OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

DISCLAIMER

This document has been produced without formal United Nations editing. The designations employed and the presentation of the material in this document do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations Industrial Development Organization (UNIDO) concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries, or its economic system or degree of development. Designations such as "developed", "industrialized" and "developing" are intended for statistical convenience and do not necessarily express a judgment about the stage reached by a particular country or area in the development process. Mention of firm names or commercial products does not constitute an endorsement by UNIDO.

FAIR USE POLICY

Any part of this publication may be quoted and referenced for educational and research purposes without additional permission from UNIDO. However, those who make use of quoting and referencing this publication are requested to follow the Fair Use Policy of giving due credit to UNIDO.

CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

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

UNITED NATIONS

[redacted]

INTERREGIONAL SYMPOSIUM ON THE APPLICATION OF MODERN TECHNICAL PRACTICES IN THE IRON AND STEEL INDUSTRY TO DEVELOPING COUNTRIES

11-26 NOVEMBER 1963

STEEL SYMP.1963/
Technical Paper/B.10
26 September 1963

ENGLISH
Original: RUSSIAN

D04787

COMPARISON OF STEEL-MAKING PROCESSES:

THE PROSPECTS FOR WORLD STEEL PRODUCTION - THE CHOICE OF PROCESSES

by

The Steel, Engineering and Housing Division,
United Nations Economic Commission for Europe

A detailed economic comparison of the results obtained by means of various steel-making processes widely used in industry would appear to show that, when new steel plants are built in the next few years, preference will be given to the installation of oxygen converters of the LD and Kaldo types. There will also be a considerable expansion in the production of electric steel. On the basis of the available data concerning long-term plans for the development of steel production throughout the world, it may be estimated that the total capacity of oxygen converters of various types will rise to 100 million tons by 1965 and, according to some forecasts, to 200 million tons by 1970. The following conclusions may be drawn from these plans for the development of oxygen converter steel production:

(a) No new acid Bessemer shops will be built;

(b) There is little probability that new bottom-blown Thomas converter shops will be built, even for blowing with nitrogen-free mixtures;

(c) Only in special circumstances will the construction of new open-hearth shops with fixed furnaces be possible; the construction of tilting open-hearth furnaces and of shops based on cold-charged, open-hearth furnaces is unlikely;

(d) Oxygen converters of different types and electric-arc furnaces will be built in new steel shops;

(e) The construction of new Rotor installations in the near future is not envisaged. Of the two types of rotating steel-making vessels, only Kaldo furnaces are likely to be erected.

These forecasts of the future development of steel production are based on technical and economic data which are given in the report.

Comparison of steel-making processes

At the end of 1962 the United Nations published a study entitled "Comparison of steel-making processes", by the Secretariat of the Economic Commission for Europe. The ECE Steel Committee considered the study at each successive stage in its preparation, and pertinent comments were made by the Committee itself, by most governments of States Members of the United Nations, by individual representatives and by other experts. Accordingly the study reflects the prevalent, if not the unanimous view of the economic aspects of the further development of various methods of steel production.

Further, the study is - by virtue of its date of publication - the most up-to-date work in the technical literature of the problem of selecting steel-producing methods; and its main ideas and conclusions should therefore be discussed at our Symposium in order that they may be used for selecting the most economical method of producing steel in any given set of circumstances.

The study consists of a preface and six chapters. The first chapter briefly reviews the development of steel-producing methods from the middle of the eighteenth century to the present day. The various phases in the development of steel metallurgy in the past are critically analyzed from the stand-point of present-day knowledge, and an account is given of the various stages in the development of different methods of steel production in European countries and the United States of America at different times in the period under consideration. Chapter I provides, in concise form, everything needful for an understanding of the technical and economic factors which have led to the development or decline of particular methods of steel production in different periods.

The second chapter describes the role of oxygen and electricity in their application to various methods of steel-production. By quoting extensively from the technical literature, the authors demonstrate convincingly that inadequate production and high costs were the main reasons why electricity and oxygen were not generally used until long after it had been established theoretically that they ought to be used if steel-production processes were to be speeded up and better-quality steels produced. These two factors - the high cost of oxygen and the high cost of electricity - seriously retarded the application of electricity and oxygen in steel-making, and also held up the design of large-capacity steel-making plants using electricity or oxygen or both. This is quite natural considering that scientists, technologists and designers always concentrate their attention on more immediate problems rather than on those which may arise at some indefinite period in the future.

The diagrams reproduced in chapter II show the direct relationship between the technical and economic indicators of electricity and oxygen production and the extent to which they are used in metallurgy.

The rapid progress made in recent years in the production of oxygen - and, even more so, of electricity - has opened up vast possibilities for the use of both in metallurgy; and the current increase in the amount of steel produced in electric-arc furnaces and oxygen convertors would have been impossible without the valuable efforts of a large number of specialists in electricity, mechanics, chemistry, industrial design, economics and other fields.

The third chapter describes the properties and qualities of steel produced by different methods. The preparation of this chapter involved much more work than any of the others, and expert advice was sought from a large number of specialists in different countries. Moreover, the various ideas set forth in the chapter did not meet with unanimous acceptance, and an objective assessment of them will only be possible in the light of practical experience gained in the production and use of steel in the next few years.

The main reason for this difference of views is that - as the authors quite rightly point out in the prefix to the study - "Comparing steel-making processes is an extremely difficult task, as it is not yet possible to give any complete assessment of the quality of steel produced by different methods. The main point is that the quality of steel cannot be characterized by the results of any single test, as it can express itself in many different characteristics. Another difficulty is that the quantitative figures of some of these characteristics are not yet known, even for identical grades of steel produced by various methods. Moreover, in the methods of steel production comprising different stages of whole technology, it is frequently possible to obtain the same level of a particular property - e.g. of a given tensile strength or notch toughness - in one case by one combination of various stages and in another by a different combination. To simplify the problem in the present enquiry, on the one hand only the most common characteristics of steel are considered, and on the other, subsequent stages of the metallurgical processes after steel-making itself - e.g. rolling conditions or heat treatment - are assumed to be the same for all processes, since they are not necessarily connected with a given steel-making process."

The comparison made in the study is confined to steel-making processes which are already in large-scale industrial use or likely to be developed extensively in the next decade. These include -

(i) The basic open-hearth process;

(ii) The basic electric-arc furnace: open induction and vacuum furnaces (both arc and induction) and acid arc furnaces are not included, as their share in total steel output is insignificant;

(iii) The Thomas (or basic Bessemer) process;

(iv) Top-blown oxygen converter processes (LD, LD-AC and CLF processes);

(v) The Kaldo process;

(vi) The Rotor process.

The study does not contain any detailed analysis of the duplex processes (the converter-electric furnace, converter-open-hearth furnace and open-hearth-electric furnace).

The study is concerned only with the most common characteristics of steel quality: chemical composition, the main mechanical properties, and the response of these properties to temperature changes, ageing treatment or cold deformation, weldability and content of non-metallic substances.

As no established data are yet available even for these characteristics, it was not possible to include in the study more than a few representative examples.

One of the undoubted merits of this chapter is the extreme care with which it has been prepared, reference being made to many works by outstanding metallurgists in several countries. In a summary of the fairly detailed exposition of the available factual information and the conclusions based upon it, the author points out that:

> "Purely from the technical point of view, all steel-making processes offer wide possibilities of improving the quality of steel produced. But this is frequently not feasible economically. All the conclusions set out in this chapter are based on the specific properties actually attained in different types of steel. There is yet another point to be stressed in this connexion. It is extremely difficult to give any general assessment of the quality of steel, since the service conditions and, accordingly, the requirements for different characteristics of steel quality differ so widely. Thus one customer may emphasize one characteristic and a second another. The situation is

further complicated since" - as J.H. van der Veen has quite rightly pointed out - "apparently insufficient common knowledge exists about the correlation between test criteria and service behaviour. Bearing in mind all these reservations, it would seem possible to conclude that steel produced by any oxygen convertor process is at least as good as open-hearth steel".

This is a very important admission. To go a stage further, it should be noted that, with the general increase in the production of oxygen and the decrease in oxygen costs, this admission alone is a sufficient argument for advocating the production of steel in oxygen converters as a serious alternative to the well-developed and well-established open-hearth method. This is clear from a comparison of all outlays for each of the two types of production. It is now common knowledge, indeed, that factors such as the cost of equipping all plants for producing steel in oxygen converters, the cost of the steel so produced, labour productivity, specific converter productivity and other converter production indicators are economically more favourable than the corresponding figures for open hearth production.

Thomas steel blown with an oxygen-carbon dioxide mixture may be identical with open-hearth steel, and may actually have a lower nitrogen content. The same is true of soft boiling Thomas steel blown with a steam-oxygen mixture.

Converter steel blown with atmospheric air has certain advantages of its own; but, although it contains less of the other admixtures, it has a high content of some contaminating elements (phosphorus, nitrogen, and sometimes oxygen). For some purposes its mechanical characteristics are less satisfactory.

Thomas steel blown with enriched air occupies an intermediate position between Thomas steel blown with atmospheric air and steel blown with mixtures not containing nitrogen.

One positive fact which emerges is that in present-day steel classification more attention is paid to mechanical properties than to the steel-making process used.

The contents of chapter III were the subject of some highly-animated and extremely valuable discussion when the chapter was being prepared.

There is an old proverb which says that, where there is discord, truth will out; and it is to be hoped that periodical discussions based on extensive, far-ranging and up-to-date practical experience in the production and use of steels of different types, together with the vast amount of research being done in this field, will soon produce unequivocal answers to many problems which are still unsolved today.

The whole of chapter IV is devoted to a comparative study of the adaptability or flexibility of existing industrial steel-making methods in relation to the raw materials processed and to the product-mix of the steel produced, and to a comparison of specific fuel consumption, due allowance being made for the different composition of the charge and for the amount of heat which can be saved with each method in shops where associated processes are carried out. This approach to the assessment of the economic advantages and disadvantages of the various steel-producing methods is in itself evidence of an endeavour to produce completely objective results, unaffected by the author's personal preferences for any particular production method. The author has been obliged to introduce a number of hypothetical elements - for instance, the "heat content" of scrap, or the specific fuel consumption in blast furnaces and for the production of the gases and electric energy consumed in steel-making. But the assumptions increase, rather than impair, the reliability of the calculations, which are of necessity only approximate.

The same chapter includes a comparison of existing steeel-making plants from the point of view of their convertibility to mechanization and automation, at least at the present time.

It also contains information on the specific consumption of raw materials and refractories, yield, labour productivity per single worker, the advantages and disadvantages of the continuous smelting of steel and the heating of ingots in soaking pits, and the annual output of steel-making plants per ton of installed capacity.

As with the preceding chapters, all the information given in chapter IV is based on production data from many metallurgical plants in different countries; and this information in turn serves as a basis for ideas which are developed in greater detail in Chapter V, dealing with investment costs for the construction of steel-making plant and accessory equipment (allowance being made for economically interrelated production processes), and production costs when the prices of raw materials and the material content of the charge are comparable.

It is appropriate here to emphasize one particular feature which is widely known to specialists. This is that economic calculations within the limits of one enterprise or group of enterprises working in similar circumstances in a given area do not give rise to any particular difficulties, largely because a great deal of experience has already been accumulated in making calculations of this kind, and also because in these cases a relatively small number of variables are involved in the calculations.

But, as soon as there is an increase in the number of production methods, types of raw material and power resources to be compared, and as soon as allowance has to be made for different prices in different areas, economic comparison techniques become increasingly complicated, and more and more hypothetical elements and simplifications have to be introduced. As a result the degree of accuracy of the calculations is considerably reduced, and the results are merely approximations.

This makes it exceedingly difficult to select objective calculation conditions for technical and economic comparisons suitable for use in various countries in which resources for the development of iron and steel production are by no means the same.

This is obviously the main reason why so few comparisons of this kind are to be found in the existing technical literature. The study under consideration to some extent fills this serious gap, and introduces some new elements into the technique of economic comparisons.

The study contains a technical and economic analysis of all steel-making plants, except cold-charged open-hearth furnaces, Thomas converters blown with atmospheric air, and Rotor installations.

The first two types of plant were excluded from the comparison on the ground that it is very unlikely that any new plants based on these processes will ever be constructed again.

The Rotor process was excluded partly because no plants of this type are - as far as is known - likely to be constructed in the near future, and partly because there is virtually no information on capital outlay and operating costs for this production method.

Nor does the study contain any reference to the duplex processes, since, although these production methods (particularly the oxygen converter-electric furnace process) may be used in the future, their share in total steel output is small.

It is common knowledge that one of the most important characteristics of a steel-making process is the possibility of using it with wide variations in the composition of the raw materials processed and in the product-mix of the steel produced. Because of the very limited adaptability of the Thomas and Bessemer processes, the former can be applied only to the processing of high-phosphorus, the latter to that of very low phosphorus hot iron. Further, the quantity of scrap which can be processed in converters blown with atmospheric air rarely exceeds 5-6 per cent of the total charge. These drawbacks have led to the very advanced and extensive development of open-hearth steel production, which is much more flexible from the point of view both of the wide variations tolerated in the composition of the iron to be processed (this may be charged either liquid or in pigs) and of the proportion of scrap used, which may vary from 20 to 80 per cent.

The use of oxygen has made it possible to increase the proportion of scrap to 20 per cent of the total charge in bottom-blown converters, and as much as 40-50 per cent in large top-blown converters. In the latter, too, iron of almost any phosphorus content can be processed quite successfully.

Electric furnaces can be worked on virtually 100 per cent of scrap; and modern top-charged electric arc furnaces can be charged with either bulky or light and voluminous scrap.

In regions where a considerable amount of scrap is available but pig-iron production either does not exist at all or is insufficient, open-hearth and electric arc furnaces are more flexible and rational than converters, including oxygen converters. If, however, oxygen converters are combined with hot wind cupolas, they also may be successfully used in such regions.

Rough calculations have shown that the investment costs for a cupola-oxygen converter shop with an annual capacity of 300,000 tons are only slightly higher than those for an electric furnace shop of the same capacity, and markedly lower than those for an open-hearth shop working on a cold charge. With charges at equal prices, the cost of the steel produced in an electric-furnace shop is approximately the same as that of steel produced in a cupola-converter shop.

In recent years extensive work has been done in different countries on the use of hot iron in electric furnaces. In some countries the process of electric steel production using up to 25 or 30 per cent of liquid iron and with oxidation of the charge's impurities by gaseous oxygen, is now being adopted fairly widely. At the Brymbo steel works in the United Kingdom, the process of pre-treatment of hot iron, with oxidation of impurities by gaseous oxygen in a special installation, is applied to iron having a phosphorus content intermediate between those of open-hearth and of Thomas iron (between 0.4 and 0.8 per cent). During this pre-treatment the silicon is almost fully oxidized, and the phosphorus content is decreased to between 1 per cent and

2.5 per cent, depending on the carbon content in the finished steel. Pre-treated in this way, the metal is subsequently charged to electric steel-making furnaces, in quantities usually about 50 per cent but rising experimentally to 80 or 90 per cent of the total charge. The use of pre-treated liquid metal in electric furnaces considerably increases their productivity and accordingly decreases the specific consumption of electric power and electrodes.

Another electric steel-making process has been worked out at the Louis von Roll Ironworks (Gerlafingen, Switzerland). Here the liquid iron produced in electric smelting furnaces, without any intermediate treatment, is directly charged into the electric steel-making furnace and the process of oxidation of impurities is fully accomplished in this furnace. One feature of this process is that, for the oxidation of pig-iron impurities, not gaseous oxygen but the iron-ore oxygen is used.

In both these processes the transformer capacity of electric furnaces can be utilized much more fully than with direct charging of hot iron and oxidation of its impurities by gaseous oxygen.

Electric-arc furnaces are generally recognized as occupying the best position from the point of view of flexibility of the product-mix of steel. Only for the production of very soft steels are they slightly inferior to converters. Open-hearth furnaces are also suitable for producing not only carbon steels but also a wide range of alloy steels. In the early years of the industrial application of the LD process, it was thought that this process could be successfully used only for production of the common grades of carbon steel. During recent years, however, certain modifications have enabled LD vessels to produce not only every grade of carbon steel, but also a wide range of alloy steel having not more than 5 to 6 per cent of alloying elements - i.e. virtually any grade of alloy steel which can be produced in an open-hearth furnace. Kaldo vessels have a flexibility in relation to the product-mix of steel which is at least equal to, and perhaps even better than, that of open-hearth furnaces.

Another important point in comparing different steel-producing methods is the specific productivity of steel-making installations. According to approximate calculations, and taking into account expected improvements in processes, different steel-making installations may show the following annual productivity per ton of installed capacity:

Low-phosphorus iron	Tons
Open-hearth furnace with oxygen	1,000 - 1,200 (a)
Cold-charged electric-arc furnace	1,500 - 2,000
Electric-arc furnace with pre-refined metal	2,500 - 3,000
Electric-arc furnace with 50-70% of liquid iron	2,500 - 3,000
LD converter	7,000 - 9,000
Kaldo	5,500 - 7,500
Rotor	5,000 - 6,000

High-phosphorus pig-iron	Tons
Tilting open-hearth furnace with oxygen	900 - 1,000
Electric-arc furnace with pre-refined metal	2,500 - 3,000
Electric-arc furnace with 50-70% direct liquid iron	2,000 - 2,500
Thomas converter blown with oxygen-enriched air	8,000 - 9,000
Thomas converter with steam-oxygen or oxygen-carbon-dioxide mixture	7,000 - 8,000
Top-blown oxygen converter (OLP, LD-AC, or LD-Pompey process)	6,000 - 7,000
Kaldo	5,000 - 6,000
Rotor	4,000 - 5,000

This means that to attain a constant level of annual productivity of, say, 500,000 tons per year per unit, steel-making installations of the heat sizes listed in the following table have to be built:

(a) According to preliminary data, open-hearth furnaces with oxy-fuel jets can attain a productivity of 1,500 - 2,000 tons per year per ton of capacity.

Table 1

Heat size of the different types of steel-making vessel producing 500,000 tons of steel annually

(in tons)

Type of iron	Open-hearth furnace	Electric-arc furnace using			Top-blown oxygen converter	Kaldo	Rotor	Thomas converters		
		Cold charge	Pre-refined metal	Direct blast-furnace iron				Oxygen-enriched air	Steam oxygen	Oxygen-carbon-dioxide
Low-phosphorus	415-500 (250-350)(a)	250-335	165-200	165-200	55-70	65-90	85-100	-	-	-
High-phosphorus	500-550	-	165-200	200-250	70-83	85-100	100-125	55-62	62-70	62-70

Source: Secretariat calculations.

(a) Preliminary figures for oxy-fuel process.

Processes where steel is tapped in small batches, and in shorter periods of time, are more suitable for the application of continuous casting than processes producing steel in large heats with long intervals between. Furthermore, the cost of continuous-casting installations will be much lower, and the co-ordination of steel-producing and steel-casting installations much easier in the first case than in the second.

All modern steel-producing units are characterized by a high level of mechanization and by the application of different means of automation. However, some processes are evidently better suited to a high level of mechanization and automation than others. It is quite clear, for example, that the level of mechanization of scrap-charging of top-charged electric furnaces is higher than that of open-hearth furnaces. In the modern converter installations it is possible to attain, at the same expense, a higher level of mechanization and automation of charging hot metal, fluxes and iron ore. It appears from all the data available that electric furnaces, either cold-charged or with direct hot iron, give the highest yield; then follow, in the case of low-phosphorus hot iron, the Kaldo process, open-hearth furnaces employing standard processes, and LD converters whose yield is considerably lowered by brown fume formation. Open-hearth furnaces with oxy-fuel seem to give a still lower yield owing to higher iron losses. When treating high-phosphorus iron with the recuperation of the second slag, a better yield can be expected from oxygen converters, particularly from Kaldo vessels, than from open-hearth furnaces, and often a far better yield - with the same phosphorus content - than from bottom-blown converters. The direct processing of high-phosphorus hot iron in electric furnaces results in a higher yield than that attained by any other steel-making process. However, this conclusion is based on a very limited amount of data.

The consumption of raw materials in different steel-making processes depends on the type of process and on the composition of the materials used. Approximate figures on the specific consumption of the main materials used in different processes are presented in the following table:

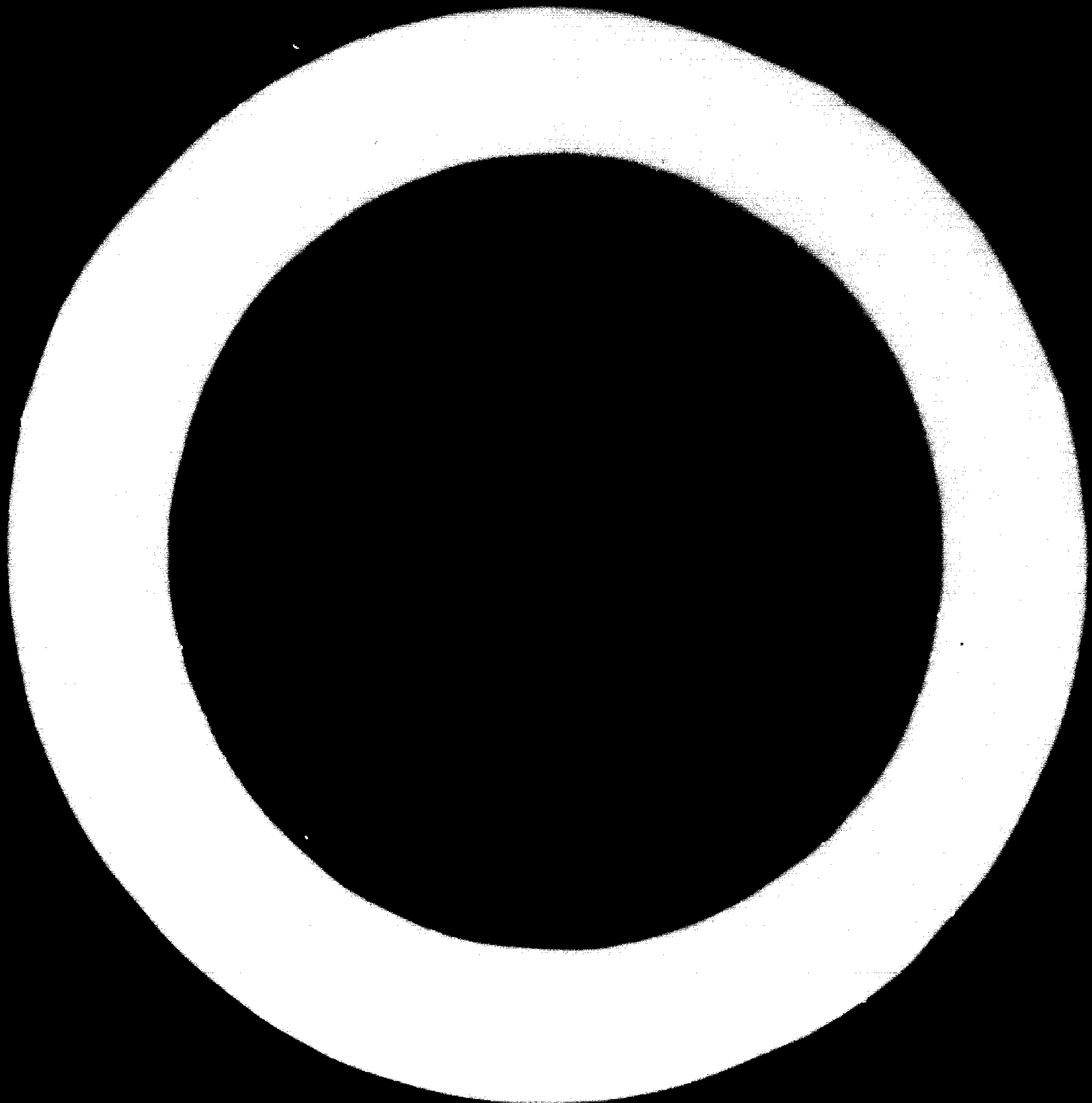


Table 2

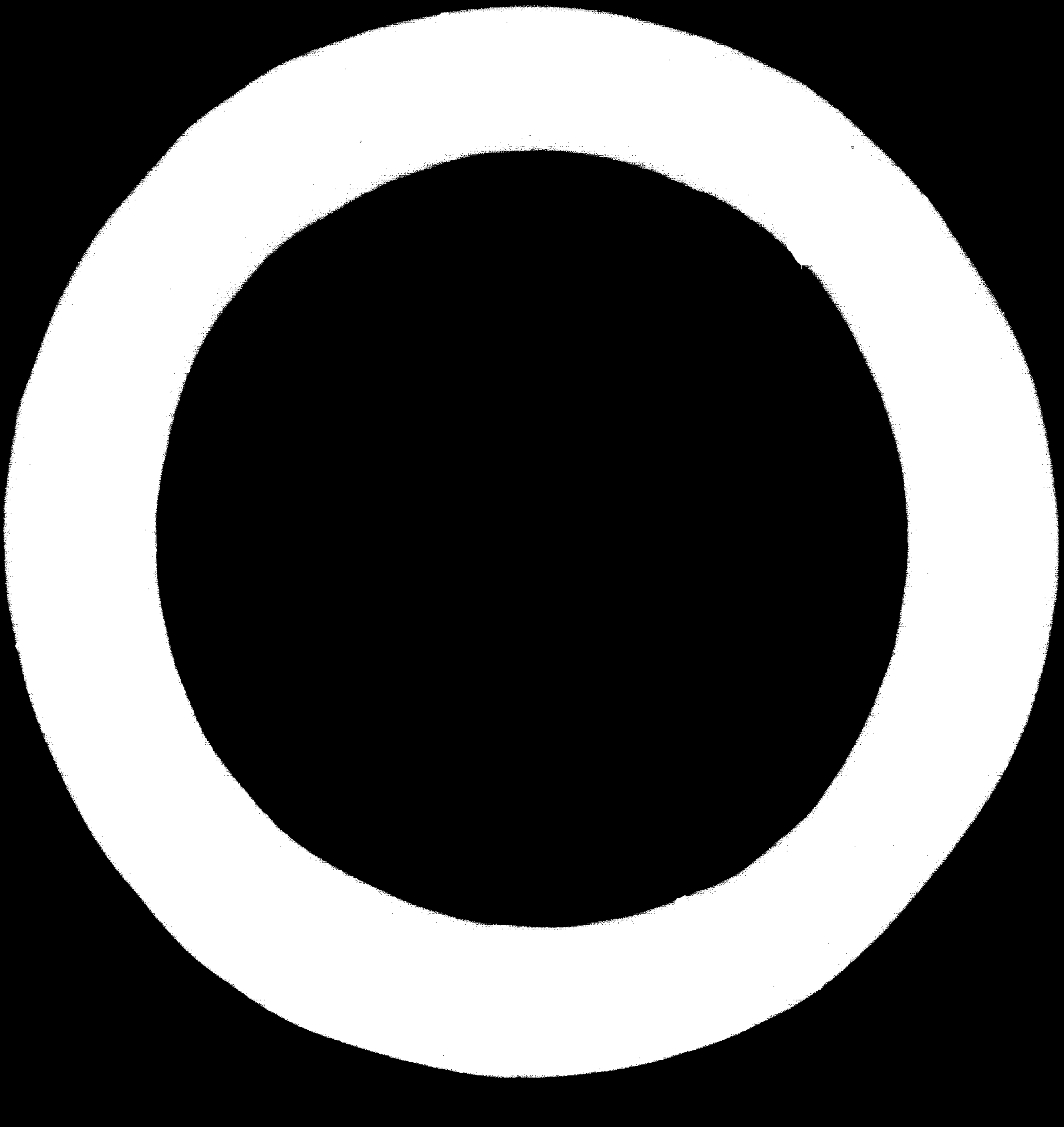
Specific consumption of the main materials used in steel-making

(in kg and m^3 per ton of steel)

Steel-making process	Total metallics[a] (kg)	Iron-ore (kg)	Lime or limestone (kg)	Refractories (kg)	Wind (m^3)	Oxygen (m^3)	Carbon dioxide (m^3)	Steam (kg)
Low-phosphorus iron								
Open-hearth:								
Cold-charge	1,086	20	30	25	-	15	-	-
Hot-charge:								
Standard practice:								
70% iron, 30% scrap	1,070	30	120[b]	40	-	30	-	-
50% iron, 50% scrap	1,078	60	90	40	-	25	-	-
With oxy-fuel jets	1,144	20	120	50	-	50	-	-
LD: 70% iron, 30% scrap	1,128	-	50	8[c]	-	50	-	-
LD: 75% iron, 25% scrap	1,130	-	50	8[c]	-	50	-	-
Kaldo: 70% iron, 30% scrap	1,083	55	50	15	-	60	-	-
Kaldo: 55% iron, 45% scrap	1,111	-	40	15	-	50	-	-
Electric:								
Cold-charge	1,077	10	25	10	-	10	-	-
Hot-charge:								
With direct hot iron	1,033	120	50	15	-	-	-	-
With pre-refining	1,139	20	80	15	-	30	-	-
High-phosphorus iron								
Thomas:								
Atmospheric air	1,139	-	130	10	300	-	-	-
Enriched air	1,138	-	110	12	200	25	-	-
Oxygen-steam	1,149	-	130	15	-	50	-	50
Oxygen-carbon-dioxide	1,149	-	130	12	-	45	30	-
Open-hearth	1,064	90	160[b]	50	-	35	-	-
OLP, LD-AC, LD-Pompey: 70% iron	1,115	-	100	10	-	55	-	-
OLP, LD-AC, LD-Pompey: 75% iron	1,116	-	100	10	-	55	-	-
Kaldo: 70% iron, 30% scrap	1,076	55	110	20	-	60	-	-
Kaldo: 55% iron, 45% scrap	1,103	-	90	18	-	55	-	-
Electric:								
Direct hot iron	1,031	140	80	20	-	-	-	-
Pre-refining	1,130	20	100	30	-	35	-	-

Source: Secretariat calculations.

(a) Excluding finishings
(b) Limestone
(c) Using dolomite: somewhat lower with magnesite.



Two groups of steel-making processes are clearly distinguishable from the point of view of energy consumption: in the first group (open-hearth and electric furnace processes), energy external to the steel-making process has to be delivered, while in the other, which includes all types of converters, the internal chemical energy evolved during transformation of the liquid iron into steel is sufficient to cover the total heat demand. In the latter group, the use of oxygen releases a vast amount of excess heat which can be utilized either for re-melting scrap, or for reducing iron from iron ore, or for decomposing steam or carbon dioxide. In the Kaldo and Rotor processes, where almost all the heat from the carbon oxidation can be usefully absorbed, the potential proportion of scrap or iron ore is particularly considerable. Kaldo vessels, owing to their most efficient heat utilization, give the lowest heat consumption of all steel-making utilizations using a considerable proportion of iron; that is particularly true if in the Kaldo process only scrap is used for cooling. Steel-making processes using a large proportion of scrap show a relatively lower heat consumption than those effected with 70 to 95 per cent of hot iron. It should be mentioned that the specific heat consumption of Kaldo vessels working on 55 per cent iron and 45 per cent scrap is lower than in open-hearth furnaces re-melting 70 per cent scrap, and very near to that of electric arc furnaces where the proportion of scrap is as high as 95 per cent. Summarizing the figures on specific consumption of materials and fuel in different steel-making processes, it is easily seen that the oxygen-blown converter processes re-melting 25 to 45 per cent scrap give the best results, while the specific consumption of materials, excluding refractory materials, is lowest in electric furnaces.

A major characteristic of any steel-making process is its labour productivity and corresponding man-power requirements. Labour productivity is naturally higher in processes with a high level of mechanization and automation - a trend which is bound to develop in the future with the inherent possibilities for fuller mechanization, particularly for oxygen-converter processes.

It has been calculated that the man-power requirements for a shop of one million tons annual capacity are as follows, taking man-power consumption of an open-hearth shop as 100 per cent:

	Percentage
Electric furnace shop	129
Thomas shop	51
Kaldo process	76
LD process	65
LD-AC steel-making shop	72

On this basis, and taking annual capacity at a level of three million tons of steel, the following figures may be reasonably assumed:

	Man-hours per ton	Index
Open-hearth (fixed; low-phosphorus iron)	0.5	100
Open-hearth (tilting; high-phosphorus iron)	0.65	130
Electric furnaces, cold-charged	0.4	80
Electric furnaces using hot pre-refined metal	0.35	70
Electric furnaces using direct hot iron	0.35	70
Thomas	0.25	50
LD	0.28	56
LD-AC, OLP, LD-Pompey	0.31	62
Kaldo	0.33	66

Chapter V contains certain considerations on investment and production costs. There is extensive literature on the investment costs of different steel-making processes, but most of it deals with a combination of two processes, usually open-hearth and electric or open-hearth and LD. Reliable comparisons of different processes are infrequent, and even restricted figures differ widely. Thus, if the investment cost per ton of annual capacity of an open-hearth furnace shop is taken as 100, the figures for the LD process are variously fixed at between 28 and 90, for the Kaldo process at between 35 and 100, and for electric furnaces at between 50 and 100. It is evident that this wide range can be explained only to a limited extent by varying local conditions. The major methodological point, therefore, is what exactly should be included in the comparison. Some argue that only investment costs incurred in the steel-making process itself should be considered, and that investment in ancillary shops and other related industries should be disregarded. The majority consider that useful comparisons are possible on a more comprehensive basis, including associated departments and installations.

Average figures on the investment cost for open-hearth and oxygen-converter shops in the USSR, calculated by the Central Iron and Steel Designing Institute of the USSR, are given in the following table:

Comparison of investment cost for open-hearth furnaces and for LD converters

(in percentages)

Item	Open-hearth furnaces	Converters
Steel shops alone	100	58-67
Including other shops of iron- and steel-works	100	62-69
Including also related industries	100	82-86

Source: Information supplied by the USSR authorities

It may be seen from these figures that, while calculating only capital investment in the steel-shop, the LD process is 33 to 42 per cent cheaper than the open-hearth process, and this difference is reduced to only 14 per cent to 18 per cent if other stages are included. A similar point arises for electric steel - i.e., whether or not to include the investment required for adding to electric power station capacity.

Comparative calculations based on the figures for steel-shops with annual capacities of 500,000 tons, 1 million tons and 1.5 million tons, have been prepared by one company having a wide experience in the oxygen-converter process. Where capacity is 1 million tons, the make-up is as follows:

	Tons
6 open-hearths, each of	250
8 electric furnaces, each of	150
4 Thomas converters, each of	50
5 Kaldo vessels, each of	100
3 LD vessels, each of	45
3 LD-AC converters, each of	60

It would appear from these calculations that the differences in capital costs of different types of shop are smaller than one would expect from the various publications referred to previously. For example, an electric furnace shop with a capacity of 1.5 million tons came to 98 per cent of the cost of an open-hearth shop of the same capacity. The corresponding figure for Kaldo is 92 per cent, for LD-AC 78 per cent, and for LD 70 per cent, of the cost of an open-hearth shop. These figures appear to be too high compared with those found in many other publications.

Data are also available on the investment costs of different types of steel-making shop in the United Kingdom. These estimates are based on the capital costs of a new integrated steelworks of at least the minimum size required for efficient operation under modern conditions. If the investment cost per ton of steel in a steel-shop with fixed open-hearth furnaces using oxygen is taken at 100, the investment costs of other types can be expressed as follows:

	Steel shops only	Steel shops plus additional blast-furnaces and sintering capacity
Fixed open-hearth furnaces without oxygen	145	123
Tilting open-hearth furnaces	156	146 - 180(a)
Ajax furnaces	101	118 - 152(a)
Thomas converters with oxygen-enriched air	95	160
Thomas converters, steam oxygen-blown	95	162
LD	93	120
LD-AC	93	120 - 159(a)
Kaldo	124	129 - 164(a)
Electric furnaces	83	-

To make a valid comparison of investment costs of different steel-making processes, it is essential to include investment, not only in the steel shops themselves, but also in ancillary processes and related industries. In each case it is assumed that one steel-making process only is used, i.e. that there is no duplexing and no combination of different steel-making processes in the same iron and steel

---

(a) Depending on the quality of the iron ore.

works. The basic composition of the charge for open-hearth furnaces, all types of oxygen converter and hot-charged electric furnace has been taken as 70 per cent hot metal and 30 per cent scrap.

The calculations have been based on Swiss francs per ton of annual capacity. Average annual steel-making capacity of steel shops is assumed to be approximately 3 million tons; and it is also assumed that modern steel-making equipment is installed in each case, which implies the following approximate heat size:

	Tons
Open-hearth furnaces	500
Bottom-blown converters	80
LD, LD-AC, OLP, LD-Pompey and Kaldo	150-200
Electric furnaces	150-200

Furnace productivity and capital costs of open-hearth furnaces, depending on their capacities, are as follows:

(in tons and percentages)

Furnace capacity (tons)	Annual furnace productivity (%)	Capital costs per ton of furnace capacity (%)	Capital costs per ton of annual production (%)
70	100	100	100
130	160	70	81
185	181	50	73
250	220	40	65
370	290	30	55
500	330	25	52

Source: Information supplied by the USSR authorities.

From a comparison of a wide range of data it can be seen that in all processes involving the production of steel from charges containing a considerable portion (70% - 95%) of pig-iron the oxygen converter in its various forms, and Thomas converters with enriched air, are the cheapest; bottom-blown processes employing steam-oxygen or oxygen-carbon dioxide mixtures are more expensive owing to a higher consumption of pig-iron and a lower yield of steel. Quite logically, total investment cost within each process is bigger, the higher the share of iron in the charge. The cold-charged electric furnace has clearly the lowest investment cost when calculated on the basis of both iron and steel works and on the basis of the entire economy. However, it is clear that these figures are not wholly comparable with those for other processes, since the charge is almost entirely in the form of scrap, to which no investment cost was ascribed.

Summarizing the considerations examined in chapter V on the cost of steel, it may be concluded that in all comparable conditions oxygen converters can secure the most economical results from the point of view of steel production costs and of capital investment, whether at the sole level of steel-shops or including also related branches of the iron and steel and other industries. As for investment costs, it is not yet possible to make reliable calculations of production costs of steel made from the products of direct reduction, although such calculations would be extremely valuable as a basis for a proper assessment of the economic advantages of direct-reduction processes.

CONCLUSIONS

On the basis of this comparison of the economic results obtained from various steel-making methods which are in large-scale industrial use, it may be said that, whenever new steel-making plant is to be constructed in the next few years, thorough study and preference will usually be given to oxygen converters of the LD and Kaldo types. Production of electric steel is also likely to increase considerably. Information available on long-term plans for the development of steel-production throughout the world suggests that the total capacity of oxygen converters of different types will have increased to 100 million tons by 1965; and, according to some forecasts, it will reach the figure of 200 million tons by 1970. In the light of these plans for developing the production of steel in oxygen converters, it is possible to draw the following conclusions with a reasonable amount of confidence:

(a) No new Bessemer shops will be built;

(b) There is little probability that new Thomas converter shops will be built, even for blowing with nitrogen-free mixtures;

(c) Except in certain specific circumstances, it is unlikely that any new open-hearth shops will be built with fixed furnaces; the construction of new tilting open-hearth furnaces and cold-charged furnaces is also unlikely;

(d) New steel shops will be equipped with oxygen converters of different types and electric-arc furnaces;

(e) New Rotor installations will not be built in the near future. Of the two types of rotating steel-making vessels, only Kaldo converters are likely to be erected.

What is far less certain is which of these two processes - oxygen converters and electric furnaces - will be used and to what extent, and in what conditions one or the other will be preferred. Another interesting question is to what extent the two different types of oxygen converter - LD and Kaldo - will be used. The following general conclusions would appear reasonable:

(a) If scrap is abundant and generally cheap, cold-charged electric furnaces are the most economical, always assuming that the price of electricity is sufficiently attractive. Even in such conditions, however, oxygen converters together with hot cupolas might be preferable;

(b) With a hot charge consisting mainly of low-phosphorus iron, the classical LD process at present appears to be the most attractive for common steel. But it is quite possible that, even in this case, powdered materials such as lime and iron ore will be delivered into the vessel with the oxygen stream; this is the main feature of the OLP and LD-AC processes. On the other hand it is also possible that, owing to their higher yield and better heat utilization, Kaldo vessels will be applied even for the transformation of low-phosphorus iron. If a sufficiently reliable and economically sound electric-furnace process using a hot charge is finally evolved, it will undoubtedly find a wide use, particularly in regions and countries with cheap electric power;

(c) A combination of cold-charged electric furnaces working almost entirely on scrap, and oxygen converters with their rather limited possibilities to re-melt scrap, might be attractive, since it enables the use of a charge of any pig-iron scrap ratio and is at the same time sufficiently flexible from the point of view both of the product-mix of steel and of the possible fluctuations of the proportion of scrap in the total steel-making charge;

(d) For the transformation of a hot charge with high-phosphorus iron, three steel-making processes are most likely to be used in the future:

(i) Kaldo, with its higher yield and more satisfactory heat utilization and, consequently, with wider possibilities of using scrap and/or iron ore. It is not yet sufficiently clear, however, whether or not this process can achieve the same economic results, in terms of investment cost per unit of annual capacity, as the top-blown converters of the LD type.

(ii) The OLP and LD-AC processes seem to be particularly attractive, both technically and economically. While their application gives rise to some additional expenses for the preparation and transportation of powdered lime, the utilization of lime in this form offers possibilities of a more precise regulation of the processes themselves.

(iii) The LD-Pompey process seems also to be attractive since, with the recuperation of the second slag, the formation of the first slag is easily attained even with the use of lumpy lime and, on the other hand, the amount of lime to be charged is relatively small. At the same time, however, it seems that the equipment for crushing, screening and transportation of lime in lumps costs practically the same or only slightly less than in the case of utilization of powdered lime, but the accuracy of control of the physical and chemical conditions of steel-making is, of course, greater in the latter case.

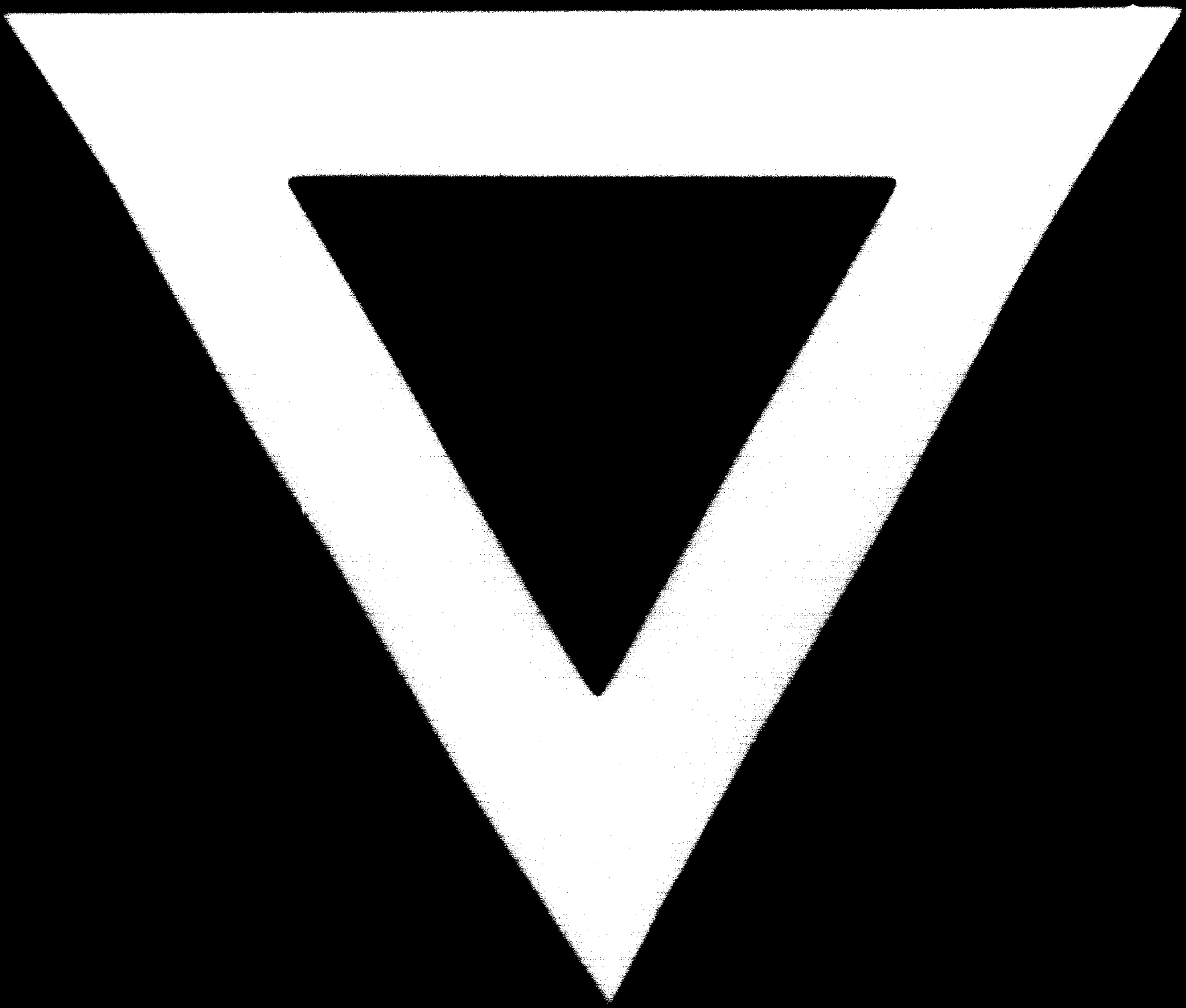
(iv) Electric furnaces with or without pre-refiners will be used for the transformation of high-phosphorus hot charges only if and when a suitable process for such charges has been worked out.

It would be wrong, however, to use these conclusions as an argument for condemning the open-hearth furnace and other steel-making processes to premature extinction. The great advances made in open-hearth production technique over the past ten years, and the large share of open-hearth steel in total world output, indicate that this process will retain its present importance at least for several decades to come, and there is a possibility too that further technical improvements may bring about substantial changes in the relative technical and economic efficiency of different steel-making processes.

It should be remembered that the production of killed carbon steel in large-capacity natural gas-fuelled hot-charged open-hearth furnaces is at the present time more economical than the production of the same type of steel in electric furnaces. The cost of electric steel is lower than that of open-hearth steel only on the rare occasions when the cost of the hot iron is unusually high and there is a considerable difference between the cost of iron and scrap.

In the USSR investment costs for the construction of a steel shop with 180-ton electric furnaces are about 30 per cent lower than for a shop with 250-ton open-hearth furnaces. On the other hand, if one includes capital outlay on related industries (power, transport, coal), investment costs for the two types of shop are about the same. Hitherto electric furnaces have been used mainly for the production of high-quality alloy steels. Further, the different methods evolved to improve the operation of converters bottom-blown with oxygen-enriched air have also produced satisfactory technical and economic results in several cases; and a number of firms in different countries have accordingly decided that there are no grounds for doing away with converters of this type during the next few years.

When a new steel-making plant is to be constructed, a comparison of steel-making processes ensures a correct assessment of all the economic factors involved in selecting the most suitable type of installation; and the most effective way of making existing plant more economical is to improve its operating technique in every possible way. The replacement of bottom-blown converters by top-blown oxygen converters is a striking example of the results that can be obtained by technical modifications and improvements.



4. 4. 74