## OPEN HEARTH PROCESS

## OF MANUFACTURE





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## ON THE OPEN HEARTH PROCESS OF STEEL MANUFACTURE. AN INVESTIGATION OF THE RELATIVE MERITS OF AN INTERRUPTED AS DISTINGUISHED FROM A CONTINUOUS

#### PROCESS.

#### INTRODUCTORY.

Sir Henry Bessemer's paper on "The Manufacture of Malleable' Iron & Steel without Fuel", read before the British Association on August 11,1856, and R. Mushet's patent of September 22 1856, for the addition of Manganese to Bessemerized metal, introduced to the world, Steel, as we know it today. Bessemer made steel by blowing air through molten iron and thereby burning out from the latter it's Silicon, Carbon and Manganese, the heat of combustion of these elements sufficing to maintain the metal in a suitably fluid condition. The process was conducted in an acid lined vessel and no phosphorus was removed. It followed that the phosphorus content of Bessemer steel was slightly greater than that of the iron from which it was made, and that, since not more than 0,10% phosphorus is desirable in steel, only such ores of iron as contained .06% phosphorus or less, were available for the manufacture of Bessemer iron. In view of the dephosphorization accomplished in the Puddling process, etc., it is not surprising that shortly after Bessemer's successful innovation metallurgists became keenly alive to the necessity for a pneumatic process which should also dephosphorize, and that as early as 1860, Peter Ritter von Tunner, Wedding and others made various experiments to this end; experiments which culminated about 1867, in

the successful development of the Thomas - Gilchrist Bessemer process, which by means of lime additions and a converter lined with calcined dolomite bonded with tar, accomplished the remaval of phosphorus from the metallic charge. It was found however, that the phosphorus was not materially attacked until silicon, carbon and mangahese had been entirely removed, and that, to furnish the heat necessary to fluidity during the "after blow" not much less than 2.00% of phosphorus should be present in the iron; that is, to make Basic Bessemer iron, an ore with at least about 1.00% of phosphorus was necessary.

These two processes then, the Acid Bessemer and the Basic Bessemer left absolutely untouched the problem of making the new Ingot steel from ores containing between .06 and 1.0% of phosphorus, except to such small extent as these ores could be mixed, in the Blast Furnace, with ores of very high or very low phosphorus content, or as iron made from such ores could be diluted with scrap in the Siemens Open Hearth Furnace.

The Open Hearth process, first successfully operated by the Siemens brothers in Birmingham in 1867 - 1868, effected the oxidation of the carbon and silicon of the pig-iron, not, as did Bessemer, by means of atmospherin air, but by melting the pig-iron with additions of oxides of fron, in a Siemens regenerative furnace. About the same time the Martins, in France, developed a similar process, but instead of oxides of iron they used admixtures of steel scrap, thus proceeding upon the principle of dilution, and for the rest, relying upon the oxidizing action of the furnace gases and slag.

Both the Siemens brothers and the MM. Martin, like Bessemer, used an acid lining, or rather, hearth, in their furnace, and, also like him, were consequently unable to dephosphorize. The Acid Open Hearth process, as we know it, is a combination of the Siemens and Martin processes, and uses ore and scrap interchangeably or together, according to conditions.

About 1880, Messrs Thomas and Gilchrist turned their attention to the application of a basic lining, or bottom, to the Siemens furnace, and within the two or three years following, dephesphorization was successfully accomplished in the basic lined Siemens furnace in the commercial way. The process of making steel in a regenerative furnace on a basic bottom, from pig-iron, solid or molten, iron ore and lime, with or without scrap, constitutes what is known as the Basic Open Hearth process.

Since 1885, or thereabout, the gradual exhaustion of the world's supply of low phesphorus iron ores and the growing necessity of depending for steel upon the almost unlimited deposits of ores whose phosphorus content is above the acid Bessemer limit and below the basic Bessemer limit, - these factors, coupled with the increasing severity of engineering specifications for structural and other steel - have been

largely responsible for the development of the Basic Open Hearth process into what is today THE steel making process, par excellence. The perfect adaptability of this process to the refining of any combination of pig-iron and iron and steel scrap of almost any composition, it's simplicity and perfection of control, are nothing short of marvellous. It

has, nevertheless, as compared with the extremely rapid Bessemer process, the disadvantage of slowness, a fifty ton Open hearth heat requiring from eight to fourteen hours, depending upon the raw materials used, whereas, by the Bessemer process, ten tons of fluid pig iron can be converted in as many minutes. It is true that the Open Hearth yields more steel per ton of metallic charge than does the Bessemer because the iron ore usually charged in the former contributes more or less of it's metallic content to the bath, and because it avoids certain mechanical losses that are almost inevitably suffered in a pneumatic process. Naturally enough, however, time Ironmasters have set their, standard by the less elastic and more wasteful, but more expeditious Bessemer process, more especially since the latter was first in the field. For this reason we find that ever since it's inception the Basic Open Hearth process has been the subject of innumerable experiments looking to a closer approximation to the Bessemer time standard. The majority of such experiments have, of themselves, been failures. Others, notably the Talbot, Surzycki, Duplex, Bertrand-Thiel and Hoesch processes, have attained to some measure of success. In some cases, at all events, that success has consisted merely in approximate parity, real or fancied, with straight Basic Open Hearth performance. It can scarcely be said that any of these reputed shorter methods has been universally recognized as in all cases definitely superior to the pagent process.

The Bertrand-Thiel process consists essentially in car-

rying the refining operation to a certain point in a primary hearth and then transferring the metal to a second hearth, in which fresh reagents, with or without scrap have been previously charged and preheated, the primary slag being carefully held back and discarded. The refining is then completed in the secondary hearth. In the Hoesch process, which is really a modified Bertrand-Thiel, metal and slag are tapped from the primary sizg hearth into a ladle, fresh reagents are charged into the same hearth and the metal returned thereto, the primary slag being retained in the ladle. The Hoesch process therefore, metallurgically speaking, is merely the Bertrand-Thiel carried out in one furnace instead of in two.

Such processes as these may be called "interrupted processes" as distinguished from the parent process which finishes the refining in one stage, and which, for this reason, I have referred to in the title of this theses as a continuous process. Inasmuch, however, as the use of this term also suggests such processes as the Talbot, which is beyond the scope of the present investigation, I shall, in what follows, speak of the original Open Hearth process as the "straight basic process", an expression which, though somewhat unacademic, is widely used in the art. The inventors of the interrupted processes claim for them the following advantages over the straight basic process;-

1. Greater daily output per furnace, more especially when the iron to be refined is high in phosphorus.

2. Higher yield of ingots per unit of metallic charge.

3. Lower ore and lime consumption per ton of ingots.

4. The production from a phosphoric pig-iron of a saleable slag, due to the concentration of the bulk of the phosphoric acid in the smaller volume of primary slag.

5. The ready production of low phosphorus steel from high phosphorus iron.

6. Greater uniformity of product with variable raw material.

After a careful study of the published data, one appears to be forced to the conclusion that these claims, however well justified in fact, are far from being satisfactorily proven by the printed evidence thus far adduced. It seems to be true, in some cases at least, that by an interrupted process more steel has been obtained from two open hearth furnaces than had previously been obtained from them by the straight basic process; but did the latter, as previously carried out, represent the best possible practice under the conditions, or were the conditions comparable? In other words, given two furnaces of modern size and construction, operated according to the most approved straight basic methods, can their output be increased by the use of an interrupted process, without other change, i.e. by working them either in series, according to the Bertrand-Thiel, or in parallel, by the Hoesch method? The question, metallurgically and commercially, is of the highest importance.

Harbord says, (Metallurgy of Steel, p. 198 et seq.); - "To ensure this" (Bertrand-Thiel) "dephosphorization, combined with rapid work, xham a very shallow bath of metal, about six to

eight inches deep is necessary, and consequently, very large furnaces must be used, far larger than the ordinary basic furnaces for the same weight of metal. - - So far no plant has been erected with large furnaces capable of holding 50 tons of metal, so that it is difficult to form an estimate as to what will be the speed of working in a large furnace of 50 tons capacity, or more. From the surface area of the Kladno furnace, it appears that an ordinary Siemens furnace of 50 tons capacity will not held more than 25 tons of metal when working the Bertrand-Thiel process, so that although the speed of werking is undoubtedly greatly increased, the quantity of metal turned out for the same number of charges will be enly half that obtained from an ordinary Siemens furnace of the same surface area and hence the 50% greater output claimed by the patentees, would necessitate very rapid working indeed."

Such a guarded opinion from so eminent an authority is significant indeed, and has been here quoted at length as in itself constituting a strong plea for further light.

### EARLY WORK

In 1894, the Prager Eisenindustrie Gesellschaft at Kladno, Behemia, operated besides their basic Bessemer plant, two basic Open Hearth furnaces, one of twelve, and the other of twenty-two tons capacity. By an accident of construction, the level of the smaller furnace was fifteen feet above that of the larger, which, also, was thirty-six yards distant from the other and in front of it. The Kladno pig-iron averaged;-

3.5 - 4.0 % .5 - 2.0 Carbon Silicon Phosphorus 1.5 .05 - .10 Sulphur .6 (nl) Manganese

For the dephosphorization of such metal relatively high lime and oxide charges were necessary, more particularly if very low phosphorus were required in the finished steel. The greater the amount of reagents charged, the longer is the time occupied by the refining. O. Thiel of the Prager works states(n2) that in a 15 ton furnace with iron of approximately the above composition.only two 12 ton heats could be made in 24 hours. This, of course, was excessively slow, and demanda remedy. If two substances react on each other, chemically, the dilution of these two substances by inert substances will retard their speed of reaction. If at the beginning of the refining operation in the Open Hearth furnace there are added reagents sufficient for the removal of only a portion of the impurities present in the iron charge, and if, when these reagents are exhausted the resulting slag is completely removed from the furnace, and fresh lime and oxides are added, the speed of reaction is greater than if the total amount of lime and oxides had been added in the first instance, those portions first exhausted remaining as a diluent for the balance. Such was the line of reasoning which, about 1894, led the late Ernst

(nl) E. v.Maltitz. Iron Age Aug. 10. 1905. p. 349.

(n2) Stahl u. Eisen XVII p403.

Bertrand and Otto Thiel of the Prague works to take advantage of the peculiar juxtaposition of their two Open Hearth furnaces, using the upper one as a Primary furnace, and at a certain stage allowing the metal to run down into the lower furnace in which had been preheated, meanwhile, oxides and lime, with or without varying proportions of scrap. The results of this modus operandi have been widely published and discussed(nl). Without any doubt they represent a great improvement on previous Kladno practice; but as the data published seem to lack certain of the features necessary to a comparison with modern Open Hearth practice, they need not here be set forth. Suffice it to say that on a basis of these experiments, the interrupted process was perpetuated at Kladno, and was intraduced at other works, -notably at the Creusot works, at Brymbo, and at the Hoesch works in Dortmund, Germany.

Possibly the best comparative idea of the process may be gleaned from information published concerning it's operation at Dortmund. The following figures summarize the results there obtained. (n2).

HOESCH WORKS. DORTMUND. 1905.

Date		First Ran, J	Seco	and Run
Tota	l Hours	120	144.	
Heats Furn	made	47.	61.	
Hear	th Area	21'x 10'.	21 <sup>•</sup> x	10'.
(nl)	Trans. Am. Inst E. Bertrand. Jo	.Min.Eng. J. H. ur.I.& S.Inst.	<b>art</b> shorne.Se 1897.1.115.	pt.1896.
	A. Ledebur. Stal	hl u. Eisen XXI	II.p.36.	
	Pottgiesser.S	tahl u. Eisen X	XIV p.619.	
	Darby & Hatto:	n.Jour. 1. & S. 1	nst.1905.1.r	p125 et seq.
(n2)	loc.cit.	tani u. Gisen. 1	ATO'NO:2 T	če 11.

Second Run. First Run 18 tons. Rated Fice Capity. 18 tons. 878t. 15 cwt. 695t.1 cwt. Molten Pig used Broken Moulds 6t. 10cwt. Light & plate scrap 157t.10 cwt. 3t. 12 cwt. 189t. 16 cwt. 3 cwt. 7 cwt. 15t. Ferro-Manganese 8t. 1 cwt. 6t. 4 cwt. 12t. Ferro-Sil.& Spiegel 1099t. 13 cwt. 873t. 6 cwt. Total Metallic Chg. 104.51% 18t 908t. 8 cwt. 104.02% 1149t. Good Product Yield Av'ge W't of Heat 19t. 6 cwt. Heats per fice per day of 24 hours. 4.7 5.0 Product per furnace 95.8 tons. 90.8 tons. per 24 hours Non-Metallic Charge per ton of ingots was as follows;-402 498 lbs. lbs. Swedish Ore 76 128 针 Mill Scale 185 Ħ Ħ 203 Lime 94 Ħ Ħ 140 Limestone Total Limestone 448 Ħ 433 11 equivalent Total Lime equi-Ħ **259** 545 296 Ħ valent Ħ Ħ 580 Producer Coal Average time of secondary heat 2 hrs. 33 '. 2 hrs. 22'. Ditto - Primary ht. approximately the same, probably somewhat shorter. ANALYSES. S. C. **P.** Mn. Si. 1.8 Molten Pig 1.5 .07 • 🕈 🖛 • 5 1.0-2.0 .2 Primary Metal .015 .. 04 -Finished Steel MnO Al<sub>2</sub>03 P205 CaO SiO<sub>2</sub> FeO 3.93 1.60 22.-25. 48.86 4.0 11,40 Primary Slag 4.67 12.40 17.03 1.90 5**.0**0 46.28 5.9 Secondary Slag 

Summing up the combined results of the two runs, we find that steel of excellent quality was made in two furnaces at the rate of 7.8 tons per hour - that is, 3.9 tons per furnace per hour. It is also readily calculated that the steel made in 24 hours per square foot of hearth area was .446 tons,-a remarkably good performance in view of the grade of pig-iron

MgO

charged. There was also produced, calculated on the basis of phosphorus, slag, of commercial value to the amount of .11 tons per ton of ingots. The statement is also made that a saving of 4 shillings per ton of steel directly resulted from the substitution of the Bertrand-Thiel for the regular process ملي ا previously employed in those furnaces. Similarly definite data regarding previous regular practice, do not accompany the figures above quoted. It would at first glance seem reasenable to ask, in view of the very considerable saving just recorded, and whereas there were in the Hoesch shop four Open Hearth furnaces of the same capacity, why only two of them are described as operating according to the Bertrand-Thiel method and why, later, when two larger furnaces were added to the equipment, only the new furnaces made use of the interrupted process, all four of the older furnaces being relegated to the straight basic process. The reason for this apparent inconsistency is probably twofold. In the first place, the Hoesch Company makes basis Bessemer steel as well, and it's policy with reference to the interrupted process, which requires molten pig iron, would necessarily be regulated by the available supply of that commodity over and above the requirements of the Bessemer Converters. In the second place, the interrupted processes use only a limited amount of scrap, and the straight basic process would probably have to be employed in a certain number of their furnaces, to economically dispose of the considerable amounts of scrap that are inevitably currently produced in a works of that size.

#### THE HOESCH PROCESS.

After an extended trial, it was found at Dortmund, that there were certain practical difficulties in the way of the Bertrand-Thiel process. For one thing, by reason of the lower temperature and heavy lime charge therewith, the hearth of the primary furnace builds up badly, while the hearth of the finishing furnace was rapidly attacked. Also, on account of the unequal times of primary and secondary heats respectively, one furnace was compelled to wait on the other. For this reason, in the summer of 1905, they began to perform the whole operation in the furnace, and in this way the growth of the hearth during the first period was very successfully utilized as a protection against the waste of the second period. The process was patented by the Hoesch works under D.R.P. 189871 - 1905. After the completion of two new 30-ton furnaces, this Hoesch Process, which, as already stated, is metallurgically a modification of the Bertrand-Thiel, was regularly carried out in them from May 1.1907, onward . "The process" (Petersen. Stahl u. Eisen, loc.cit.) "is substantially as follows; - the furnace is charged with lime and oxides (chiefly Swedish, Minette and Spathic Ores and Roll-scale). After a short interval molten iron is charged, and the reaction begins almost immediately. As soon as the heat boils clear and is hot enough, metal and slag are tapped into a ladle and the slag skimmed off. Meanwhile the furnace is freshly prepared with Lime, Oxide and Scrap and the primary metal poured back in, the refining proceeding thereafter with great rapidity. The following data

have been arranged and calculated from Dr Petersen's paper;-The figures, unless it is otherwise indicated, are in metric tons. The period covered is the year 1808 - 1809.

HOESCH PIG & SCRAP PROCESS. PROCESS. 10,146 16,494 Total hours 3962 Heats made 1711 1 Furnaces used 1 24.41 x 111 21' x 10' Hearth area 18 tons. 11754.9(16.11% 5605.1(7.68%) 30 tons. 36218.8(74.72%) 83.8(.17%) Rated furnace cap'ty. Molten pig-iron used Scrap iron 51906.9(71.15% 398.7(.54%) 116.4(.16%) 3170.9(4.36%) 11631.7(24.00%) 404.8(.84%) 7.08(.02%) 121.0(2.25%) Steel scrap Ferro-Manganese Ferro-Silicon Spiegel 72952.9 70465.6 96.60 Total Metallic Charge 48462.6 Good product yield % 50606.0 29.57 4.04 Good product per heat 17.81 Heats per fice per 24 hrs. 5.76 Good product per f'ce per 24 hours 102.6 119.5 The Non-metallic charge per ton of ingots was;-Ore & roll-scale 478 lbs. 19.8 1bs. 207 8**9.0** 546 Lime 权 546 Ħ Producer coal 1 6.6" 24.2 1 Coke Slag produced per ton of ingots, Primary .126 metric tons. Ditto - Secondary .118 m.t. .147 Average time of heat, Primary (about) 4 hrs 81 ) 4 hrs 10' Secondary " 1 hr. 48' Gross tons per square foct of bath surface per 24hrs. .438 .480 ANALYSES. C. P. Mn. Si. S. 1.05 .41 3.20 1.82 .084 Molten pig-iron Primary metal 1.95 .15 tr. .07 .44 .048 Finished steel tr. .07 .015

Slags. SiO<sub>2</sub> Fe. Mn. CaO.  $P_2O_5$ . MgO. Al<sub>2</sub>O<sub>3</sub>. Hoesch, Primary 11.00 4.63 4.76 41.91 24.93 7.20 2.10 "Second. 13.20 14.10 5.54 40.13 7.47 7.50 2.99 Straight O.H. 15.50 15.75 11.00 40.22 2.25

It therefore appears that in the three processes referred to in the foregoing, steel was produced at the Hoesch works at the following rates per square foot of bath surface per day of 24 hours;-

1.	By #	the "	Bertrand-T	hiel	process #	in "	2 1	782-1 307-1	18t. 30t.	furnaces furnace	.446t.
3.	Ħ	Ħ	Straight O	pen 1	Hearth"	Ħ	ī	uni	18t.	1	.480t.

As will be seen, however from the nature of the metallic charge, from the small lime and ore additions, and from the low phosphoric acid in the slag, the regular Open Hearth heats were rather scrap melting heats, and partook of the nature of acid heats on basic bottom. On the other hand they were made chiefly from cold stock, which offsets to some small extent, the fact that the Bertgand-Thiel and Hoesch processes, as there exemplified, had to do with a very high phosphorus pig iron. Under these conditions, however, the straight Open Hearth is seen to have a very heavy margin in it's favour. As to whether or not this margin would have assumed a minus value had Thomas iron, and high lime and oxide charges been substituted for the relatively small and pure charges that were used, we are so far, not enlightened.

#### INVESTIGATION.

I gladly availed myself of an opportunity which came to me in November 1913, at the works of the Dominion Iron & Steel Company at Sydney, Nova Scotia, to conduct experiments looking to the establishment of the relative merits of the Bertrand-Thiel, Hoesch and straight basic Open Hearth processes. These experiments, the conditions surrounding them, and the deductions which they permit, will now be dealt with.

The pig-iron, which was supplied from a Mixer, in the modten condition, was of the following composition, as regards nonferrous elements,

Carbon Silicon Phosphorus 1.47. Sulphur .06 .20 Manganese

The Ores used were a Magnetite and a Hematite, both very suitable, physically, for Open Hearth work, and in the Bertrand-Thiel and Hoesch heats, some Manganese ore, the latter being used to conform with conditions indicated by the slag analyses given above, as obtaining in Dortmund practice. Analyses of the ores were as follows;-

In the straight basic practice, only limestone is used as a rule; in the experiments with interrupted processes, hewever, calcined lime was used, in order, as before, to duplicate Dortmund conditions. Analyses of these materials were;-

SiO<sub>2</sub>  $Al_2O_3$   $Fe_2O_3$  CaO<sub>3</sub> CaO MgCO<sub>3</sub> MgO S. Limestone 3.09 .75 .94 89.60 (50.17)5.09 (2.42) .045 Lime 4.12 1.14 1.60 - 85.84 - 4.00

The Ferro-Manganese employed contained very uniformly \$0.00% Mn., and the Ferro-Silicon, 50.00% Si. The furnace chosen for the work was a fifty-ton,tilting basic Open Hearth furnace of the Campbell type,fired by Producer gas. The area of the hearth at the slag-line was 25' x ll' or 275 square feet. The maximum depth,from centre hearth to fore-plate level was thirty-six inches.

Of straight basic practice in this furnace, the following heat, made from the above raw materials, may be considered as in all respects typical, and as constituting a fair basis for comparison with the interrupted processes.

Heat No. 519.

Began charging 4.45 A.M.

31,450 lbs. Limestone 5,500 Magnetite 9,700 34,300 Ħ Hematite Ħ Rail Crops 29,000 7.50 A.M. Ħ Mixer Iron 8.00 Ħ Ħ -28,700 Ħ Ħ 8.10 Ħ Ħ 22,700 2.10 P.M. Slag test, SiO<sub>2</sub> 23.44. Fe 5.85 CaO 45.32  $P_2$  13.37 4.05 P.M. Metal test, C. 41 P. 050 S. 048 4.30 " " C. 34 P. 040 4.40 " Slag test, SiO<sub>2</sub> 15.68. Fe 5.56 CaO 51.41  $P_2O_5$  11.36. 4.55 Tapping. Used 1600 lbs. FerroManganese and 360 lbs.of coke in the ladle. Aluminium was added in the moulds in the proportion of  $l_2^1$  ounces per ton of steel. 1500 lbs. of Flu-

or Spar was used in this heat.

Ladle test, C. .58 P. .035 S. .037 Mn. .95 Time of heat, 12 hrs.10'.

Total Metallic Charge116,300 lbs.Ingots110,300 "Yield ,percent,94.8

On the basis of this heat, which as already stated is typical, allowing the necessary time for bottom repairs etc. between heats, and eliminating extraordinary delays on metal,

charging machines, cranes etc. which are a function not of the process, but of the general equipment, number of furnaces etc., it may be calculated that from these raw materials, in the furnace described, there are produced 12.5 heats of fifty tons each, in a week of 156 working hours; 96.1 tons in 24 hours; and .350 tons per square foot of hearth area in 24 hours.

Since, in view of Dortmund practice, a bath depth of thizty-six inches appeared excessive, I raised the bottom of the furnace selected for the experiments, by means of Magnesite additions, suitably sintered on, until the maximum depth was reduced to about 30 inches. I also reduced the size of the heats to about 40 tons each, the bath surface being in this manner maintained as before, at 275 square feet.

In this furnace I began charging the first Hoesch heat at 9.50 P.M. on November 5th.1913. The materials were disposed in the following manner;-

North door.	Middle door.	South	doo <b>r</b> .
box lime. 12 " ore. 1 " lime.	2 boxem ore. 3 " lime.		lime. scale. ore. lime.

The lime was put on the flat in the end doors, in order to fill slight depressions that existed at these points. These materials were all in the furnace at 10.35 P.M.. The Mixer metal was ordered for 11.05 P.M., allowing just one half hour for the cold stock to heat. Owing to a ladle change it was delayed 20 minutes, and was charged as follows;-

11.	25P. M.	Mixer	metal	40,300	lbs.
11.	40 "	11	#	31,700	11

Reaction began shortly, and proceeded with considerable vigour, but not violently, gradually subsiding towards 2.00 A.M. when the bottom was found to be clear. Slag and metal testa were taken at this point and showed;-

Metal.

C.2.22 P.239 S.063. SiO<sub>2</sub> 19.76 Fe 4.04 CaO 42.58 17.03. P205 Slag.

At 2.30 A.M. metal and slag were tapped into a ladle suspended from a 75-ton crane, and the slag was drained off as completely as possible over the lip. The slag was very puffy, and even with heavy drenching was only with extreme diffigulty retained in the box into which it was poured.

After tapping, the furnace was immediately righted, and , beginning at 2.38 A.M. fresh reagents were charged as follows,

Middle door. South door. North door. 1 box Magnetite, 1 box Hematite. 2 boxes crop-ends.1 box crop-ends. 12 " lime 1 " lime. box Hematite. box crop-ends. 3/4" lime. 1 box Manganese ore divided between the three doors.

At 2.50 A.M. this stock was all charged and the metal was immediately returned to the furnace, being poured over the lip of the ladle into a charging hole situated at the back of the furnace. The pouring occupied 17 minutes, being finished at 3.07 A.M. . Very noticeable during the tapping and pouring of this primary metal were the dense clouds of red oxide fumes that arose from the metal in the runner, and in the ladle,-so dense as to suggest the end of the after-blow of an over-blown basic Bessemer heat. The primary metal emitted these characteristic fumes during the pouring of every Hoesch and Bertrand-Thiel heat that was made. It does not

at first sight appear clear why the metal evolves these fumes in the presence of more than 2.00 % of Carbon, and does not evolve them to anything approaching the same extent, at tapping time, and in the presence of less than half of one percent of carbon, and at a stage when one would naturally expect a more or less oxidized condition of bath.

The explanation is probably to be found in the more acid nature of the slag of the primary heat, it being well recognized in the art that a "lean" slag, and "wild" metal at tapping time, are frequently concomitant.

After the metal was returned to the furnace, the bath lay sluggish for about three quarters of an hour, this being the natural consequence of the introduction of so much cold stock, without any interval for pre-heating. At the end of this time, as the metal gained temperature, reaction began, and proceeded with moderate vigour, finally quieting down at about 6.30 A.M. At 7.00A.M. the bottom was clear, and as the slag had a resinous lustre, indicating insufficient lime, and as the fracture of the metal test suggested the presence of undue amounts of phosphorus, I added a box of lime to the slag. Metal tests taken at this point, and thereafter, showed;-

Time taken.	С.	<b>P.</b>	s.
6.55 <b>A</b> .M. 7.20 " 7.45 "	•52 • <b>3</b> 7	.065 .055 .055	.050 .043

The "sticking" of the phosphorus at this juncture showed that there was still a dearth of lime in the slag. A second extra box was therefore added at 8.00 A.M.. It was quickly

"cut up", and a metal test taken at 5.30 A.M. showed, -C. 29, P.045. The heat was tapped at 5.50 A.M. 1100 lbs.Ferro-Manganese, 350 lbs. Ferro-Silicon and 360 lbs. Coke were add ed in the ladle. 4 lbs. of Aluminium was distributed among the moulds.

Resume.

First period. Began charging, 9.50 P.M. Tapped 2.30 A.M. Time of primary heat, 4 hrs. 40 minutes.

Primary charge;-

Lime 10,800 15s. Magnetite 12,100 Roll Scale 1,900 Mixer Metal 72,000 Tapping tests;-Metal C 2.22 P.239 S.063 Slag. SiO<sub>2</sub> 19.76 Fe 4.04 CaO 42.58 P<sub>2</sub>9<sub>5</sub> 17.53.

Second period. Began charging 2.35 A.M. Tapped 8.50A.M. Time of secondary heat, 6 hrs. 20 minutes.

Secondary charge;-

Magnetite 2,700 2,000 Hematite 1,700 Manganese Ore 4,800 & 2500. Lime 17,800 Crop Ends P. .065 C. Time. s. Metal tests. .52 .050 6.55 A.M. 7.20 # .055 .043 45 .055 Ħ .29 P205 Slag. 8. 25A. M. SiO<sub>2</sub> Fe CaO MnO. 13.40 7.31 8.43 49.53 5.30 Total time of heat, 11 hrs. 00 minutes. Analysis of finished steel, P.037. S.040 Mn.96. **C.** 54

Total metallic charge 91,250 lbs. "Product 88,000 " Yield 96.5%.

From this heat many lessons were learned. It was seen, for instance, that rather less lime might be used in the first

Hea	at First Se	<b>d</b>	HAN NI			.UOINEY GNO	038 - 36
N	hrs.min.hr	S DIFE	FOTTOT	-OTIE	NomEd .d	I -Jengan	-JameH
64	+. 4 - 40 6 -	363 2.	350	1,100	00 7 . 300	2,700 1.7	2,000
6	5 4 - 45 6 -	.s .s.	350	1,150	6,200	3,100 -	2,300
66	4 - 10 5 -	008	350	1,050	000,0 000	3,100 1.7	2,700
67	4 - 40 7 -	. 000 2.	350	1,050	00 6,000	3,100 1.5	2.700
68	5 - 00 6 -	.s -	-	625	000.0 00	3.100 1.7	-
69	4 - 20 5 -	600 Z.	-350	1.000	000.3 00	3.100 1.5	-
70	3 - 00 5 -	.5 00	300	1.025	000.3 000	2.000 1.5	2.400
71	2 - 50 4 -	800 2.	350	020.8	001.3 00	3.000 J.S	1.600
72	2 - 55 4 -	_	300	000.1	000.8 000	-L 000-E	000 0
73	2 - 20 4 -	_	-	650	000.2 00	3,200 3,8	000.0
74	3 - 25 6 -	.5 03	-	3.000	000.7.000	- F. 000 F	000.0
75	4 - 40 6 -	us ada	085	000.5	000.2 000	16% 0004C	000.5
76	2 - 20 5 -	Le 800	ORE	000.0	001.2 001	the war a	000,5
77	3 - 00 5 -		ARE	00010	00046 000	NE CONSC	00005
79	3 - 20 4 -	0 030	000	ana r	00510 000	ted DOSec	000.0
80	3 - 05 5 -	i e seg	MCC	00044	001=5 000	32200 23	2,100
81	3 - 35 3 -		000	00017	001*9 001	3,200 2,1	004.5
82	3 - 05 5 -	C.S OSL	350	003	000 6,000	3.100 L.S	2,200
83	3 - 15 5 -	San Olda	350	800	100 6,300	5,200 2,1	2,200
84	3 - 15 4 -	r.s =	300	1,000	000 \$ 000	5,200 1,1	-
85	3 = 35.6	120 2.1	350	1,000	000 6,000	2,000 1,1	2,800
86	3 - 10 5	s.s para	300	1,000	008.3 001	3,000 3,1	2,200
87	3 00 5	(.s 04 -	300	1,000	000 6,000	3,200 2,1	-
2 2 1	7 - 00 5 -	L.S OF	350	1,000	100 5,600	3,000 1.	2,000
do	7 - 10 4 - 1	.s .s.		1,000	- 6,000	Q.500	- 00
09	5 - 20 5 - 1	·	300.	1,000	- 6,100	5,000	2,000
90	5 - 40 7 - 1		-	600	500 6,000	4,500 14	2,200
91	2 - 45 6 - 1	200 2.1	350	1,100	200 6,000	6.400 1.1	-

period, and that more was necessary in the second. Then too, though the furnace crew was a picked one, the men were not familiar with the Hoesch routine, and required a little time to become habituated. In the main, however, the general description just given, faithfully portrays the course of each of the twenty-six Hoesch heats that immediately followed this first one. Throughout the series I regularly took at suitable times, slag and metal tests, which were carefully analyzed. To render possible an accurate comparison with the straight basic process, I give, in Table I. full details of the heats of this Hoesch series. This table, summarized in form correspond ing to that used above for the Dortmund data, is as follows;-

Total time 243 hrs.34' Heats made 27 Furnaces used 1 25' x 11' Hearth area 40 tons Rated furnace capacity 879.3 tons-79.00% Mixer Iron used 218.4 Ħ Steel Scrap 19.62 11.7 Ħ 1.05 •33 Ferro-Manganese Ferro-Silicon Ħ 3.6 1113.0 Ħ 100.00 Total Metallic Charge Ħ Ingots 1094.0 98.3 40.5 Yield, percent, Ingots per heat tons Ingots per f'ce per 24hr.107.9 Ingots per sq.ft. bathsurface per 24 hrs. •393 " The non-metallic charge was;-Total lbs.per ton gross tons. ingots. Magnetite & Scale, primary. 155.0 317.3 79.6 38.9 Magnetite, Secondary, 21.2 Hematite, 34.1 16.7 Manganese ore, 188.3 Lime, primary, 92.0 73.8 secondarv 151.0

Slag produced was;-Tons per ton Total of ingots. gross tons. 173.0 .158 Primary. .103 Secondary. 16 minutes. Average time of primary heat 3hrs. 58 11 11 26 secondary Ħ Ħ 42 Ħ Ħ Ħ total Average of the analyses. Ρ. s. Mn. Si. C. 1.47 .060 4.25 .20 Mixer Iron, typical, 1.00 2.34 .239 .054 tr. Primary Metad. tr. .041 .030 . 88 .08 .55 Steel, typical, SiO2 Fe P205 MnO CaO 41.45 19.24 5.27 17.00 Primary Slag 6.08 49.90 12.35 Secondary " 7.99

It will be seen that the first six heats of the series, No's. 64-69 inclusive, were distinctly slower than the majority of the remainder, and it is only fair to assume that the relative slowness is due in large measure ure to lack of familiarity, on our part, with the routine of the process. In view of this, I have considered it advisable to eliminate these figures from the calculation of the average time of heat, and to base the production rate of the process on the average of the last twenty-one heats. The time of the first period is reckoned from the beginning of charging to tapping of primary metal. The time of the second period is from tapping of primary to tapping of finished steel. The returning of primary metal to the furnace, which in the first heat occupied 17 minutes, was subsequently managed in 7 - & minutes. This operation must be cautiously performed, as the metal is very fluid, and with the slightest splash, corruscates in a most spectacular way. This would be expected from a relatively hot high carbon metal, practically free from Silicon. It will be found that the Primary slags as calculated from the charge, are lower in silica than the actual average analysis. This is chiefly accounted for by the fact that certain amounts of siliceous Mixer slag not infrequently entered the furnace with th e iron.

Following the Hoesch series, seven heats were made according to the original Bertrand-Thiel process, using the same furnace for a secondary hearth, and a similar one situated next to it, for a primary hearth. The bottom of the Hoesch furnace being by this time lowered a lmost to it's former level, largely due to the charging of the Ore directly upon it, as above indicated, I was able in the Bertrand-Thiel series to use a somewhat heavier charge without altering the area of the bath-surface.

The main features, proportions of charge, yield etc.of the Bertrand-Thiel heats were in all respects identical with those already recorded for the Hoesch heats. Of the former, therefore, only a short account will be given.

Time of Wt. of Ingots.	•
Heat No. Secondary Heat. 1bs.	
93 4 hrs 55 <sup>1</sup> 102,700	
94 5 ° 05 ° 105,500	
<b>95</b> 5 <b>*</b> 30 <b>*</b> 103,400	
96 5 <sup>*</sup> 25 <sup>*</sup> 115,900	
97 6 1 15' 108,600	
98 6 10 99,300	
<b>99</b> 5 <b>00</b> 117,300	
Average time, 5" 29"	

336 tons. Ingots produced Average weight per heat 48 Av, analysis of primary metal, C 2.10 P .200 S .055 slags. SiO2 Fe P205 CaO 42.02 18.05 19.44 4.44 Primary Secondary 12.32 8.40 48.32 7.88 Typical steel C.54 P.020 S.035 Mn.80

The total time of the run ,allowing interval for bottom repairs, was forty hours twenty minutes; that is, production was at the rate of 8.331 tons per hour, or 199.944 tons in 24 hours for two furnaces, or .364 tons per square foot of bath surface per 24 hours. This is slightly better than the regular Open Hearth rate, but inferior to that of the Hoesch heats in the same furnace. There was noticeable, even in this short trial, a very distinct tendency to building up on the part of the primary furnace hearth, just as was observed at Dortmund.

I observed the following characteristics in these heats;-

1. The secondary period being the longer, as already observed for the Hoesch heats in this furnace, the primary metal. of the Bertrand-Thiel was ready for transfer at least two hours before the secondary hearth was prepared to receive it. The primary hearth therefore was to all intents and purposes idle for a great part of the time. The primary metal, for the same reason, was rather lower in carbon and phosphorus than in the Hoesch process.

2. The scrap, ore and lime charge of the secondary heat was pre-heated to some extent before the primary metal was poured upon it. Reaction, therefore began more promptly than in the Hoesch secondary. This, as will be observed, had it's effect on the time of the secondary heat which, with a 45-ton bath was only three minutes longer than the Hoesch 40 ton secondary. Taking everything into consideration, there seemed no prospect of further advantage along these lines, and I decided to revert to the Hoesch process in the same furnace as before, in order to determine what advantage, if any, would be gained by using heavier charges. With this in view I made a further series of twenty, 50-ton Hoesch heats. The charges were in the same proportion as the first series. The yields were of the same order. Primary metal also, and the slags, were the same as before, although I was unable in this case, unfortunately, to obtain analyses of more than a few of the very complete series of metal and slag samples that I took.

The results, as to time and tonnage of the 50-ton Hoesch run, here follow;-

	TIME	
	First Second	
Heat	Period. Period. Total.	Ingots.
No.	hrs.min.hrs.min.hrs.min.	lbs.
100	4 - 20 7 - 10 11 - 30	122.000
101	3 - 007 - 40 10 - 40	120,400
102	3 - 007 - 0510 - 05	107.900
103	4 - 356 - 5511 - 30	109.100
104	6 - 20 6 - 30 12 - 50	115.500
105	3 - 25 6 - 40 10 - 05	115.800
106	3 - 108 - 0511 - 15	127.900
107	3 - 406 - 3010 - 10	115.300
108	2 - 406 - 359 - 15	120.400
109	4 - 006 - 3010 - 30	114,900
11ó	3 - 256 - 5510 - 20	118,700
111	4 - 156 - 0510 - 20	118,400
112	4 - 307 - 55 - 12 - 25	120,400
113	4 - 35 8 - 15 12 - 50	120,000

	First Second	
Heat	Period. Period. Total.	Ingots
No.	hrs.min.hrs.min.hrs.min.	lbs.
114	2 - 45 5 - 30 8 - 15	117,600
115	<b>3</b> - 55 6 - 20 10 - 15	112,700
116	3 - 357 - 25 11 - 00	114,200
117	<b>3</b> - 50 <b>7 - 0</b> 5 10 - 55	118,000
118	<b>3 -</b> 25 <b>6 - 3</b> 5 <b>10 -</b> 00	120,000
119	3 - 40 7 - 35 11 - 15	120,400
Ave rage	3 - 48 6 - 58 10 - 46	
<b>-</b>	· · ·	alid a l

Ingets produced Average weight per heat 1048.9 tons. 52.4 "

The total time of the run,allowing interval for bottom making,was 221 hours 45 minutes; that is, production was at 24 the rate of 4.73 tons per hour, or 113.52 tons per hours; or .413 tons per square foot of bath surface in twentyfour hours.

We are now in a position to discuss the points of advantage claimed for the interrupted processes by their inventors. As an aid to the consideration of these claims, I tabulate relevant deductions from the data adduced in the

foregoing.	Straight Open Hearth.	Bertrand Thiel.	Hoesch. 40-ton.	Hoesch. 50-ton.	
Bath area, sq.ft. Fices employed Avige heat, tons.	275 1 50	275 2 48	275 1 40,5	275 1 52.4	
heat, Primary Secondary Total 1	- 5 .2 hrs10'5 (2	hrs 29! "29! hearths)	3 hrs 16' 3 5 # 26' 6 8 # 42'10	hrs 481 " 581 " 461	
Tons per f'ce per 24 hours. Tons per sq.ft.	96.10	99.97	107.86	113.52	
of bath in 24 hr Metallic charg Mixer Iron Crop ends Ferro-Manganese Ferro-Silicon a	s350 69.12% 29.49 1.39) d lib.)	.364	•393 79.00% 19.62 1.38	.413	

Non-metallic chg.per ton ing	Straight O.H. ots.	Bertrand Thiel.	Hoes 40-t	ion.	Hoesch 50-ton.
Limestone, 1bs. Magnetite " Hematite " Total Fe in ores. "	639.0 112.0 197.0	Lime	<b>339.3</b> 396.9 43.4 249.7	<b>(±</b> 567	Limestone)
Yield of ingots per ton met, ch Merchantable sl per ton ingots. Typical phospho in steel.	g. 94.8% ag lbs. none rus .035050	О ,	98 <b>.3</b> % 354 .0200	5 940	

DISCUSSION OF THE CLAIMS. IN THE LIGHT OF THESE EXPERIMENTS.

1. Unmistakeably, in the case of a phosphoric iron, the use of an interrupted process renders possible, from the same furnace and like raw materials, a greater output than can be obtained by the Straight Open Hearth process. The explanation is to be found largely in two facts,-

(a) Much of the time of the straight Open Hearth heat is occupied in raising the lime charge from the bottom of the furnace. When the limestone charge amounts to 31000 lbs. as in the typical Straight heat given above, the time so occupied becomes seriously long. For reasons obvious to those skilled in the art, half the amount of stone can be raised in less than half the time required by the undivided whole. It may be remarked also that if lime be entirely substituted for this amount of stone, the delay is almost equally serious, because lime in bulk is harder to raise than limestone, for physical reasons, and because of the absence of the agitation that results, in the case of limestone, from the liberation of CO<sub>2</sub>. also, as will shortly be noted, in the absence of limestone, a heavier ore charge is necessary, which increases the bulk of material to be raised from the hearth, and , to a corresponding extent, makes for delay.

(b). In the straight process, the entire volume of slag must be made sufficiently basic to dephosphorize to the extent desired in the finished steel, and to ensure proper tapping conditions. In the interrupted process the primary slag need not be nearly so basic, and the secondary slag also, containing less silica and phosphoric acid, gives a low phosphorus steel, free from wildness, even when somewhat less basic than a similarly good slag in the straight basic process. From this it follows that the tetal lime required by the interrupted process is less than for the straight basic process under the same conditions.

Of the two interrupted processes, it has been seen that the Bertrand-Thiel has an advantage over the Hoesch, in that the second instalment of lime and ore is preheat ed befere the metal from the primary hearth is charged up on it. This advantage, however would appear to be more than offset by the fact that the Bertrand-Thiel requires two furnaces, and that in it the primary hearth is idle for well nigh half of **be**'s time. Also , the primary hearth becomes built up with lime accretions. These objections te the process were realized by the Hoesch officials, and led to their development of the Hoesch modification. The investigation above described, shows that their action was

well advised.

It is interesting to compare the rate of production attained in the Sydney experiments, with that given in the foregoing for the Bertrand-Thiel and Hoesch processes, respectively, at Dortmund.

				Gross tons per
Bertrand-Thi	el.Dortmund	.17t.f	urnace	.446
Heesch,	1	30t.	11	.438
Hoesch,	Sydney,	50t.	11	.413

Herein lies one great difference between possibly a majority of, at least, the older Continental works, and North American works. The Continental furnace is smaller, and even where mechanical charging machines are used, more of the lime and ore are shovelled into the furnace by hand. From the point of view of speed, hand shovelling, within certain limits, is better. A certain amount of the lime and ore can be placed on the hearth-bottom without causing delay by the time necessary to raise them, and for rapid decarbonization, the ore must come from the bottom .

Dephosphorization, however, or rather, fixing of the phosphoric acid, takes place at the slag-line. Under favourable conditions dephosphorization occurs with extreme rapidity during the earlier stages of the heat, while the bath is still relatively cool. If , during these earlier stages, the lime and ore that are necessary for oxidizing and fixing the phosphorus are still buried in a heap on the hearth bottom, the phosphorus is little affected. If, on the other hand, an adequate supply of both is available

at the slag-line, the phosphorus may be rapidly and permanently removed. If it be attempted to supply the lime and ore to the slag in quantity, by means of the machine, the slag is at first chilled, and reaction delayed; when the chilling is finally overcome, the reaction proceeds with undue violence. It follows that, ideally, except for sufficient bottom charging to form an innitial slag covering for the bath, the lime and ore for dephosphorization should be shovelled.

It should be mentioned that the chilling just referred to is to a very large extent obviated in the Talbot process, where the amount of heat stored in the bath is very great.

It is safe to assume that at Dortmund, in the Hoesch heats, though, as a matter of fact a mechanical charger is there employed, there was a greater amount of shovelling than at Sydney. This, probably, would be sufficient to account for the slightly greater production rate of the Dortmund Hoesch as against the Sydney Hoesch.

The Sydney Bertrand-Thiel production rate was found as above shown to be lower than that for the Sydney Hoesch.

We find the reverse to be true at Dortmund, and without doubt the explanation is this; - the 17-ton furnaces at Dortmund are hand-charged. The lime and one would therefore be shovelled as required. Hand-charging a 17-ton furnace is a severe task enough, and no one who has attempted to shovel iron one into a 50-ton furnace at full heat, to

say nothing of distributing it across the bath surface, will be inclined to maintain that it is practicable to acquire the increased production rate in a large furnace by hand-shovelling; although it must be admitted that there is a midway course which we, on this side of the Atlantic, are sometimes prone to overlook. It may be here stated that there is great need, in Open Hearth practice, of a charging machine which shall be capable of feeding to any desired portion of the bath surface, small amounts or ore and lime as required.

2. The attainment of higher yield of ingots per ton of metallic charge, in so far as it is a legitimate claim to make, appears to be justified. It is doubtful, however, whether or not it is fair to consider yield as an intrinsic function of any process. Open Hearth steel-making consists in to a large extent eliminating from pig-iron, constituents other than iron, the elimination being accomplished in every case by a combination of oxidation and dilution. If the Open Hearth charge consist entirely of pigiron, the oxidation is accomplished by means of additions of iron oxide, the reduced iron of the oxide, in so far as it is in excess of the amount constitutionally required by the slag, entering the bath as a diluent.

If the charge be part pig and part steel scrap, not only does the latter act as a diluent, but it is oxidized during melting down, to an extent depending upon whether the scrap is light or heavy, upon the sharpness of the

furnace, etc., and the oxide so formed, at the expense of the original metallic charge, acts upon the iron as an eliminant.

If the pig-iron be charged cold, it's constituents also will undergo oxidation during melting. Molten iron, is charged as a rule, only after the slag-forming ingredients, scrap, etc., have been thoroughly preheated in the hearth, so that it is in this case very soon protected from the direct action of the furnace atmosphere.

Lime is, of course, non-oxidizing, but limestone liberates CO<sub>2</sub> which is distinctly oxidizing. For this reason, as is well known in the art, when limestone is used, much less ore is needed for a given charge, than when lime is employed.

Now, of all the eliminants enumerated, viz;-Ore, Scrap, flame and furnace gases, and limestone, the only one that adds to the bath, is Ore. The others, by their action, directly diminish the weight of the metallic charge. It is obvious, therefore, other things being equal, that when we speak of a process as giving a high yield, we simply mean that it employs relatively little, or no scrap, and that we the oxidation is accomplished wholly, or nearly so, by iron ore. Yields, be it **in**derstood, are calculated on the basis of metallic charge only, and quite ignore the iron ore.

Once iron, is any form whatsoever, has found it's way into the steel furnace, there are only four directions open to it. (a) It may appear as good product. (b) It may be

held, either chemically or mechanically in the slag. (c). It may, due to violent reaction, careless handling, overfilling, or other cause, drip from furnace, runner, ladle or moulds; or it may solidify prematurely as part of the ladle skull. In either of these cases it may, or may not, be recoverable as pit-scrap. (d). It may disappear with the out-going gases as fume. Most of these several possible sources of loss, given equal care in handling, partake of the nature of fixtures for any one set of conditions. In the straight basic process, when all the limestone and and ore are charged at once, there is apt to be, when the ore is rising, a violent reaction, causing foaming over of slag with more or less of metal. This tendency to foam is much less marked in the Hoesch heats, but is offset in the latter, by the extra ladle-skull, and by the danger of loss incidental to the transfer of the primary metal.

In view of these considerations, it is not surprising that the interrupted processes have been found in this investigation to give, as their inventors claim for them, a higher yield than the straight basic process. That there is no material difference between the iron econcmy of the interrupted process and that of the straight process appears from the balance sheet shown on p.33-a.

From another point of view, to say that a certain Open Hearth process is characterized by high yield, is almost tantamount to describing it as inelastic; for although the Open Hearth process, in so far as it employs iron ore, may well be considered a true direct process

#### 33 - a.

IRON BALANCE SHEET - TYPICAL STRAIGHT BASIC HEAT.

IRON IN CHARGE.

80,000 34,300 1,600 331,450 5,500 9,700 Total	lbs. n n n	Mixer Metal Crop Ends Ferro-Man. Limestone Magnetite Hematite	@	93.00% 98.00 12.00 .73 57.49 49.51	_	1bs. Fe. 74,772.0 33,614.0 192.0 229.6 3,162.0 4,802.5 116,772.1	

#### IRON RECOVERY.

110,300.0 lbs.	Ingots @	98.50%	108,645.5 -	93.05%
Shot in slag	Siag	5.00 2.00	1,391.9 -	2.53
Pit-Scrap Skulls,loss,etc. Total	by differ	rence	2,980.9 - 116,772.1 -1	2.54

IRON BALANCE SHEET - 40 TON HOESCH CAMPAIGN.

IRON IN CHARGE.

			•	tons Fe.
879.3	tons	Mixer Metal	@ 93.00%	817.75
218.4	Ħ	Crop Ends	98.00	214.03
193.9	11	Magnetite	57.49	111.47
21.2	#	Hematite	49.51	10.50
1617	Ħ	Mn. Ore	1.13	.19
165.8	Ħ	Lime	1,12	1.85
11.7	11	Ferro-Man.	12.00	1.41
3.6	Ħ	Ferro-Sil.	50.00	1.80
Total			 e	1159.00

#### IRON RECOVERY.

1094.0 tons Ingots	<b>@ 98.</b> 50	1077.59 -	93.00%
173.0 " Slag	5.27	9.12)	2.94
112.5 " "	9.48	10.67)	
Shot in total slag Pit-Scrap	5.00	14.28 21.88	1.89
Skulls, loss, etc. by	difference,	25.46	2.17
Total		1159.00	100.00

for the production of steel from ore ,it is, nevertheless, frequently desirable, commercially, to be in a position to vary the charges of ore or scrap, limestone or lime, abselutely at will. In any steel-works a certain amount of scrap is produced, and unless it can be promptly and economically disposed of by remelting, there is rapid accumulation and corresponding financial loss in the shape of interest on investment. Any process, therefore, which limits or stipulates the percentage of scrap to be charged, in other words, which is not, in this respect, wholly elastic, can not be used to the exclusion of all other process-For this reason the Hoesch process would probably es. never entirely crowd out the straight basic process from any works. Along the same line of argument it is also to be noted that the Hoesch process proper, makes no direct provision for the remelting of cold pig-iron, some quantity of which is usually made during the week-end, and that the fullest realization of the advantages of the process, postulates a plentiful supply of molten metal.

3. We find that the lime consumption is lower, and the ore consumption higher in the Hoesch process than in the straight basic process. The ore, however is probably no higher, and probably is slightly lower than it would have been in the latter, had less scrap been charged, and had lime been substituted for limestone. The interrupted process, however, stipulates lime, instead of the cheaper limestone, and in this way, as well as by specifying a

relatively low scrap charge, makes the higher ore consumption a necessity. These circumstances must not be lost sight of in computing the relative cost of an interrupted process.

4. We find that there is produced by the interrupted the processes, a phosphatic slag of high solubility and in every way suitable for a fertilizer. Owing to the necessity for a high lime content in the entire body of straight basic slag, as already explained, the phosphoric acid content is in that case too low. Also, it is necessary, in "cutting up" the lime in the straight process, to use fluor spar as a flux, and for reasons not distinctly understood, though well recognized, the presence of fluor spar throws the phosphoric acid into the insoluble condition, making it unsuitable for use as a fertilizer. No spar was used in the Hoesch heats.

5. Since metal and slag, at the end of an Open Hearth heat may be regarded as a system in equilibrium, it follows that, ceteris paribus, lower phosphorus in the slag connotes lower phosphorus in the metal. The bulk of the phosphorus being removed in the primary slag of the Hoesch process, and the second slag being correspondingly low in phosphorus, we should expect the finished Hoesch steel to be lower in phosphorus than straight Open Hearth steel from the same raw materials, and with a similarly basic slag. The present investigation showed that the expectation is fulfilled in fact, the tendency of the Hoesch heats being distinctly towards lower phosphorus.

Adverse critics of the Hoesch process have observed that the slag change necessary to a low phosphorus product, can be effected by skimming, and without removal of the metal from the furnace. This course is followed, for instance, in electric furnace practice. It may safely be stated, however, that while, with care and time, slag can, by skimming, be fairly completely removed from a small stationary furnace, and from a somewhat larger tilting furnace, possibly up to 15 or even 20 tons capacity, with larger sizes than this no complete removal of slag can be accomplished without undue metal loss, the difficulty increasing with the bath area. Moreover, even with the small furnace, one must depend, in one's absence, entirely upon th e fidelity of the workmen. Upon the whole, it seems justifiable to consider that only some such complete and positive removal of slag as is involved by the metal transfer.can be relied upon in general, large-scale practice.

6. Under the conditions obtaining when the Bertrand-Thiel process was introduced, it is probable that this precess did much in the way of achieving a uniform product from variable raw materials, since all Silicon - the most troublesome of variables - and the greater part of the phosphorus are removed with the primary slag, and any such trifling irregularity as a tenth of one per cent or so of

carbon or phosphorus can be corrected with a little additional lime or ore, if necessary. At the present day, however, nearly every steel plant using hot metal, draws it from a pig-iron mixer, which blends and equalizes the blast furnace iron, and may even materially desiliconize and desulphurize it. In view of this fact, therefore, this last claim loses much of it's importance as an argument in favour of the interrupted process.

#### TEMPERATURES.

In the foregoing account of my investigation I have made no mention of bath temperatures. My failure to do so has been intentional, because no thomoughly satisfactory method for regularly determining such temperatures has yet been worked out. Measurements of the temperatures of molten iron and steel have been made with the optical pyrometer, e.g. leChatelier & Boudouard, "Measurement of High Temperatures" p.306. quote;-

Tapping	the pig-iron, beginning	1400	deg.C
- W -	" " ond.	1500	H -
Flow of	steel into ladle, beginning,	1580	11
11	" " end.	1420	11

An optical pyrometer was not available for this investigation, and in any case, the metal as it runs from the fuznace is always envelopped in a mantle of burning gas, and clouded by fumes - more especially was this the case with the primary metal - so that pyrometer readings under the circumstances, may or may not represent temperatures. It was attempted to obtain readings with a Brown radiation

instrument, but the flame and fume referred to, quite precluded the possibility of consistent **se**sults. Obviously, a reading obtained by sighting the pyrometer upon the interior of the furnace , may represent the temperature of the back-wall, of the flame, or of the slag, and to offer such reading as the temperature of the metal underlying the slag, is most apt to be grossly misleading.

By sighting into a blind tube, immersed in a steel bath, if a tube could be obtained large enough and strong enough for the purpose, and sufficiently resistive to withstand the extreme temperature of the bath, and the corrosive action of the slag, until it's interior remained constant at the temperature of the bath surrounding it, good indications might be had by means of either the optical, or the radiation pyrometer, or even by the platinum-rhodium thermocouple. Such tubes, so far as I am aware, are not available.

I had hoped, in connection with this investigation, to make a systematic record of bath temperatures, and to this end, I made extended preliminary experiments along two lines, which I shall briefly indicate.

1. I attempted to use a pyrometer of the Siemens calerimeter type, made especially large for this purpose, substituting for the Nickel ball of the Siemens instrument, a quantity of about 500 g. of moltem metal taken from the bath (by means of a test spoon carefully pre-heated and slagged so as to be as nearly as possible at the temperature of the bath) and quickly poured through a small

aperture in an asbestos and felt cover, into the calorimeter water. The thermometers used were graduated in tenths of one degree. After the final thermometer reading, the chilled metal was lifted out in a little copper basin of known weight and that had been placed at the bottom of the calorimeter to receive it, and basin and metal were dried and weighed together. With molten pigiron dipped from the Mixer, several remarkably concordant observations were made in this manner, though the indications were that published data on the specific heat of iron did not fit the case very closely. With metal from the Open Hearth furnace, however, I found that if the test were poured from the spoon fast enough to avoid serious loss of heat in transit, there was violent surface boiling and ejectment of water from the Calorimeter, and endeavours to remedy this defect, clearly indicated that a body of water sufficiently large to absorb the totality of the heat of the steel, would involve the use of excessively unwieldy apparatus.

2. Lacking the blind refractory tube above referred to as the desideratum, I endeavoured to utilize a four inch steel pipe, 61 inches long, open at both ends, but fitted at one end with a sheet-iron cap. The draw-tube of the Brown pyrometer measured 21 inches, extended, and to this length, the draw-tube was inserted in the uncapped end of the pipe, and centred in it by means of distance pieces. In this way, the end of the draw-tube farthest from the eye-

piece was exactly forty inches from the capped end of the pipe, that is, it was at a distance of ten times the internal diameter of the pipe, from the capped end. Before setw ting up in this manner, the pipe and cap had been thoroughly heated to burn from them any oil or carbonaceous manter, and then allowed to cool. After setting up, the pyrometer connections were made, the pipe was grasped in suitable grips, the Open Hearth furnace door was raised, and the capped end of the pipe was plunged through the slag and into the metal of the bath. As was intended, the sheet iron cap withstood the passage through the slag, but burned through when the steel was reached, exposing, for observation, the metal surface, free from slag.

Unfortunately the pipe promptly became filled with dense brown fumes, probably due to the oxidation of the sheet-iron, and the galvanometer needle moved only feebly.

Also, the pyrometer mirror was damaged by flying metal shot, and it was considered inexpedient to continue experimenting with methods which, theoretically attractive, were evidently unsuited to the conditions with which they had to cope. As to what the temperatures were at the various stages of the different processes investigated as above described, I do not feel justified in saying more than this, - that if the temperature of the Mixer metal charged was 1400 deg.C. and that of the finished steel at tapping was 1580 deg.C., then, the temperature of the primary metal as tapped would be about 1490 deg.C., since, as far as

might be judged by the eye, it's temperature was about midway between those of the mixer-metal and of the finished steel, respectively.

#### GENERAL CONSIDERATIONS.

So far,I have confined the discussion of the interrupted processes, to their effect upon the output of one furnace, and so far the findings, with the one exception of that regarding elasticity, have been distinctly in favour of the Hoesch process, which we have seen to be the more efficient of the two interrupted processes described. Let us consider now a shop of ten 50-ten Open Hearth furnaces operating by the Hoesch process. Will such a shop multiply by ten, the advantage so far proven, for the Hoesch over the Regular process in the case of a single furnace?

1. Consider the charging side of the furnace, assuming two charging machines for a row of ten furnaces.

(a) In the straight process, when a furnace is waiting for a charge, there is merely the case of lost time, which is serious enough, of course, but no material is spoiling meanwhile.

(b) In the Hoesch process, while the furnace is waiting for the secondary charge, the ladle full of primary metal is hanging on the crane on the casting side, and cooling, all the while. Any serious charging machine delay therefore means heavy loss through skulling, and possibly the loss of the whole primary heat. It would therefore appear that for Hoesch equipment, at least 50% more charging capacity is desirable.

2. On the casting side of the furnaces, assume three overhead cranes, each of 75 tons capacity.

(a) By the straight process, ten furnaces would give each day of 240 furnace hours, about nineteen heats of 12 hours 10 minutes each. The tapping and teeming of these nineteen heats, along with slag removal, ladle shifting and miscellaneous work, will keep the three cranes fairly well occupied, bearing in mind that crane capacity must be provided not merely to do a fixed amount of work each day, but such that, without letting slip any part of the day's work, a crane will be available for any purpose at any moment.

(b) By the Hoesch process, the ten furnaces would give us nearly twenty-two heats in the 240 furnace hours per day, each heat having to be tapped and poured twice, making the equivalent of fourty-four heats daily, to be handled by what we have with reasonable accuracy assumed to be crane capacity for nineteen heats. Slag handling would also be doubled, since the primary slag, which is valuable, must be kept separate from the secondary slag which is worthless. Crane equipment must therefore be substantially added to, and the crane runway and distance between furnaces, and consequently the total length of the building must be increased, if one Hoesch furnace is to be prevented from interfering with another, and thus neutraliz-

ing the advantage accruing from the process per se.

Obviously, from this point of view, the question of continuous versus interrupted processes becomes one which cannot be answered by a metallurgical investigation, but which must be decided for each shop individually, after a careful study of all the conditions surrounding the case.

allen Pulnary Scott.

april 8th. 1914.