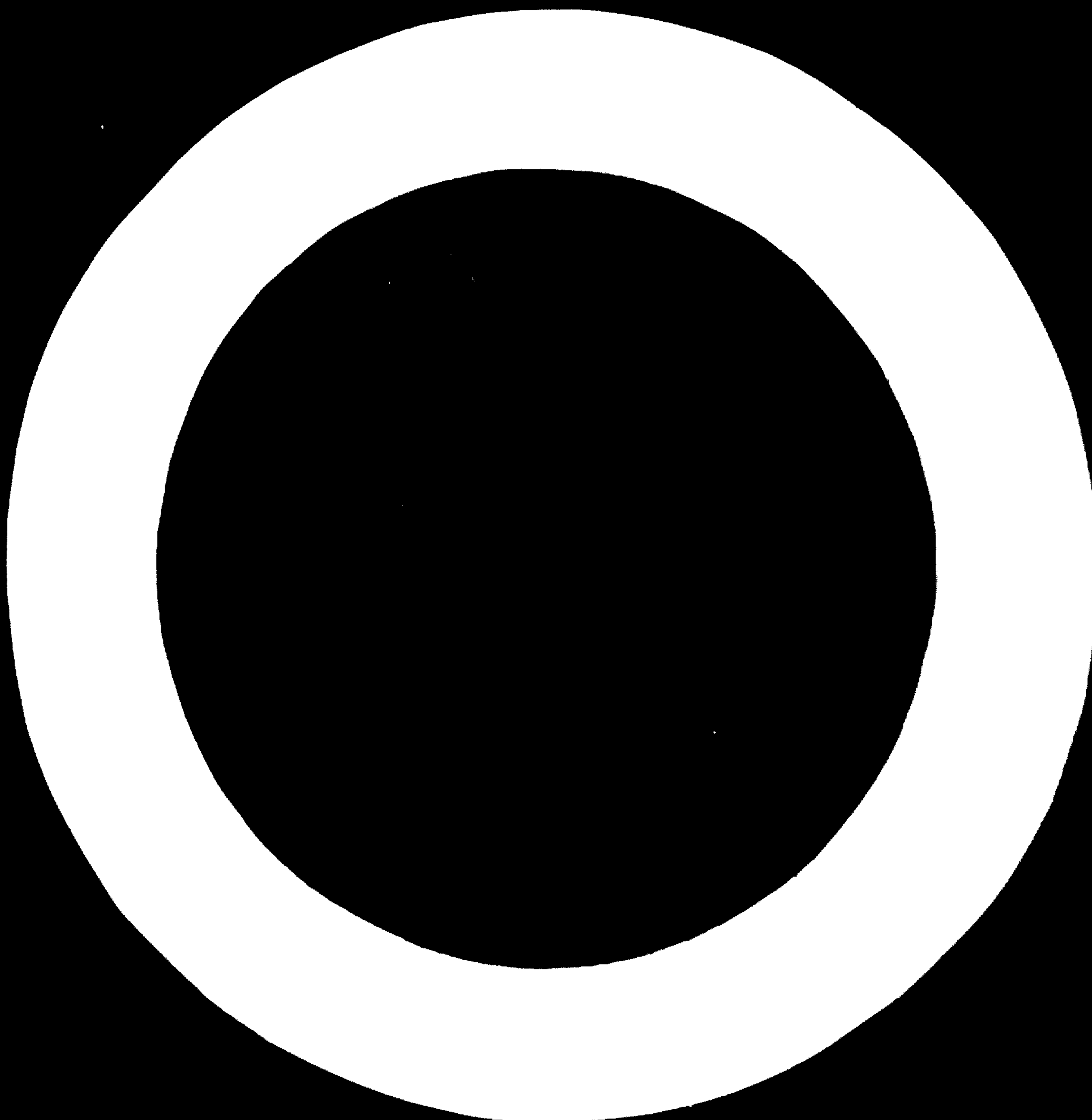
SUMMARY

The theoretical grounds for using natural gas in the metallization of iron-ore pellets are adduced. Thermodynamic analysis testifies unconditionally to the thermodynamic possibility of reducing ferric oxides with methane. The effect of various factors on this reduction, and its mechanism, are examined.

The processes occurring during the metallization of pellets by natural gas were studied in a pilot installation and their principal technological parameters were determined.

The results obtained in a semi-industrial 'grid-tubular furnace" installation using natural gas and a combined reductant (natural gas and anthracite) are given.

The report shows that the process of metallization of pellets can be intensified by introducing finely-crushed solid fuel into the blend to pelletize the metallized fines, and by pre-heating the material before charging it into a tubular furnace.



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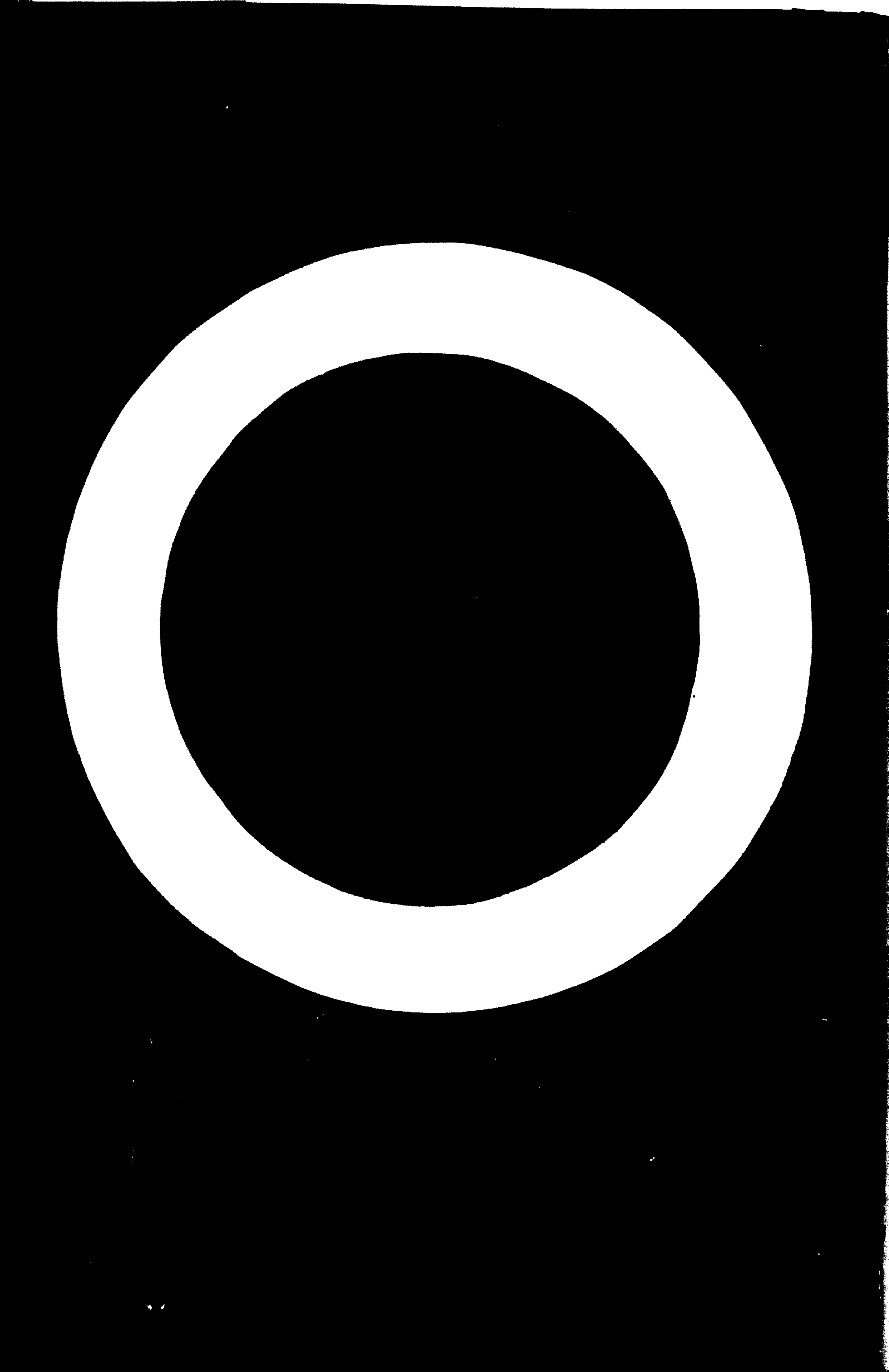
THE USE OF THE MIDLAND - ROSS - DIRECT REDUCTION PROCESS IN SMALL OR MEDIUM SCALE IRON AND STEEL PLANT

Submitted by the Government of Federal Republic of Germany

(Prepared by Mr. W. MASCHLANKA of KORF STAHL AG., Baden-Baden
Mr. P. KEHL and Mr. P. KNOCH of HAMBURGER STAHLWERKE GmbH.)

SUMMARY

On 19 October 1971, the direct reduction plant of Messrs. Hamburger Stahlwerke was put into operation after a construction period of 14 months within the scope of a new integrated iron and steel plant. This installation is part of a newly designed iron and steel plant where the coking plant, blast furnace, LD steel plant, ingot casting and blooming train were replaced by a direct reduction plant, electric arc furnace and a continuous casting plant. The report concerns planning and layout of the Midland Ross direct reduction plant. It includes a description of the new installations and first results of the operations.



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RESEARCH ON PROCESSES OF DIRECT REDUCTION OF IRON FROM ORES

Submitted by the USSR

Authors: N.I. Savelov, V.C. Voskoboynikov, V.F. Knyazev

SUMMARY

Processes of direct reduction of iron from ores (cokeless metallurgy) have nowadays become fairly widespread. They vary considerably in both plant and reductants.

For a technical and economic evaluation of these processes and to determine their place in the general scheme of metallurgical production, it is useful to classify them according to the technological properties of the product.

The paper proposes and broadly examines a system of classification of various iron-making processes from ore to end product (including blast-furnace and smelting conversion as well as direct reduction processes).

The following new direct reduction processes have been developed industrially:

- Preliminary reduction of ore for blast furnaces;
- Preliminary preparation of ore for the electro-furnace process (heating and partial reduction);
- Production of sponge-steel for steel smelting;
- Production of iron powder.

Direct processes of steel making from ore (in a single stage or with a single plant) have not yet emerged from the research phase.

The paper also examines the present state of research in the Soviet Union on the production of sponge iron in shaft furnaces and the continuous process of making sponge-iron briquettes (agglomerates).

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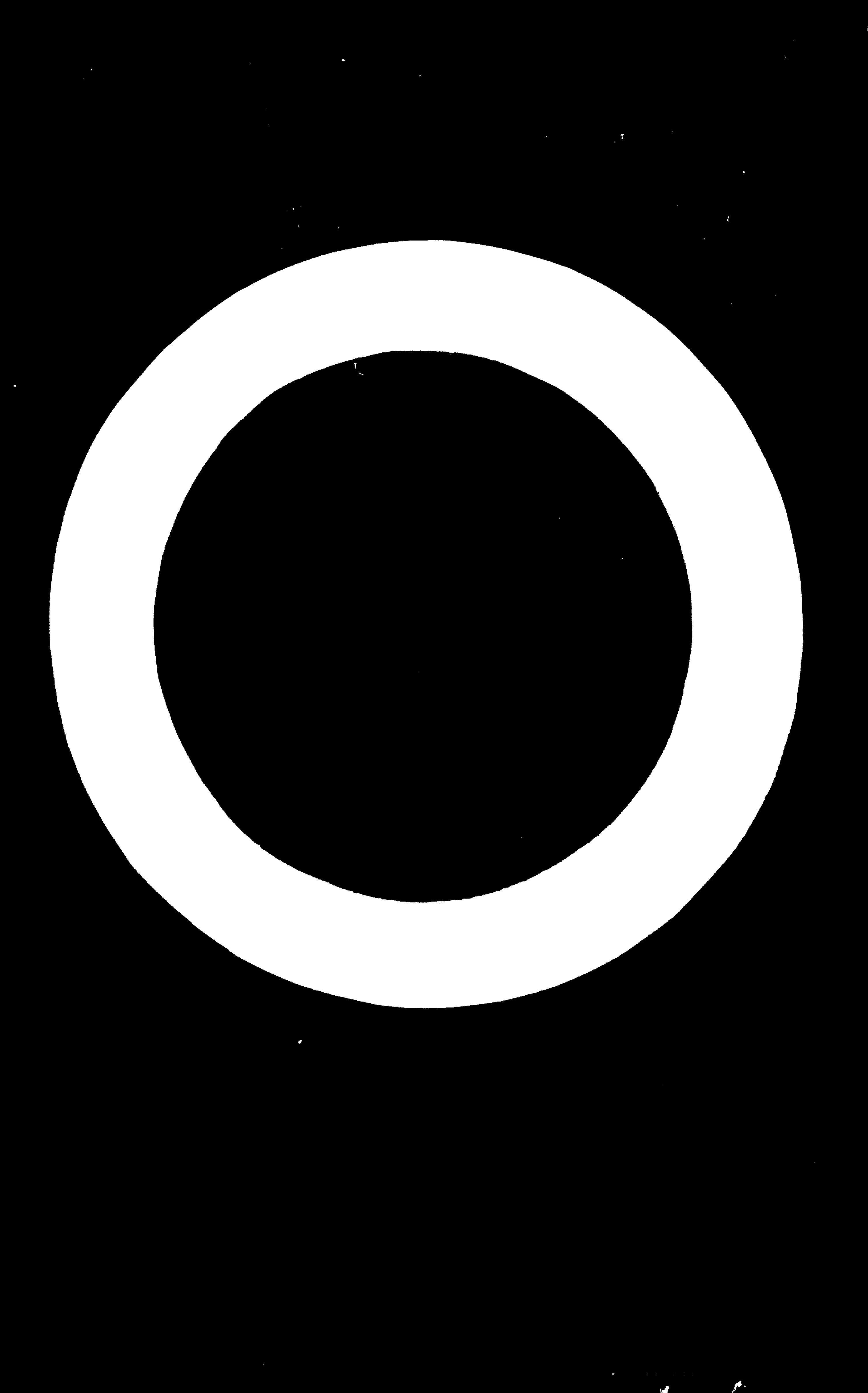

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SOME OBSERVATIONS ON THE FUTURE OF DIRECT REDUCTION FROM THE STANDPOINT OF PHYSICAL METALLURGY

Submitted by the Government of Belgium

(Prepared by Mr. P.H. Gielen,
Physical Metallurgy Laboratory,
Catholic University of Louvain, Belgium)

SUMMARY

Many difficulties have been encountered in introducing, consolidating and expanding the use of the so-called "direct reduction" methods in the iron and steel industry. This is probably due to the vast scale and large output of existing steelworks, which require substantial investments.

It is conceivable that, for scientific reasons of fundamental metallurgy, these direct reduction processes may soon supersede, partly or completely, the traditional foundry techniques. When that happens, the iron and steel industry will come to look quite different, steelworks will shrink to a more human scale, while their output will retain - it is to be hoped - its high competitiveness with other products.

The trials carried out with direct reduction in various part of the world seem to us a sufficient indication that technicians of real ability are tackling the problem. It will of course be for the steelmaker to apply the results of these trials on an industrial scale and to decide for himself which of the processes tested is the most economic and produces steel of the best quality.

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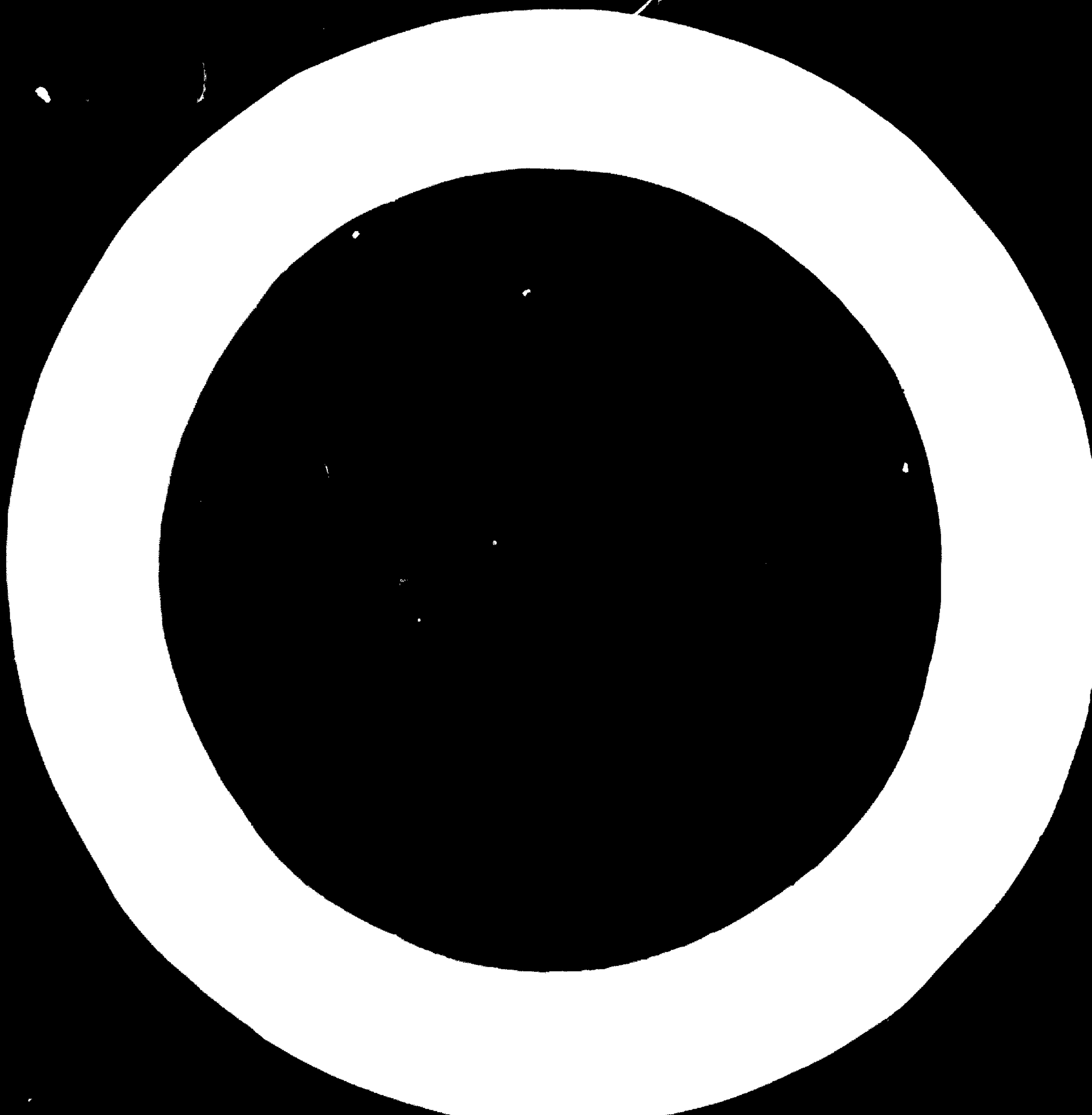

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THE NOVALFER PROCESS - ECONOMIC ASPECTS

Submitted by the Government of France

Prepared by Mr. G. Igounenc

Summary

The Novalfer process is a continuous direct reduction process for iron ores and oxides. It uses powdery ores, which are treated in fluidized beds. Fluidization of the ore is obtained by the circulation of the reducing gas, which is pure hydrogen or a mixture containing a high proportion of hydrogen.

The reduction of iron oxides to metallic iron is a balanced reaction in which the convention of the hydrogen to steam is incomplete and the non-utilized fraction is therefore recycled, apart from a small proportion which is removed from the reduction circuit to keep the concentration of impurities to a reasonable level. The reduction temperature is controlled to avoid ignition and calcination (particle agglomeration).

Selection of ore The Novalfer process is most suitable for:

- Ores found in the powdery state and readily fluidized, i.e. with a particle size between 50 and 500 or 100 and 1,000 microns.
- Ores with a low friability, a requirement generally better met by metamorphic than by sedimentary ores.
- Highly oxidized ores (e.g. hematite; other ores, such as magnetite, must first be roasted to complete their oxidation and improve their reductibility.

The effect of the Novalfer process differs according to whether the ore is pure or impure. With pure ores, the rate of reduction shows a marked decrease at temperatures between 650° and 750°, when the degree of reduction reaches 75 to 85 per cent. Ores containing impurities in molecular combination with the iron do not show this anomaly.

Effect of the degree of reduction Pure grade ores are generally used for the Novalfer process. It is therefore easy to achieve a degree of reduction of 75 per cent, but difficulties begin beyond that stage. Without going into a detailed explanation, it may be said that, with cooling followed by a second reduction stage, degrees of reduction in the region of 90 to 95 per cent can be achieved without difficulty.

Because of the need to use a two-stage process, the cost of the 92 per cent reduced product is obviously higher. The increase in cost compared with the 75 per cent reduction product is to be investigated in greater detail.

Effect of pressure Reduction under pressure offers several advantages:

- The section of the furnaces, piping and traps can be reduced, for the same capacity, in proportion to the increase in pressure.
- The compression ratio in the gas recycling can be lowered, thus reducing energy consumption.
- The partial pressure of the water vapour in the regenerated reducing gas can be decreased, thus raising reducing capacity.

These three advantages give a lower production cost for the reduced ore.

Effect of plant capacity Increases in the capacity of the reduction plant lead to a continuous decrease in costs.

Increases in the capacity of the hydrogen-producing units lead to a reduction in the cost of the reducing gas which takes place in several stages.

- At a capacity of 500-600 t/day of reduced iron, the reforming of natural gas or petroleum under pressure produces sufficient steam for the requirements of that process, including requirements for regeneration of the CO^2 adsorption liquors.
- At a capacity of 1,500 to 2,000 t/day of reduced iron, heat recovery, in the form of high pressure/high temperature steam, produces not only enough energy to make the process self supporting but more than covers the principal requirements.

Conclusion Direct reduction, which has been recommended for meeting demands substantiall less than the capacity of modern blast furnaces in the range of 50 to 200 t/day, for instance, could be adapted much more economically to the huge projects likely to be undertaken during the next ten years, such as the construction of reducing plants with a capacity of 10 million tons a year in Canada, Brazil, Africa and Australia.

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THE PUROFER PROCESS

Description - First Industrial Results - Heat Balance

Submitted by the Government of the Federal Republic of Germany

(Prepared by Messrs. H-D. PANTKE and G.H. LANGE, Thyssen Niederrhein AG)

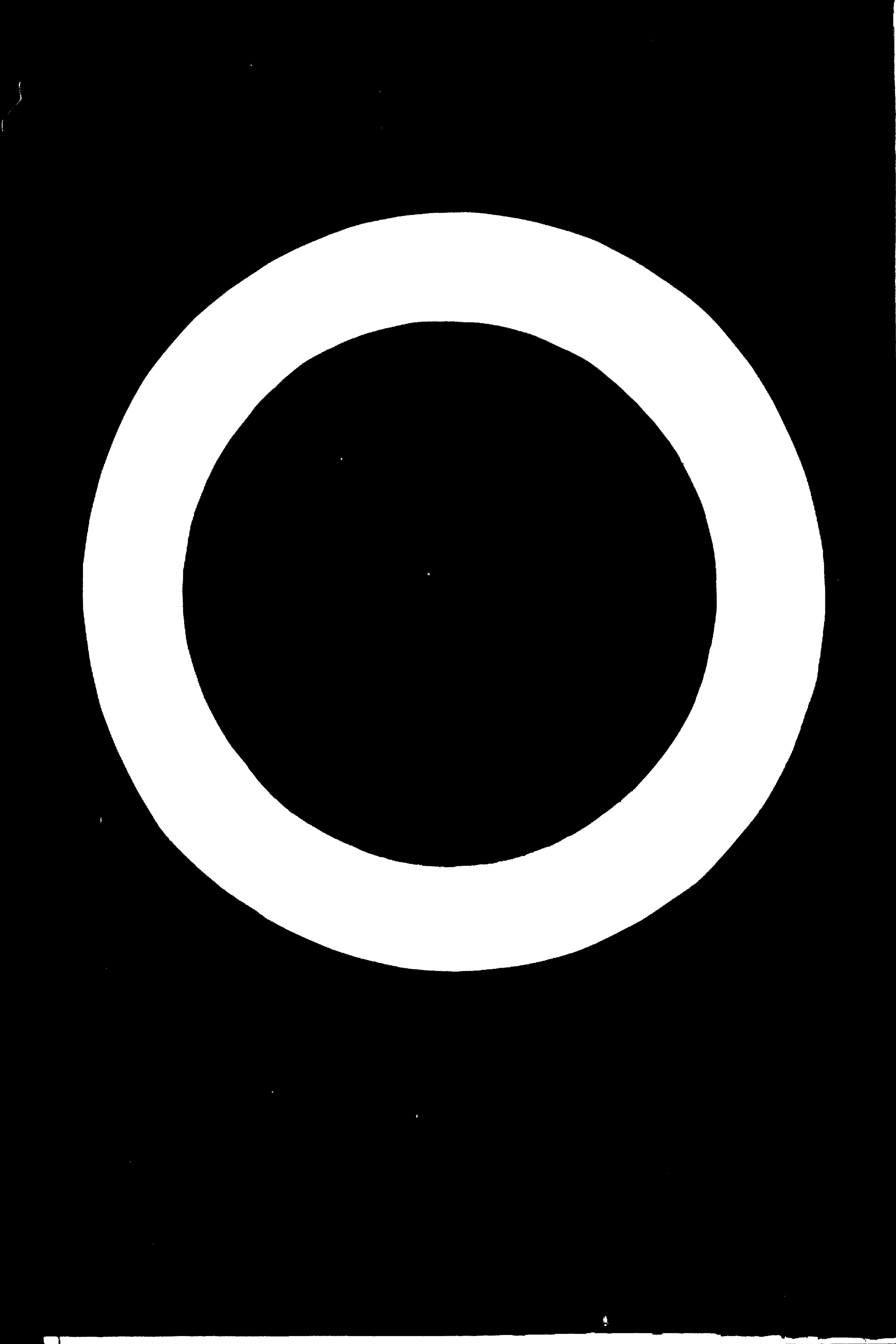
Summary

In the conventional blast furnace the source of process heat and at the same time, the raw material for the production of reducing gas is metallurgical coke, the price of which is increasing. Even now the cost of natural gas, referred to the thermal unit, is everywhere lower that the cost of coke.

In the PUROFER process natural gas is the raw material for the production of reducing gas and is the source of process heat. In this process the shaft furnace is similar to the upper region of the shaft of a conventional blast furnace - the cyclic operation requires two regenerators per shaft furnace. The temperature at which the reduction gases enter is determined by the reduction and softening behaviour of the ores and/or pellets charged and is of the order of 900-1000°C.

The process is not susceptible to small quantities of sulphur introduced into the system. Cooled PUROFER sponge iron is not pyrophoric and can be stored under cover indefinitely.

A report is given of operational experiences in the Oberhausen PUROFER plant and also a discussion of the comparative economics of the process and the 'heat balance' involved.



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ARMCO'S METALLIZING PROCESS

Submitted by the Government of the United States of America

Prepared by [illegible] MARSHALL
Armco Steel Corporation, Middletown, Ohio

SUMMARY

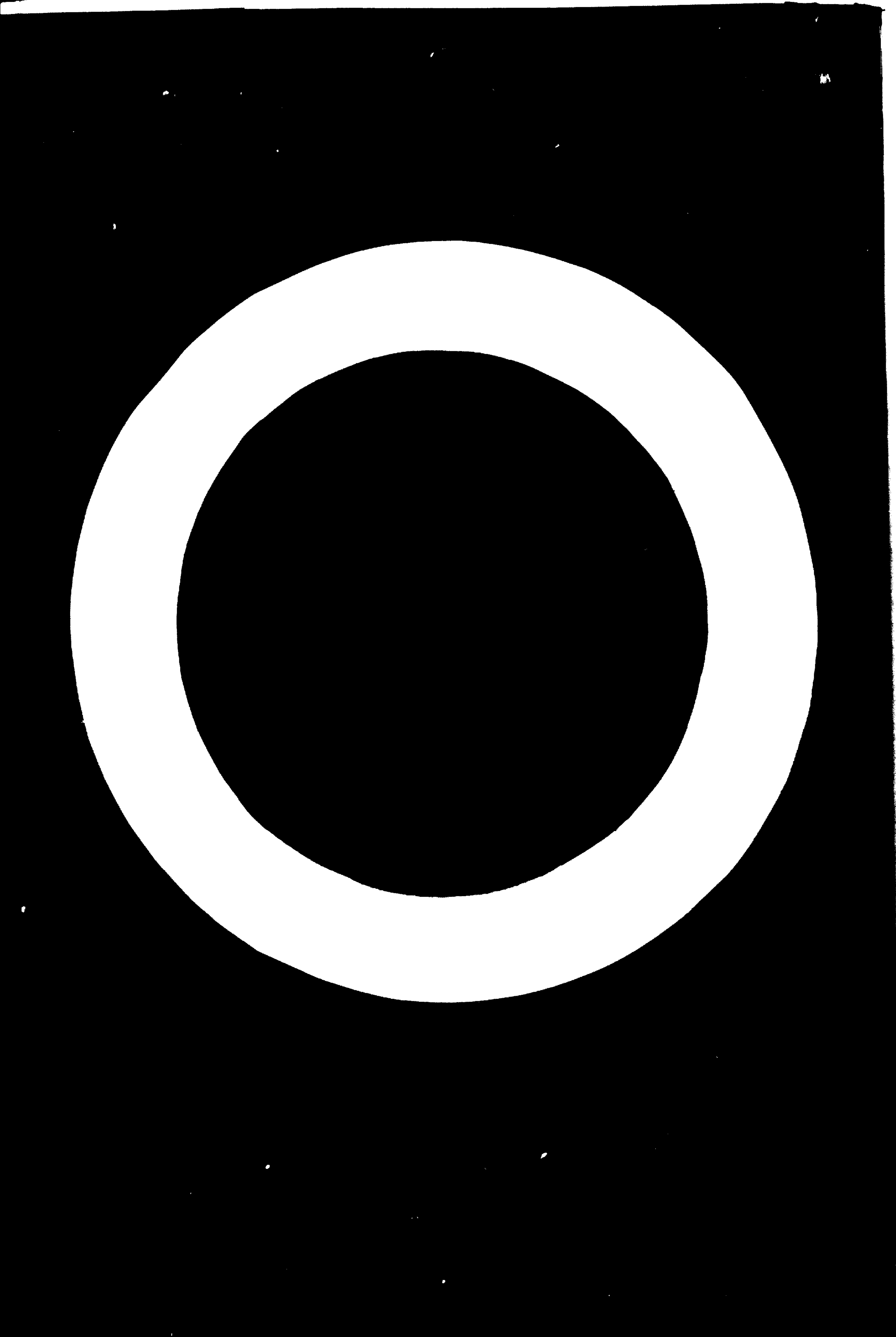
Oxide pellets and sized lump ores are metallized at 1600-1700°F, while moving downward through a shaft furnace counter current to hot reducing gases.

Natural gas was reformed in pebble stoves with recirculated top gas. This lowered the natural gas requirement to about 11 million BTU per ton of iron in the metallized product.

Over 3000 tons of metallized pellets were produced in the 50 ton per day pilot plant. The product contained about 92 per cent Fe, 2 per cent O_2, 1.5 per cent C and 2 per cent SiO_2. It was used to replace scrap in the electric steel melting furnaces, in amounts up to 30 per cent of the charge with good results.

A plant to produce 500 to 1000 tons per day is under construction at Houston, Texas. It is expected to reach a production rate in this range during the summer of 1972.

This plant will obtain its reducing gases by catalytic reforming of natural gas with steam in tubular reformers. The decision to use reformers rather than stoves was based on the earlier availability of materials for reformers, as compared to high temperature refractories for pebble stoves. Also excess steam generating capacity, available from the sensible heat in the reformer flue gases, provides power for pumps that recirculate gases and cooling water, at less cost than purchased electric power.



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CARBOTHERMIC PROCESS FOR THE REDUCTION OF IRON ORES

Submitted by the Government of Hungary

(Prepared by Mr. László Visnyovszky, MSc. metallurgical engineer
Dr. János Horváth, MSc. metallurgical engineer, Generaldirector
János Illyés, BSc. metallurgical engineer, Head of the Scientific Department)

SUMMARY

In the Hungarian Ferrous Research Institute detailed investigation into the effective process mechanisms and kinetics of reduction have been carried out to develop a direct reduction method of higher productivity with a simple process technology and lower investment cost.

The main point of the carbothermic process elaborated by the Institute consist in the conclusion that solid carbon reduces iron oxides more rapidly than CO or H_2 gas and that the reduction can be carried out in an inert atmosphere as well, for instance in nitrogen. The rate of reduction is independent of the ore type, i.e. hematite or magnetite.

In the paper the theoretical background of the carbothermic process and model experiments for the realization in practice are discussed.

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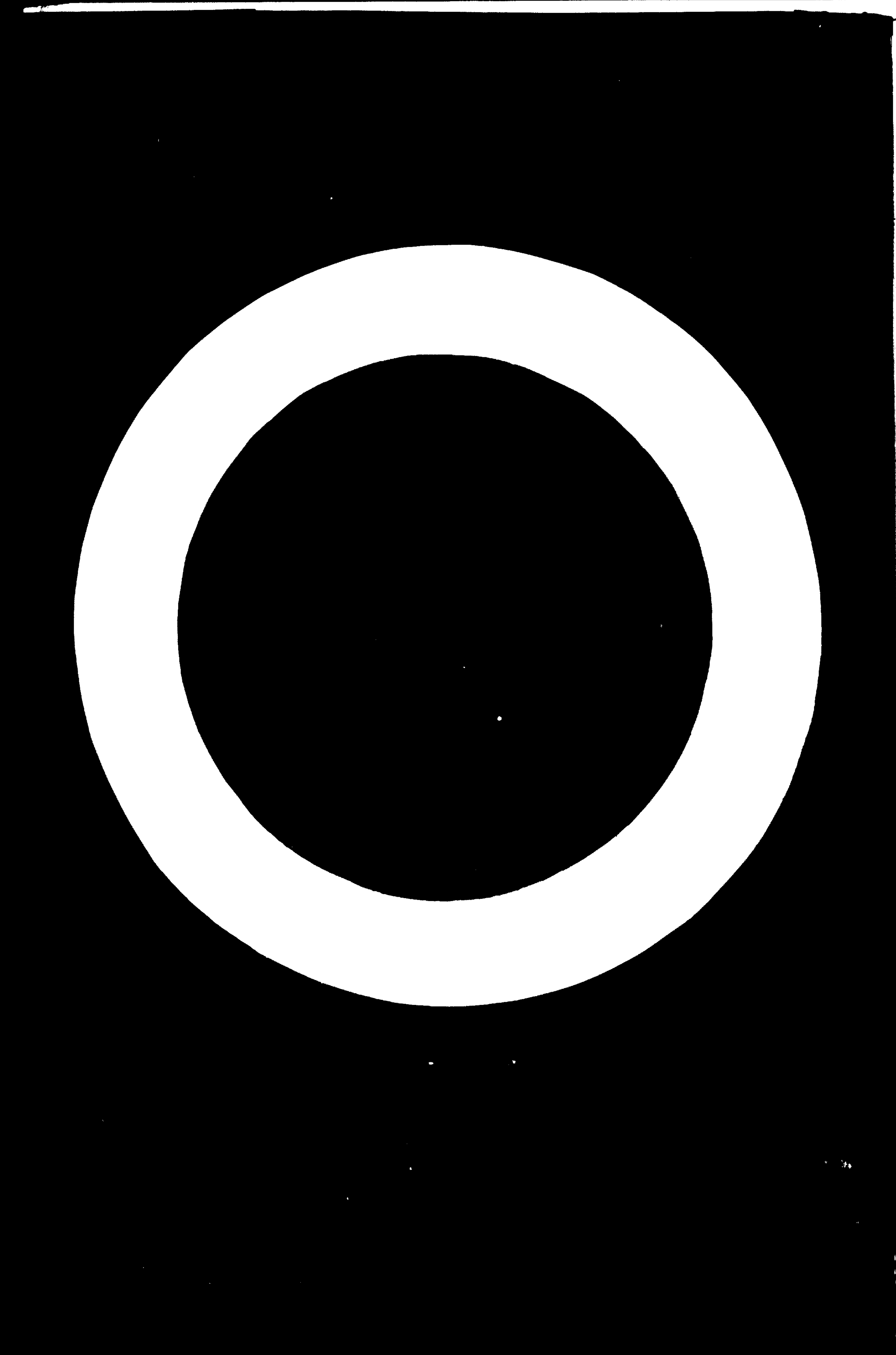

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THE MAKING OF FERROCARBON AND ITS USE IN THE REDUCTION OF FERRIC OXIDES

Paper submitted by the USSR

Authors: B.A. Borok et al

The principle properties required in a solid reducing agent are high reactivity and low sulphur and ash content. Most of the mineral fuels known and produced nowadays fall short of these requirements.

A new method of making sponge iron whereby ferrocarbon obtained by treating sponge iron or ferric oxides with natural gas is used as the reductant so as to accelerate the reduction process and reduce its temperature was proposed in the USSR in 1965. This method is based on the use of ferrocarbon instead of the agents commonly employed for reducing iron ore.

The paper examines various processes for making ferrocarbon. Optimal temperatures for these are established. The properties of ferrocarbons made from different iron-containing raw materials are investigated. The process of making ferrocarbon by decomposition with natural gas is examined and a comparative analysis of the production of ferrocarbon on clinker is given. The grounds for the choice of plant to make ferrocarbon are stated. Technical and economic data on the production of iron powder by reduction with ferrocarbon are quoted.

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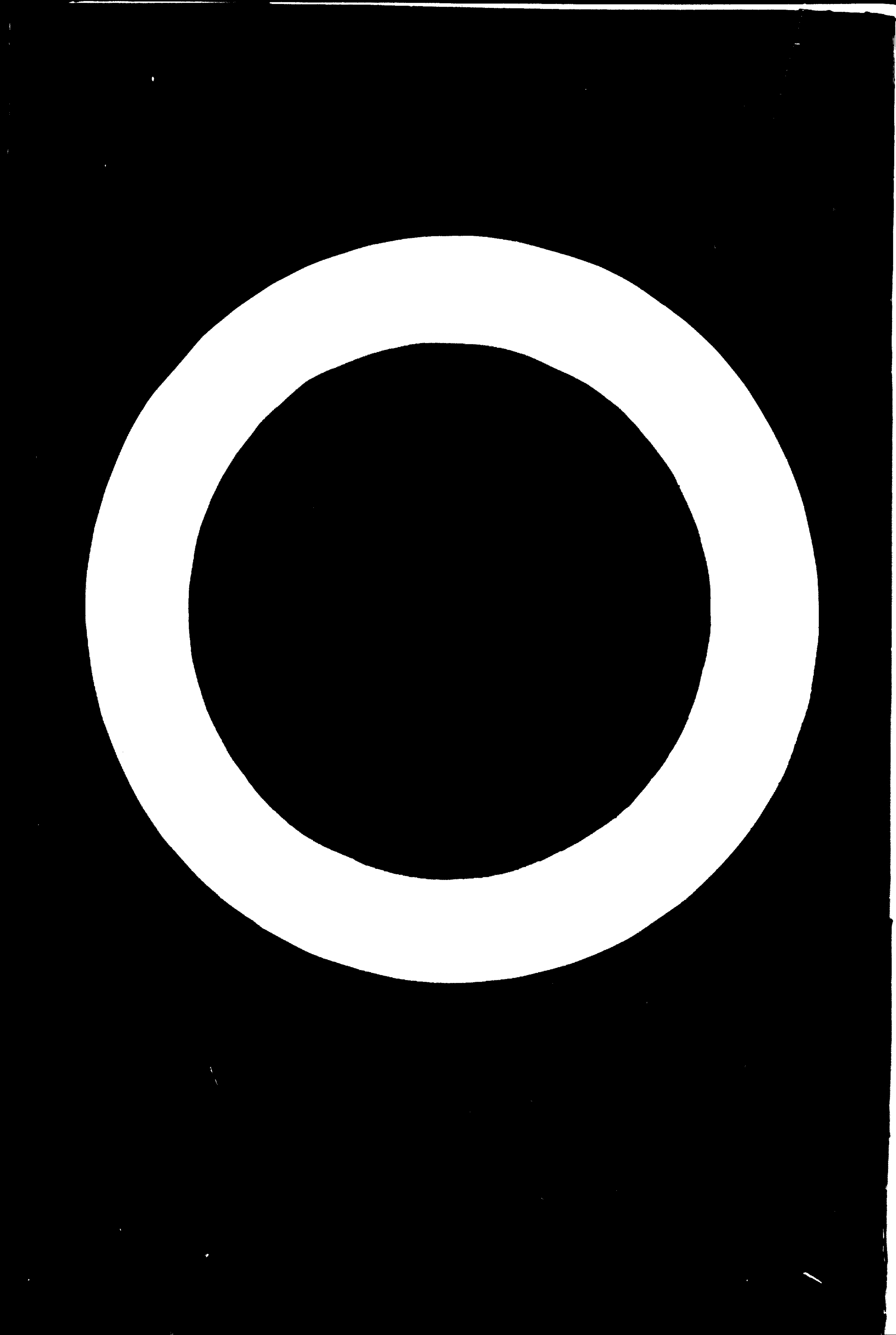

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EVALUATION OF PROCESSES OF DIRECT REDUCTION OF IRON ORES, TRENDS IN THEIR DEVELOPMENT AND FUTURE PROSPECTS

Paper submitted by the USSR

Authors: A.I. Gimmelfarb and A.N. Semenov

SUMMARY

Conditions for the development of processes of direct reduction of iron:

Changes in the development of the basic fuel and energy resources of the iron and steel industry;
Limitation of resources of scrap of guaranteed purity, stable composition and cost;
Improvement in the quality of steel smelted from products of direct reduction of iron ore;
The possibility of organizing small-scale iron and steel production (construction of mini-plants).

2. Brief description of the present state of processes of direct reduction of iron ores.

3. Technical and economic evaluation of processes of iron-ore reduction.

Making sponge iron and metallized crude iron;
Making liquid metal;
Use of products of direct reduction of iron ores in pig-iron and steel smelting.

4. Trends in the development of processes of direct reduction of iron ores:

Growth of production capacities and progressive increase in outputs of sponge iron (metallized pellets);
Expanding use of sponge iron in steel smelting;
Attempts to develop new high-temperature processes for making iron directly from ores;
Evolution of technological systems of iron ore reduction with atomic energy.

5. Prospects of development of processes of direct reduction of iron ores.

In the short term (until 1980);
In the longer term (1990 to 2000).

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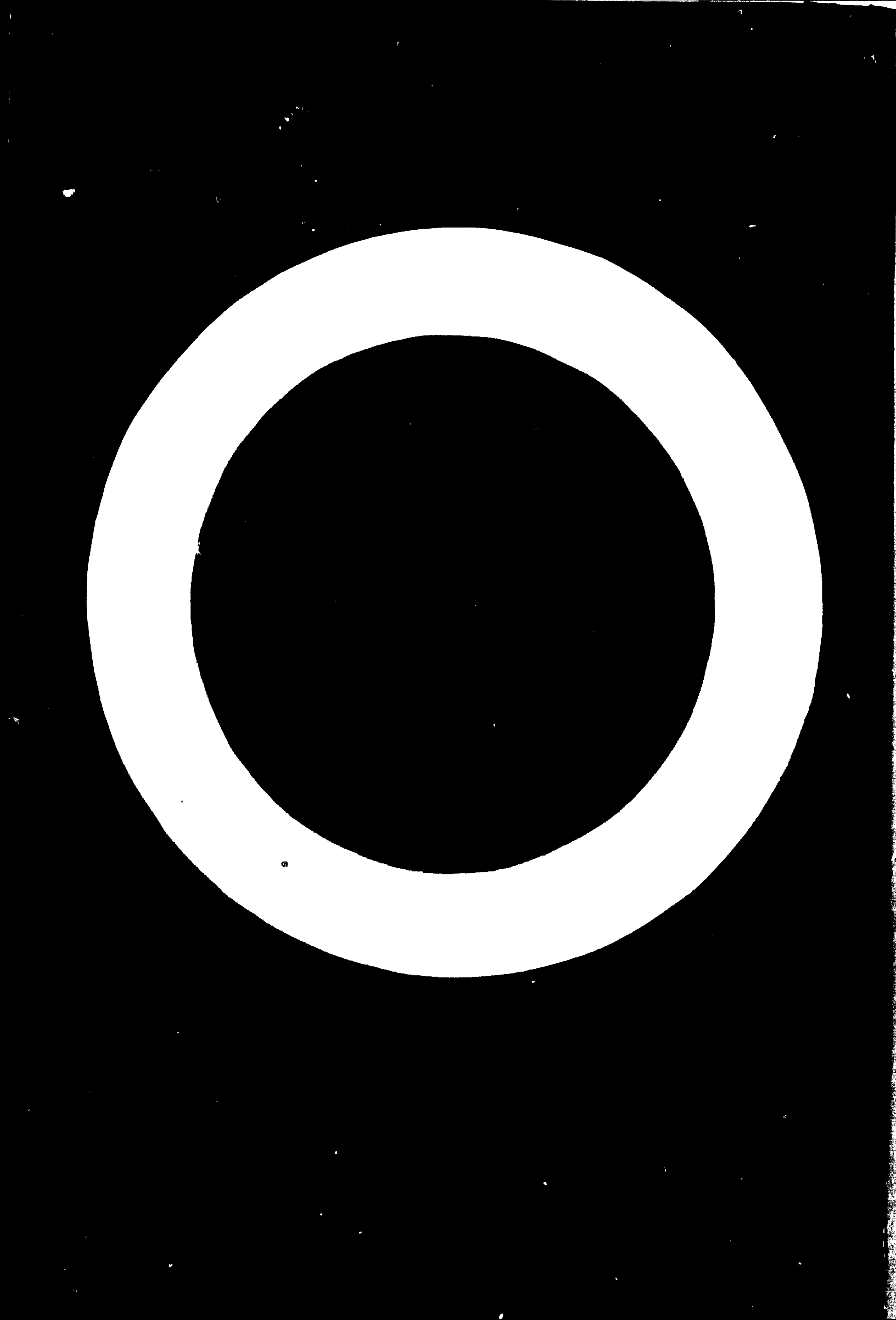

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SEMINAR ON DIRECT REDUCTION OF IRON ORE: TECHNICAL AND ECONOMIC ASPECTS
Bucharest (Romania), 18-23 September 1972

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THE HYL DIRECT REDUCTION PROCESS - PAST, PRESENT AND FUTURE

Submitted by the Government of the United States of America

Prepared by R. Lawrence, Jr.

SUMMARY

The full text of the paper covers the history of the HyL Process, its chronological development to date, and current prospects. It also details the operating data for the plant at Puebla, Mexico, for the 22 months of operation from May 1970 to March 1, 1971.

It emphasizes the necessity for, and persistent lack of, operating data to assist those evaluating the current process contenders.

The following specific information is reported:

1. HyL plants have produced 4,163,100 tons of reduced iron ore and pellets since 1960 from which 5,150,000 tons of steel have been produced in electric furnaces.

2. The Puebla plant, which, since May 1970, has been operating on high grade oxide pellets, has produced a total of 484,550 metric tons of reduced pellets in a period of 22 calendar months from May 1970 to March 1, 1972. The annual average production was 264,300 metric tons.

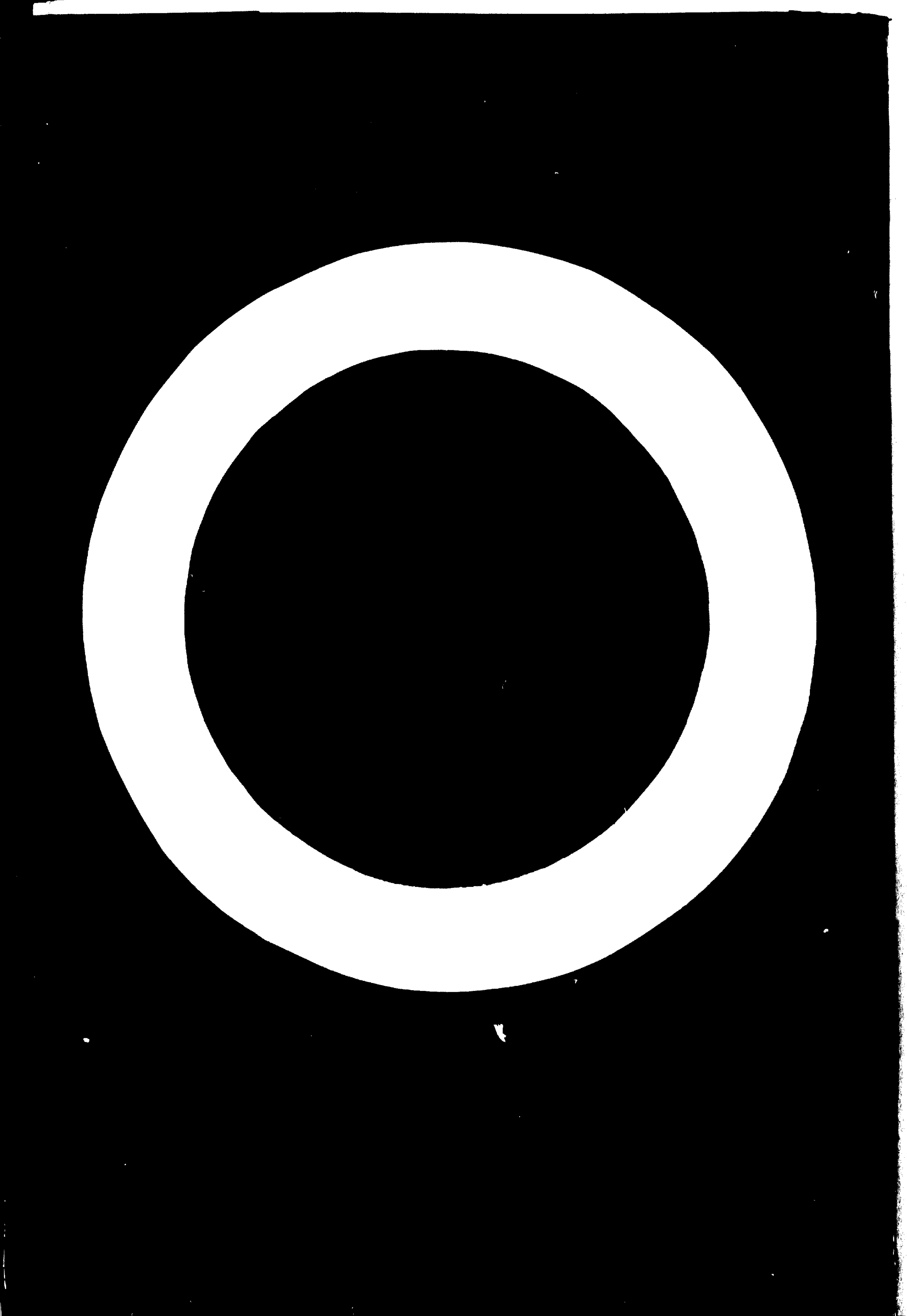
   The annual rated capacity of the plant was 228,000 metric tons. The average production for 670 calendar days was 723 metric tons per day. The plant has operated at 116 per cent of rated capacity for 22 consecutive months.

3. The process can produce metallics ranging from 70 per cent metalization to 95 per cent. The product is non-pyrophoric, and 69,870 metric tons have been shipped during the 22 months covered by the report in open gondola rail cars without protection from the elements, with minimum loss of metalization.

4. There are 22 geographical locations for which HyL installations are under consideration, with a total annual rated production of 10,400,000 metric tons of reduced product. Seven of the proposed locations will use naphtha as the source of reductant and fuel. The smallest installation is rated at 200,000 annual tons; the largest, at 1,650,000 annual tons.

5. A full description of the process is given.

6. Larger individual reactor sizes are now feasible.



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GENERATION OF METALLURGICAL REDUCING GAS

Submitted by the Government of Italy
(Prepared by Mr. Kenneth D. Demarest, Foster Wheeler Corporation)

Summary

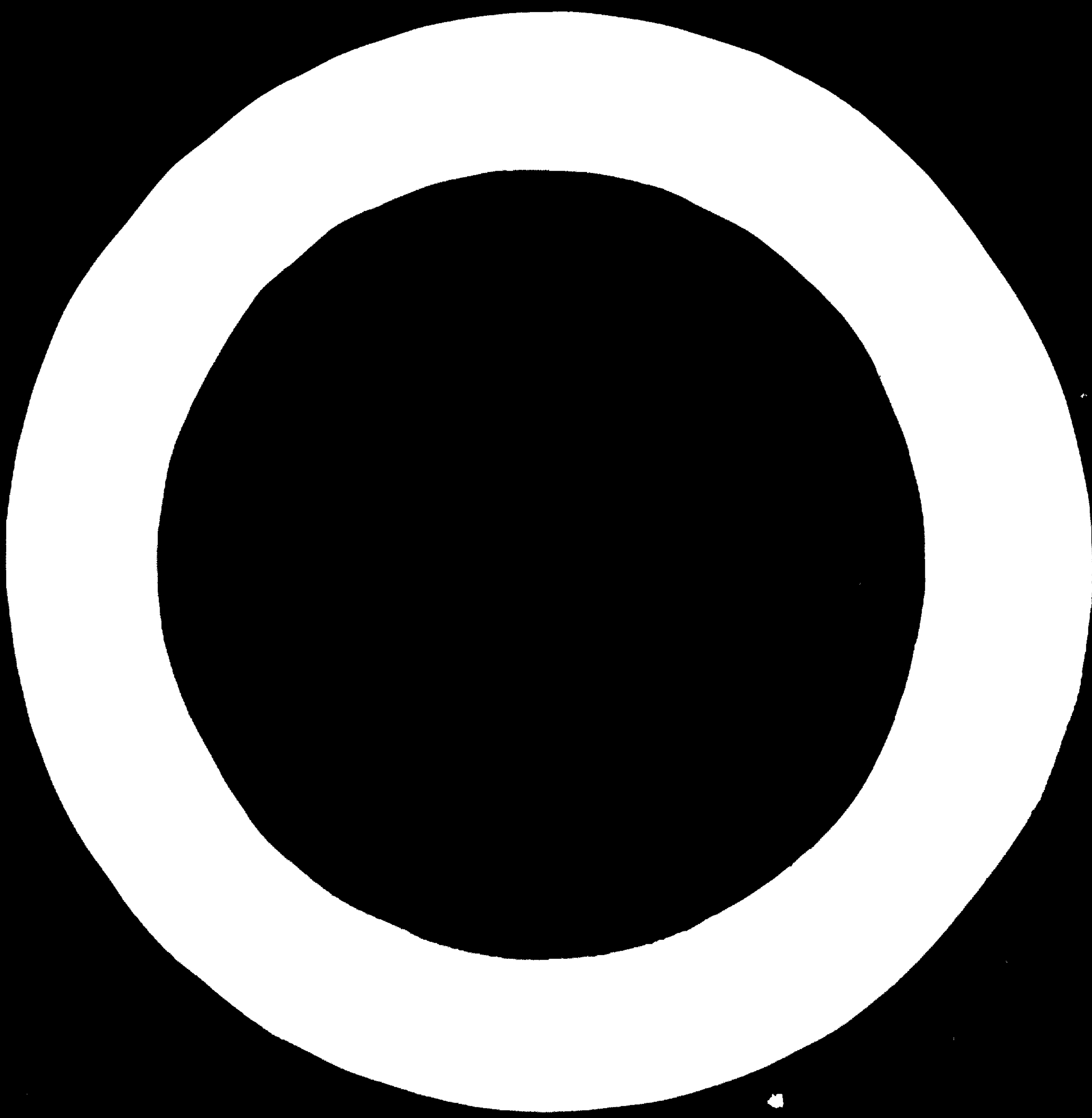
Growing interest in direct reduction of iron ores focuses attention on means of generating reducing gas. Expresses intention of reviewing technologies reflecting use of petroleum derived hydrocarbons as well as coal and coke.

REDUCING GAS REQUIREMENTS

Present and discuss the thermodynamic criteria of reducing gases and quality level required.

REDUCING GAS GENERATION

First reviews coal and coke methods presently used. Then describes development and technological basis of partial oxidation and steam hydrocarbon reforming, both applicable for generating reducing gas from petroleum derived hydrocarbons. Means of adaption and operating requirements for generating suitable quality gas are established.



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THE INCREASING PRODUCTION AND USE OF DIRECTLY-REDUCED IRON ORE:

Forecasts for 1975 to 1985

Submitted at the invitation of the Government of the host country

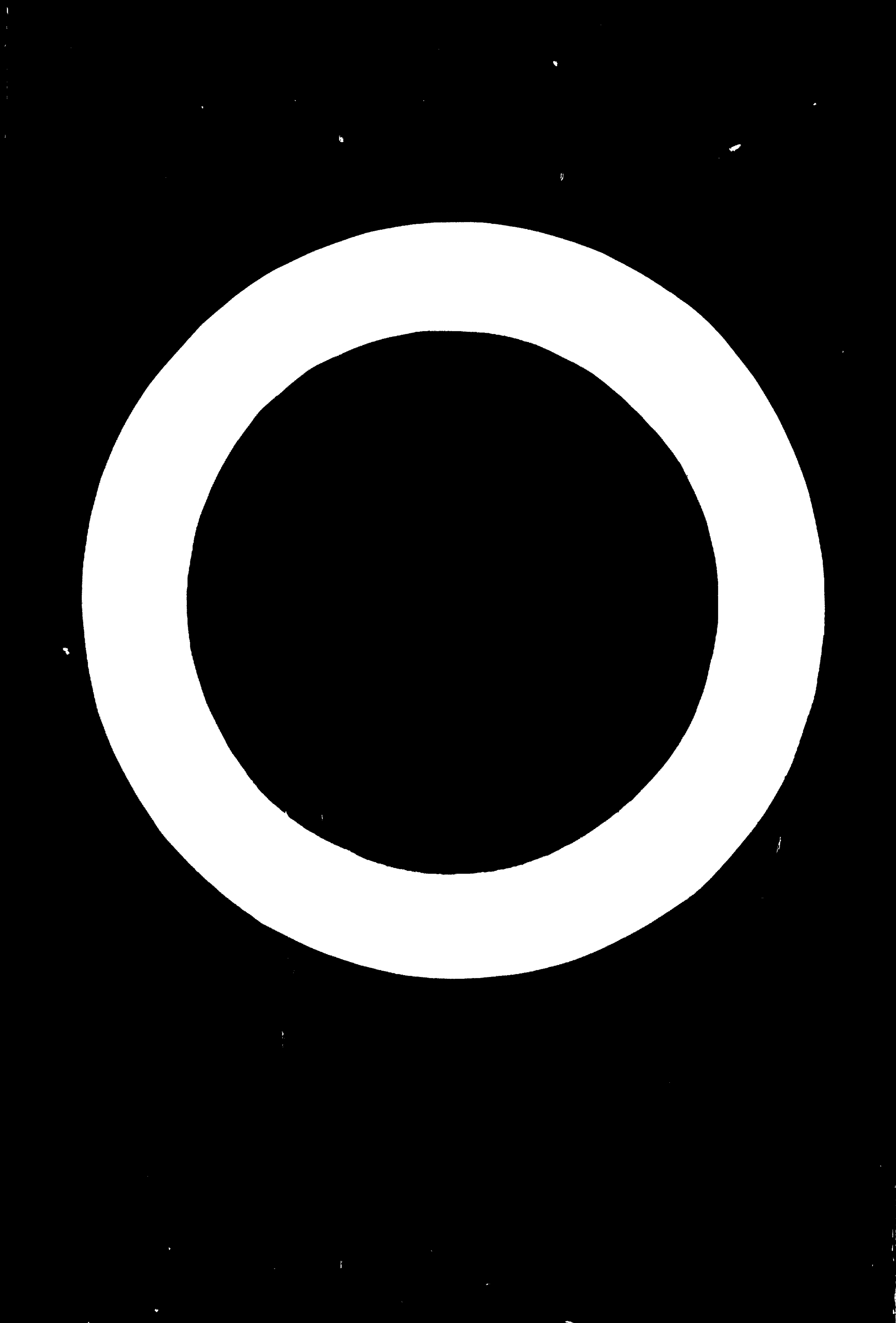
Prepared by Mr. Jack Robert Miller
Iron & Steel Industries Consultant
Columbus, Ohio

SUMMARY

This paper contains a review of the present state of the direct reduction development in the steel industry, worldwide, and forecasts that global raw steel production and consumption will reach a total of 7[illegible]5 million tons in 1975, 915 million tons in 1980, and 1015 million tons in 1985.

Incidental to this growth in worldwide steel output and use are pressures for raw materials -- iron ore, pig iron, scrap, coking coal, fuel, and energy -- which in nearly all cases support the need for prereduced iron ore. The early development of a fully viable prereduction technology is therefore essential and inevitable.

The potential demands for prereduced materials are estimated at 11 million tons in 1975, 64 million tons in 1980, and 124 million tons by 1985.



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SL/RN PROCESS - PRODUCTION OF SPONGE IRON USING SOLID REDUCTANTS

Submitted by the Government of the Federal Republic of Germany

Prepared by Dr. H. SERBENT Dr. W. [illegible]
LURGI CHEMIE UND HÜTTENTECHNIK G.m.b.H.

SUMMARY

The SL/RN Process is a method of producing sponge iron with solid reductants in a rotary kiln. It was developed by joint effort of the Steel Company of Canada Ltd., Lurgi Chemie und Hüttentechnik GmbH., Republic Steel Corp., N L Industries Inc., and has, in the meantime, been introduced on an industrial scale.

The reactions taking place in the ore/reductant burden passing the kiln can be described as the interaction of two partial reactions which, when combined, result in direct reduction of FeO:

(a) $FeO + CO \rightleftharpoons Fe + CO_2$

(b) $CO_2 + C \rightleftharpoons 2\ CO$

(c) $FeO + C \rightleftharpoons Fe + CO$

The reduction capacity is essentially influenced by the reactivity of the solid reductant applied so that the selection of the correct type of reductant is of paramount importance.

The following factors are especially important for an optimum application of the process: quantity and quality control of raw materials supply, correct relationship of heat supply and feed rate, filling degree of kiln and mixing properties of the individual components.

The SL/RN Process enables a great variety of different raw materials to be applied. Optimum feed materials are lump ores and indurated pellets. Concentrate fines are normally pelletized prior to reduction, the pellets being hardened by using part of the heat contained in the rotary kiln waste gas. In some special cases, it is also possible to directly feed fine ores.

Sponge iron reduced according to the SL/RN Process is an excellent feed material for steel-making. Its composition depends on that of the raw ore. In spite of its porous structure, it is not pyrophoric and is virtually not subject to reoxidation when stored in dry condition.

So far five plants have been built for a total ore throughput of 2.2 million tpy. The sixth plant is under construction. In connexion with the start-up of these plants, the following problems had to be solved:

1. Adaptation of machinery and equipment as well as operating conditions to the actual raw materials properties which varied in most cases from those available for previous tests.

2. Control and stabilizing of raw materials conditions.

3. Modification of the rotary kiln heating system aiming at avoiding local overheatings and formation of accretions.

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SOME CONSIDERATIONS ON THE REDUCTION OF BLENDED IRON ORES IN FLUIDIZED BEDS AND THE UTILIZATION OF HIGH DENSITY BRIQUETS OF PREREDUCED MATERIALS

Submitted by the Government of ITALY

Prepared by Messrs. A. Di Candia, G. Litigio - Italsider S.p.A

SUMMARY

The Authors have taken into consideration the most favourable conditions for the reduction of blended iron ores in fluidized beds.

It has been evidenced that the linear velocity of the fluidizing gas is affected in a rather limited measure by the different densities of the ores in the blending. It appears appropriate to achieve the reduction in two subsequent stages using hydrogen or a reducing gas with a high hydrogen content and a reduction temperature of about 570°C. The grain size should be about 1 mm. The reduction pressure should be determined by trial within the range of 2 - 16 atm.

By briquetting the prereduced blended fines having a vast total specific area, high density briquets will be obtained. These briquets when used in the burden of a submerged arc furnace, will reduce the volume of the high electrically conductive burden components, with a considerable advantage for the operating conditions.

These briquets, when used in the blast furnace, will greatly contribute to achieving a very high productivity.

Finally, a hypothesis was put concerning the most rational blast furnace profile operating with a high percentage of prereduced components in its burden and it was expressed the opinion that such a profile would not differ from the profile of a traditional blast furnace.

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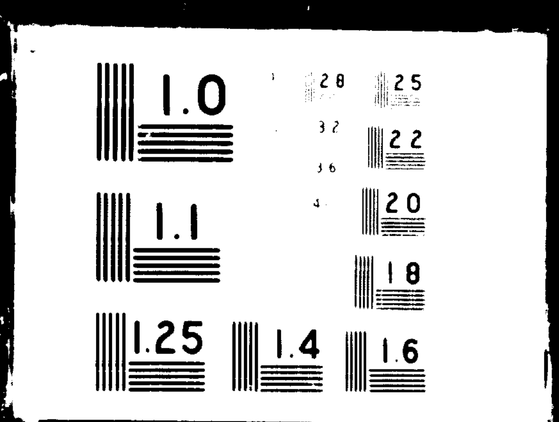

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THE KRUPP SPONGE IRON PROCESS - ITS PRODUCTS AND APPLICATIONS

Submitted by the Government of the Federal Republic of Germany

Prepared by:

Dr.-Ing. Günter Meyer, KRUPP Industrie- und Stahlbau, Essen
Dr.-Ing. Rolf Wetzel, KRUPP Forschungsinstitut, Essen
Dr.-Ing. Uwe Bongers, KRUPP Industrie- und Stahlbau, Essen

SUMMARY

Interest in the direct reduction process 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 authors describe the essential features of the KRUPP SPONGE IRON PROCESS based on lump ores, fine ores and concentrates. Krupp's semi-commercial pilot plant, consisting of a combination of travelling grate and rotary kiln, is described and its operation explained with reference to the processing of a hematitic concentrate. The experience gained in processing a wide variety of raw materials is dealt with in detail. 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.

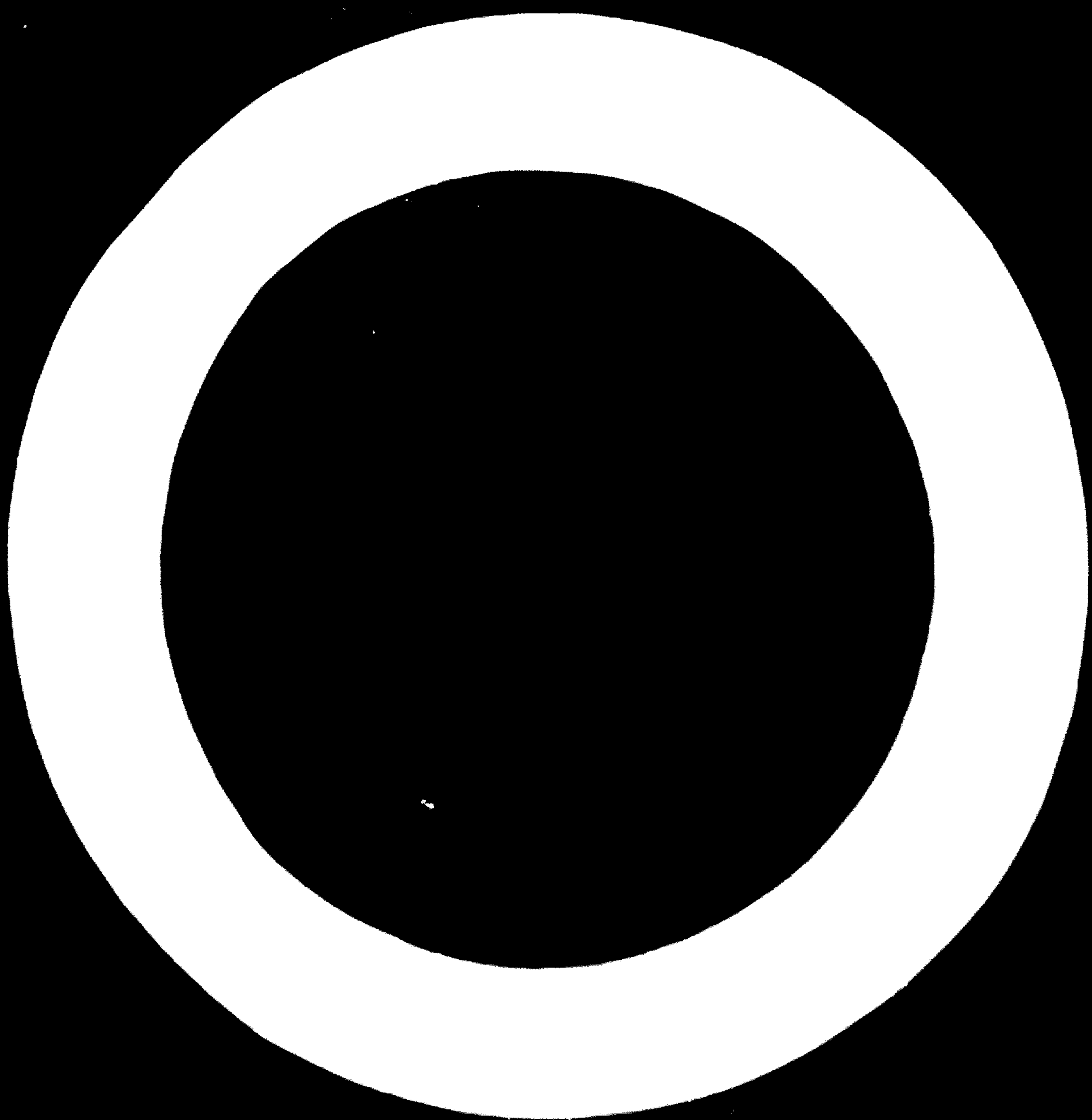
The fact that the use of sponge iron can be of advantage for the various steelmaking processes, and more particularly the electric steelmaking process, is now generally recognized. Nevertheless, one should not overestimate the potential for increased production, especially where steelmaking operations are already largely optimized.

Criteria to be considered in assessing the comparative merits of sponge iron in relation to scrap as melting stock are discussed.

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 per cent or 13 per cent 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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SESSION II - RAW MATERIAL AND ENERGY SITUATION FOR DIRECT REDUCTION

INTRODUCTION OF PAPERS AND SUMMARY OF TOPICS FOR DISCUSSION

Prepared by

Messrs. J.W. Shea and H.A. Jansen, Union Carbide Europe, S.A. (United States)

1. There are ten papers to be presented in this session. These provide a great amount of very useful information on general and specific energy requirements, including availability and costs, methods of producing reducing gases, including consideration of the kinetics and thermodynamics, relationship of direct reduction processes to ore properties, as well as the technological causes and methods of prevention of oxidation of reduced product. Descriptions of the various processes and factors influencing selection are given.

2. It seems logical to divide these papers into three general groups, the first dealing with general energy requirements, the second with reducing gases and the third with iron ore, and reoxidation, as follows:

GROUP 1

Paper II-1, by J. ASTIER, D. CASA, JON AND SCHNEIDER, France, "Energy in Pre-reduction Processes and Various Dies in Steelmaking".

Paper II-3, by A. ANTONIOLI, Italy, "Diversification of Energy Sources for the Iron and Steel Industry".

Paper II-2, by W. WENZELL and F.R. BLOCK, Federal Republic of Germany, "Long Term Trends in the Process Technological Application of Nuclear Heat to Iron Making".

GROUP 2

Paper II-11, by H.D. PANTKE and G.H. LANGE, Federal Republic of Germany, "Requirements Governing the Composition of Reducing Gas for Iron Ore Reduction".

Paper I-12, by K.D. DEMAREST, Italy, "Generation of Metallurgical Reducing Gas".

Paper II-8, by S. SPARCHEZ, L. SZABO and A. PALFALVI, Romania, "The Use of Methane in the Reduction of Iron Oxides".

Paper II-9, by O. HATARASCU, Romania, "Study of Iron Ore Reduction by Gases Derived from Conversion of Methane with CO_2".

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GROUP 3

Paper II-5, by U. KALLA, H.J. KÖNIG, G.H. LANGE and H.-D. PANTKE, Federal Republic of Germany, "Processes for the Direct Reduction of Iron Ores in Relation to Ore Supplies".

Paper II-10, by H. KNOP, H. NAGEL and W. THUM, Federal Republic of Germany, "Reoxidation in Connexion with the Storage and Transportation of Metallized Ore".

Paper II-6, by H.W. GUDENAU, W. WENZEL, H. LUSSI, H. BECKER and G. REUTER, Federal Republic of Germany, "Plastic as a Protection Against Reoxidation of Sponge Iron".

GROUP 1

3. All processes to make iron and steel require the expenditure of energy. In addition to considering which forms of energy are suitable, and the requirements of the process, it is necessary to consider availability and price, as well as the influence of the steel industry itself, which is not only expanding, but changing its structure. The papers in this group present a broad review of the various prereduction and steelmaking processes and their energy requirements, the world energy situation and short and long range trends which, it is hoped, will help bring this very important subject into more perspective.

4. Paper II-1. In their paper, ASTIER and his colleagues review the worldwide evolution of energy consumption and trends by different types. While the rate of increase per year in energy consumption has been declining slightly, it is still expected to be more than 4 per cent in the next decade and between 3 and 4 per cent up to the year 2000. It is also noted that total energy requirements per ton of steel are declining and changing in source materials.

5. The authors first evaluate the energy balance of a plant operating with the classical steelmaking method of blast furnace and basic oxygen converter, and report exceptionally low energy consumption, blast furnace iron being produced from rich ores using 370 kg of coke and 100 kg of fuel oil per ton. Overall energy consumption per ton of finished steel, including reheating, rolling, etc., is given as 5.2 Gcal/ton. It is noted that this figure is 22 per cent less than the national average in France in 1969.

6. In their evaluations of the various direct reduction systems, the authors give informative and valuable background information and process descriptions, pointing out that the comparisons are limited to those processes already in production and/or in an advanced state of development. In establishing the energy balances, difficulties were encountered because of different energy sources, types of ores, types of prereduced materials, local conditions, availability of information, etc. The authors therefore caution that too great importance should not be attached to the quantitative comparisons of data.

7. After establishing, and in some cases, estimating the energy balances for the direct reduction processes, the authors then compare these, on the basis of liquid steel production, with the classical system. Data are also given, based on mathematical model studies, of the anticipated energy requirements if 45 per cent of prereduced materials are charged in a blast furnace.

8. These comparisons show that energy requirements for the direct reduction/electric arc furnace systems are slightly higher than for the classical system, but the authors comment that further development of direct reduction processes will reduce energy consumption to the point where it should be just slightly higher than the best figures for the classical system.

9. The authors conclude that with the rapid development of the direct reduction processes, modern steelmaking is oriented toward two parallel and complementary paths, the classical system and direct reduction/arc furnaces. All of these developments will benefit the steel industry with respect to the energy situation.

10. As the authors have stated, the energy consumption for the classical method is approaching the theoretical minimum. An important consideration here is that while blast furnace efficiency has improved substantially in the past 15 years, the process itself has been in large scale production without major basic changes aside from capacity per unit, for well over 100 years. It can be said, therefore, that a basic process has been progressively refined over the course of many years.

11. In contrast, direct reduction is still relatively young in terms of production units and since technology and improvements based on operating experience will continue, including, very likely, the benefits of scale through larger units, more efficient operations will evolve. It must also be pointed out that, in the comparison of energy requirements, an exceptionally efficient classical example is used.

12. It should be noted that in Paper I-2, by MASCHLANKA et al, presented in Session I of this Seminar, energy requirements of an operating direct reduction/electric arc furnace steel plant are quoted as nearly the same as for a conventional plant. Applying actual prices to the types of energy, however, puts total energy prices lower than the conventional plant.

13. Paper II-3. In his paper, ANTONIOLI reviews the shortage and increasing price of coking coal, which he ascribes mainly to the great expansion of the Japanese steel industry, increased demands for all kinds of energy and greater use of low sulphur coals by electric power stations to reduce air pollution. It is estimated that the cost of blast furnace coke may reach $ 50 a ton by 1980.

14. In reviewing the relative cost of alternative fuels, the author points out that the natural gas calorie now costs 40 per cent of the coking coke calorie, but that world reserves may only last about 45 years at the present level of demand, or possibly less than 20 years with increasing demand. This should bring the steel industry to very serious consideration of alternative fuels and, among these, one which shows a great deal of promise is the use of nuclear energy.

15. In connexion with the availability of uranium, the author believes that sources have been inadequately described and important new deposits are now in process of discovery. In addition, if the extraction costs of uranium go up only slightly, it is to be expected that the supplies will increase dramatically.

16. In evaluating the various ways of using nuclear energy, the production of hydrogen from water electrolysis seems to be the best, although present comparative fuel costs put this development many years away. For the next 20-30 years, although there are

still problems to be solved, a necessary option appears to be to use part of the nuclear heat to produce hydrogen from natural gas for use in fluidized beds to reduce iron ores, the prereduced product being converted to steel in electric arc furnaces.

17. From the standpoint of economics, such a steelmill should be a completely integrated plant where all of the power produced is utilized within the mill. It must therefore be large enough for the minimum economic size of nuclear reactor. This means an annual production of about 3.5 million tons of steel, and operation at a very high load factor. For such a plant, six UHP arc furnaces charged with hot prereduced material plus 20 per cent return scrap are contemplated, each furnace producing 75 tons of liquid steel per hour.

18. The author gives an economic comparison of steel costs of the classical method compared with nuclear reduction/arc furnaces and shows that, with coke costing from $ 21 to $ 27 per ton, nuclear steel would be cheaper than conventional. As coke prices increase, the savings will become greater. If coke costs $ 35 per ton, the cost of steelmaking by this concept would be from $ 3 to $ 5 less per ton than by the conventional process and these savings could go as high as $ 5 to $ 10 per ton if the price of coke became $ 50 per ton.

19. The author believes that the cost of nuclear energy will remain much more stable than that of other energy sources, particularly coking coal and that uranium could therefore be in a position to control the price of coking coal. If this technology should proceed, it would be expected that the conventional blast furnace route would probably be confined to areas nearer to coking coal deposits and, as pointed out by ASTIER et al, in Paper II-1, the net result would be that this proposed system and the classical system would complement each other.

20. In his paper, the author presents a very comprehensive and well documented report, which should arouse considerable interest and questions. One question concerns the investment costs quoted. It seems that $ 47 per ton for the conventional system is very low, even if coke is to be purchased and that the differential in favour of the nuclear steelplant could be greater than shown. In view of the worldwide concern with air and water pollution, the author's comments on these points and whether the cost of such equipment is included in the investment figures, would be welcomed.

21. <u>Paper II-2</u>. In this paper Messrs. WENZEL and BLOCK point out that reduction of iron ore requires large amounts of energy and that, while heat from fossil fuels can be obtained cheaply in some areas of the world, not all of these fuels are suitable for iron making. In particular, the blast furnace requires coke which is not only costly to produce, but which cannot be obtained from every kind of coal. It is to be expected that all types of fossil fuels will increase in price in the future, in the case of natural gas and oil due to limited resources and in the case of coal due to increase in the cost of mining.

22. It therefore becomes necessary to investigate other sources of energy, an obvious possibility of which is nuclear energy. Probably the best method of utilization of this type of energy would be in the electrolysis of water into hydrogen and oxygen, but this will become practical only after the development of electrolysis cells of low capital

investment and a high degree of efficiency. Even now, however, the cost of nuclear energy is quite low when compared with other fuels, which will accelerate the development of reactors which can reach suitable high gas temperatures. The successful application of nuclear heat energy for industrial processes is considered so important that research work is being carried on all over the world.

23. In considering this process route for steelmaking, the authors point out, as does ANTONIOLI, the possibility of using nuclear reaction heat for gasifying oil, methane and lignite, to be used in shaft furnaces or fluidized beds for ore reduction with the electrical energy created used for melting the sponge iron by electric arc furnaces.

24. The possibility of using reduction gases in the blast furnace is considered, one difficulty being good gas penetration into the inner parts of the furnace. In contrast, the shaft type furnaces for direct reduction, or fluidized beds, do not have this problem.

25. The nuclear reactor must be a certain minimum size to be economical. Since the reactor heat itself cannot be transported over long distances, the gas generator must be located close to the reactor and the most economical solution would be for the reactor plant also to be close by. The authors consider the possibility of transporting the reduction gases by pipeline to a number of consumers and conclude that this could be practical within a range of 100 km. Although the gases would have to be reheated, this could be done by the off gases from the reduction plant.

26. It is pointed out that high temperature reactors are best used in combination with gas and electricity generating plants. It therefore seems logical to consider the establishment of a central energy plant supplying both reduction gas and electrical energy to a number of satellite plants using direct reduction and arc furnaces.

27. It would be very interesting to have the authors' comments on the relative costs of steelmaking by this concept as compared with a large integrated plant, as proposed by ANTONIOLI in Paper II-3.

GROUP 2

28. The papers of this part of the session deal with the principles of gaseous reduction and the production of reducing gases for direct reduction processes. Such gases can be obtained from fossil fuels, by the conversion of synthetically produced gases, however the most important source is natural gas, the main component of which is methane. The ways of manufacturing the reducing gas for direct reduction as proposed by the various authors are different, but any such gas must have carbon monoxide and hydrogen as main components.

29. Paper II - 11. The authors PANTKE and LANGE give a comprehensive review of the fundamental principles of gaseous reduction and the composition and production of reducing gases. Gas processes can use gasified fossil fuels, natural gas, methane, residual ammonia synthesis gas, gasified naphtha. All these gases have to be converted to a mixture of carbon monoxide and hydrogen.

30. The economics of a gas based reduction process are governed by the chemical utilization of the reducing agent. The utilization factor is controlled by the kinetic, i.e. the rates of reaction with the ore, and the thermodynamics which are given by the equilibria in the iron-oxide - gas systems, furthermore by the total heat requirements of the reactions taking place. The gas utilization of carbon monoxide in the reduction of iron ore depends on the iron-carbon-oxygen equilibrium diagram, i.e. on the temperature and type of iron oxide to be reduced. In the same way the gas utilization of hydrogen is controlled by the iron-oxygen-hydrogen equilibrium system. Technical reduction gases consist of carbon monoxide and hydrogen as well as residual gases like carbon dioxide and water vapor. The last two gases diminish the total reducing potential available, the consequence being a need for a higher gas throughput in the direct reduction unit. The reduction rate is also decreased by the difference between the equilibrium carbon dioxide content and the actual carbon dioxide content in the reducing gas, which determines the degree of oxidation of this gas. With an increasing degree of oxidation the consumption of reducing gas and consequently of primary gas does increase as well.

31. The reducing gases in reduction processes do not only serve as reductants, but also supply to the reactor the process heat, which is used for heating up the ores, to compensate heat losses from the system and to cover the required reaction heat. Reaction heats for reduction with carbon monoxide and hydrogen for the different iron oxides are given. For a shaft furnace the influence of gas utilization and the composition of the reducing gas on the volume of gas required for a 95 per cent reduction of hematite of 1000^{o} C is also discussed. The conversion of fossil fuels to reducing gases and the required heats of reactions are tabulated. Most of the processes need addition of external heat.

32. The most important gaseous fuel for the production of reducing gases is natural gas, the main componet of which is methane. This can be converted by partial combustion with oxygen, recuperative reforming with steam, or with recycled carbon dioxide from the direct reduction process. In order to obtain an autothermic reforming process, a far higher amount of oxygen must be made available, than required by stoichiometric conditions. Gases with a high oxidation factor have a too low reduction potential, therefore carbon dioxide and steam contained therein have to be removed. After removal of these additional heating is necessary, which adversely affects the general economics of the process.

33. Reducing gases with a low oxidation factor are desirable, because no intermediate treatment is necessary. The introduction of additional heat from regenerators, recuperators or partial internal combustion in combination with regenerators makes this possible. The authors discuss three examples of the production of a reducing gas, gas manufacture with steam in a recuperator, with air in a regenerator and with gas recycling in a regenerator.

34. The HyL process is discussed as an example for recuperative gas manufacture with steam. Energy requirements are now 4.4 Gcal per ton of iron. The regenerator principle for reducing gas production is reviewed for regenerators using air and, in another concept using portions of unused top gas from the process in recycling.

35. If recycled top gas is used in the regenerative steam reforming, its chemical heat is completely utilized and no by-product energy has to be accommodated. The amount of total fuel requirement reduction by gas recycling in a direct reduction process depends on the degree of the oxidation of the ore, the desired degree of metallization of the product, primary gas composition, the gas utilization, extent and frequency of steam separation, and the heat losses of the system. The operating data for the manufacture of reducing gases from hydrocarbon from liquid fuels with oxygen are given.

36. Natural gases from different deposits vary in their composition in a fairly wide range, as also described. A content of nitrogen increases the gas consumption in the direct reduction process, the same is true for carbon dioxide content, however to a lesser extent. Hydrogen sulphide in natural gas has to be removed because sulphur is corrosive to the equipment and poisons the catalyst. The degree of oxidation in a reducing gas determines the methane requirements of a direct reduction process, but to a lesser degree when off-gas recycling is applied.

37. Paper I - 12. The growing interest in direct reduction of iron ores and the resulting importance of process for making reducing gases are described by DEMAREST. Various technologies to make reducing gases are available and the author focuses attention especially on the use of petroleum derived hydrocarbons as well as on coal and coke.

38. As mentioned previously by PANTKE and LANGE, this paper also gives the thermodynamic criteria for the production of reducing gases, and in addition deals with the quality levels and properties of such gases. Methods of producing reducing gases from coal and coke are reviewed. For the conversion of petroleum derived hydrocarbons two processes are described, partial oxidation and steam hydrocarbon reforming. The development and technological basis of these two concepts is described. Furthermore, means of adaptation and operating requirements for generating a suitable quality gas are established.

39. Paper II - 8. In this paper SPARCHEZ and his co-authors describe the use of unconverted methane for direct reduction. Evaluations of specific hydrocarbon consumption, reduction, theoretical heat requirements for conversion and reduction processes and the heat requirements for heating the reductants are made. Three groups of direct reduction processes on this basis are classified: (a) processes using unconverted methane, or methane converted by recycled carbon dioxide and steam, (b) processes using external carbon dioxide and steam for the conversion of methane, and (c) processes using partly oxidized methane with oxygen from an external source. After development of a specific methane consumption coefficient for the processes described before, it is found that those of type (a) have the lowest methane consumption, which is also dependent on the partialppressure of steam and carbon dioxide in the resulting gases.

40. The following conclusions on reducing agent consumption and heat consumption for heating and the chemical reactions of conversion and reduction for the three processes types can be reached:

- Process (a) has the smallest reducing agent and theoretical consumption for heating the reaction components. Direct use of hydrocarbons is possible and no separate gas conversion equipment is needed.

- Process (b) needs to heat a supplementary amount of methane and vapours required for the conversion.

- Process (c) has the highest reducing agent consumption for heating the reactants however the smallest heat consumption for the chemical reaction. Total theoretical heat consumption of this process approaches that of type (a).

41. The use of unconverted methane in direct reduction is discussed by the authors and operating parameters are given. The reduction vessel operates also as a methane converter, using the steam and carbon dioxide produced during reduction. The carbon content of the produced sponge iron is controlled by the temperature and the carbon dioxide and steam content of the gases in the sponge pores. If these are high, the carbon content is low.

42. Technological conditions for unconverted methane direct reduction processes are defined:

(a) A stationary system with continuous charging of ores has to be used.

(b) Correlation between methane input and reduction speed of the oxide has to be made, this can be done by analyzing the decomposition of the resulting gases.

(c) The partial pressure of methane has to be kept outside the limits of its thermal decomposition in order to avoid soot forming.

43. Methane is introduced in the reduction zone in accordance with the amount of water and carbon dioxide formed by reduction, the resulting gases are evacuated in uniflow or ramified flow with the charge, diluting the methane by recirculating part of the top gases and producing a sponge iron with low carbon content. As a result of this work an industrial scale process to produce sponge iron powder by using methane and solid carbon was developed.

44. Paper II-9. This paper by HATARASCU covers research work by the Institute of Metallurgical Research in Bucharest on the use of Romanian methane deposits for direct reduction. The kinetics and thermodynamics for a mixture of hydrogen and carbon-monoxide have been investigated for this purpose. In the use of methane converted with carbon-dioxide the following facts must be considered: (a) the reaction of ore with undissociated methane is highly endothermic. (b) The reduction rate below 1050°C is slower with methane than with carbon-monoxide or hydrogen. (c) In order to reduce the heat consumption in the reduction reaction the carbon-monoxide content of a carbon-monoxide-hydrogen mixture gas should be fairly high.

45. The authors develop the thermodynamics and kinetics of the reduction of iron ores with hydrogen and carbon-monoxide. For the conversion of methane with carbon-dioxide the maximum and minimum oxidation conditions are given, while both are endothermic, the minimum conditions are desirable because they are less energy-consuming.

46. A laboratory unit with electrical heating for the conversion of methane with carbon-dioxide under the presence of a special nickel catalyst is described. The highest gas volume with the best chemical composition was achieved at temperatures between 900 and 1000°C. A yield factor for the methane conversion is developed, and the process parameters are determined. The authors also describe a laboratory reduction

unit, a cylindrical retort for 1 Kg of lump or pelletized ore. The reducing gas had [illegible] per cent carbon-dioxide, 48.2 per cent carbon-monoxide, 48 per cent hydrogen and [illegible] per cent methane. The lowest methane consumption was found at an ore size of 20 to 50 mm, a methane carbon-monoxide ratio of 1, a gas input rate of 100 NL/h and a temperature of 950°C. The best productivity, however, exists at the same conditions but a temperature of 800°C and the double gas flow rate. Consequently, temperature controls the methane consumption, reductant flow the productivity.

47. The laboratory unit was also modified for recycling of off-gas. No change in the reduction operation could be observed, however the carbon-monoxide and hydrogen content were lower because of a 7.6 per cent content of nitrogen. The reduction speed remains the same with recycled gas, however the economics were greatly improved because the methane consumption was reduced to less than half.

48. The authors conclude that the use of recycled and regenerated reducing gas based on methane is feasible for direct reduction, and that recycling improves the general energy balance to a great extent. An industrial scale production plant can be based on this process developed in the laboratory.

GROUP 3

49. The papers of the last group of this session contain information on direct reduction processes with relation to ore supplies, choice of process, steelmaking and also include work on reoxidation. The choice of a direct reduction process has to be made with relation to the site given, and the available energies and iron ore. Also steelmaking in electric arc furnaces with direct reduction products is discussed and economical comparisons between the direct reduction/electric furnace route and conventional steelmaking processes are made for an arbitrarily selected case. The chemistry and the process of reoxidation have been investigated and protective measures during storage and transportation are suggested.

50. Paper II-5. In the beginning KALLA and his co-authors state that the gas processes in shaft furnaces and retorts need sized ore, the fluidized bed processes fine ores or concentrates. Rotating kilns are fairly independent on ore size, depending on the fuel being used. Fluidized bed processes need particles of well defined size, and, in order to maintain a stable fluidized bed, the gas flow rate must also be kept within narrow limits. In retort process gas and/or solid carbon reduce a pre-determined quantity of ore discontinuously. If gas is the reducing agent, its even distribution inside the retort is very important, the most suitable ore size being the pellet. Even gas distribution is also the main productivity control factor in counter flow shaft furnace processes. The particle size of the ore is limited and its external shape must not change in the passing through the shaft. The smallest particle size is determined by reaching the fluidization point of the burden. The temperature maximum is controlled by the softening or sintering point of the burden, its minimum by the reducing rate.

51. Rotating kiln processes are flexible as concerning chemical composition and particle size of the ore and the solid reductant. They operate con-currently and counter-currently, determining factors are behaviour of ore during preheating, degree of reduction in the final product and type and feeding method for the solid reductant used.

52. The authors mention a world production capacity of 5 million tons per year of high metallized ore by the end of 1972. For the choice of a reduction process at a given location as main parameters, type and price of available energy as well as properties of available ores are discussed. The influence of fuel price on the production costs of sponge iron processes is given, also cost advantages from the use of ore fines are considered. The use of cheap raw materials as beach sands, benefication tailings and leach residues which cannot be treated in conventional processes is evaluated. By combination of direct reduction with another refining process iron and accompanying other metals can be separated. (For example cobalt and nickel containing ores).

53. The route from ore to steel always involves the three steps:

(1) Separation of iron from oxygen, (2) fusion of iron and gangue, (3) separation of accompanying elements. Contrary to the conventional metallurgy direct reduction assumes only the first task. The melting of iron and gangue takes place in electric arc furnaces, the separation of accompanying elements is of no importance. In the direct reduction/arc furnace metallurgy the oxygen removal takes place from the ore right through the crude steel directly.

54. The steelmaking with metallized ore is discussed. Separating the normally acid gangue by means of slag formation in the arc furnace makes the proportion and composition of gangue content an important factor.

55. Results of a 25 ton arc furnace are evaluated, a basicity of 3.0 seems to be necessary for metallurgical work. The slag weight increases with increasing gangue content of the used sponge iron, and these relations are described. This gangue content also influences the power consumption of the electric arc furnace operation. The higher power consumption with a greater slag volume can be partly compensated, as postulated by the authors, by hot charging of the sponge. Reported savings are 150 kwh per ton of raw steel with 800°C hot charging. It would be interesting to know whether such results really have been obtained from practical experience with sponge iron, or whether they are based on conclusions from the preheating of scrap for electric arc furnaces.

56. The gangue content of the ore and the resulting sponge iron influence electric steelmaking with this product to a great extent as mentioned previously, consequently the pre-removal of gangue content of the iron ore is desirable. This is compared for the conventional steelmaking route and the direct reduction/electric furnace route. The authors conclude that an economical operation of arc furnaces with sponge iron is only possible when the gangue content is less than 5.5 per cent. However, change in prerequisites and the general energy situation can alter the picture considerably.

57. The distance between direct reduction plant and steel works operating on sponge iron basis is briefly discussed. For transportation, reoxidation of a metallized ore can have some importance, it is determined by primary porosity, which depends on reducing temperature. Hot briquetting of the product reduces the sensibility to reoxidation.

58. Paper II - 10. KNOP and his co-authors state that the low heat conductivity and large inner surface of metallized ore products are the main reasons for reoxidation which can be described as a two-step rusting process, with the forming of an iron-hydroxide and an iron-oxide. Both reactions are exothermic, the produced heat is 4 Gcal per gr of oxygen, i.e. 1 per cent oxygen pick-up under adiabatic conditions can result in a temperature rise of 35°C.

59. In order to investigate the corrosion mechanism of sponge iron piles during storage and transportation extended tests have been carried out by two companies in the Federal Republic of Germany. These tests involve wetting of sponge iron piles in closed and open bunkers, behaviour of ignited sponge in closed and open bunkers, as well as reoxidation of a pile of metallized ore under extreme weather conditions. The first group of tests resulted in temperature increases from 50 to 80°C, with sea water this occured already after 30 hours. The oxygen content in the gas phase decreased in the initial part, to increase and reach a stable level later.

60. After indirect ignition, within two days a temperature raise was found in a pile in a bunker. The oxygen content in the bin atmosphere decreased. After another 150 hours temperatures of 600°C could be found only in the bin axis. Measurements of the oxygen content of the atmosphere produced more significant results than temperature measurements. Up to 14 days no real risk in transportation coming from the temperature raise could be found.

61. When a pile of sponge iron was ignited directly in an open bin, reoxidation was only found in the surface of the pile, self-extinguishing took place in deeper layers. After 6 days a temperature of 550°C was reached, the metallization was reduced only in the top layers, sand covering of ignited pile stops the reoxidiation process after a considerable short time. The last series of tests exposed sponge iron piles to heavy weather conditions. After 9 months a reoxidation up to 40 cm depth below the surface was found, total of 16 per cent of the pile suffered from reoxidation in varying degrees.

62. The basic result of these tests were that metallized ore materials which have been produced at high reduction temperatures are suitable for transportation. Also a successful sea transport over a far distance of 650 tons of sponge iron is mentioned.

63. The authors draw some general conclusions for the handling, storing and transportation of metallized ore: the best is to melt after production, if this is not possible the storage should be sheltered. Bulk shipments loading should take place in good weather. Sponge iron piles must be protected against heat, i.e. ignition. During shipment, the atmosphere of bunkers must be controlled, temperature changes of bulk shipments are first indicated by a drop of the oxygen content of the bunkers' atmosphere. If these precautions are taken, the tendency of sponge iron to reoxidize does not create problems.

64. Paper II - 6. GUDENAU and his co-authors state the fact that metallized ore products may corrode unprotected in direct contact with rain, humidity, sea or river

water. This reoxidation is caused by the higher outer and inner surface created by high porosity and in the reoxidation process, costly degrees of metallization are lost. Besides climatic conditions, other parameters influencing reoxidation are the shape of the sponge, the reduction process used to make it, the separation process at the end of direct reduction, and the porosity. In one example, quoted by the authors, a sponge iron sample with 95 per cent of reduction decreased in 30 days to 63.6 per cent of reduction under heavy corroding conditions. Also the briquetting of sponge iron does not produce sufficient results. A classic form of protection would be the application of plastics, based on hydrophobic polymers. The selected plastic protection materials must be economically applicable in a thin layer, and must not contain undesirable contaminants.

65. The application of plastic foam was found a technically feasible surface protection for piles and bunkers of sponge iron. By applying a thin foam layer, reoxidation was prevented. Another way of protecting the sponge iron is to produce a protecting film around individual pellets made from polyvinyl acetate dispersions as well as phenol combines, which both produce a sufficient temporary protection, phenolic resins giving protection over a longer period. In the foam layers mentioned before, the used polyurethane foam gave a complete protection of large piles of metallized ore.

66. The authors also discuss the cost of protective measurements with plastic materials. If plastic shells around individual pellets are applied, the costs with phenolic resins are in the range of 1.50 - 2.00 DM per ton of sponge iron. The equipment required is not complicated. Protection of large metallized ore piles can be achieved with polyurethane foam covers; the costs depend on the size of the pile. For a 7000 ton pile the authors quote costs of 1.10 DM per ton of sponge iron, for a pile of 60.000 tons only 0.50 DM per ton are mentioned.

67. The general conclusions of the authors' paper is that metallized iron ore can technically and economically be protected from reoxidation by either protective individual or by bulk plastic coatings.

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ENERGY IN PREREDUCTION PROCESSES AND VARIOUS DIES IN STEEL-MAKING

Submitted by the Government of France

(Prepared by Mr. ASTIER, Mr. DELLA CASA, Mr. JON and Mr. SCHNEIDER)

Summary

Solid fuels do not count for much in world consumption of energy, and their share is continuously growing smaller.

On the other hand, despite the large reduction in the consumption of blast-furnace coke, coal still fills a large part of the energy requirements of steel-making. There are new prospects for it, first in massive injections of hydrocarbons into blast furnaces, and secondly in advances in the prereduction of iron ore.

The energy balances for the main prereduction processes have been compiled from published figures or based on assumptions about the operation of these processes.

These balances show on examination that these processes in which the gaseous reductants are not recycled have a minimum heat consumption of 4.5 Gcal/t Fe, whereas with recycling this may be as low as 3 to 3.5 Gcal/t Fe.

Prereduction and the fusion of prereduced material in electro-furnaces open the way to steel-making without solid fuel.

The energy balances of the various processing schedules for liquid steel demonstrate the possibilities of adapting any form of energy to steel-making.

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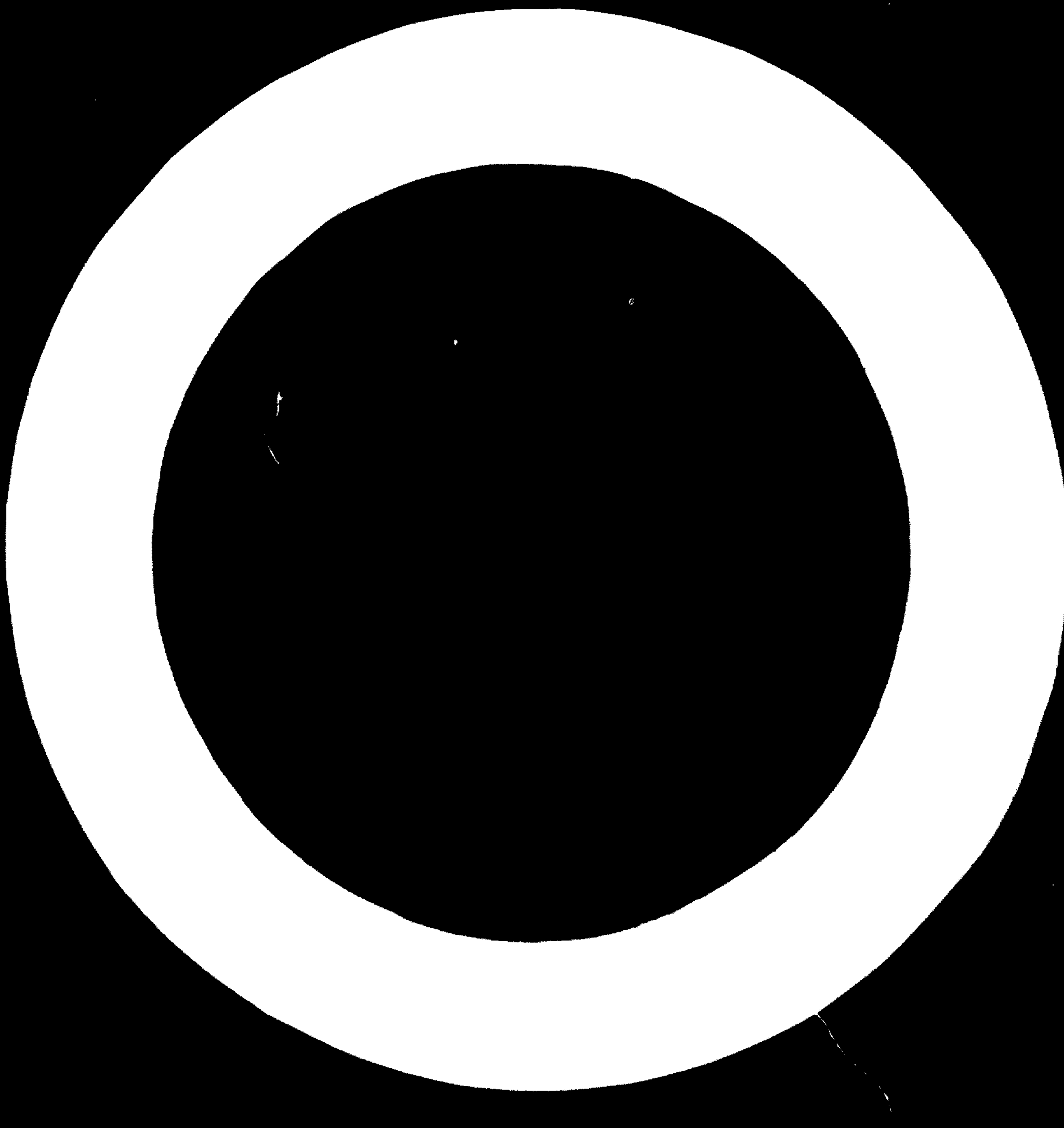

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LONG TERM TRENDS IN THE PROCESS TECHNOLOGICAL APPLICATION OF NUCLEAR HEAT TO IRONMAKING

Submitted by the Government of Federal Republic of Germany

Prepared by Messrs. W. WENZEL and F.R. BLOCK,
Institut für Eisenhüttenkunde
der Rhein. Westf. Technischen Hochschule Aachen

SUMMARY

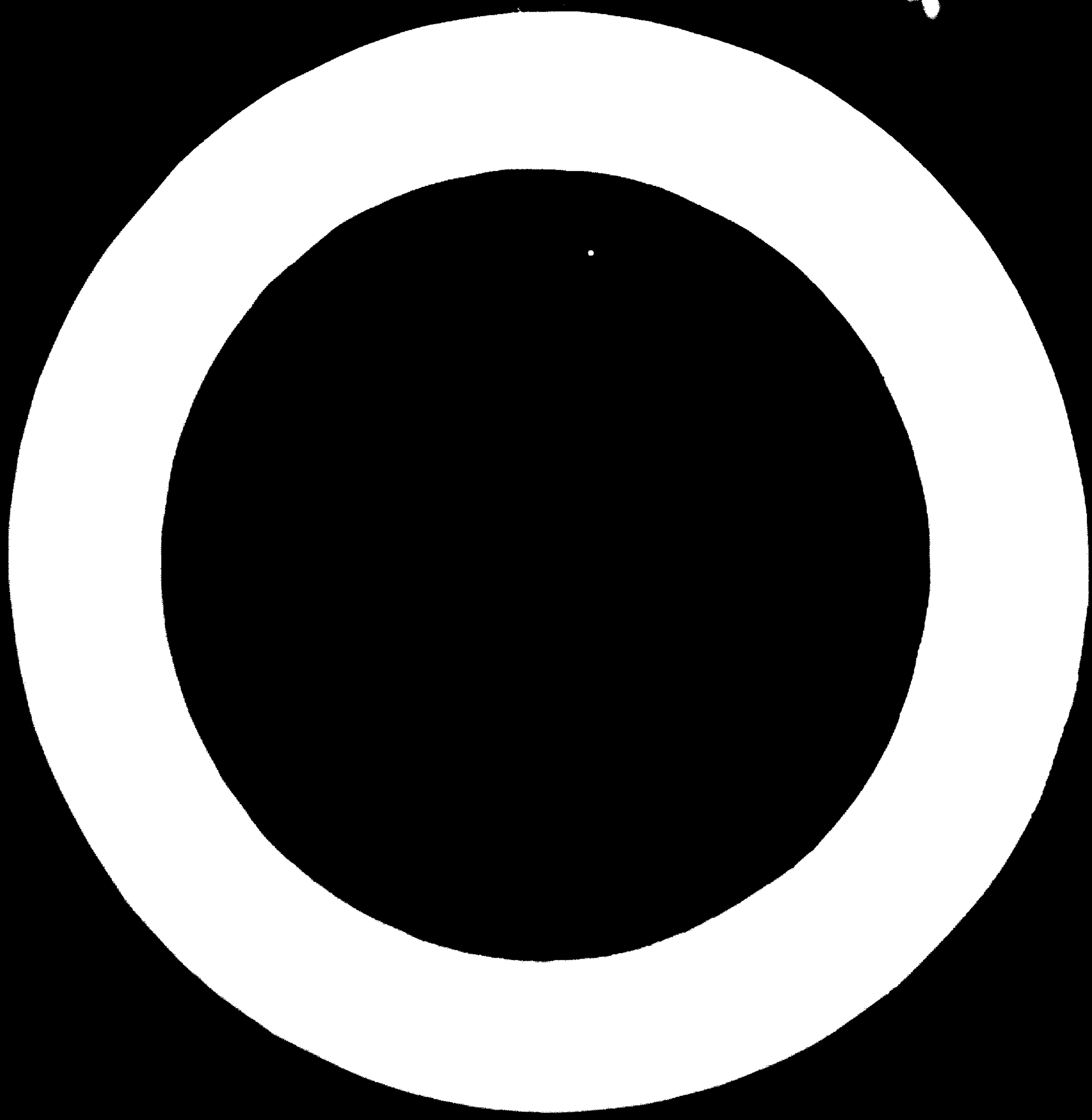
The time is foreseeable when coal and nuclear energy will be the only two sources of primary energy available in large quantities on this planet, because oil and natural gas will have been largely used up.

The price of coal will increase more rapidly than that of nuclear energy, so that the use of nuclear energy for iron and steelmaking is bound to become a practical proposition in the not too distant future. Ways to realize its potential are already being investigated worldwide.

This paper surveys the possibilities of using nuclear heat in iron ore reduction. It is shown that the major field of application is likely to be the production of large quantities of cheap reducing gas either by supplying heat to a reducing gas generator or, in the more distant future, by electrolysis of water.

Since outlet temperatures from the reactor are not likely to exceed 1400° C in the foreseeable future, direct melting is not included.

Practical possibilities of combining reactors, gas generators and smelting units are discussed and it is shown that the chemical efficiency of the gas utilization is almost ideal. Expected long term trends are surveyed.



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DIVERSIFICATION OF ENERGY SOURCES FOR THE IRON AND STEEL INDUSTRY

Submitted by the Government of Italy

(Prepared by Mr A. Antonioli)

Summary

The first part contains an analysis of the known deposits and location of the rincipal raw materials used for energy production and of the factors which could ffect their future cost. The reserves having the most even geographical distribution re those of uranium (and other similar materials) and of natural gas.

Next, a number of steel-making processes in which both nuclear energy and natural as can be used simultaneously are reviewed in the light of their feasibility and cost. f these, the one most feasible on an industrial scale appears to be a direct reduction rocess using nuclear heat, followed by smelting of the sponge iron by electric furnace n an integrated works with high-temperature gas nuclear reactor.

Lastly, an account is given of expected trends in the cost of raw materials mployed in energy production which make it possible to use steel-making processes tilizing nuclear power side-by-side with conventional steel-making processes.

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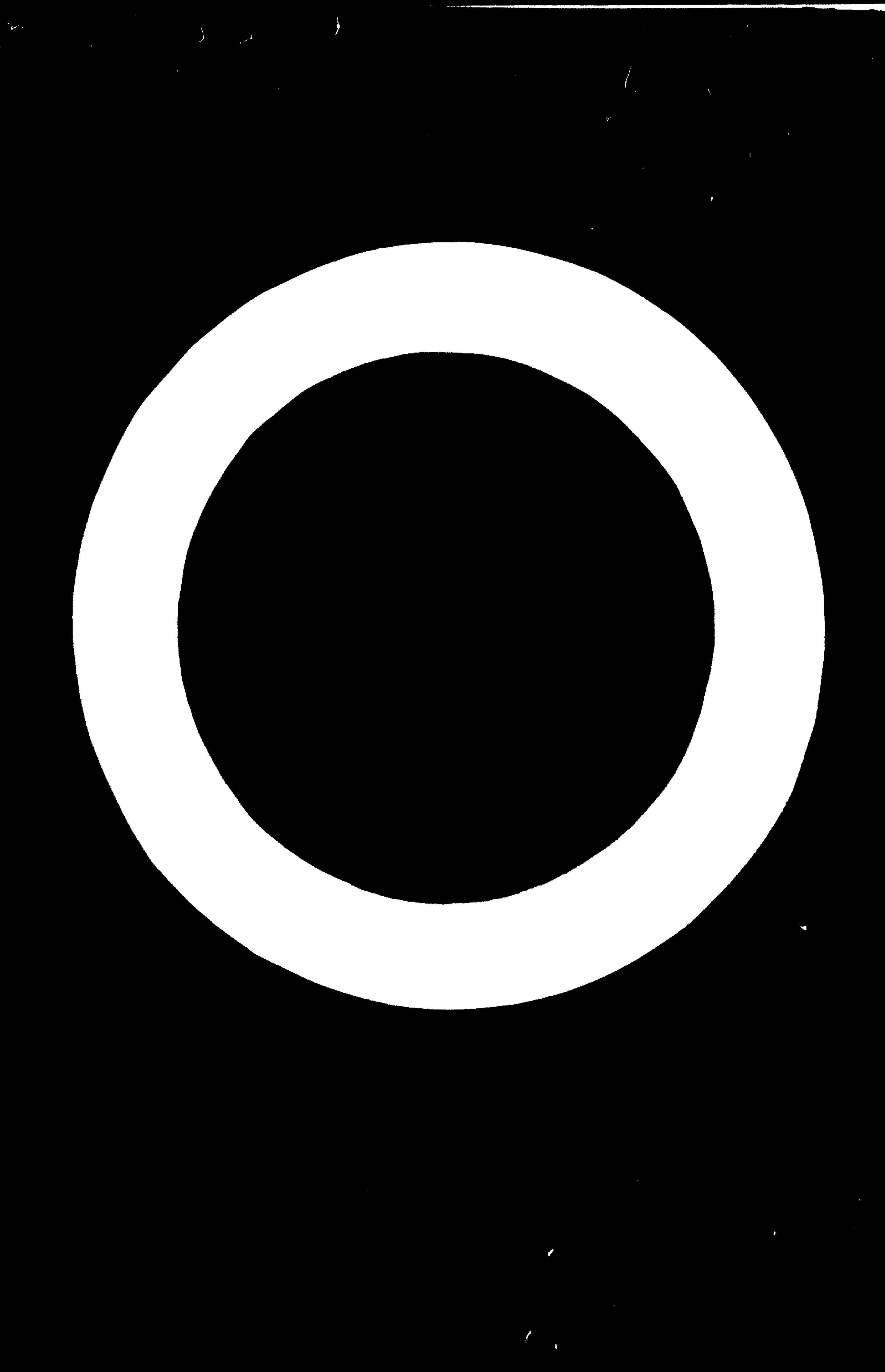

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INVESTIGATION ON FACTORS CONDITIONING THE QUALITY OF METALLIZED PELLETS IN PILOT KILNS

Submitted by the Government of Poland

(Prepared by Prof. Eugeniusz MAZANEK)

Summary

The paper presents the results of research into the production of metallized pellets in a pilot rotary kiln.

Laboratory measurements were made prior to investigations on an industrial scale. To obtain the necessary specimens, pelletizing of Krivoi Rog concentrates was carried out.

To explain the influence of the temperature on pellet compression strength during hardening in an oxidizing or neutral atmosphere, tests were carried out in the temperature range of 200-1300°C during 30 minutes. It is evident that the oxidation process has a great influence on the increase of pellets strength only to the temperature of 1100°C: above this temperature sintering of ore grains is more important and this process is the most important factor in improving pellet properties. The study of pellet reduction was intended to explain the influence of the degree of oxidation of pellets on the reduction degree and the strength of reduced pellets.

Pellets were reduced by means of pure CO and by a mixture of $CO+H_2$ at the temperature 850 and 110°C, during 60 minutes. It was shown that the compression strength of reduced pellets depends on the hardening temperature and the oxidation degree. Pellets hardened at low temperatures, when reduced by means of CO - swell and are weak. The presence of H_2 favours the increase of the degree of reduction, lowers the swelling and increases the strength of pellets.

The study of the mineralogical structure of fired (oxidized and monoxidized) pellets confirmed the conclusion that in order to obtain strong and metallized pellets they ought to be partly oxidized during the firing process: to avoid pellets swelling, the temperature of pellet hardening ought not to be lower than 800°C and the reduction ought to be carried out by means of a gas containing H_2.

Investigations in the experimental unit were carried out on the basis of laboratory results. The experimental unit consisted of a rotary kiln of 1m diameter and 10m long and the grate preheater 600 mm wide and 2.5m long. The rotary kiln was heated by natural gas: waste gases heated the green pellets on the grate to about 600°C and partly oxidized them. Fluidized coke was added to the pellets falling down from the grate to the kiln. The temperature of pellets in the front part of the kiln was 1100°C. The retention time of the pellets on the grate was 30-40 minutes and in the kiln 2.5 hours. The reduced pellets fell to the containers where they were cooled without the access of the air.

The concentrates Krivoi Rog (Fe 64.7%, SiO_2 8.4%) and Fosdalen (Fe 66.7% SiO_2 3.9%) were used during the investigations. As reductor, a fluidized coke of 86.0% C and 6% volatite parts was used. In order to obtain self-fluxing pellets of a basicity of 0.8, lime was added.

The average results show that the average metallization degree during the investigations was 82-86%. The metallized pellets produced were satisfactory for direct use in electric steel furnaces.

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PROCESSES FOR THE DIRECT REDUCTION OF IRON ORES IN RELATION TO ORE SUPPLIES

Submitted by the Government of The Federal Republic of Germany

Prepared by

Messrs. J. Kalla, Verein Deutscher Eisenhüttenleute,
H.J. König, Lurgi Chemie und Hüttentechnik GmbH,
G.H. Lange and H.-D. Pantke, Thyssen Niederrhein AG

Summary

Following a brief description of the most important process modes for direct reduction (fluid bed, reactor, shaft furnace, rotary kiln), the deciding factors for the selection of a process at a given site: cost of energy, mechanical properties and chemical analysis of the proposed iron ore are discussed. In the conversion of sponge iron to steel in the electric arc furnace, the amount and composition of the gangue play an important part. A comparison of raw steel costs in the blast furnace-BOF and direct reduction-electric furnace routes, showed that, with certain assumptions regarding location, process technology and power costs, sponge iron metallurgy becomes an economic proposition only with gangue contents below about 5.5 % (SiO_2 + Al_2O_3).

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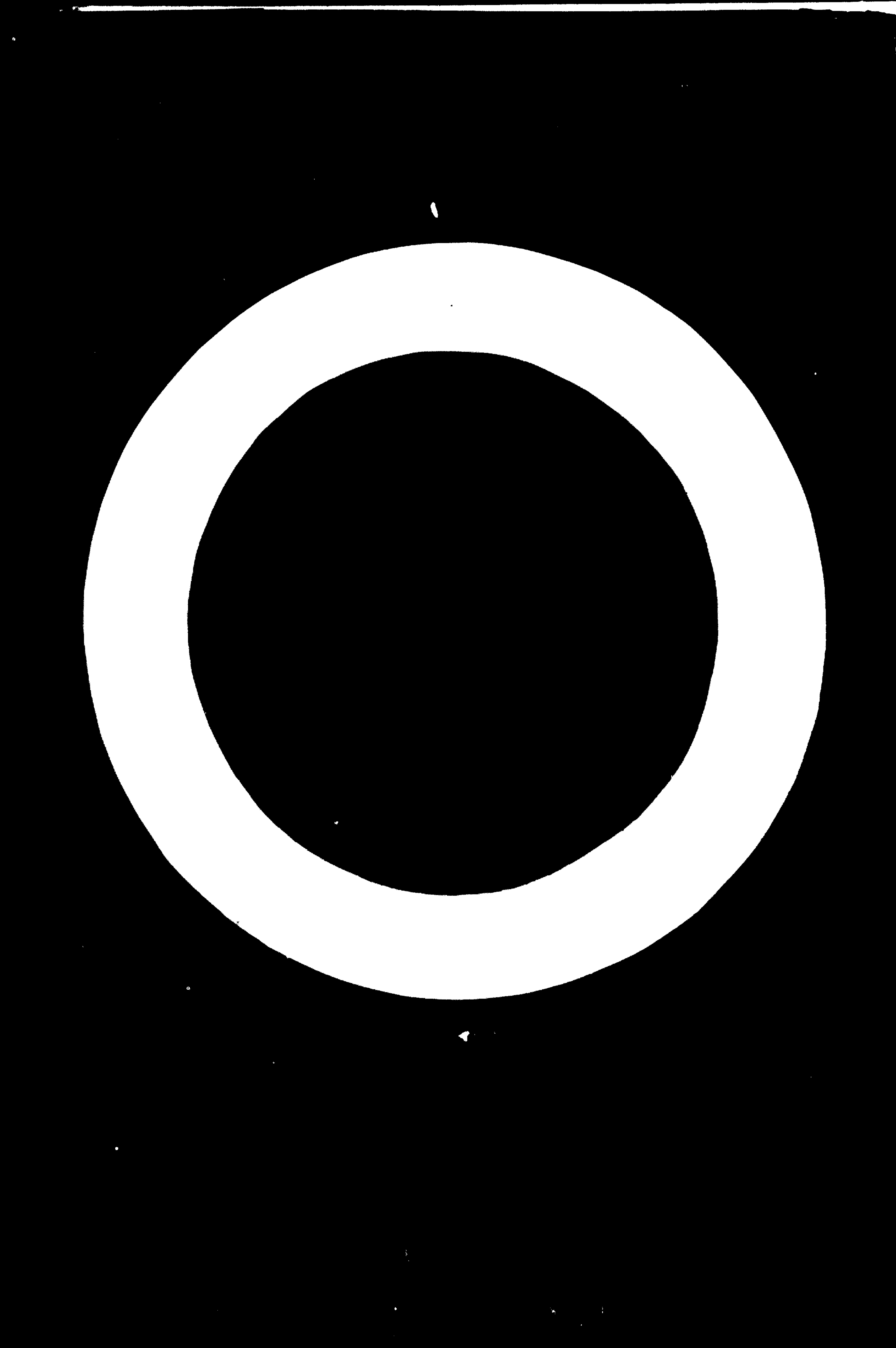

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PROTECTION OF SPONGE IRON FROM REOXIDATION

Submitted by the Government of the Federal Republic of Germany

(Prepared by Mr. H. W. GUDENAU Institut für Eisenhüttenwesen der Rhein. Westf. Technischen Hochschule AACHEN)

SUMMARY

Sponge iron will corrode if stored unprotected or transported through various climates. The corrosion will be very intensive when sponge iron is in contact with a corroding medium such as rain, high air moisture and water.

Reason for the reoxidation is the high porosity and the large specific surface of sponge iron.

Reoxidation is a depreciation of sponge iron, because the degree of reduction, which includes a lot of cost, gets lower. Therefore some measures should be taken to avoid reoxidation.

Covering with a thin layer of plastic is one of the practicable protecting measures. The procedure is economic if the cover could be produced very thin.

Our trials in Aachen showed that plastic layers give good protection against reoxidation. But the obtained thickness of cover does not usually make this process economically interesting. A good protection and an economic proposition, were covers out of polyvinylacetate and phenolic resin.

In Aachen another process to protect sponge iron was developed. It is the covering of sponge iron dumps with a thin plastic foam layer. This foam protected the sponge iron against the direct influence of water or air moisture and prevented reoxidation. A very good protection was found by the use of polyurethane foam. A layer that is sufficiently thin was obtained by using this foam and so another process was found that could be economically interesting.

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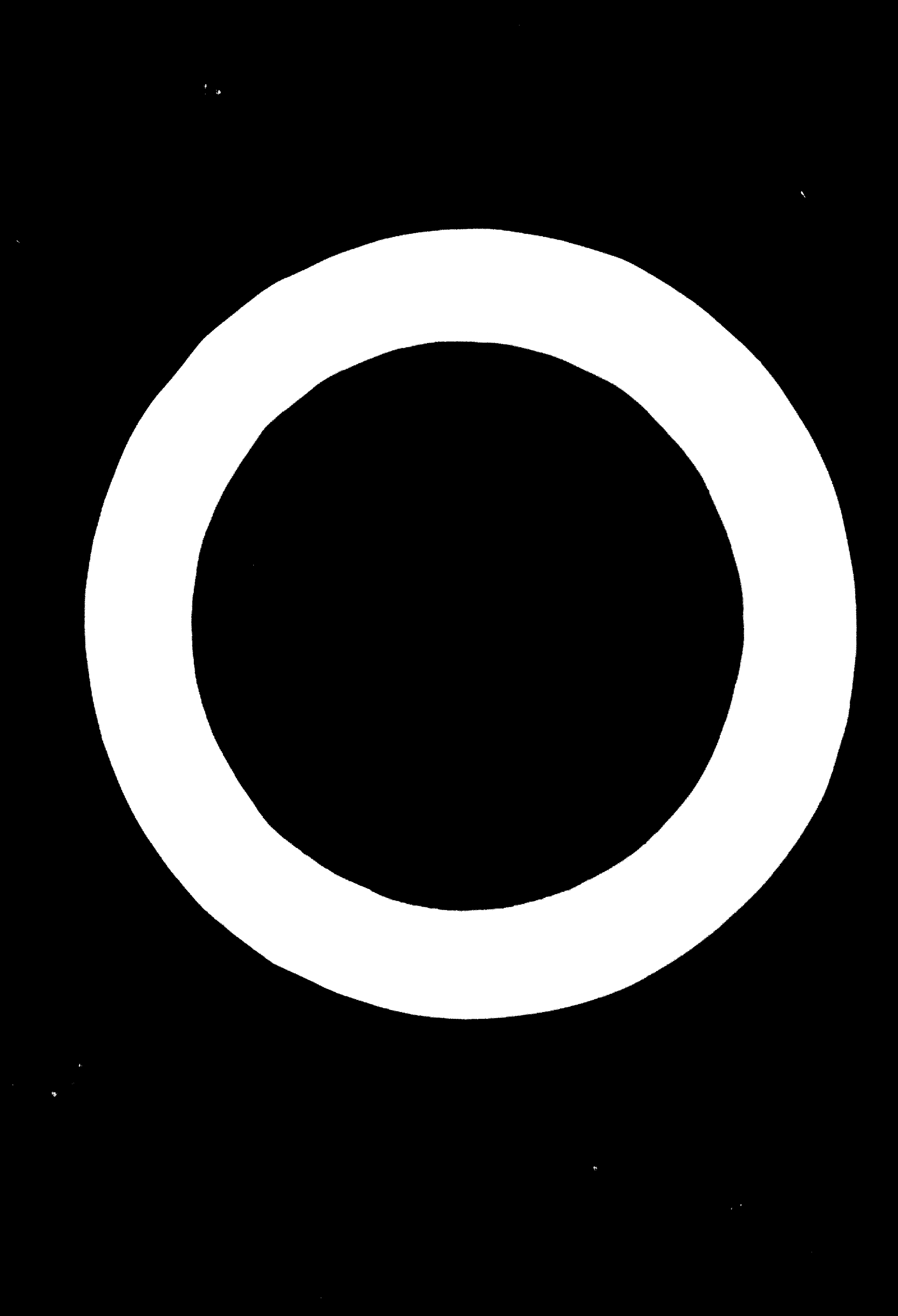

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THE DIRECT WAY FROM IRON ORE TO CRUDE STEEL USING THE LUBATTI PROCESS

Submitted by the Government of Italy

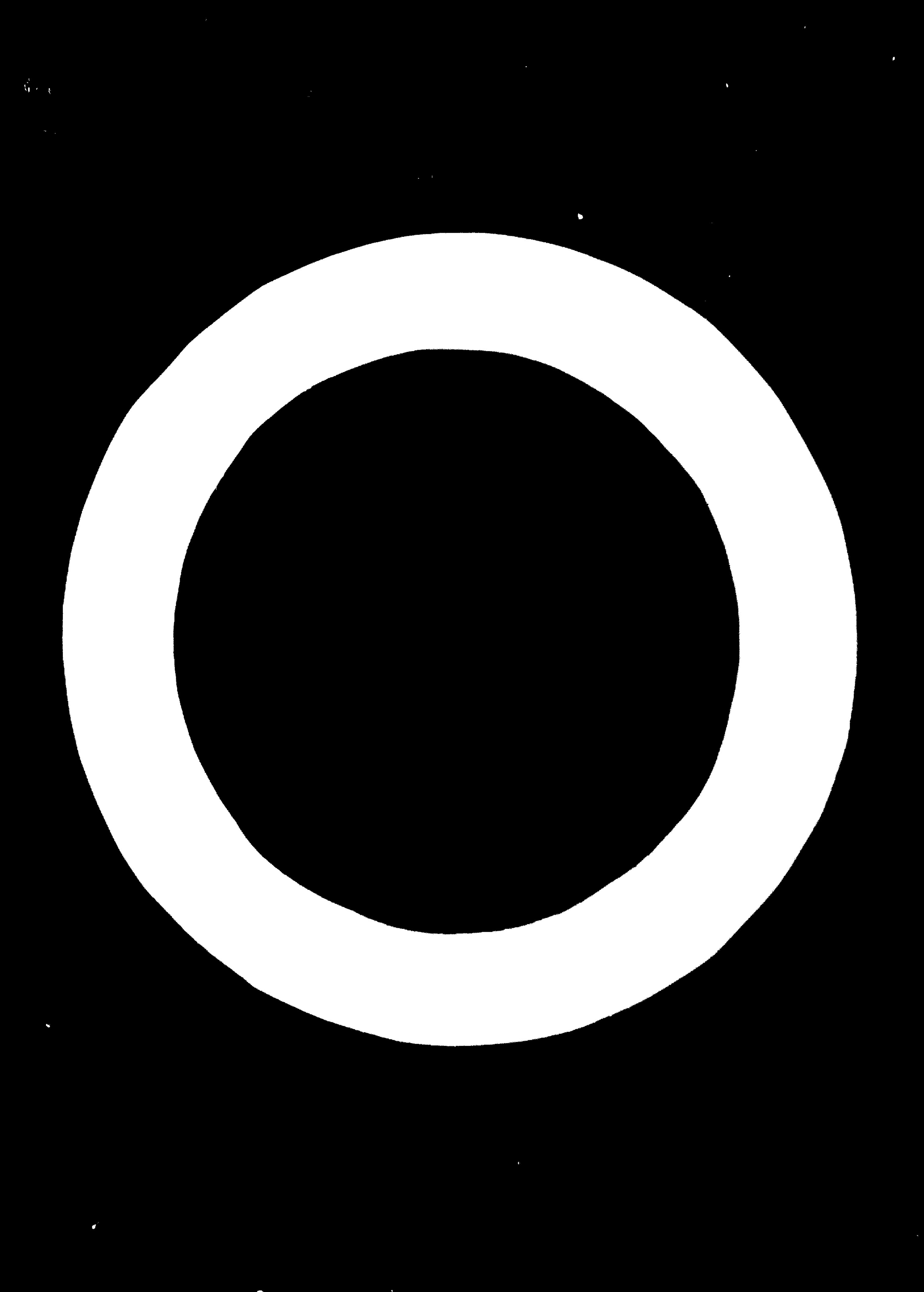
Prepared by Mr. A. T. BARNABA

Summary

The paper starts with an evaluation of the reasons which have led to abandon the industrial use of the Lubatti direct reduction process. Subsequently, consideration is being given to the possibility of re-activating this process, by improving mainly the quality of the charge which - contrary to the practice used at the time - could today consist of ore fines with a high Fe.content, well mixed with powdered coal regardless of quality.

After the review of the technical characteristics of the Lubatti process its economic viability is brought out by a calculation of the possible production costs of steel made by using this process.

GE.72-19457



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The Use of Methane in the Reduction of Iron Oxides

Submitted by the Government of Romania

(Prepared by Messrs. Z. Spârchez, L. Szabo, A. Palfalvi)

Summary

The paper deals with the main problems of the reduction of iron oxides with unconverted methane.

The theoretical reducing agent - and heat consumptions for the heating and the chemical reactions of conversion and reduction are compared for the following processes:

A. using unconverted methane or methane converted with H_2O and CO_2 formed by reduction,

B. using methane converted with vapours and

C. using reducing gases obtained by the partial combustion of methane.

The processes from group A have the smallest reducing agent consumption and the smallest theoretical heat consumption for the heating of the reaction components. The processes based on the partial combustion of methane with oxygen (air) have the smallest heat consumption for the chemical reaction, having at the same time the highest reducing agent consumption and heat consumption for the heating of the reactants.

The composition of gases resulted by the reduction with unconverted methane and the temperature from which the process may be performed are determined in the present paper.

The methane may be used unconverted for the manufacturing of sponge iron for metallurgical purposes, too. In this case, the following conditions must be fulfilled:

1. to perform the reduction in a stationary regime with continuous charging of iron oxides,

2. to correlate the methane output with the amount of iron oxides reduced in a time unit, on the basis of gas analysis,

3. to maintain the partial pressure of methane at values at which its thermal decomposition does not take place:

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- introducing the methane in the reduction zone, in accordance with the amount of H_2O and CO_2 formed by reduction,

- directing the reducing gases in uniflow or ramified flow with the charge,

- diluting the methane by recirculating a part of the gases resulted by reduction.

On the basis of these principles, an original process for manufacturing iron powder by the combined reduction of iron oxides with carbon and unconverted methane was elaborated and developed on industrial scale.

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STUDY OF IRON-ORE REDUCTION BY GASES DERIVED FROM CONVERSION OF METHANE WITH CO_2

Submitted by the Government of Romania

(Prepared by Mr. Hatarascu, Head of the Laboratory for Blast Furnaces and Direct Reduction at the Institute of Metallurgical Research, Bucharest.)

Summary

The presence of methane gas in the subsoil of Romania has caused research on the direct reduction of iron ores to be concentrated on the use of this gas as a reductant.

The research carried out at the Metallurgical Research Institute on the use for iron-ore reduction of the gases derived from the conversion of methane with CO_2 was based on thermodynamics and kinetics. The following facts were therefore borne in mind:

(1) reactions of ferrous oxides with non-dissociated methane are highly endothermic;

(2) reduction at temperatures below 1050°C is slower with methane than with CO or H_2;

(3) to reduce the heat consumption required in reduction reactions, the CO content of a gas made up of CO and H_2 should be fairly high.

Two alternative experiments were carried out.

The first studied the reduction process with gases obtained by converting methane with carbon dioxide and eliminating them into the atmosphere after reduction. The second studied the reduction of iron ores with regeneration of these gases, by burning the methane and then recycling them in the reduction process.

From the start the purpose of the experiments was to establish the main conditions for obtaining gaseous reductants by converting methane with CO_2 by the use of nickel catalysers. The main characteristics of the conversion process were determined, i.e. the conversion temperature, reductant flow, degree of effective conversion, time of contact, expansion factor and so on. The chemical composition of the gaseous reductant was 1.8 per cent CO_2, 48.2 per cent CO, 48 per cent H_2 and 2 per cent CH_4.

The reduction of the iron ores was studied in a plant in which the oxygen elimination was determined with a balance.

GE.72-10478

The research carried out by the first method identified the thermodynamic and kineti[c] features of the reduction process and their effect on the specific consumption of methane and on plant productivity.

Reduction temperature is the most important factor for the specific consumption of methane, whereas plant productivity is mainly affected by the gaseous reductant flow.

By making certain modifications it was also possible to adapt the laboratory plant for reduction tests with regenerated gases after conversion of the methane with CO_2 and subsequent recycling.

With similar operating conditions (temperature, ore granulation, gaseous reductant flow and so on) the reduction processes followed the same course.

The ore used in the reduction tests was hematite with 65 per cent Fe content, imported from India.

These experiments showed that direct reduction of iron ore by an industrial process could be profitable.

end

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17 July 1972
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REOXIDATION IN CONNEXION WITH THE STORAGE AND TRANSPORTATION OF METALLIZED ORE

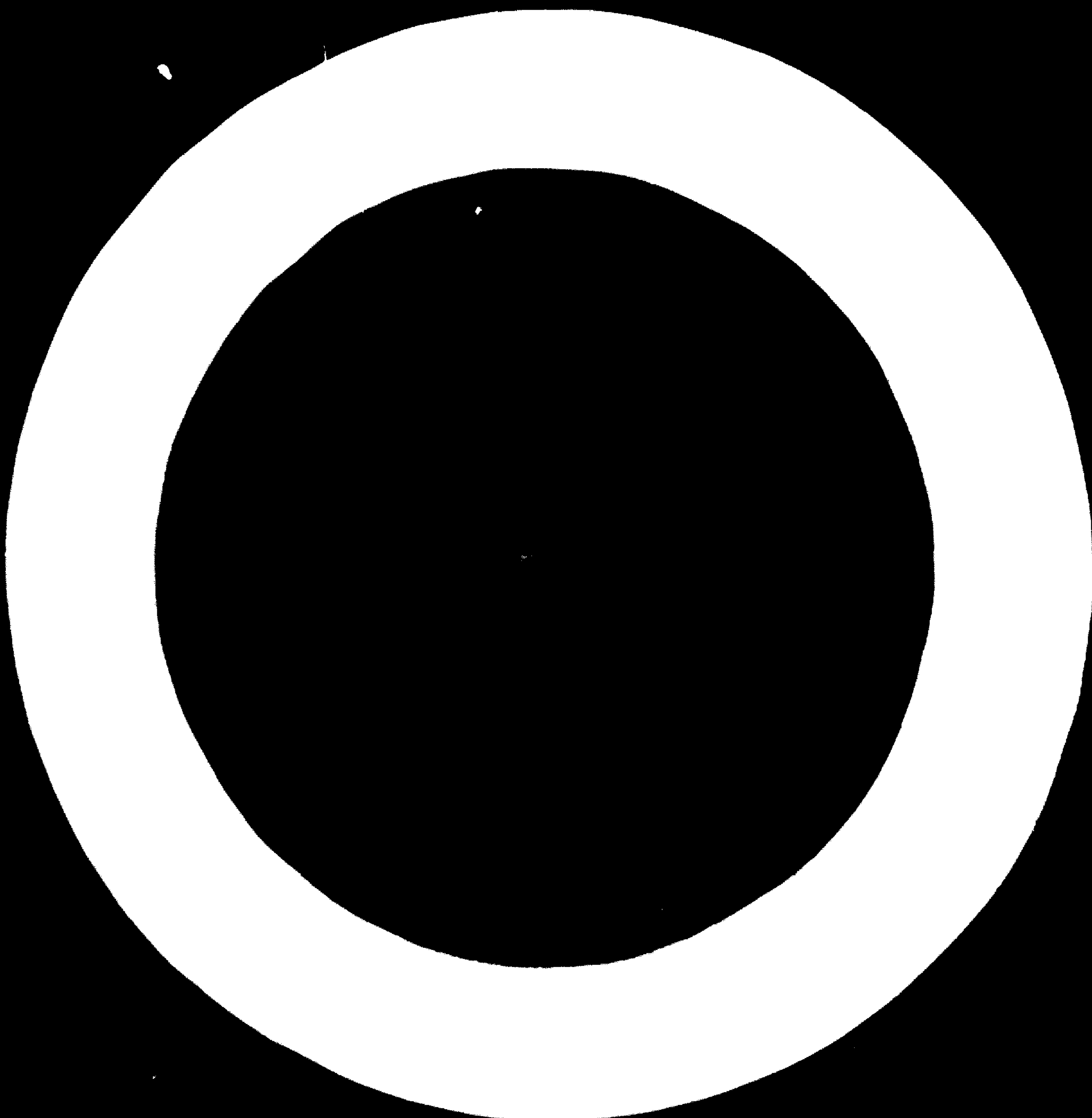
Submitted by the Government of the Federal Republic of Germany

(Prepared by Messrs. H. KNOP, Thyssen Niederrhein A.G., H. HAGEL, W. THUMM, Lurgi Chemie und Hüttentechnik GmbH.)

SUMMARY

During the direct reduction of iron ore with CO and H2 a rather coarse iron structure is obtained, which offers a wide area of attack to the oxygen and the atmospheric humidity. The tendency of the metallized ore to rusting and scaling is stronger than that of pig iron and steel. It could lead to the development of heat, causing substantial rises in temperature, originating from the exothermic reaction of rusting. Furthermore some changes in atmosphere of closed bins during oxidation can occur, in particular drop of oxygen and development of hydrogen, carbon monoxide and dioxide. In such cases control of bin atmosphere should be provided. Apart from safety requirements the elimination or slowing down of reoxidation is reasonable for metallurgical aspects since the market value of the metallized ore decreases at increasing oxidation.

Experience from the first greater bulk shipment of SL/RN-metallized ore from Hamilton (Canada) to Nagoya (Japan) and from a series of industrial scale tests at the Purofer-Plant in Oberhausen (West Germany) showed that the oxidation tendency of metallized iron ore is no hindrance for a world-wide application. Practical proposals are given to prevent the metallized iron ore from oxidation during storage and transport.



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Requirements Governing the Composition of Reducing Gas for Iron Ore Reduction

Submitted by the Government of The Federal Republic of Germany

Prepared by Dr. Heinz-Dieter Pantke
Georg Herbert Lange
Thyssen Niederrhein AG
Oberhausen/Rhineland

Summary

Fundamental principles of gas reduction. The production of reducing gas from solid, liquid and gaseous fuels. Influence of sulphur-, nitrogen- and carbon dioxide-contents on the suitability of natural gas as a raw material for the manufacture of reducing gas. Influence of the degree of oxidation of the reducing gas.

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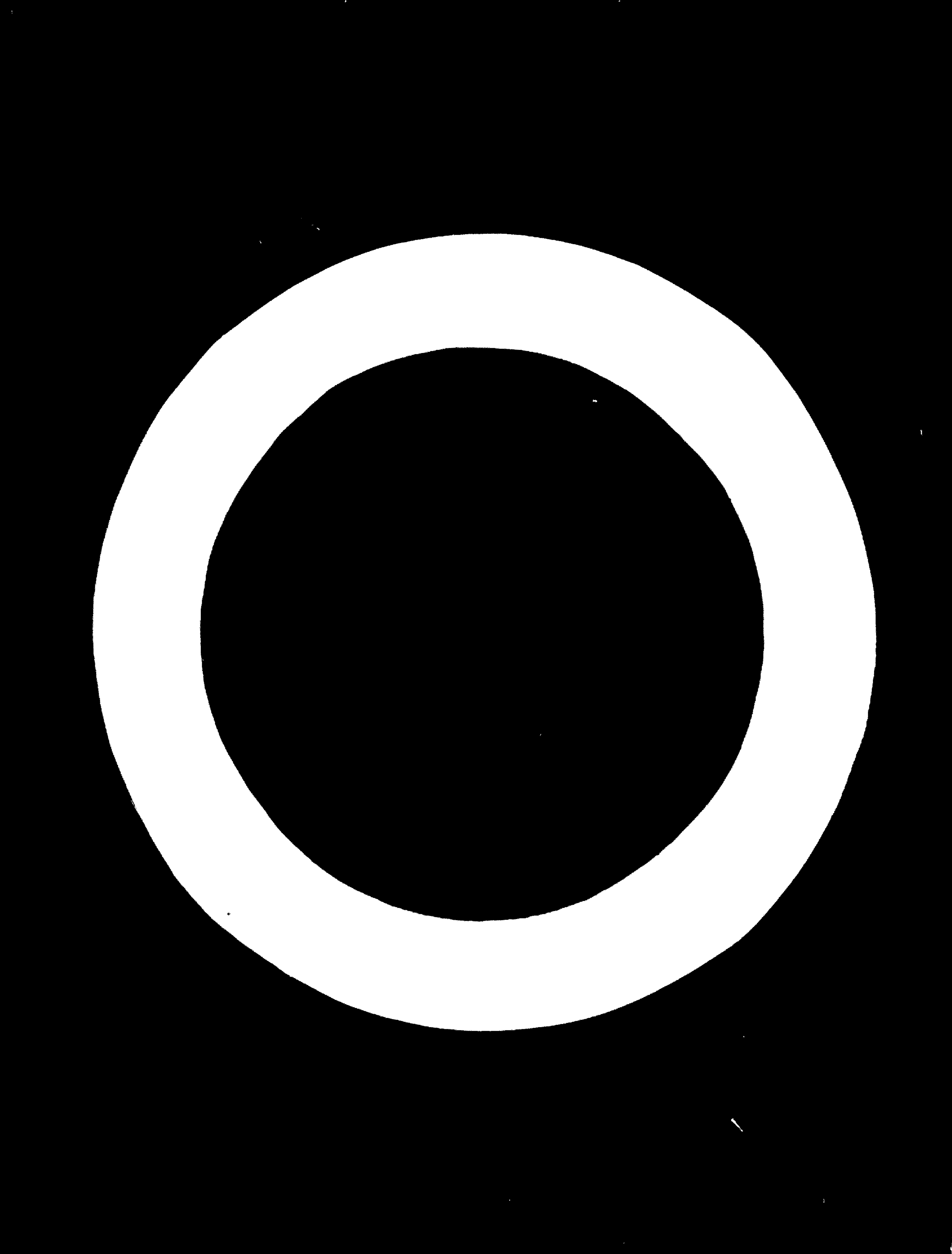

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ENGLISH
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SESSION III. THE PLACE OF DIRECT REDUCTION IN IRON-MAKING AND STEEL-MAKING

PRESENTATION OF PAPERS SUBMITTED AND SUMMARY OF THE SUBJECTS OF DISCUSSION

Prepared by Mr. A.T. BARNABA (Italy), Manager, ITALSIDER

1. The reports assigned to Session III can certainly not be said to form a homogeneous whole. There are papers dealing with the original processes of direct reduction outside - and even in - the blast furnace, and papers on the use of direct-reduced material in the electric-arc furnace. There is also a report specifically concerned with the economic aspects of the use of direct-reduced material in Romania.

2. The first paper to be considered in the order of presentation I thought it desirable to adopt is that by Messrs. Hateraseu, Tripsa and Dian. This paper explains why the pilot reactor plant was abandoned for the present ICEM shaft-furnace process.

3. The reactor-type reduction plant, which was very small, being designed for a daily output of half a ton, comprised three reactors or retorts. In the first the ore was heated with waste gas from the direct-reduction reactor, while the third reactor was used in the final phase, with fully-reducing gas. Several aspects of this process are reminiscent of the HyL process, used in Mexico and already amply described at this Seminar.

4. In the ICEM reactor process the reducing gas was obtained by reforming methane with air. It was immediately realized that the high nitrogen content of the reducing gas was the primary cause of the very low rate of reduction. On that account, and also because they sought to develop a continuous process for sponge-iron production, the authors abandoned the reactor system and concentrated their experiments on a continuous process for the production of sponge iron in a shaft furnace, using a reducing gas obtained by reforming methane with recycled gas, i.e. gas partially exhausted through having already passed through the charge of ore for one phase of reduction.

5. By improvements in the reforming plant it was found possible to obtain reducing gas containing 35-45 per cent CO and 40-50 per cent H_2. The authors hope to find a satisfactory embodiment of this process in which, more particularly, the consumption of methane is reduced without lowering the sponge-iron reduction ratio.

6. It would have been preferable to discuss this report at session I, because the ICEM process in its first version was comparable to the HyL process considered by Mr. Lawrence at session I, whereas in its present version it is quite close to the other modern shaft-furnace processes, such as EUROFER, MIDREX, and [illegible]. At all events, we hope that the discussion will be very lively.

GE.72-20609

7. Next in order will be the paper by Mr. Mazanek, giving particulars of an interesting investigation of factors affecting the properties of pellets, particularly their compression strength and reducibility, for it is on their strength and reducibility that the behaviour of the pellets during reduction depends.

8. The results obtained in the many experiments are embodied in a series of graphs showing more particularly the relationship between baking temperature and on the one hand the reducibility and on the other the strength of pellets.

9. There are also comparisons between reduction processes carried out with a gaseous mixture of CO and H_2, demonstrating the advantages of increased percentages of H_2.

10. There is also a study of pellet swelling and the deposit of graphitic carbon, both of which phenomena become more marked as the percentage of CO in the reducing gas rises.

11. The author also gives us a series of photomicrographs showing how pellet structure varies with grade of ore and with baking treatment. These microphotographs are of practical as well as of scientific value, because they explain the behaviour of the different pellets.

12. There then follows a somewhat curious report, the paper by Messrs. Poos, Vidal and Michel. I have the impression, if they will forgive me for saying so, that they wrote it with an ironical smile. They seem to be saying, with regard to the various systems of direct reduction: "But that can all be done in the blast furnace, and much more simply!" But, seriously, they acknowledge that such a procedure, i.e. the use of certain direct-reduction techniques in the blast furnace, while feasible in practice, would be economic only with blast furnaces having a capacity in excess of 2 million tons a year. And on that point we can well agree, because in the present state of advancement of direct reduction it is common knowledge that direct reduction with a blast furnace having a capacity of 2 million tons a year could be competitive only in very special conditions.

13. In their paper the authors discuss the possibility of direct reduction of the ore in the upper parts of the blast-furnace shaf , by injecting reducing gases at the bottom of the shaft, above the main tuyères, using the same method as in the various direct-reduction processes. The principal advantages that could be derived from this process, if successful, would be:

(a) the reduction of coke consumption to the minimum required for melting and carbonizing the metallized material; and

(b) an increase in the furnace's productivity.

14. The paper by Messrs. Poos, Vidal and Michel is truly most interesting, and we hope that their experiments will be fruitful even though some of the experts with us here have no great sympathy for that monster the ever-bigger and ever-more-powerful blast furnace.

15. The fourth paper is the first in a series of reports describing the possibilities of using sponge iron in the charges of electric reduction furnaces and electric steel-making furnaces.

16. Mr. König is the author of this fourth report, which is entitled "Results of and remarks on the use of directly-reduced material in conventional electric reduction furnaces". Mr. König studies the effect of a charge consisting wholly or in part of direct-reduced material on the operation of the electric reduction furnace. The charges of direct-reduced material naturally give this furnace the advantage of savings in energy and coal while increasing its productivity. This is undoubtedly feasible, and the author, fully aware of this possibility, makes it his business to examine every factor that can affect the operation of a reduction furnace charged with sponge iron, and the consequent advantages and disadvantages thereof. He deals specifically with.

the composition of the crude ore and the degree of reduction of the sponge iron; and

the increase in the furnace's output capacity.

17. In this connexion we should consider figures 2 and 3, which show the respective increases in production capacity of the electric reduction furnace and the blast furnace as a function of Fe content. The author then goes on to consider other aspects of the operation of the electric furnace charged with directly-reduced material, namely:

influence on the volume and calorific value of the top gas; and

influence on the composition and temperature of the pig iron.

18. He then moves on to the conclusion that, even now, the combination of the direct-reduction process with reduction in the electric furnace may be an economically viable solution for countries which have no coking coal, particularly if on the other hand they have cheap electric power.

19. The next paper is by Mr. Post who deals with the theory and practice of melting sponge iron in electric-arc furnaces, and in particular with furnace-charging techniques. More particularly, he regards the batch charging of sponge iron as absolutely irrational, and considers continuous charging of the furnace to be the rational system.

20. In this connexion he considers two systems, the IRSID and the CONTIMELT. In the IRSID process, developed in France by the Institut des Recherches Sidérurgiques, the sponge iron is fed through a central hole in the furnace roof. According to the author, this process has so far been tried out only in a small 6-t arc furnace, and he thinks it probable that certain difficulties would be encountered if it were applied in furnaces of higher capacity.

21. The author then discusses the CONTIMELT process developed by STELCO (Steel Company of Canada) and Lurgi Chemie und Hüttentechnik (Federal Republic of Germany) with the co-operation of Republic Steel Corporation (United States). The report includes a diagram of furnace charging in the IRSID system, but none is included of the CONTIMELT charging system. It is known that with the latter system the furnace is likewise charged via the roof through three holes, each between an electrode and the furnace wall.

22. Mr. Post communicates, through a series of tables and diagrams, the data obtained in a large number of operations. The data are readily comparable because they relate to homogenous sets of experiments. The care with which this research programme was carried out vouches for the validity of the conclusions emerging from it.

23. Unfortunately I have not seen the texts of the session-III papers III-12 and III-5, but only very brief summaries of them. We do not mean this as a criticism of the authors, because what they have to say will be quite new. The papers in question are the report by Messrs. Noda, Furuhashi and Ushiyama on experience in UHP arc-furnace operation and that by Messrs. Kehl and Voss on the use of metallized pellets in electric-arc furnace steel-making processes.

24. The paper by Mr. Noda and his co-workers will describe experience in charging by the CONTIMELT system, into a 70-t 45-MVA UHP arc furnace, material directly reduced by the SL/RN method. The paper by Mr. Kehl and Mr. Voss will be of interest to us because it will contain information on the operation of the Hamburg steelworks with directly-reduced MIDREX, charged, if I am not mistaken, by the simple IRSID system or a system very similar to it.

25. The next paper to be considered is the report by Messrs. Morelli and Urgnani entitled "The use of sponge iron in an electric steel plant". The two topics dealt with in this paper are:

(a) the system used for charging the directly-reduced material into the electric steel-making furnace; and

(b) a comparison of the operating results of two steelworks having similar plant but one using scrap alone and the other using scrap with high proportions of directly-reduced material.

26. Before describing in detail the specific system adopted for electric-furnace charging by TAMSA at Vera Cruz (Mexico) the authors briefly review the other charging systems and explain why they were prompted to choose the present lateral charging system, in which the directly-reduced material is injected through an opening in the furnace wall.

27. I hope a discussion on this subject among the experts present will be possible, because the papers submitted do not point to a sole and exclusive conclusion concerning the systems used for charging directly-reduced material into electric steel-making furnaces; it may be that the discussion will bring out the reasons why different methods have to be chosen.

28. So far as the second part of the paper by Messrs. Morelli and Ingnani is concerned, it must be said that the results which have been compared do not relate to fully-comparable steel plants. However, it seems clear that the 50 per cent sponge-iron charge did not lower productivity, while there was a slight increase in electric power consumption because of the larger quantity of slag caused by the sponge-iron's not having been prepared from a very high-grade ore.

29. Only very brief mention is made in the paper of an improvement in the quality of the finished product through the use of high percentages of directly-reduced material in place of scrap. We should be grateful to the authors if in introducing their papers they would be good enough to furnish particulars enabling us to form a general idea of this qualitative improvement and of its economic consequences.

30. The next paper is the report by Messrs. Kudryavtsev and Pchelkin entitled "Continuous smelting of hot metallized pellets in an electric furnace". As the title indicates, the report considers the interesting problem of charging hot directly-reduced material into electric steel-making furnaces. On the basis of calculations and the results of a very large number of tests the authors give figures which leave no room for doubt as to the great advantage of the hot charge.

31. If before being charged into the electric furnace the directly-reduced pellets are already at a temperature of 700-800°C, the smelting time is reduced by 25-30 per cent and the electric power consumption is consequently lower.

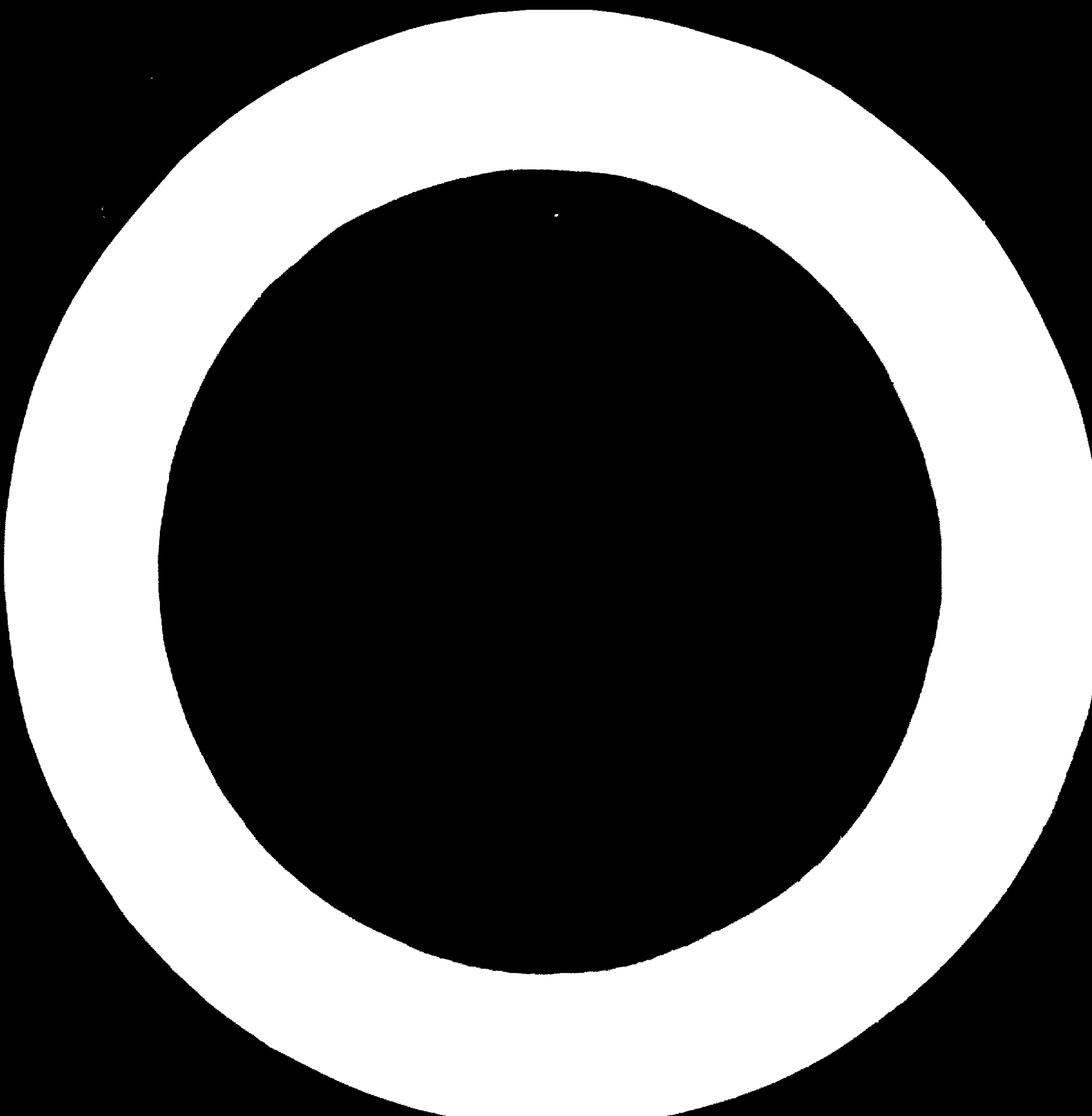
32. A comparison of charges of hot sponge iron with charges of cold scrap shows that the saving in electric power effected by pre-heating the sponge iron can offset the extra power consumption caused by the greater quantity of slag from the sponge iron, even at 350 kg of slag per ton of steel.

33. Alongside the data demonstrating the advantages of hot-charging directly-reduced material the authors have developed practical formulae inter-relating on the one hand the degree of pre-heating of the sponge iron, the degree of metallization of the sponge iron, the slag/metal ratio and, lastly, the composition of the sponge iron and on the other the size of furnace, its productivity, and the specific consumption of electric power. The technicians meeting here will certainly pay close attention to the report by Messrs. Kudryavtsev and Pchelkin, because the subject is of interest to all electric-furnace steelmakers, whether they use directly-reduced material or the conventional scrap process.

34. The next report, by Messrs. Cosma and Hătărascu, considers a problem common to countries having no coking coal but having hydrocarbons. In such countries it seems logical to employ a direct-reduction process to produce sponge iron for use as part of the blast furnace charge so as to save coke, or for electric steel-making.

35. On the use of sponge iron in the blast furnace the authors carried out experiments in a small blast furnace of 0.7 m diameter, while the tests concerning the use of sponge iron in steel-making were carried out in electric furnaces of 0.5 and 5 t. The coke consumption in the experimental blast furnace seemed to us to be very high. At all events, the authors have given precise information on the total savings of coking coal achievable by using sponge iron in the charge.

36. In assessing the advantages and disadvantages of using sponge iron in the blast furnace and in the electric steel-making furnace the authors calculated the maximum cost for sponge iron that could still be regarded as economic. They intend to carry out further experiments in blast furnaces, and also in electric furnaces of higher capacity. In this connexion I very much hope that some of the experts here present will be able to give us experimental data obtained elsewhere in similar research.



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Bucharest (Romania), 18-23 September 1972

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DIRECT REDUCTION IN THE BLAST FURNACE

Submitted by the Government of Belgium

Prepared by A. Poss, R. Vidal and R. Michel

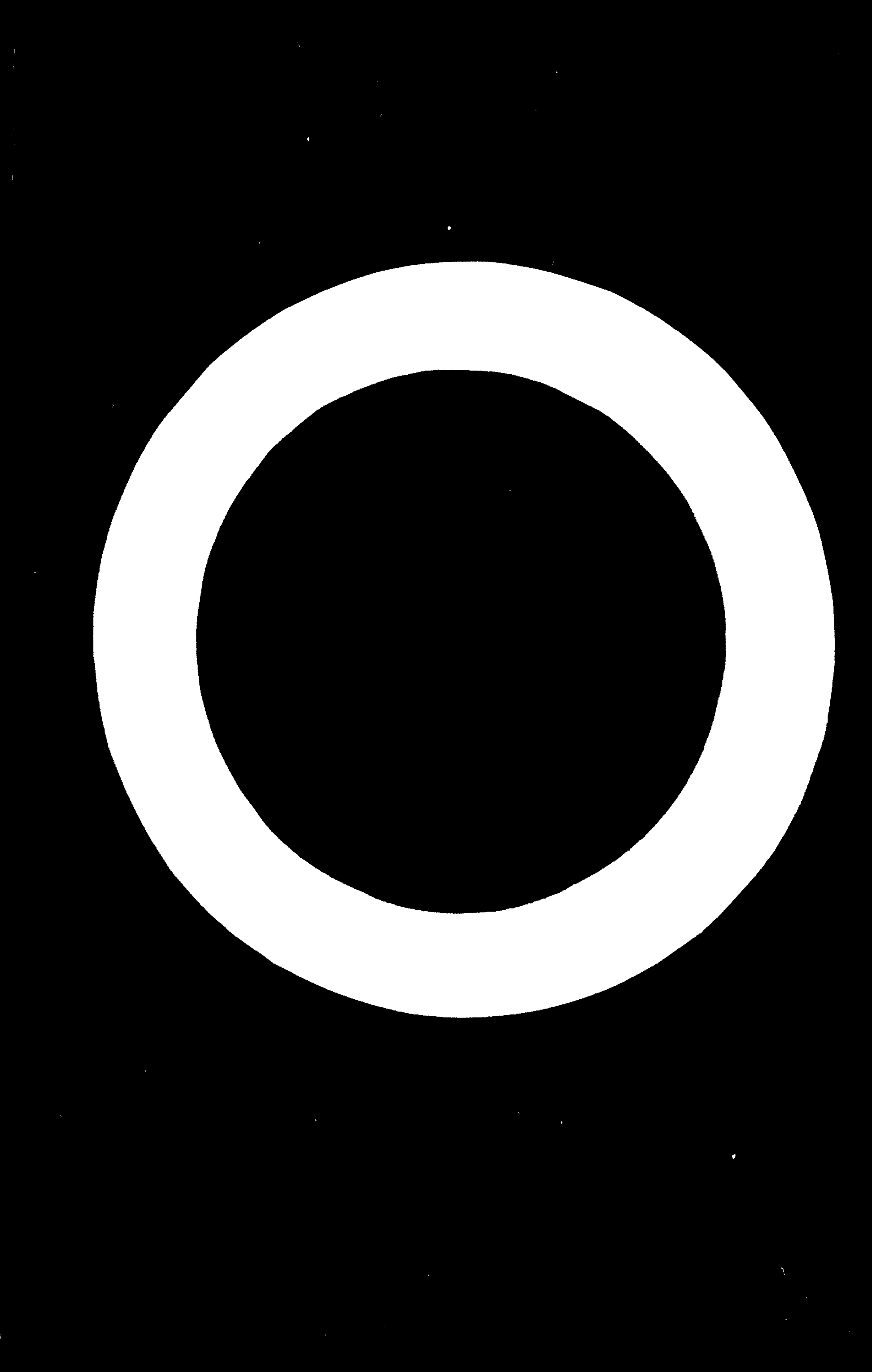
Summary

This paper considers the possibility of applying in the blast furnace some of the techniques used in direct reduction, and thus of making blast furnace products more competitive.

There is a brief description of one of these techniques - an operation using injections of hot reducing gases at the bottom of the shaft, with or without injections of fuel oil in the main tuyéres. With this technique, the blast furnace would offer the same advantages as direct reduction processes in the shaft furnace or in a stationary shaft, and at the same time become very flexible as regards the type of power required.

The conclusion is reached that tests in the blast furnace with combined injections of hot re-formed gases at the bottom of the shaft and of fuel oil in tuyères have demonstrated the technique's efficiency at the pilot stage, particularly as a means of reducing the coke/pig-iron ratio.

From the data for two plants with an output of 2 and 8 million tons of steel per annum respectively the cost of producing pig iron and the cost of producing pre-reduced pellets with a metallization rate of 95 per cent was calculated. It was found that, for a price per Gcal gas of 2 accounting units, the direct reduction - electric furnace method is not competitive with the blast furnace-converter method unless the price of coke exceeds 72.5 and 78 accounting units per ton for the two plants respectively. This situation only grows worse as the price per Gcal gas increases.



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Bucharest (Romania), 18-25 September 1972

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[illegible] 1972
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Original: FRENCH

DIRECT REDUCTION OF IRON ORES IN A SHAFT FURNACE - ICEM PROCESS

Submitted by the Government of Romania

Prepared by: Mr. O. H[illegible]rascu, Chief,
Blast Furnace and Direct Reduction Laboratory,
Bucarest Metallurgical Research Institute (ICEM)
Mr. I. Tripsa, Professor, Doctor, Agrégé,
Bucarest Polytechnic and Mr. L. Di[illegible]n, Scientific
Research Worker, Bucarest Metallurgical Research
Institute (ICEM).

Summary

At the Metallurgical Research Institute research has been conducted into ways of obtaining the direct reduction of iron ores by the use of methane. The research is continuing. The aim is to produce sponge iron for steel-making in electric furnaces and to produce pig iron in blast furnaces with a lower specific consumption of coke.

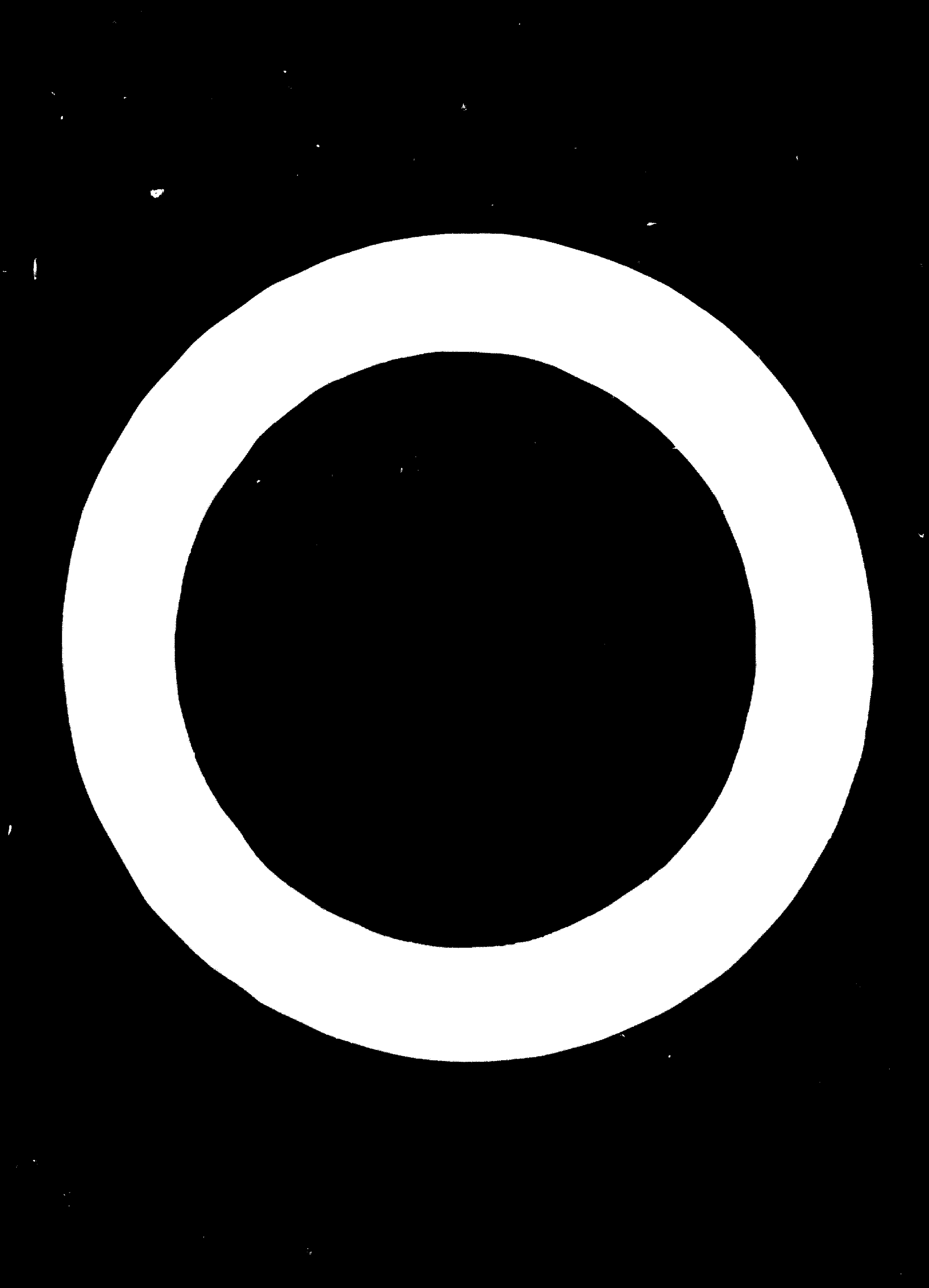
The preliminary research at the pilot level was centred on the use of reducing gases obtained by converting methane with air in tilting furnaces. The plant designed in accordance with this process has produced sponge iron at a reduction ratio of approximately 95 per cent. Because of the fairly high nitrogen content of reducing gases, the research was carried out with reducing gases containing more than 85% CO + H_2.

A process has been designed based on the use of these gases in a shaft furnace. The gases are obtained by the conversion of methane with CO_2. The process provides for recycling of the gases discharged during reduction and for their regeneration by the addition of methane. The methane is converted with the CO_2 derived from the iron ore reduction process.

Experiments to develop the process were conducted at ICEM in a pilot plant having a capacity of two metric tons of sponge iron per day. The plant consists of a vertical shaft furnace with a cubic capacity of 2.2m³, two converters for regenerating and re-heating the gases, and two wet scrubbers also serving as dry dust separators.

The process and plant have made it possible to obtain sponge iron at high reduction ratios.

The experiments were made with iron ore from India (Goa) having an iron content of 65 per cent. Sponge iron produced at a reduction ratio of 85 per cent required a total consumption of 750 Nm³/t of methane. Through a series of improvements it has been possible to reduce this consumption and to produce sponge iron with a specific methane consumption of less than 475 Nm³/t.



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RESULTS OF AND REMARKS ON THE USE OF DIRECTLY-REDUCED MATERIAL IN CONVENTIONAL ELECTRIC REDUCTION FURNACES

Submitted by the Government of Federal Republic of Germany

(Prepared by Mr. Horst KÖNIG, DEMAG)

SUMMARY

In contrast to the modern blast furnace, which reduces iron ores mainly with the carbon monoxide given off by the fuel coke (exothermic process), reduction in the electric arc furnace is carried out with solid carbon, in view of the low shaft height, or with the carbon monoxide reformed from the carbon dioxide given off by the solid carbon (heavily endothermic process). Heat is provided by the electrical resistance set up when the furnace electrodes are immersed in the charge.

It will be appreciated that, for these reasons, reduction work carried out prior to the electric furnace process will yield substantially bigger savings in energy as compared with similar conditions for the blast furnace process. Again, the capacity increase for the electric reduction furnace as charged with direct-reduced material is considerably greater as compared with the blast furnace process.

In the paper, the applicable values are discussed, and the effects of charging direct-reduced material into the electric reduction furnace are considered. Finally, a report is given on actual results as obtained in the operation of an industrial-scale direct-reduction plant with linked electric reduction furnace.

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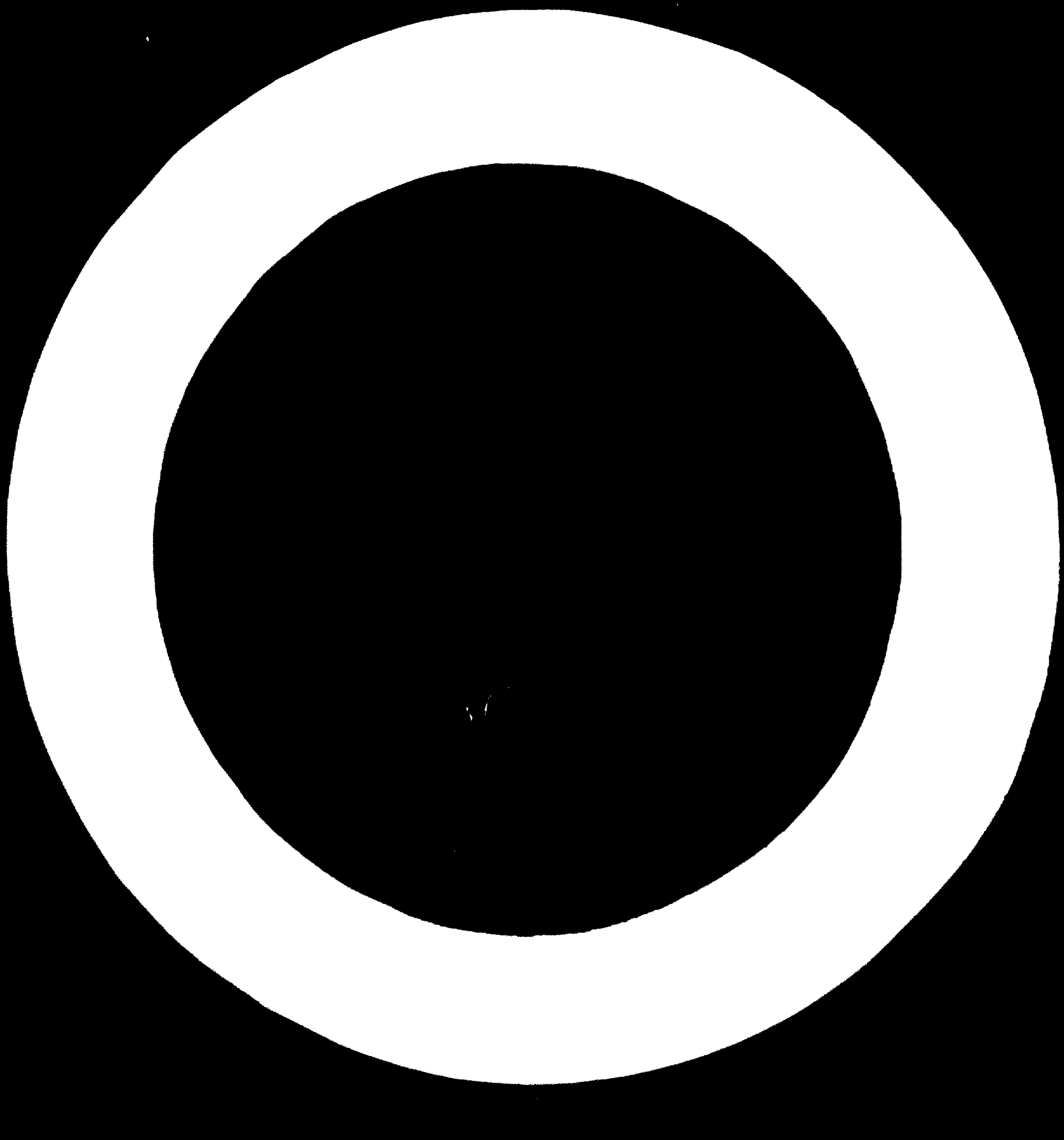

ECONOMIC COMMISSION FOR EUROPE
COMMITTEE ON GAS

SYMPOSIUM ON THE OPTIMUM SOLUTIONS OF PROBLEMS IN THE TRANSPORT AND DISTRIBUTION OF GAS IN ORDER TO MEET DAILY AND SEASONAL PEAK LOADS

Bucharest (Romania), 2-5 October 1972

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IMPROVING BLAST-FURNACE PERFORMANCE WITH HIB
EXPERIMENTAL-BLAST-FURNACE RESULTS

Submitted by the Government of the United States of America

(Prepared by Messrs. D.G.White, P.B.Stubbs, R.J.Rygiel and M.M.Harris.)

Summary

In the past few years, the efficiency of the blast-furnace process, as reflected by decreasing coke rates, has been greatly increased by the use of agglomerated and sized iron-bearing burden materials. United States Steel Corporation has a new iron-ore agglomeration plant that is designed to produce 75-per cent reduced iron-ore briquettes, called High-Iron Briquettes (or HIB), having an iron content of about 86 per cent. This facility, located at Puerto Ordaz, Venezuela, is the world's largest plant for producing a prereduced burden material, with a rated capacity of up to one million metric tons of HIB per year.

Because they are highly reduced in addition to being uniformly sized, the HIB's constitute an exceptional blast-furnace burden material. Prereduction of the burden is the ultimate modification to blast-furnace practice for achieving maximum process efficiency and productivity. The United States Bureau of Mines and the Steel Company of Canada have previously reported that a prereduced burden can lower blast-furnace coke rate by as much as 50 per cent with an even higher percentage increase in hot-metal production rate. Similar results will be presented here from a study conducted with the United States Steel experimental blast furnace to evaluate HIB as a blast-furnace burden material.

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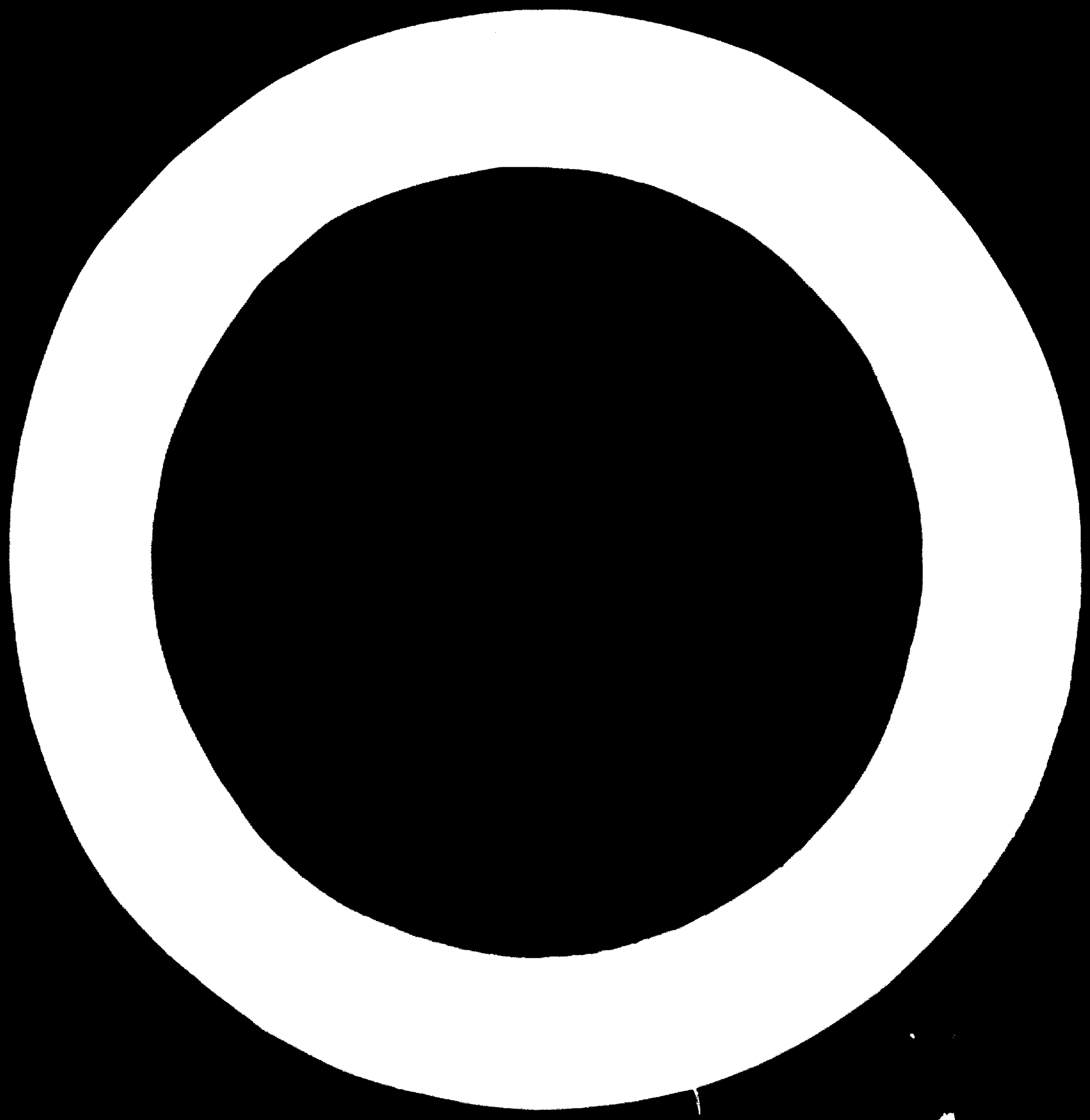

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7 April 1972

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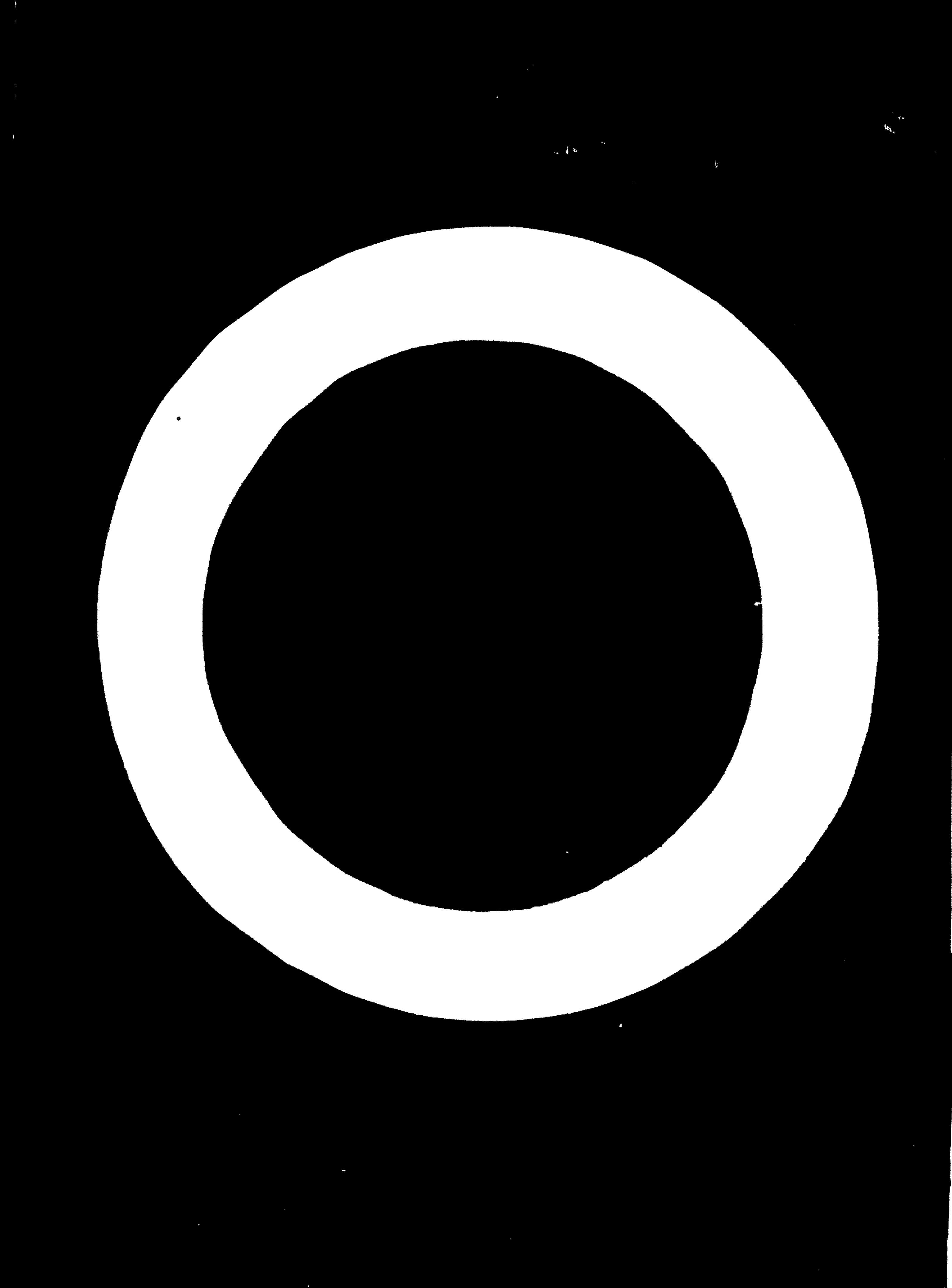
THE USE OF METALLIZED PELLETS IN ELECTRIC-ARC FURNACE STEELMAKING PROCESSES

Submitted by the Government of the Federal Republic of Germany

(Prepared by Messrs. P. KEHL and H. VOSS
HAMBURGER STAHLWERKE GmbH.)

SUMMARY

Since the autumn of 1971, metallized pellets have been used in the electric steel plant of Hamburger Stahlwerke GmbH, for their steelmaking process. Both the equipment used for continuous feeding operations and the melting technique applied are described. The report concerns the metallurgical working operations of melts smelted with metallized iron ore pellets and gives particulars on the reduction of feeding times achieved by this process. It also includes data on power consumption as well as on improvements of the electrical operating behaviour during the smelting process. In addition steps made towards the improvement of wall stability during the smelting of metallized iron ore pellets are discussed.



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PRESENT AND FUTURE ASPECTS OF THE USE OF SPONGE IRON IN ROMANIA

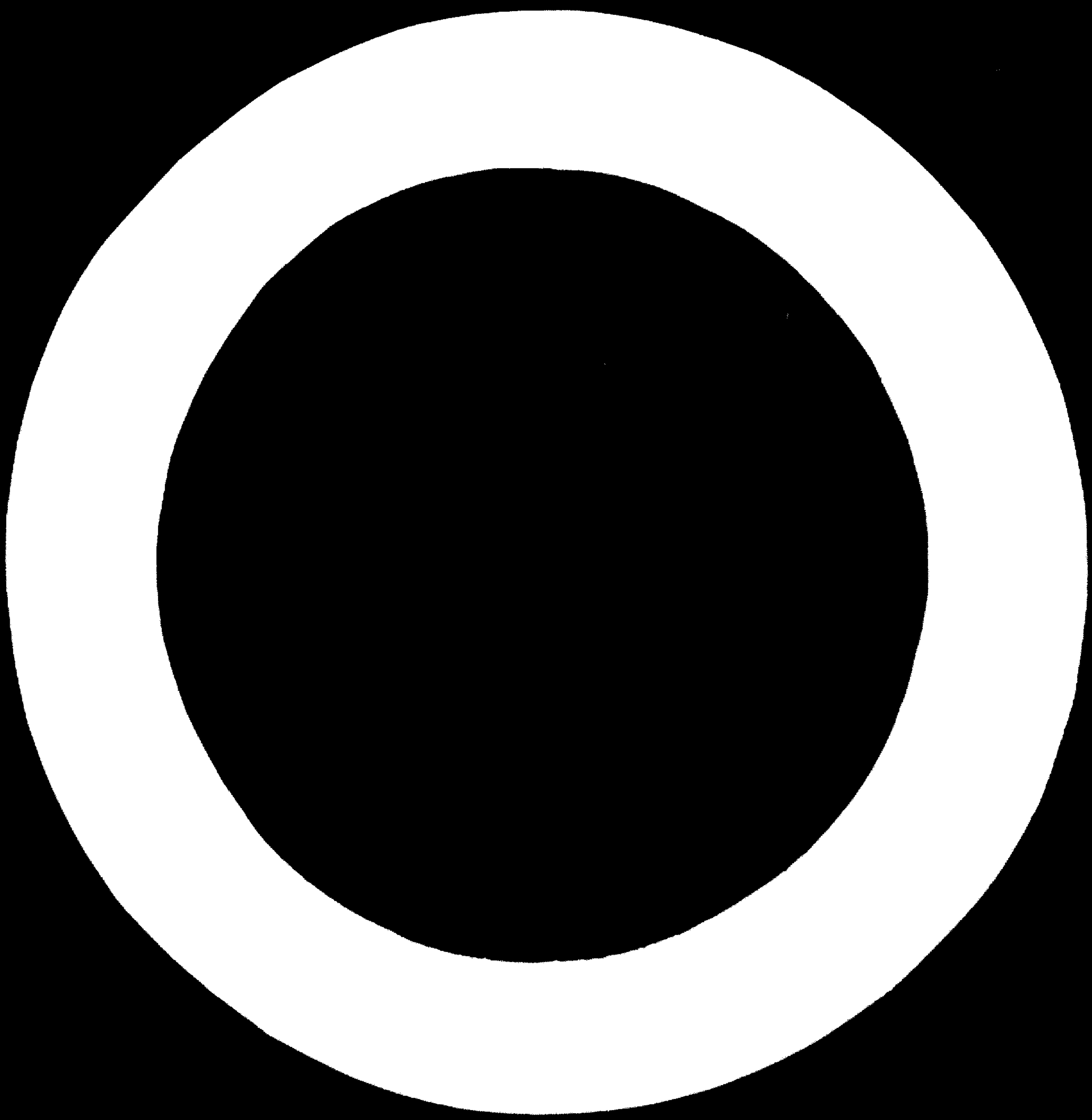
Submitted by Romania

Authors: D. Cosma, Deputy Scientific Director
O.V. Hătărascu, Chief, Blast Furnace and Direct Reduction Laboratory
C. Avram, Chief, Iron and Coke Department
(Metallurgical Research Institute, Bucharest - ICEM)

SUMMARY

The authors describe the conditions under which the use of sponge iron in blast furnaces or electro-furnaces as a partial substitute for scrap becomes advantageous for the Romanian steel industry. The reasons are given for Romania's interest in applying direct reduction processes, particularly those using natural gas. The results of tests on the use of sponge iron in blast furnaces and electro-furnaces are briefly stated.

Analysis of limiting conditions shows that the use of sponge iron is more economic in the electro-furnace than in the blast furnace. The cost of the furnaces should therefore not exceed one-quarter of the value of the ore required to make the sponge iron.



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[illegible]/Sem.Dir.Red./Sem./[illegible]-7
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Original: [illegible]

CONTINUOUS SMELTING OF HOT METALLIZED PELLETS IN AN ELECTRIC FURNACE

Submitted by the representative of the USSR

Prepared by V.S. [illegible] and S.[illegible]. [illegible]

SUMMARY

Because it can be relied upon to be free from harmful admixtures, sponge iron is used in a number of countries for steel-making in furnaces of up to 150 tons capacity. Tests and calculations have shown that the smelting of hot metallized pellets requires the expenditure of less electric power than smelting with cold scrap and that this advantage disappears only where the slag factor rises to a very high level (0.85 where the furnace efficiency is 0.5). In recent years studies have been carried out in the USSR on the continuous smelting of hot (1000°C) metallized (75-95%) pellets in 0.5 and 10-ton furnaces. The technical and economic indices of these tests are given in the report.

Experiments and calculations have shown that pre-heated charges, their degree of metallization, the slag factor and the specific composition of the metal, determine the dimensions of the electric furnace, its productivity, its efficiency and the specific consumption of electric power, these relationships being expressed by specific formulas; it has been shown that a substantial reduction in the consumption of electric power used in smelting, with a corresponding increase in the productivity of electric furnaces, can be attained by the use of hot rather than cold metallized pellets.

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3 OF 3

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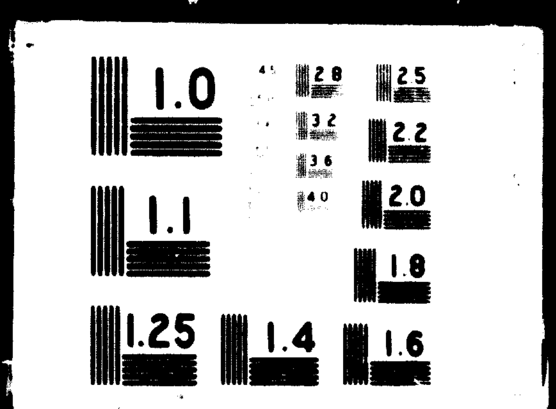

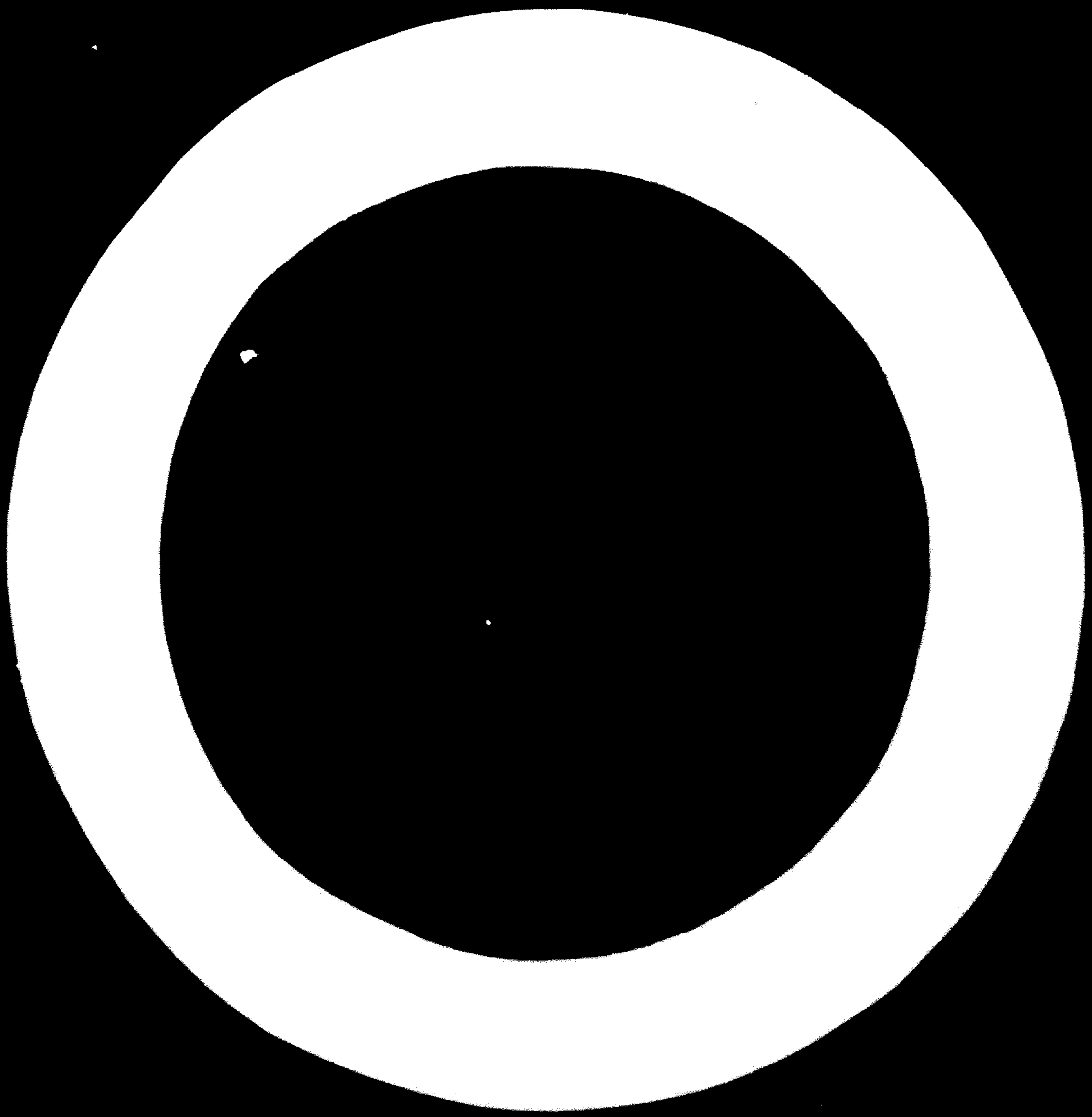

ECONOMIC COMMISSION FOR EUROPE
STEEL COMMITTEE
SEMINAR ON DIRECT REDUCTION OF IRON ORE: TECHNICAL AND ECONOMIC ASPECTS
Bucharest (Romania), 18-23 September 1972

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REVIEW OF THE SITUATION OF PREREDUCTION IN SPAIN

Submitted by the Government of Spain

Prepared by Messrs. ROQUERO, BONED, KOENTING, PENACHO and ARANGUREN

Summary

In the first part of the paper, brief comments are given on the development of prereduction in Spain. The interest in prereduced products is justified by the economic problems arising in scrap supply and from the fact that Spanish scrap prices exceed those prevailing in other European countries. The paper gives consideration to raw materials and other factors which may determine the production of prereduced material as well as the location of possible full-scale plants. Finally, the authors present the current research programme on the subject of prereduction, which has recently been started by the National Centre for Metallurgical Research (Centro Nacional de Investigaciones Metalurgicas - CENIM), and which will last for four years.

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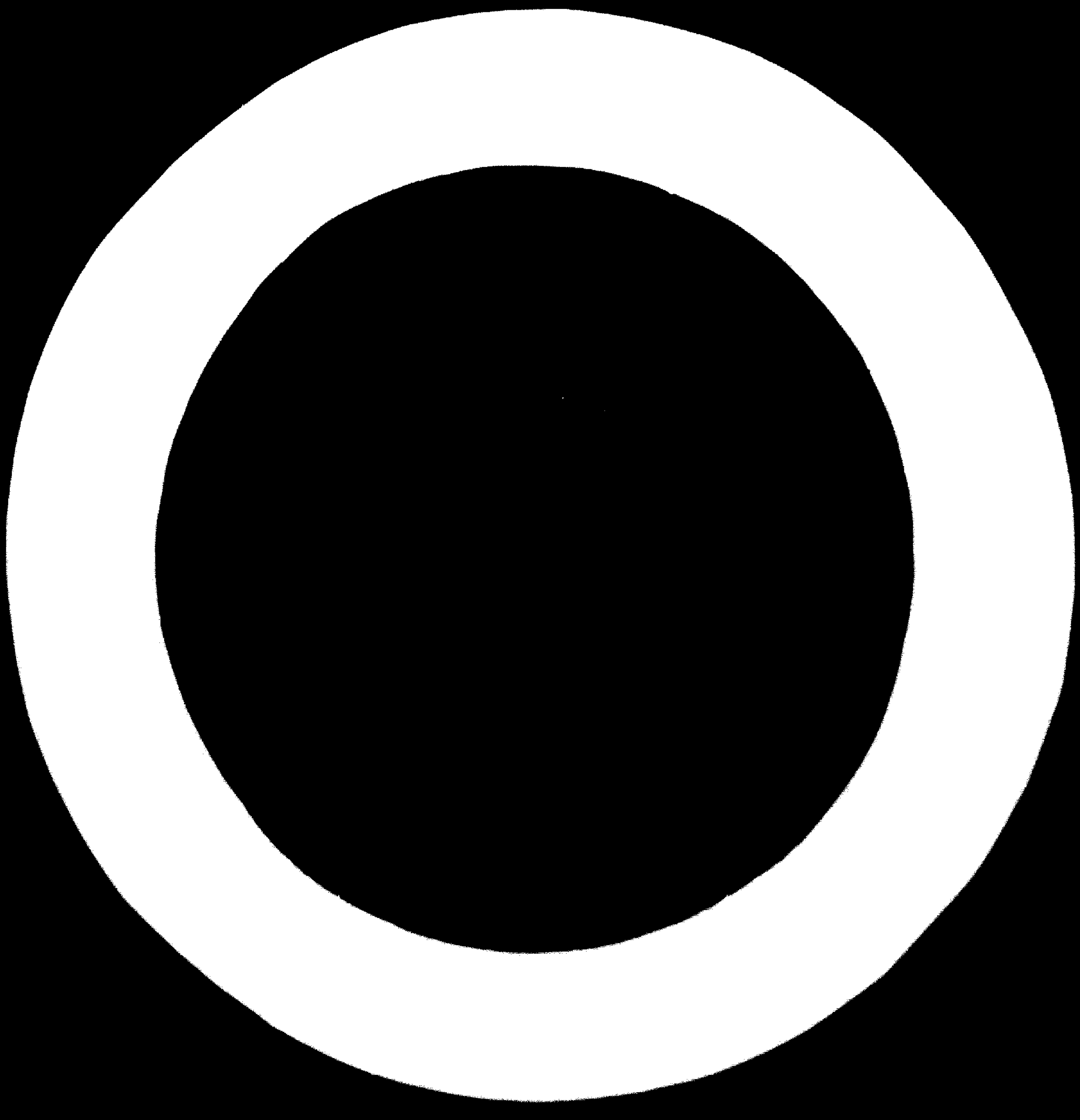

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USE OF SPONGE IRON IN ELECTRO-FURNACE STEEL-MAKING

Submitted by the Government of Italy

Prepared by Mr. G. Morelli, TAMSA (Italy) and Mr. G.B. Urgnani, TECHINT (Mexico)

Summary

The paper surveys and discusses data (practical experience, productivity, consumption, etc.) on the use of products of direct reduction in electro-furnace steel-making.

The data relate to an electrical steel-works which has been operating for five years with a charge of 50 per cent sponge iron, and are compared with the data for another steel-works with the same layout and the same type of production operating with a normal charge of 100 per cent scrap.

The sponge iron is obtained in a direct-reduction plant by the HyL (Mexico) process.

The survey also examines the problem of continuous throughput of sponge iron in the electro-furnace by various processes.

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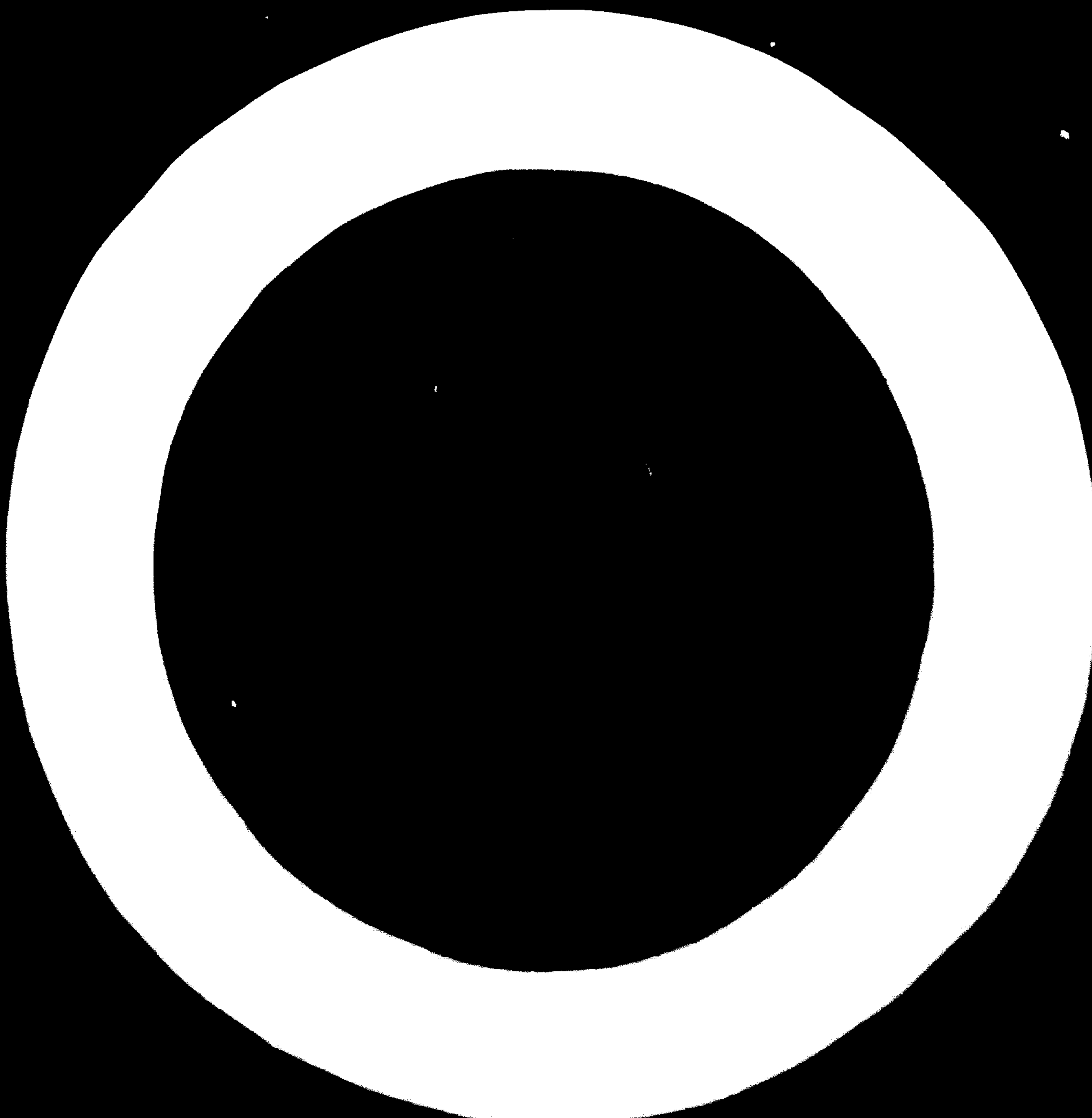

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UNIDO's Technical Assistance Activities in the field of the Iron and Steel Industry including Direct Reduction Processes

Submitted by the Secretariat of UNIDO

Prepared by Mr. B.R. Nijhawan

Summary

This background paper outlines the nature, type and scope of technical assistance activities of UNIDO in the field of the iron and steel industry and also refers to the technical assistance projects concerning direct reduction processes for the production of sponge iron.

Reference has also been made to supporting activities of UNIDO in the field of the iron and steel industry including the proposed "Third Interregional Iron and Steel Symposium" expected to be held in Brazil during 1973. The spectrum of activity in the above fields is as wide as it is interesting and challenging and UNIDO is striving to fulfil the demands made.

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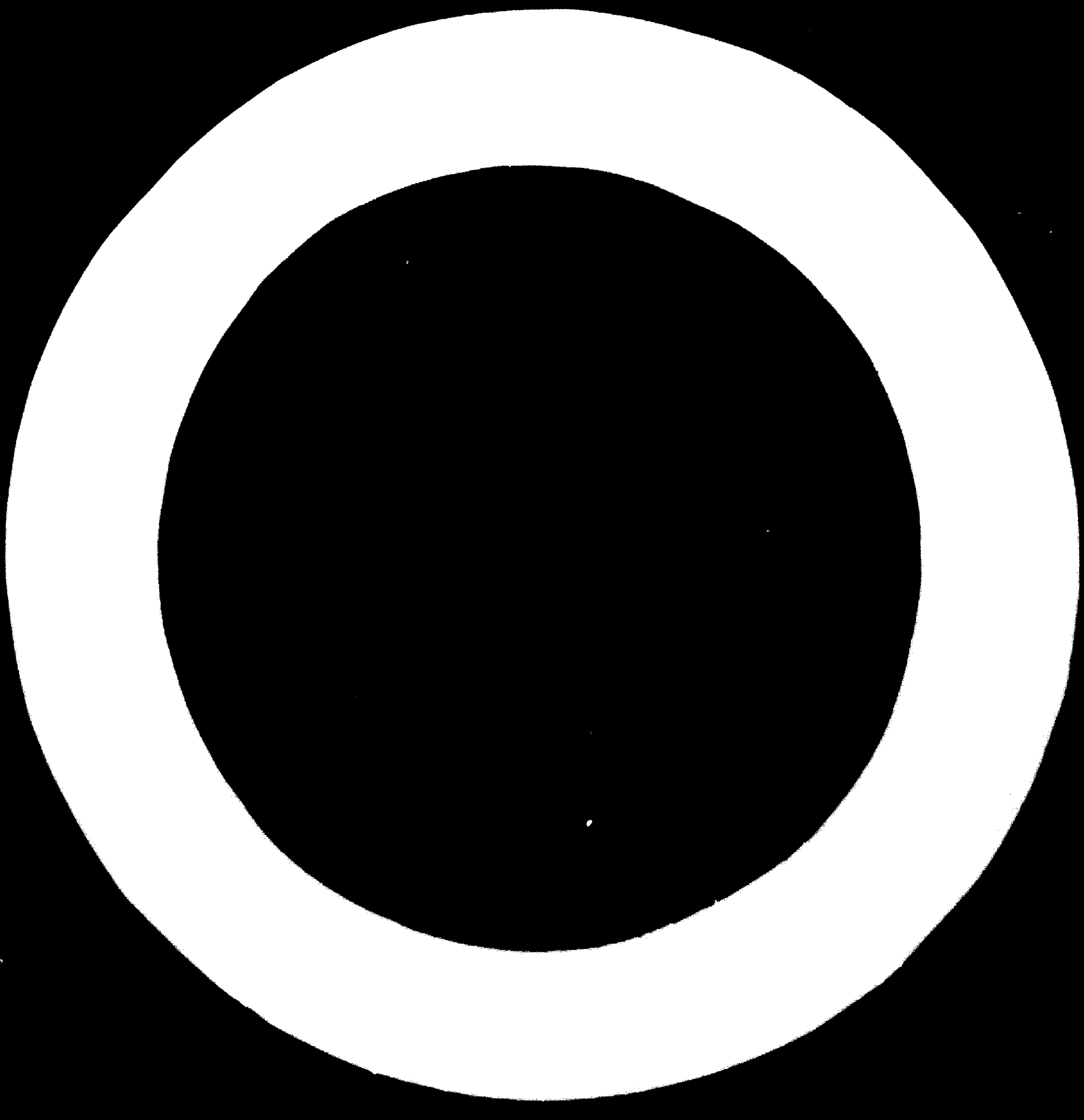

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Theory and Practice of the Melting of Sponge Iron in Arc Furnaces

Submitted by the Government of the Federal Republic of Germany

(Prepared by G. Post, Lurgi Chemie und Hüttentechnik GmbH)

SUMMARY

The only feature common to all the existing direct reduction processes is their preference to melt the high metallized sponge iron in arc furnaces. The three best known methods for this are the batch charging process, the IRSID process, and the Continelt process.

Already from the mere description and discussion of these processes, it becomes obvious that the Continelt process has the greatest potential advantages. This is mainly due to the capability of this process to increase the furnace productivity by feeding and melting the sponge iron continuously and carrying out the metallurgical measures simultaneously. Therefore the Continelt process is investigated in detail from a theoretical and practical standpoint.

The theoretical part uses for the first time the results of a mathematical model. The influence of the main factors on the productivity and power consumption is investigated under defined conditions which are typical for the production of carbon steels in large arc furnaces. Under these conditions the productivity of the conventional scrap melting arc furnace can be increased by up to 30 per cent. The value of this maximum and the corresponding sponge iron percentage in the charge depends mainly on the duration of the refining period of all-scrap practice. Under the same conditions the power consumption is slightly increased with rising sponge iron ratios in the charge. The slope is mainly influenced by the gangue content of the sponge.

The theoretical findings are compared with the actual test results from 5 different arc furnaces being divided into 2 groups:

Group A, characterized by a furnace tap weight of 90 to 135 t confirms the theoretical results completely, as follows:

(a) The productivity is increased by up to 20 per cent over all-scrap practice. This maximum corresponds to 10 - 25 per cent sponge iron in the charge.

(b) The power consumption is steadily and slightly increased with increasing sponge iron percentages.

The test results of group B do not quite fit into the scope of the theoretical prerequisites, because the furnace tap weight is only 10 to 23 t. The only productivity figure being available for this group indicates a productivity increase as high as 45 per cent over all-scrap practice. In contrast to group A, the power consumption is 10 to 15 per cent below the all-scrap level at 20 to 30 per cent of sponge iron in the charge. The explanation for the different behaviour of large and small furnaces is given in the paper.

Further practical aspects of the application of the Contimelt process are described briefly. This includes the choice of the most suitable continuous charging equipment. In this connexion, reasons are given why the gravity feeding through one or three holes of the furnace roof is preferable to slinger techniques through the furnace side wall or door.

The theoretical and practical findings allow the following conclusions:

(a) The Contimelt process is superior to all the other sponge iron melting processes including the conventional all-scrap melting.

(b) The conversion costs are minimized and lower than for all-scrap heats in the range 10 to 30 per cent of sponge in the charge. In this range, the sponge iron has its highest value which is above that of scrap.

(c) High percentages of sponge in the charge are justified from a mere cost standpoint only if the Fe unit from sponge is cheaper than from scrap.

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