THE OPTIMUM METHOD FOR CONVERTING SPONGE IRON TO STEEL IN ARC FURNACES

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Abstract

Four different process techniques for the melting of sponge iron in arc furnaces are judged by evaluating operating results from a great number of arc furnaces up to 200 tons tap weight. Taking the power consumption and productivity as criterions the Contimelt process, i.e. the continuous melting under liquid bath conditions with overlapping of the melting and refining period, has proven to be the optimum process. By applying this process technique it has been possible to increase the productivity, as compared with all-scrap practice, by up to 45% with small and up to 20% with large furnaces. The power consumption decreases by up to 15% with small and increases slightly with large furnaces. The mechanism of the change of productivity is explained with the aid of a mathematical model by varying the most important parameters. Practical aspects of the Contimelt process such as questions of protecting the refractories, optimum metallization of the sponge iron and quality of the steel are discussed as well as the iron yield proving to be at least as high as for all-scrap heats. Among the different charging techniques and devices the continuous roof charging through one or three pipes seems most recommendable.

Introduction

In all the existing direct reduction processes the arc furnace is preferred to convert the products to steel. This fact stresses the general importance of the arc furnace for the direct reduction route regardless of the reduction process applied. This knowledge has already led steelmakers in India and abroad to the conclusion that no new arc furnaces shops should be planned without at least making allowances for the space necessary for the sponge iron handling devices.

However, it is not easy to interpret the different results available from a large number of commercial arc furnaces charged with sponge iron. Therefore, this paper is to clarify these apparent contradictions, to find out the optimum method for converting sponge iron to steel in arc furnaces, and to explain in detail some of the merits and problems of this optimum process.

Comparison of different process techniques (18)

For investigating the exiscting operating results it is essential to differ strictly between two terms: The term "*process technique*" describes the phenomena in the bath and slag area while the term "*charging technique*" covers only the kind of material transport to and into the furnace. The following charging techniques have become known:

1. Bucket charging
2. Continuous charging through the furnace roof using one or three holes
3. Continuous charging through the side wall by slingering or blowing.

They are of minor importance as far as the melting parameters are concerned and are therefore only briefly discussed later on.

The process techniques to be compared here are:

1. Batchwise melting
2. Iceberg process (IRSID) i.e. continuous melting maintaining a heap of unmolten sponge iron.
3. Continuous melting under liquid bath conditions *without* overlapping of melting and refining period.

4. Contimelt process (Lurgi and partners)
   i.e. continuous melting under liquid bath conditions *with* overlapping of melting and refining period.

For judging these process techniques the relative change of productivity and power consumption compared with all-scrap heats have been chosen as criterions. The values reported here are taken from literature and plotted against the percentage of sponge iron in each case. The results are shown in Figs. 1 to 4 for each of the individual process techniques mentioned above.

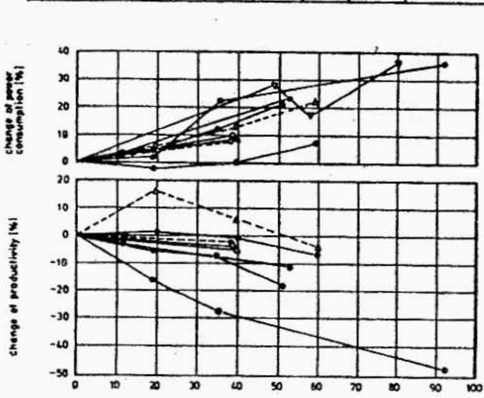
The batchwise melting process (process technique No. 1) is carried out by charging batches of sponge iron, pure or mixed with scrap, with the aid of scrap buckets or chutes and melting one batch after the other. The charging technique is not very different from scrap charging. However, the melting process is characterized by two differences, namely the formation of a higher slag volume due to the gangue content in the sponge iron and a strong tendency to form accretions and agglomerates, which are very difficult to melt.

The operating results (1 to 6) in Fig. 1 demonstrate that with an increasing percentage of sponge iron the power consumption increases relatively rapidly and the productivity decreases. Reasons for this are the mentioned slag volume and the residual iron oxide content in the sponge iron. The fact that hardly a test series exceeds the 60% sponge iron limit is attributable to the formation of agglomerates starting at about 30 to 40% of sponge iron. These agglomerates can only be removed by time-consuming measures such as oxygen lancing or overheating of the bath.

The so-called Iceberg process (process technique No. 2) developed by IRSID is characterized by the continuous charging of sponge iron onto an unmolten sponge iron heap. The feed rate is regulated in accordance with the melting rate of the sponge iron. The arcs are shielded against radiation losses by burning in niches of unmolten sponge iron and the bath has liquidus temperature only. As compared with all-scrap practice, theoretically no dramatical change in productivity can be expected as the time savings by a higher average power input and a lower number of scrap recharges are just about compensated by a higher power requirement caused by the increased slag volume. An overlapping of the refining with the melting period was not tried out and seems unfeasible because the refining work can be carried out more easily during the time necessary for heating up the bath from liquidus to tap temperature. The operating results (7 to 9) in Fig. 2 confirm these considerations only partially.

Whilst the 10 ton furnace showing no change of productivity and a high increase in power consumption is in line with the theory, the 6 ton furnace shows a change of productivity between zero and 65% at the same proportion of sponge iron. A reasonable expla-

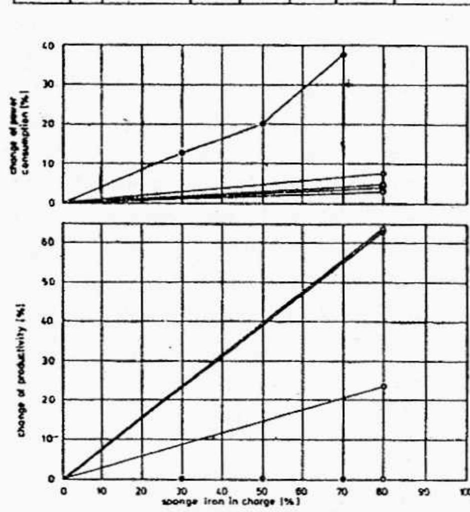
origin of sponge	symbol	author	No. of heats	furnace tap weight [t]	Fe_{tot} in sponge [%]	power consumption	productivity referring to
Wiberg	•—•	C.-E. Falk	125	50	82.0	total	melt in
RN	•—o	W. R. Weaver	13	85	95.3	total	power on to tap
RN	•--o	W. R. Weaver	20	135	95.3	total	power on to tap
RN	•—•	O. Masi and P. Cannizzo	25	60	90.5	total	power on to tap
RN	▲—▲	J. S. Breitenstein	no data	123	95.2	melt in	power on to tap
RN	▲--▲	J. S. Breitenstein	no data	77	95.2	melt in	power on to tap
RN	▼—▼	J. S. Breitenstein	no data	12	92.7	melt in	no data
Wiberg	•—•	J. L. Stålhed	40	30	90.0	total	tap to tap
Hyl	•—•	J. Celada and G. Muller	215	90	88.8	total	tap to tap



Operating results for the batchwise melting process

Figure 1

origin of sponge	symbol	author	No. of heats	furnace tap weight [t]	Fe_{tot} in sponge [%]	power consumption	productivity referring to
SL/RN	•—•	M. Wahlster et al	27	10	90.3	total	tap to tap
SL/RN	o—o	J. Antoine et al.	5	6	93.0	melt in	melt in
SL/RN	o—o	J. Antoine et al.	4	6	89.6	melt in	melt in
SL/RN	o—o	J. Antoine et al.	5	6	90.3	melt in	melt in
SL/RN	o—o	J. Antoine et al.	13	6	90.5	melt in	melt in



Operating results for continuous melting maintaining unmolten sponge iron (Iceberg process)

Figure 2

nation could neither be found for the maximum increase nor for the wide scatter. The final judgement of this process is not yet possible on the basis of these few contradictory results from only two small furnaces. However, with large furnace there is the danger of the high energy arcs destroying the iceberg permanently leading to many small floating agglomerates which cause short circuits and are difficult to melt.

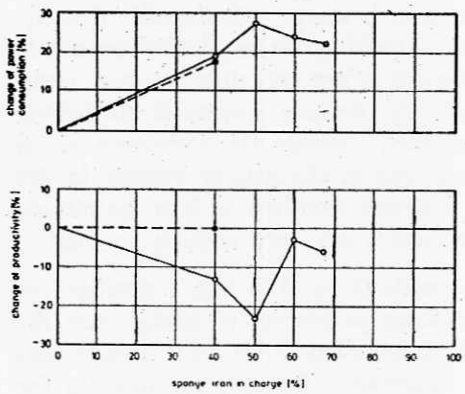
This principal disadvantage can be avoided by continuously charging the sponge iron into the liquid bath. In this case every sponge particle is separately surrounded by liquid slag, thus the probability of forming solid agglomerates is low. The continuous charging starts after forming a hot heel either by melting an initial scrap charge which can also be mixed with sponge iron or by retaining part of the previous heat. The continuous feed rate is adjusted to the power input, holding thereby the bath temperature at least 20°C above the liquidus temperature. As the bath is liquid and iron-bearing material of known composition is charged, the metallurgical work can be carried out during the melting period.

In some cases the melting and refining period cannot be overlapped, for example if special steels are to be made or the sponge iron is too high in sulphur and phosphorous as compared with the final steel composition. If this process (process technique No. 3) is applied, the power consumption should increase in comparison with all-scrap heats due to the gangue and residual oxygen content in the sponge iron. Consequently, the productivity should slightly decrease or remain constant because normally the power input is somewhat higher than with scrap. Fig. 3 containing the operating data on this process technique (10,11) confirms these theoretical considerations fully.

In most cases, the refining can be carried out simultaneously with the melting resulting in an increase in productivity. This process technique (No. 4) is also known as Contimelt process. The increase in productivity should influence the power consumption favourably as time-dependent heat losses can be saved. The operating data in Fig. 4 on 6 different furnace (6, 12 to 16) show clearly that this process improves the furnace productivity considerably as compared with all-scrap practice, namely by 30 to 45% for small furnaces with a tap weight below 25 tons and by 15 to 20% for large furnaces with a tap weight of above 85 tons. It is to be mentioned at this point that two of the productivity curves have a maximum at about 20 to 35 per cent sponge iron in charge, the reason for which will be explained later on. According to Fig. 4 the power consumption is decreased in comparison to pure scrap heats by up to 15% for small furnaces at a proportion of sponge iron in charge between about 20 to 45 per cent; however, it is increased slightly for large furnaces without exceeding the 15 per cent limit.

When comparing these different techniques against each other on the basis of their actual operating data, the Iceberg process (process technique No. 2) has to be omitted because the scattering of results is too great and the number and the size of furnaces are

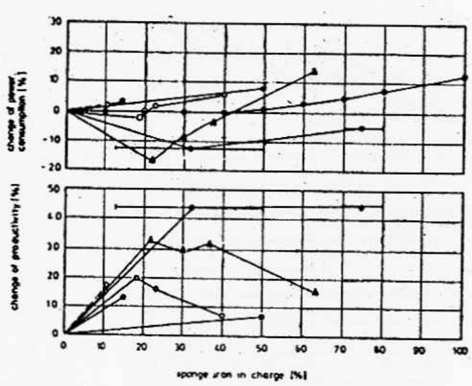
origin of sponge	symbol	author	No. of heats	furnace tap weight [t]	Fe_{tot} in sponge [%]	power consumption	productivity referring to
SL/RN	○—○	T.A.Williams et al.	25	200	92.2	total	charge to tap
SL/RN	●---●	H.Noda et al.	16	76	92.2	total	power on to slag off



Operating results for continuous melting under liquid bath conditions without overlapping of melting and refining

Figure 3

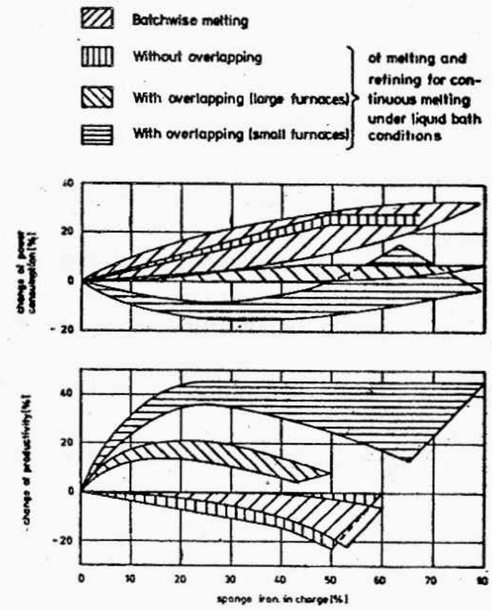
origin of sponge	symbol	author	No. of heats	furnace tap weight [t]	Fe_{tot} in sponge [%]	power consumption	productivity referring to
SL/RN	○—○	E.L.Fogleman	56	135	89.1	total	tap to tap
Fior	●--●	Fogleman et al.	108	135	92.0	total	tap to tap
Fior	●—●	N.McCallum and R.J.Peters	12	120	92.3	total	power on to tap
Hyl	●—●	J.Celada and G.Muller	no data	90	88.8	total	tap to tap
Midrex	●—●	P.Kehl a.H.Voss	200	85	94.0	melt in	———
SL/RN	●—●	G.Sibakin et al.	no data	23	91.8	total	tap to tap
SL/RN	▲—▲	E.Eisermann and G.Post	16	10	91.2	total	tap to tap



Operating results for continuous melting under liquid bath conditions with overlapping of melting and refining (Contimelt process)

Figure 4

too small. From Fig. 5 where this comparison has been made, it is evident that the Contimelt process, i.e. the continuous melting under liquid bath conditions with overlapping of the melting and refining period is by far the optimum process with regard to both productivity and power consumption. Small furnaces predominating in India so far are favoured by this process technique in comparison with large ones as the productivity and power consumption are improved over a wide range of sponge iron in charge. With large furnaces the productivity is increased too, but a slight increase in power consumption is observed. With the process technique Nos. 1 and 3, which seems to be equivalent but compare unfavourably with the Contimelt process, the productivity is unchanged or worse than with scrap heats and the power consumption is steadily increased wtih growing proportions of sponge iron charged.

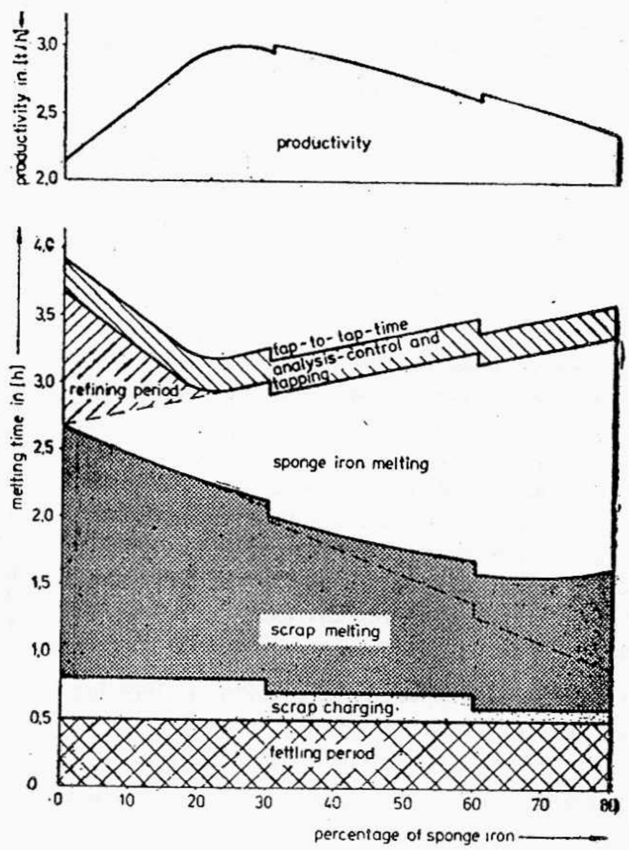


Comparison of operating results for different process techniques

Figure 5

The Contimelt process

After ascertaining the optimum process technique it seems desirable to investigate more thoroughly this specific method of converting sponge iron to steel. At first the mechanism of the change in productivity and power consumption as compared with all-scrap practice is to be interpreted on a theoretical basis, as the number of operating results discussed previously is not yet sufficient to examine influencing factors other than the percentage of sponge iron and the furnace size. Tackling first the *productivity*, Fig. 6 shows the principal development. With increasing proportions of sponge iron the tap-to-tap time passes a minimum corresponding to a maximum in productivity because the conventional refining work is increasingly carried out during the continuous melting period. If the sponge iron proportion is raised beyond this decisive minimum no further reduction of the tap-to-tap time is possible as the refining period is already completely eliminated. On the contrary, the tap-to-tap time is increased again as the influence of the gangue and residual iron oxide content in the sponge iron as well as the lower initial filling degrees of the furnace gain influence resulting in a decreasing productivity curve. It is to be remembered in this connection that two of the operating curves in Fig. 4 confirm the form of the schematic productivity curve of Fig. 6.



Correlation between percentage of sponge iron melting time and productivity

Figure 6

These principal and qualitative considerations have been quantified with the aid of a mathematical model recently (17,18). Here only the main assumptions and results are to be repeated. This case study investigates the production of plain carbon steel is a furnace tapping 50 tons and over and fed alternatively with two types of sponge iron with a metallization degree of 94 per cent each:

Type A with 94.5 per cent total Fe, 3 per cent total gangue incl. 2.1 per cent SiO_2.

Type B with 90.5 per cent total Fe, 7 per cent total gangue incl. 4.9 per cent SiO_2.

In Figs. 7 and 8, the results are summarized regarding productivity and power consumption respectively for 4 different cases:

a) UHP practice and average organization of furnace operation

b) HP practice and average organization of furnace operation

c) UHP practice and optimized organization of furnace operation

d) HP practice and optimized organization of furnace operation

In each of these cases there is a difference between a long separate refining period of 45 minutes and a short refining period of 15 minutes for all-scrap heats, and between the two sponge iron types specified above. The main teachings from Fig. 7 showing the development of the productivity are:

1. As compared with 100 per cent scrap heats an increase in productivity up to 30 per cent is possible under favourable conditions, i.e. if a long refining time on scrap heats is available for saving, and if a pure sponge iron is melted.

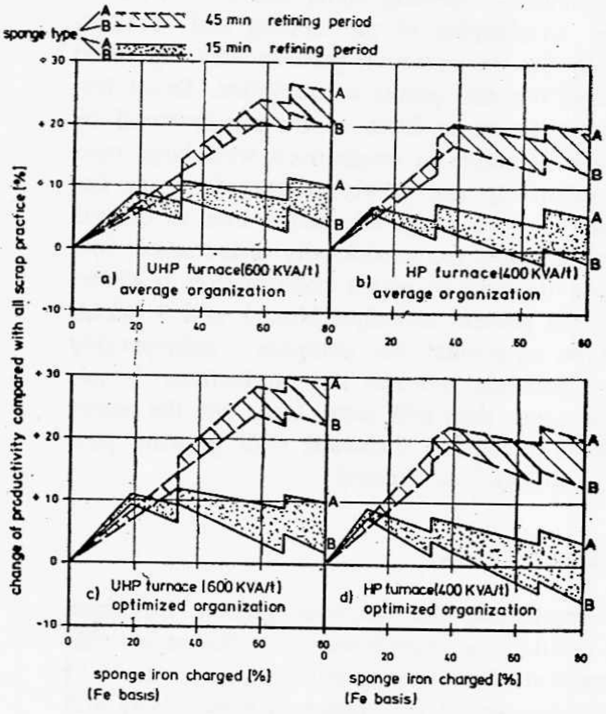
However, even at a refining time of 15 minutes only a productivity increase of up to 10 per cent can be reached with a good sponge iron. Only if the worst conditions are combined (Fig. 7d) i.e. a high percentage of poor sponge iron is charged and a short refinery period is available for saving, the all-scrap productivity can be undercut.

2. The maximum in the aforementioned productivity curves can be recognized again. Its height and position on the ordinance can vary considerably. This fact could not be shown by the operating results because of lack of data. From Fig. 7 it can be seen that this maximum can vary between about 15 and as much as 70 per cent of sponge iron charged, thus the merits of the Contimelt process from a mere process technical standpoint must be weighed for each case individually.

3. In contrast to a wide-spread opinion, a UHP furnace with optimum organization (Fig. 7c) has the highest potential for productivity improvements.

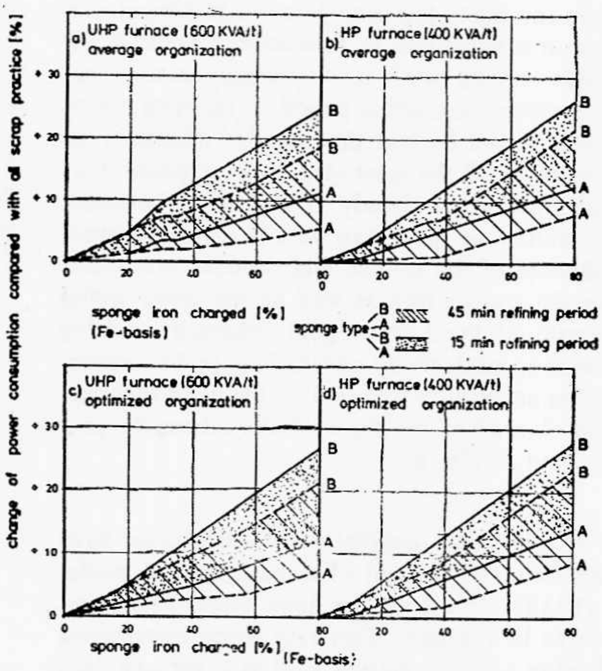
From Fig. 8 the following, with regard to the *power consumption*, can be derived.

1. In large furnaces power can hardly be saved by the Contimelt process as compared with all-scrap practice. However, the increase is very low with pure sponge iron. As the operating data in Fig. 4 had shown, this result looks quite different for small furnaces in which a decrease in power consumption was observed.



Increase in productivity for CONTIMELT process

Figure 7



Relative change of power consumption for CONTIMELT process

Figure 8

2. The great difference in the curves concerning the sponge iron types A and B indicates the great influence of the gangue content. In the productivity curves of Fig. 7, the duration of the refining period which can be saved on scrap heats has been the overwhelming influence.

It is to be stressed at this point that the prerequisite for this model as well as for a successful practical Contimelt operation is the close *control* of the chemical and thermal conditions of the bath. Samples should be taken about every 10 minutes during the continuous feeding period. Whilst the highest transformer tap is used all the time, the feed rate is adjusted to the measured temperature, the carbon content is corrected by blowing oxygen or carbon breeze, and the slag basicity is corrected by adjusting the feed rate of the lime also being continuously charged.

As the arcs burn with full power on the open bath throughout the continuous feeding period, the consumption of side *wall refractories* is sometimes not without problems due to radiation attacks. Such problems are nearly non-existent with small furnaces, however, they can become critical with large UHP furnaces if protective measures are not taken.

The following protective measures were successfully applied in various combinations:

1. Operation with UHP techniques, i.e. adjustment of short electric arcs.
2. Formation of a foaming slag in which the electric arcs submerge.
3. Sponge iron feeding at low bath temperatures. By this means the side walls are protected for a rather long time by unmelted scrap.
4. Operation with intensive bath turbulence.
5. Application of hollow electrodes: Here the arcs burn partly inside the electrodes in a trumpet-shaped hollow space.

The data published so far prove that up to a transformer capacity of approx. 30 MW, the consumption of the side wall refractories is comparable to that of all-scrap practice (12,13,15). Unpublished test results lead to the conclusion that the power limit mentioned above can be extended, if the protective measures are applied consistently and with routine.

The operation with an intensive bath turbulence is the most essential measure. The protection of the side wall is effected by an improved cooling of the arc area and a shielding of the arcs by a barrier of slag fountains and waves. At the same time, the heat efficiency of the arcs is improved thus compensating or even over-compensating the energy thermodynamically required for the reduction of the residual iron oxides in the sponge iron. For creating the bath turbulence a certain content of residual oxygen is essential to serve as the source for the CO-formation. The two opposite influences, i.e. improved heat efficiency and thermodynamical heat consumption, lead to an *optimum metallazation* as already recognized by Sibakin (15) in 1967 and shown in Fig. 9. In the meantime, experience has indicated that the optimum metallization is between about 90 and 95 per cent but the exact value must be so far be tried out separately for each case. At a first glance one would estimate a lower *iron yield* for the Contimelt process than for all-scrap heats, as the slag volume is normally higher and additionally in many cases a continuous slag-off practice has to be applied. However, just the contrary is indicated by Fig. 10 representing an evaluation of the operating data available on the Contimelt process as well as on the similar process technique No. 3, the continuous melting under liquid bath conditions without overlapping the melting and refining period. Despite the great number of potential parameters and methods of yield calculation the following tendency can well be recognized from Fig. 10: If considering the pure Fe yield Y_1 and the operating yield Y_2 in which the gangue is subtracted it is obvious from the equal, less than and more than signs in the last column that these yields are nearly always greater for sponge iron than for all-scrap heats This is supported by the small diagram in Fig. 10 up to 100 per cent sponge iron charged.

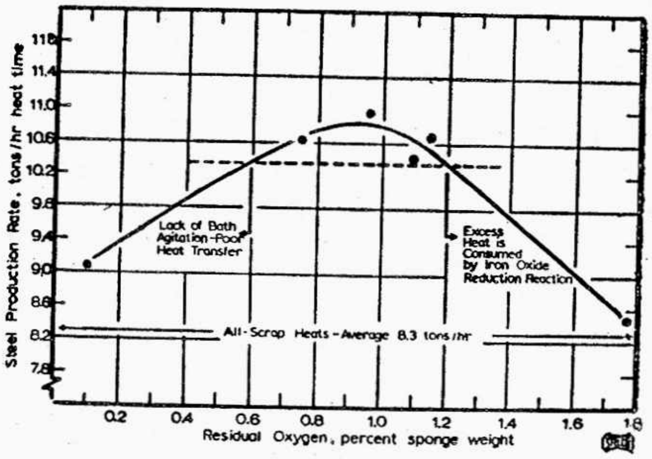
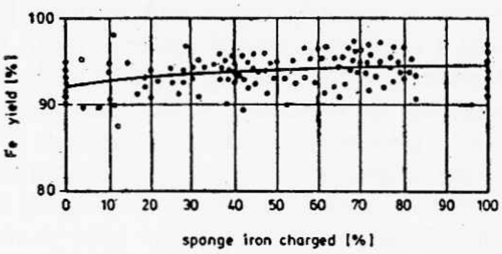


Figure 9

author	sponge charged [%]	sponge composition Fe_{tot} [%]	gangue [%]	method of calculating yield	judgement of yield sponge heats ≷ all-scrap heats
T.A. Williams et al.	40 to 68	92.2	6.0	Y_1	(no data) = (no data)
N.Mc Callum et al.	15	92.3	4.2		(no data) ≧ (no data)
P. Kehl a. H. Voss	3 to 100	94.0	3.5	Y_2	(see diagram) > (see diagram)
H. Noda et al.	40	92.2	6.3		93.5 % > 93.0 %
H. Noda et al.	40	92.2	6.3	Y_3	91.4 % < 93,0 %
E.L. Foglemann	10.5	92.0	3.7		(no data) = (no data)
J.G. Sibakin et al.	15 to 50	91.8	7.0		90.1 % ≧ 90.0 %
J.G. Sibakin et al.	70 to 80	89.5	9.2		89.5 % < 90.0 %
J.G. Sibakin et al.	70 to 80	94.6	4.3		94.2 % > 90.0 %



$$Y_1 = \frac{\text{tons of Fe in steel}}{\text{tons of Fe charged}} \cdot 100$$

$$Y_2 = \frac{\text{tons of steel}}{\text{tons of (Fe bearers-gangue in sponge)}} \cdot 100$$

$$Y_3 = \frac{\text{tons of steel}}{\text{tons of Fe bearers charged}} \cdot 100$$

Iron yield for continous melting under liquid bath conditions

Figure 10

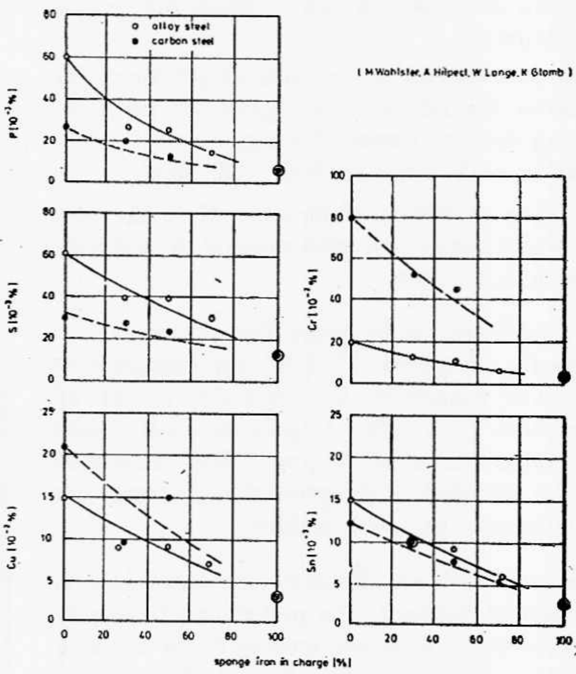
Thus it can be concluded that in the limits shown in Fig. 10 less iron is lost in Contimelt heats than in all-scrap heats. However, regarding the operating yield Y_3 which includes the gangue content no tendency can be found. This slight movement to the disadvantage of the Contimelt process is understandable as the iron content in scrap is normally higher than in sponge iron.

The *quality of the steel* produced with the aid of the Contimelt process was always at least as good as comparable steel grades from scrap. This is due to the greater cleaning effect of the steadily boiling bath and the very low level of trace elements in the sponge iron. The latter fact is documentated by Fig. 11 and allows either producing better steel or replacing the expensive scrap grades with cheap scrap in combination with sponge iron.

Charging Techniques

The Contimelt group have built charging systems for quite a number of arc furnaces and they have had advisory functions for the erection of several others. This concerns primarily the roof charging technique but includes also the slingering through the side wall.

Fig. 12 shows how a small electric arc furnace of normal design can be consequently re-equipped with extraordinary simple means for operation with the Contimelt process. The equipment has been built for test purposes and can, therefore, be removed from the



Trace elements in liquid steel after melting different proportions of sponge iron

Figure 11

furnace after the tests. More elaborate is the charging equipment shown in Fig. 13 for a 70 t UHP furnace. By means of this installation, apart from sponge iron also lime and ore can be continuously charged into the furnace at metered rates.

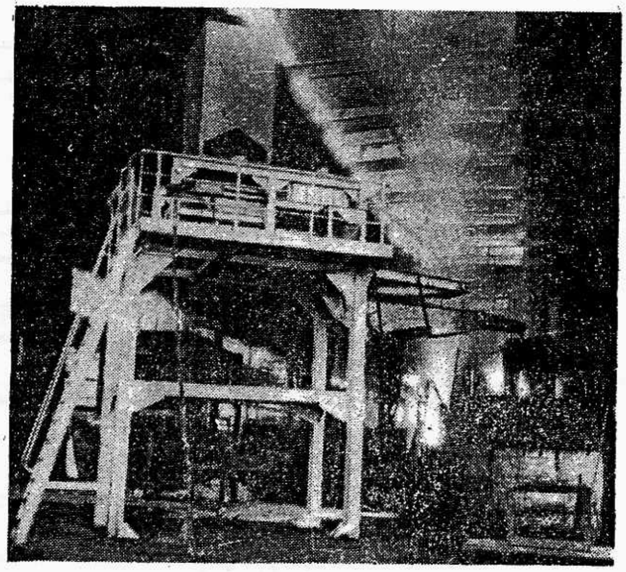
Fig. 13 shows how the sponge iron feeding devices are arranged in a new steel plant. The furnace bins are installed in the roof structure of the steel plant building. Sponge iron, lime and other materials are discharged from the bins via weigh feeders and pipe systems. By this means, the natural gravity can be utilized for handling and the furnace floor is kept clear from additional equipment. This arrangement of the feeding system has been chosen, for example, by New Zealand Steel and by Hamburger Stahlwerke in Germany.

If the sponge iron (plus lime and other materials) is charged by gravity through the furnace roof either one central hole in the roof or three openings can be chosen, each of the latter being arranged between one electrode and the furnace wall. Charging through a central hole will be advantageous in the case of:

(a) small electric arc furnaces,

(b) feeding of sponge iron briquettes.

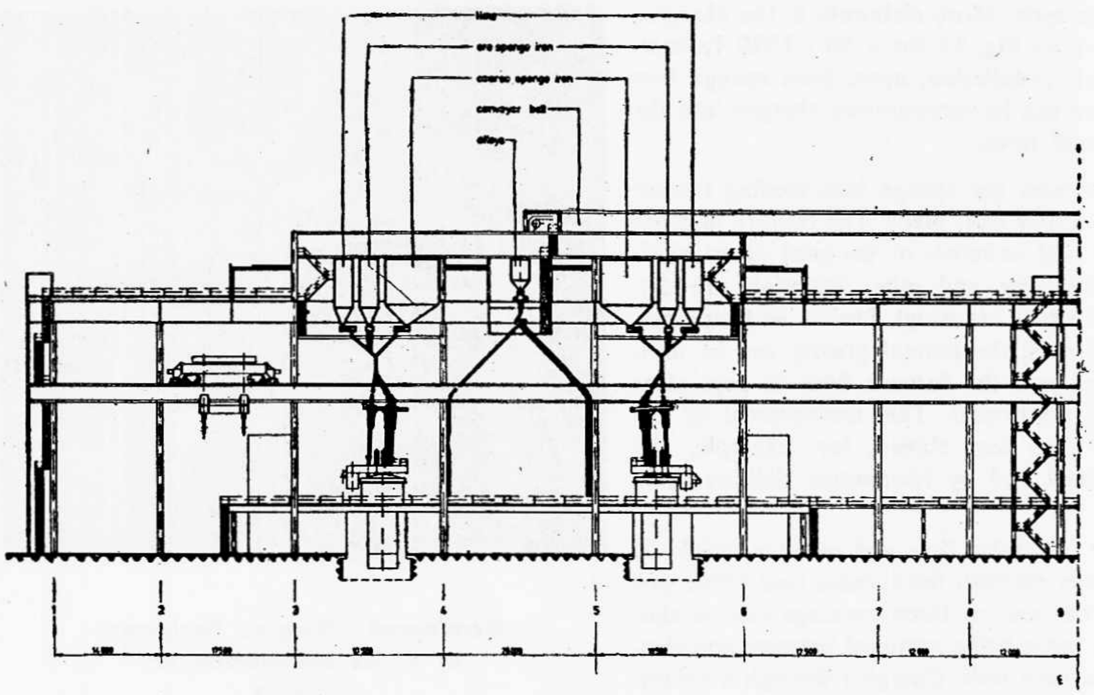
In the case of relatively large electric arc furnaces and for the melting of unbriquetted sponge iron, it is advisable to apply the three-hole charging technique.



Continuous Charging Equipment of a 10t Commercial Arc Furnace

Figure 12

Figure 13



Continuous Charging Equipment of a Contimelt Steel Plant

Figure 14

In one of the test series within the Contimelt group (10) the feeding of the sponge iron by a slinger apparatus through a hole in the furnace side wall was tried out. Although these tests were successful, this charging technique recommended only in steel plants where the existing building conditions do not allow for the installation of a gravity feeding system. The main reasons favouring the gravity charging technique are:

a) The furnace floor should be kept clear from additional installations.

b) In case of a breakdown of the high speed slinger apparatus operating under hot and dusty conditions the feeding of the sponge must be interrupted.

Conclusions

After the Contimelt process has proven superior to the other melting techniques of sponge iron in arc furnaces only this specific melting technique is to be finally discussed here with emphasis on the question of the *optimum percentage* of sponge iron in charge.

As previously indicated the Contimelt process is characterized by a *process technical optimum,* defined as this percentage of sponge iron where the consumption figures are the lowest and simultaneously the productivity is the highest. Theoretically this value can vary between about 15 and 70 per cent of sponge iron in charge (Fig. 7). The operating data have further confined the range to about 20 to 35 per cent as the most probable range (Fig. 4).

As the term "optimum percentage" has to be defined more clearly as the "*most economical percentage*" the process technical optimum is only part of the story. The other part mainly covers influences such as availability and price of scrap and sponge iron and quality and price of the final steel product. As these parameters are at least as important as the process technical parameters, but can hardly be quantified on a general basis, the question on the optimum percentage must be left open. Generally spoken a much higher percentage than the so-called process technical optimum will, for instance, be the most economical percentage in the following cases:

1. If the scrap price per Fe unit is higher than the sponge iron price or cost, respectively.

2. If the desired steel qualities cannot be met with the scrap grades available.

Both of these points seem to partially prevail in India, thus here a tendency will probably develop in the future to apply a proportion of sponge iron in charge which is higher than the process technical optimum.

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Discussion

Mr. S. Dharanipalan, (Bhilai Steel Plant, Bhilai): The author has analysed electric smelting under Process techniques and charging techniques. I have got a question regarding the charging technique. As the productivity of steel-melting in Electric arc furnaces increases, it is perhaps in the minds of metallurgists to have three hole charging of sponge iron. Is there any unit working in your country with three hole charging in bigger furnaces. Perhaps with three hole charging the boiling section will be more uniform in the bath and not localised as shown in your film and it will have some effect on the yield of steel.

Mr. G. Post (Author): No doubt, the three hole charging is the ideal technique from the standpoint of a uniform distribution and a large area of boiling. However, in commercial practice there are additional limitations to be taken into account. First of all, the handling of three different material streams calls for a sophisticated charging device being more expensive and complicated to operate and calls for three additional holes in the roof being difficult to realize particularly with small furnaces. As there is no direct comparison between one and three hole charging existing so far with the same furnace and both the charging techniques are applied successfully in the world I am advocating for the simplest solution and that is the one hole charging. In Germany two 90 t furnaces are operated commercially at Hamburger Stahlwerke and a 55 t and a 10 t furnace are operated on a test basis, all of them with one hole charging. The three hole charging has been tried by The Steel Company of Canada in a 23 t furnace, by Lukens Steel in a 135 t furnace, and by Daido Steel in a 70 t furnace on which the film was taken. The same charging is routinely applied in the 40 t furnace of Acos Finos Piratini in Brazil starting at the middle of this year.

Dr. A. K. Chakraborty, (Alloy Steel Plant, Durgapur): i) I would very much like to get some idea of **gas contents** (H_2, N_2, and O_2) in the finished metal (ii) What specific properties of slag are generally aimed at?

Mr. G. Post (Author): In general it is to be expected that the contents of hydrogen and nitrogen in the finished steel are lower in sponge iron heats than in all scrap heats because the steady boiling action means a strong cleaning effect. I cannot prove this statement regarding the hydrogen as no test results are known to me. Regarding the nitrogen the results show a relevant improvement. Under reference No. 14 of my paper a reduction from 100 ppm for all scrap heats to 70 ppm for 70 per cent sponge iron heats is reported. Reference No. 10 reports nitrogen contents as low as 30 to 40 ppm in the furnace, but 60 to 70 ppm in the ingot. Unpublished results by The Steel Company of Canada show a gradual drop in nitrogen before tap from 70 ppm on all scrap heats to about 30 ppm for Contimelt heats depending on the percentage of sponge iron in charge. The behaviour of the oxygen content is not yet mentioned in literature. The first values being published soon (reference No. 16) do not deviate from the normal range observed with all scrap heats at the same carbon content. It may be added that never an additional consumption of deoxidisers was observed with sponge iron heats.

Physically it is generally aimed at a thick layer of a foaming and boiling slag during the continuous feeding period. Chemically the slap is kept at a basicity (CaO/SiO_2) of between 1.2 to 1.5 as long as no desulphurisation and dephosphorisation are required. If the latter applies the basicity is gradually increased to values between 2.5 and 4 during the last stage of continuous feeding eventually accompanied by continuous deslagging through the door without interrupting the material charging. The low basicity slag is less conductive resulting in a better submerge of the arcs and they have a lower FeO content as compared with usual highly basic arc furnace slags.

Contribution by Dr. A. B. Chatterjea (National Metallurgical Laboratory, Jamshedpur) I wish to compliment Mr. G. Post, for a very interesting paper containing large amount of informative data. In view of the questions raised earlier on the quality of sponge for steel making, it is now appropriate to offer some comments by way of contribution.

Since sponge iron is largely used in electric steelmaking instead of scrap, the question of degree of metallisation of sponge iron and the amount of other gangue contents associated with it is of obvious importance, as the requirement of electrical power increases with gangue content, and simultaneously the furnace productivity decreases. There cannot be any divergence of opinion that sponge iron with a very high degree of metallisation is preferable. However, to attain complete metallisation in industrial scale by any process of direct reduction is rather difficult and impracticable. Several examples can be cited. As we are aware, commercial HYL plants are in operation at Monterrey, Vera Cruz and Puebla, Mexico, for last several years. The average degree of metallization varies between 88—92%. At Humburger Stahlwerke Hamburg, employing the Midland—Ross process with Malmberget pellets (67.7% Fe, 0.48% Al_2O_3, 1.55% SiO_2) an optimum degree of metallization of approximately 95% was attained. In the 500 tons/day Purofer Plant, the average degree of metallization varied from 90—95%. Sponge iron made in these plants has been satisfactorily converted into steel in industrial scale.

Based on physio-chemical considerations, the degree of metallization in gaseous direct reduction process can possibly be higher than in a solid reductant process, although factors like the time of residence, temperature, and the presence of excess of reductant are of significance. In SL/RN process, the degree of metallization in pilot plant trials varied 95 to 97% depending on the nature of the raw materials. In commercial kilns based on Krupp sponge iron process, a degree of metallization of 93—94% has been assumed. At the New Zealand Steel Plant, Glenbrook, reduction kiln (SL/RN Process) with sub-bituminous coal yields of beneficiated titano-magnetic beach sand in a rotary sponge iron analysing about 10% TiO_2, 9% FeO, 70% metallic Fe (degree of metallization 90%). A feed comprising of 25% steel scrap and 75% sponge iron is satisfactorily converted into steel in UHP furnaces essentially following the 'Contimelt' process. About 500 Kg of carbon as char is added for the reduction of FeO from sponge iron. After the removal of primary acidic slag containing 30% TiO_2, lime is added and the bath is lanced with oxygen. From these data, it is clear that sponge iron with low degree of metallization has been successfully used for steelmaking in commercial scale. The optimum degree of metallization of sponge iron should, therefore, be viewed from the overall economics of production of sponge iron and its conversion to steel by electric steelmaking process, as elimination of a certain residual amount of FeO in the first stage of direct reduction can be more costly than its conversion to slag during the second stage comprising of electric steelmaking. Besides, as has been mentioned in the paper, a certain amount of FeO in the sponge iron is necessary to have boiling action.

Mr. Post has correctly emphasized the need of economic appraisal of optimum metallization as the additional cost for higher degree of metallization should be lower than or equal to the additional cost in steelmaking with slightly higher amounts of FeO in the sponge.