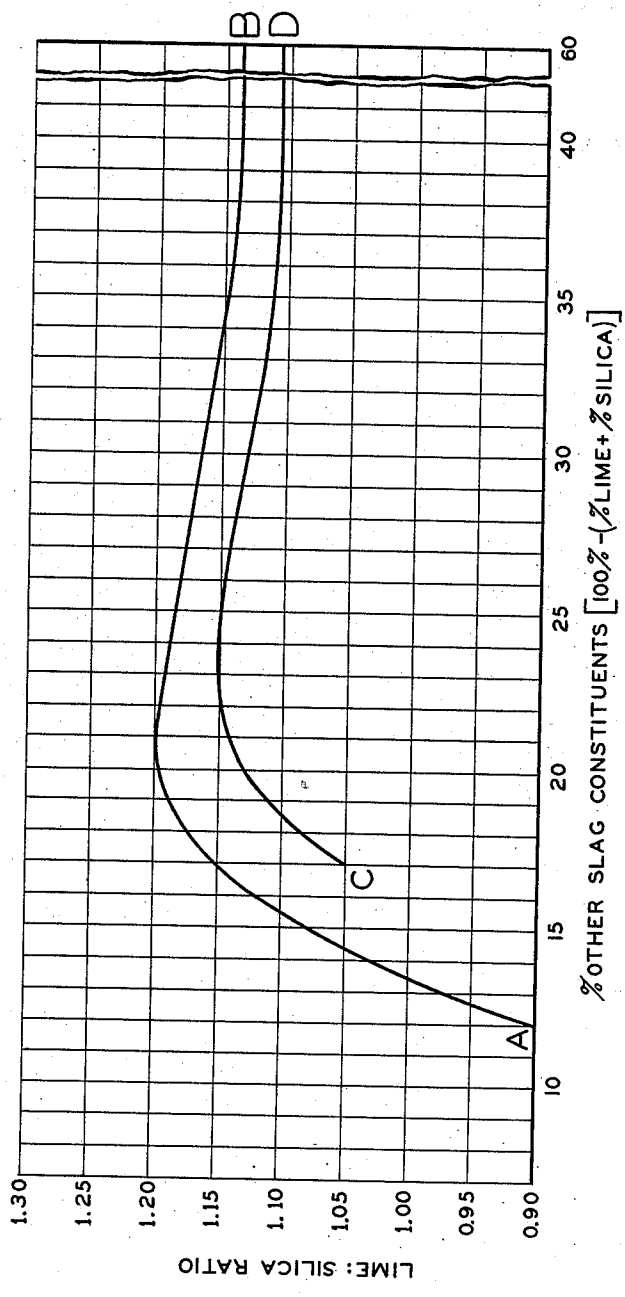
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ZINC SMELTING

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FIG. 1



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ZINC SMELTING

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This invention relates to the smelting of oxidic zinciferous material and, more particularly, to the electric arc furnace smelting of oxidic zinciferous ore.

Because of its inherent simplicity and the absence of such requirements as special charge preparation, the electric arc furnace smelting of zinc has attracted much thought and speculation. Numerous proposals have been advanced heretofore for the electric furnace smelting of zinc, but to the best of our knowledge those proposals which have been reduced to practice have not been successful in producing massive zinc metal. These consistently discouraging results over a period of decades have not been caused by the difficulty of smelting the zinc ore because such an ore can be smelted with facility at the temperatures which are readily obtained in an electric furnace. The difficulty encountered heretofore has resided in the condensation of the zinc vapor produced by electric furnace smelting. In spite of more optimistic predicitions, physical embodiments of prior art proposals have resulted in the production of vast quantities of blue powder to the substantial exclusion of massive metallic zinc.

In a general sense, the smelting method of our invention, applied to the smelting of oxidic zinciferous ore, resembles those of the prior art in that it produces three products—zinc vapor, a molten slag, and a metallic iron product resulting from reduction of the iron oxide which invariably accompanies the zinc in its ores. As pointed out hereinafter, our method is also applicable to the smelting of substantially iron-free oxidic zinciferous materials and in such case the products of the smelting operation do not include metallic iron. We have found, however, that when the smelting of oxidic zinciferous material is carried out at a temperature within the range of 1250° to 1450° C. at the interface between a molten slag bath and a floating layer of the zinciferous charge, the zinc vapor produced by such smelting is substantially free from the dust-forming impurities which appear to have been largely responsible for the improper condensation of zinc vapor in the practice of prior art proposals. We have discovered that by maintaining a slag fluidity such as to insure adequate dissemination of the smelting heat throughout the slag body, we can successfully smelt zinciferous material in an electric arc furnace while substantially preventing the development of a temperature in excess of 1450° C. in any portion of the slag exposed to the furnace atmosphere, this temperature being measured as the temperature of the slag being

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tapped from the furnace. The necessary slag fluidity can be insured by the maintenance of the slag composition within certain well-defined limits in accordance with our invention.

Oxidic zinciferous ores generally comprise zinc, cadmium, lead, copper, silver and iron, essentially in the form of oxides, each of which is readily reducible by carbonaceous material at temperatures within the range of about 1250° C. to 1450° C., as well as oxides of calcium, magnesium and silicon which are not readily reducible under these conditions. In heating the entire mass of a smelting charge to a temperature within such a range in an electric furnace, it is a normal characteristic of such an operation that a substantial portion of the charge is heated to an appreciably higher temperature. When a portion of a charge derived from the reduction of oxidic zinciferous ore is heated to a temperature substantially above 1450° C., there is a pronounced tendency for one or more of the gangue constituents—lime, magnesia and silica—as well as manganese oxide, if present, to be volatilized either directly or indirectly, or both. These constituents may be volatilized directly in the form of the oxides per se, or they may be volatilized indirectly first by reduction of the oxides to the metallic form, followed by volatilization of the metals which are then reoxidized by carbon monoxide and carbon dioxide in the furnace atmosphere. Volatilization of these charge components in a relatively hot portion of the charge is followed by their solidification in a cooler portion of the chamber, and the solidified materials thereupon appear in the furnace atmosphere in the form of dust-like particles. These particles comprise the aforementioned dust-forming impurities which contribute to the formation of blue powder and which indicate the existence of furnace conditions which lead to the production of large amounts of blue powder instead of massive metallic zinc. By maintenance of a molten slag temperature within the range of 1250° to 1450° C., which is made possible by control of the slag fluidity in accordance with our invention, local overheating of the slag or charge to any temperature substantially in excess of 1450° C. is avoided and the production of dust-forming impurities in the zinc vapor-bearing smelting gases is inhibited.

Accordingly, it will be observed that we have developed a method of smelting an oxidic zinciferous material in the presence of carbonaceous reducing material in an electric arc furnace with the resulting production of a molten slag and

smelting gases bearing metallic zinc vapor substantially free from dust-forming impurities. In the smelting of oxidic zinciferous ore, a molten iron product will also be obtained. The method of our invention comprises charging the zinciferous material and reducing material into the furnace in a loose and dry condition, establishing in the charge composition such relative amounts of the zinciferous and reducing materials as to effect reduction of at least a major portion of the zinc component of the charge and such reduction of any iron present in the zinciferous material (as in the case of a zinc ore) as to preclude the presence in the molten slag of more than 6% by weight of iron oxide (calculated as Fe), further establishing in the charge composition such relative proportions of calcareous and siliceous material, with respect to the other slag-forming constituents, that upon smelting of the zinciferous material the resulting molten slag will contain not more than 85% by weight of lime (CaO) and silica (SiO_2) in a ratio between 0.9:1 and 1.2:1 and not exceeding the ratio, with respect to the total amount of the other constituents of the slag, represented by the line AB in Fig. 1 of the accompanying drawing, maintaining the slag in the molten condition at a temperature of at least 1250° C. by electric arc heating, and smelting the dry charge on the surface of the molten slag at a temperature not in excess of 1450° C. The line AB in Fig. 1 represents an experimentally determined critical relationship between the lime-silica ratio and the total amount of other constituents present in the slag. Adherence to this relationship in the manner recited assures the requisite fluidity of the slag for effective practice of our smelting method. However, optimum slag composition, corresponding to optimum slag fluidity, is obtained in accordance with our invention by so proportioning the aforementioned calcareous and siliceous material that the lime plus silica does not exceed 83% and the lime-silica ratio falls within the range of 1.05:1 and 1.15:1 and not exceeding, with respect to the total amount of other constituents of the slag, the ratio represented by the line CD in Fig. 1.

In the interest of a complete understanding of the invention, but not as any limitation thereof, it will be described herein particularly with respect to the smelting of an oxidic zinciferous ore.

In the course of our smelting operation, the zinc, cadmium, lead, copper and silver oxides present in the ore are readily reduced. Iron oxide in the ore is also largely reduced to metallic iron but it appears that some of the nascent iron tends to reduce the zinc oxide and thus become reoxidized to ferrous oxide. Although stable equilibrium conditions are not established in such a continuous smelting operation, it is nevertheless a fact that some metallic iron is formed simultaneously with the metallic zinc and that, depending largely upon the amount of reducing material present, some ferrous oxide remains unreduced in the slag. When the metallic iron is produced in the medium of a suitably fluid slag and in the presence of carbonaceous reducing material, globules of carburized molten iron form in the slag and ultimately coalesce and tend to liquate therefrom in a body below the slag. The resulting body of molten iron normally contains such an amount of dissolved carbon as to render it molten at temperatures as low as about 1150° to 1200° C. Inasmuch as the smelting heat is supplied to the upper portion of the charge in an electric arc furnace, the temperature prevailing in the lower portion of the furnace below the slag will generally be somewhat lower than that of the slag itself. In order to make possible continuous operation of the furnace, the metallic iron must be maintained in a tappable molten state while the smelting operation proceeds at a temperature within the range of 1250° to 1450° C. The iron will have a melting point below 1450° C. if it contains at least 1½ to 2% carbon and will remain molten at a temperature between about 1150° and 1200° C. if it contains about 4% carbon. If the supernatant slag is not unduly oxidic, the metallic iron product will remain carburized to the extent necessary to maintain it in the molten condition. Inasmuch as the presence of iron oxide in the slag imparts to the slag a certain oxidic character with respect to the carburized metallic iron product, we have found it to be necessary to limit the iron oxide content of the slag to a maximum of about 6% by weight (calculated as Fe, which corresponds to 7.7% FeO) in order to maintain the metallic iron product in a suitably tappable molten condition, whereby the iron product and the slag will be separably tappable, while maintaining thereabove a smelting operation within the temperature range of 1250° to 1450° C. The iron oxide content of the slag can be readily adjusted, as is well known in the art, by proper correlation of the amounts of ore and carbonaceous reducing material present in the furnace charge.

The smelting method of our invention is applicable to any oxidic zinciferous material, zinciferous ore or ore concentrate, whether naturally occurring in the oxidized state or obtained by roasting or the like. We have successfully smelted such representative zinciferous materials which varied from one extreme to the other in their zinc content. For example, such oxidic zinciferous materials as calcined Sterling Hill ore having a 20% zinc content, sintered Eagle ore concentrate containing about 55% zinc, sintered Waelz oxide containing about 70% zinc, and off-grade zinc oxide pigment containing about 80% zinc, have been smelted and metallic zinc vapor condensed therefrom with excellent condensing efficiencies. Inasmuch as our smelting method is applicable to smelting either the naturally occurring oxidic ore or roasted sulfide ore, or such ores which have been subjected to bulk concentration, it will be observed that the smelting procedure of our invention has an unlimited applicability as distinguished from the more limited versatility of other zinc smelting processes. Accordingly, any beneficiation to which the ore may be subjected prior to smelting by the method of our invention need be only for the purpose of removing the easily separated gangue material by a simple bulk concentration process, whether by flotation procedure or otherwise.

In smelting pursuant to our invention, the electric arc should be so controlled as to obtain a favorable temperature distribution from top to bottom of the furnace. The temperature at the top of the furnace is limited by the refractories used for the furnace structure, but as a guide it can be stated that furnace atmosphere temperatures of 1200°–1350° C. are satisfactory with temperatures of 1270°–1300° C. being presently preferred. The temperature adjacent the smelting zone at the interface between the fluid slag and floating zinciferous charge should not exceed about 1450° C. as pointed out hereinbefore and preferably ranges between 1350° and 1400° C.

The temperature prevailing through the slag body should be sufficient, however, to maintain both smelting conditions at its surface and molten iron-product conditions below the slag body, taking into account the chilling effect of the relatively cool charge delivered to the surface of the slag as well as the endothermic reaction characteristics of this charge. The position of the electric arc required to produce this result will depend upon the number of electrodes, furnace size, and other related variables. The electrodes should not be so deeply immersed as to provide simply slag-resistance heating for this type of heating has been found by us to be wholly incapable of counteracting the chilling (and slag freezing) effect of the floating charge. When the furnace heating is effected pursuant to the aforementioned specifications, zinc elimination from the charge, as evidenced by the zinc content of the slag, will be at least 98%.

When a zinciferous ore is smelted as described hereinbefore, the resulting slag consists of lime, silica and other slag components such as magnesia, manganese oxide, alumina and any unreduced iron oxide and zinc oxide. Of these numerous slag-forming constituents, originating both in the ore and in the ash of the carbonaceous reducing material, the lime and silica together usually comprise the major portion with the remainder being made up of the aforementioned other slag-forming constituents. In general, the lime and silica together comprise from about 40% to about 85%, and more commonly from about 60% to about 80%, of the slag. The other slag-forming constituents, including the maximum of 6% iron oxide (calculated as Fe) which may be permitted to remain in the slag as described hereinbefore, comprise the remaining 15 to 60%, and more commonly 20 to 40%, of the slag. We have found that the slag may be provided with the requisite fluidity for the practice of our smelting method if a certain definte relationship be maintained between the lime-silica ratio and the amount of said other slag-forming constituents. This relationship is represented graphically in Fig. 1 of the drawing.

As indicated in Fig. 1, we have found that the aforementioned critical relationship holds true for lime-silica ratios as low as 0.9:1 and as high as 1.2:1. The minimum lime-silica ratio of 0.9:1 represents the lowest ratio at which it is commercially feasible to recover reduced zinc and iron from the furnace charge. At lime-silica ratios lower than 0.9:1, it becomes so difficult to reduce the zinc and iron that suitable recoveries cannot be obtained at smelting temperatures ranging as high as 1450° C. The upper limit of 1.2:1 for the lime-silica ratio is dictated by slag viscosity; we have found that slags characterized by a lime-silica ratio in excess of 1.2:1 have such viscosity as to render them unsatisfactory for smelting operations pursuant to our invention. Within these limits, the aforementioned critical relationship between the lime-silica ratio and the amount of the other slag-forming constituents is represented by the curve AB, the lime-silica ratios on or below the line AB leading to the production of slags having suitable fluidity for practice of our smelting method.

The relationship represented by curve AB in Fig. 1 comprises the prescription of the maximum lime-silica ratio that can be used with amounts of the other constituents of the slag ranging upwardly from about 15% of the slag composition, the lime plus silica constituting the balance of the slag composition. Although oxidic zinc ores contain calcareous and siliceous materials in a wide range of proportions, we have observed that it is generally necessary to add lime or silica to the charge so as to obtain a lime-silica ratio in the slag, including the silica content of the coal ash, coming within the range of 0.9:1 to 1.2:1. In order to obtain such a lime-silica ratio, extraneous lime or silica may be added as required, or the requisite lime-silica ratio can be obtained by the conjoint use of two or more zinciferous ores of different calcareous and siliceous contents.

The production of a slag having the requisite fluidity for practice of our invention can be readily achieved by adjustment of the lime and silica contents of the slag pursuant to a maximum represented by the line AB in Fig. 1. In the case of a lime-base ore, in which the lime-silica ratio exceeds 1.2:1, the silica component of the slag must be increased so as to bring the lime-silica ratio down to the line AB. In the case of a silica-base ore, in which the lime-silica ratio is less than 0.9:1, the lime component of the slag must be increased to bring the lime-silica ratio in the slag composition up to at least 0.9:1 and not above the ratio represented by the line AB. The amount of silica or lime which must be added will, of course, depend upon the amount of said other slag constituents, as indicated in Fig. 1. However, as clearly shown by the line AB, the addition of lime or silica, as the case may require, must be made in such manner as to insure the presence in the resulting slag of at least 15% of other slag constituents. That is, in no event should the lime plus silica content of the slag exceed about 85% of the total slag composition. The presence of at least 15% "other" slag constituents can be attained by controlling the smelting conditions so as to leave more iron oxide in the slag, by adding extraneous slag-forming constituents such as alumina, magnesia, iron oxide, soda, or the like, or by a combination of such procedures. When using a lime-slag ratio within the limits prescribed for line AB, we have found that amounts of the other slag constituents less than about 15% by weight of the slag preclude the attainment of suitable slag fluidity. The upper limit of the amount of the "other" slag constituents is prescribed only by their naturally-occurring proportions in the ore.

Although the establishment of a slag composition characterized by a lime-silica ratio not in excess of that represented by the line AB in Fig. 1 will result in a slag fluidity sufficiently high to permit satisfactory smelting in accordance with our invention, we have found that a more narrowly circumscribed relationship between the lime, silica and other slag components leads to the attainment of slags of maximum fluidity and maximum utility. These slag compositions which are characterized by optimum smelting properties are defined by the line CD in Fig. 1. The line CD represents the maximum lime-silica ratio within the range of 1.05:1 to 1.15:1, with respect to the total of the other constituents of the slag, which is compatible with optimum zinc and iron recoveries. In obtaining optimum slag fluidity pursuant to the relationship represented by line CD, the amount of "other" slag constituents should total at least 17% of the slag composition.

Slag compositions coming within the prescription of line AB in Fig. 1, characterized by fluidity conducive to effective reduction of the zinc and

iron components of the ore pursuant to our invention, make possible the attainment of an efficiency of at least 85% in the condensation of the evolved zinc vapor as a result of more complete elimination from the vapor of the aforementioned dust-forming impurities. Slags having compositions outside of the prescription of line AB in Fig. 1, on the other hand, are characterized by such inadequate fluidity as to result in zinc vapor condensation efficiencies (i. e. the proportion of zinc vapor introduced into the condenser which is converted to molten metal) materially below 85%. This effect is readily appreciated in the following examples in which smelting conditions pursuant to our invention were substantially identical, the difference in each case being essentially a difference in slag composition which, in turn, represented a difference in slag fluidity and consequently in heat dissemination throughout the slag. A slag having a lime-silica ratio of 1.27:1, and in which the slag constituents other than lime and silica constituted 20% of the slag composition, resulted in a condenser efficiency of approximately 80%. By increasing the silica content of the slag to obtain a lime-silica ratio of 1.14:1, with a resulting lowering of the amount of other slag constituents to 17% of the slag composition, the condenser efficiency was somewhat better than 85%. A further lowering of the lime-silica ratio to 1.04:1 while maintaining the other slag constituents at 17% raised the condenser efficiency to about 90%. Based upon similar experimental data, we have ascertained that under smelting conditions pursuant to our invention, as previously set forth, slag compositions falling within the prescriptions of line AB in Fig. 1 lead to zinc vapor condensation efficiencies in excess of 85% whereas those compositions outside of the prescriptions of line AB result in condenser efficiencies that drop off rapidly to the level of 80% and below. On the other hand, slag compositions coming within the more circumscribed prescriptions of line CD in Fig. 1 make possible zinc vapor condensation efficiencies of at least 90%. To the best of our knowledge, the high condenser efficiencies characteristic of smelting operations carried out pursuant to our invention and featuring slag compositions within the limits discussed hereinbefore are obtained as the result of the exceptionally uniform temperature conditions which are established throughout such fluidly mobile slags.

The relatively uniform temperature prevailing throughout the fluid slag layer is taken advantage of, in accordance with our invention, as a means of imparting to the fresh charge the necessary smelting heat within the specified temperature range. To this end, we have found it advisable to deliver the charge to the furnace in such manner, advantageously through the furnace roof, as to provide in the vicinity of the electrodes a mass of the charge floating on the slag. Smelting thus takes place primarily at the interface between the fluid slag and the floating charge. From time to time an additional charge may be introduced with advantage adjacent the furnace walls in such manner as to provide a downwardly and inwardly sloping bank of charge which not only protects the furnace walls but supplies an additional quantity of fresh charge available for absorbing heat from the slag.

The only requirement for the physical form of charge used in practicing our invention is that it be loose and dry. By "loose" we mean that the charge should not be introduced in massive form, say, as a single large sintered block. The charge should be loose so that it will fall freely on the surface of the molten slag and spread out thereupon to an extent commensurate with the angle of repose of the charge particles. By specifying that the charge should be "dry" we mean that it should not be added in the molten condition. It is a characteristic feature of the smelting method of our invention that the charge be smelted on the surface of the hot fluid furnace slag, and this condition can be met only when the charge is introduced into the furnace in the aforementioned loose dry form. The degree of subdivision of the ore component of the charge is not critical. In general, we prefer to limit the maximum particle size of the ore in the charge to about ½ inch in diameter. Except for the problem of dusting there is no critical lower limit to the size of any of the charge particles.

We prefer to mix the charge components prior to their introduction into the furnace either in the form of a simple physical admixture or in the form of nodulized or otherwise agglomerated particles. For example, the zinciferous material (such as Waelz oxide sinter), coal and lime may be mixed together and charged directly to the furnace, or the mixture may be moistened with water and further mixed with 2% bentonite as a binder, then briquetted, dried and crushed before charging to the furnace. Alternatively, the zinciferous material alone may be briquetted, using sulfite liquor as a binder, the briquettes being fired, crushed to suitable size and then mixed with the coal and lime for direct charging to the furnace. No significant differences that could be attributed to the method of charge preparation were observed in either the smelting operation or condenser performance. In each instance, excess fines or the dust fraction may be removed by rough air separation. The charge may also be preheated with advantage to temperatures of the order of 400°–800° C. in accordance with conventional electric furnace practice. Any suitable preheating apparatus may be used for this purpose, the heat being supplied by an oil or gas flame or by the heat of combustion of the exhaust gases from the zinc condenser.

The amount of coal used in practicing our invention should advantageously somewhat exceed that amount theoretically required for the zinc and other oxides readily reduced by carbonaceous material. In general, we have found it satisfactory to use an amount of carbon (coal or coke) calculated to be 100% of that required to reduce the readily reducible oxides other than zinc and about 110% to 125% of the amount theoretically required to reduce the zinc component of the charge. Amounts of carbon in excess of 125% of that theoretically required to reduce all readily reducible oxides in the charge have been found to be ineffective in increasing either the total amount of zinc reduced or its rate of reduction. Amounts of carbon in excess of about 125% of that theoretically required are undesirable both because of uneconomical waste thereof and because of the heat-insulating effect of the excess carbon floating on the slag. Where coal or coke is used as the reducing material, we have found it advantageous to crush this component rather than use it in a relatively coarse form. For example, No. 3 coal tends to segregate in a zinciferour charge and leads to less effective reduction than No. 3 coal roll-crushed to through 4 mesh (Tyler Standard).

Condensation of the zinc vapor-bearing smelt-

ing gases produced in accordance with our invention poses no unusual problems. Although a stationary baffle-type condenser such as that described in the United States patent to Bunce No. 1,873,861 can be used for condensing the zinc vapor, maximum usufruct of our invention is realized when condensation is effected in a condenser of the type wherein the zinc vapor is brought into intimate contact with a relatively large freshly exposed surface of molten zinc. The latter type of condenser is represented by that wherein the zinc vapor-bearing gases are passed through a shower of molten zinc forcibly hurled through a confined condensing zone as described in United States Patents Nos. 2,457,544 through 2,457,551 and 2,494,551. This latter type of zinc condenser is capable of removing and condensing to molten metal all of the zinc vapor contained in the smelting gases except for that amount of the vapor corresponding to the vapor pressure of molten zinc at the temperature of the exhaust condenser gases.

The smelting method of our invention may be illustrated by the following specific examples. A charge mixture was prepared consisting of about 17.8 parts by weight of anthracite coal (in which silica comprised 65% of the ash) and 1.3 parts by weight of burned lime as an extraneous flux per 100 parts by weight of a roasted zinc ore concentrate consisting of discrete particles of ¼" diameter and finer. The zinc concentrate had the following analysis:

	Per cent
Zn	70.2
Pb	0.05
Fe	2.9
Cu	0.02
CaO	2.5
SiO_2	1.6
C	0.80
Mn	1.6
S	0.20
CO_2	0.32
Cd	0.002
MgO	0.27
Al_2O_3	0.57

This charge mixture contained sufficient iron oxide and other slag forming gangue constituents to meet the operating requirements of our smelting method as set forth hereinbefore as can be seen from the following slag analysis:

	Per cent
Zn	0.5
Fe	6.
CaO	34.8
SiO_2	32.3
MgO	2.
Al_2O_3	9.7
$CaO:SiO_2$	1.08
$CaO+SiO_2$	67.1
Other slag constituents	32.9

The charge materials, thoroughly mixed, were fed to the furnace at intervals of 2½ minutes successively through a series of six charging hoppers in the roof of the furnace at the rate of approximately 50 pounds per hour. The furnace was of conventional electric arc type, operated single phase with two 2" diameter graphite electrodes, nominally rated at 100 kw. but operated during our smelting operation at only about 70 kw.

The two electrodes were so positioned as to produce arcs adjacent the surface of the slag, the size of the arcs at the aforementioned rate of power consumption being sufficient to maintain the desired temperature conditions in the bath and in the furnace chamber above the bath. The furnace chamber temperature was maintained in the range of 1250–1300° C. during the operating period. The slag temperature, measured as the slag was tapped from the furnace, averaged about 1350° C. The zinc vapor-bearing smelting gases were passed through a splash-type condenser of the type referred to hereinbefore and the zinc vapor was condensed therein to molten metallic zinc. After correcting for handling losses, for losses of zinc vapor resulting from furnace leaks, and for the amount of fume passing through the condenser and other similar factors, the condensation efficiency in this operation appeared to be substantially 90%. The inhibition of volatilization of the refractory oxides was evident from the fact that the lime-silica ratio in the small amount of blue powder formed in the condenser was about one-third to one-half of the lime-silica ratio prevailing in the slag.

A second example of the smelting of a zinciferous material in accordance with our invention comprises the smelting of a furnace charge mixture of zinc oxide, burned lime and anthracite coal under virtually the same smelting conditions as those in the previous example. The zinc oxide was essentially 100% ZnO (79.9 Zn) and comprised a zinc oxide pigment classified as off-grade because of its failure to meet certain color specifications. Coal additions were made to the extent of 20.1 parts by weight per 100 parts of the zinc oxide to provide the required carbonaceous matter for substantially complete ZnO reduction; the lime was added to the extent of 1.2 parts by weight per 100 parts of the zinc oxide to balance the SiO_2 present in the coal ash and thereby maintain a $CaO:SiO_2$ ratio in accordance with our invention. The slag was initially compounded synthetically to produce in the furnace a molten slag having the following composition which, it should be noted, was maintained by the charge composition:

	Per cent
Fe	1.4
CaO	42.5
SiO_2	40.7
MgO	7.6
$CaO:SiO_2$	1.04
$CaO+SiO_2$	83.2
Other slag constituents	16.8

The iron present in the slag was picked up from the furnace refractory and from the coal ash, and the magnesia was introduced both as a component of the lime addition and by a deliberate addition to make up an appropriate amount of "other" slag constituents.

Since the zinc oxide pigment in the aforementioned smelting mixture required densifying before being charged to the smelting furnace, it was briquetted and the briquettes were crushed to ¼" particles before being mixed with coal and lime for furnacing. Equally satisfactory charge preparation was obtained by mixing together and briquetting the zinc oxide and lime, then crushing the briquettes, mixing the crushed briquettes with coal, and feeding the resulting mixture to the furnace. The zinc vapor in the resulting smelting gases was condensed with an efficiency of about 88% in a splash-type condenser. It will be noted that successful smelting of this zinciferous charge and effective condensation of the resulting zinc vapor were obtained without produc-

ing a metallic iron product as one of the products of the smelting operation. In the smelting of such zinciferous material in accordance with our invention, it must be borne in mind that, with the exception of the requirement with respect to the permissible amount of iron oxide in the slag, each of the other prescribed smelting conditions must be observed.

It will be seen, accordingly, that our invention offers a commercially attractive method of smelting oxidic zinciferous materials such as refuse zinc oxide, blue powder and zinc ores, and the like, in an electric furnace. The method does not require anything other than conventional electric furnace equipment for the smelting operation and, in the case of zinciferous ores, not only produces zinc metal but also a pig iron product both of which function as collectors for valuable metal by-products which can be readily recovered by conventional means. Under normal operating conditions in a commercial scale furnace there appears to be every reason to expect a recovery of 95–97% of the zinc component of the ore in the form of condensed molten zinc containing only those impurities which are now removed therefrom by conventional rectification. In the smelting of zinc ores and the like, substantially complete recovery of the lead, cadmium, copper, silver and gold contents of the ore can be realized in accordance with our invention, the lead, cadmium and some of the silver and gold being recovered from the condensed metallic zinc and the copper and the balance of the silver and gold being recoverable from the iron product. Only very small amounts of these by-product metals are lost to the slag.

We claim:

1. The method of smelting an oxidic zinciferous material with solid carbonaceous reducing material in an electric arc furnace with the resulting production of a molten slag and metallic zinc vapor substantially free from dust-forming impurities which comprises charging to the furnace the zinciferous material and an amount of the carbonaceous reducing material exceeding but not more than about 125% of the amount of said reducing material stoichiometrically required for reduction of the zinc and other oxides in the charge readily reduced by carbonaceous material and thereby precluding the presence in the molten slag of more than 6% by weight of iron oxide (calculated as Fe), further incorporating in the charge an amount of an extraneous fluxing material selected from the class consisting of lime and silica such that upon smelting of the zinciferous material the resulting molten slag derived from calcareous and siliceous components of the zinciferous material and from said extraneous fluxing material will contain not more than 85% by weight of lime (CaO) and silica (SiO_2) in a ratio between 0.9:1 and 1.2:1 and not exceeding, with respect to the total amount of the other constituents of the slag, the ratio represented by the line AB in Fig. 1 of the drawing, whereby the fluidity of the slag within the temperature range of 1250° to 1450° C. is sufficient to permit heating of the slag by an electric arc without local overheating of the charge in contact therewith to a temperature in excess of 1450° C., heating said body of slag by electric arc heating to a temperature within the range of 1250° to 1450° C., and delivering the charge to the furnace in such manner as to provide a mass of the charge floating on the slag, smelting of the charge thus taking place primarily at the interface between the fluid slag and the floating charge by the heat imparted to the charge by the slag.

2. The method of smelting an oxidic zinciferous material with solid carbonaceous reducing material in an electric arc furnace with the resulting production of a molten slag and metallic zinc vapor substantially free from dust-forming impurities which comprises charging to the furnace the zinciferous material and an amount of the carbonaceous reducing material exceeding but not more than about 125% of the amount of said reducing material stoichiometrically required for reduction of the zinc and other oxides in the charge readily reduced by carbonaceous material and thereby precluding the presence in the molten slag of more than 6% by weight of iron oxide (calculated as Fe), further incorporating in the charge an amount of an extraneous fluxing material selected from the class consisting of lime and silica such that upon smelting of the zinciferous material the resulting molten slag derived from calcareous and siliceous components of the zinciferous material and from said extraneous fluxing material will contain not more than 83% by weight of lime (CaO) and silica (SiO_2) in a ratio between 1.05:1 and 1.15:1 and not exceeding, with respect to the total amount of the other constituents of the slag, the ratio represented by the line CD in Fig. 1 of the drawing, whereby the fluidity of the slag within the temperature range of 1250° to 1450° C. is sufficient to permit heating of the slag by an electric arc without local overheating of the charge in contact therewith to a temperature in excess of 1450° C., heating said body of slag by electric arc heating to a temperature within the range of 1250° to 1450° C., and delivering the charge to the furnace in such manner as to provide a mass of the charge floating on the slag, smelting of the charge thus taking place primarily at the interface between the fluid slag and the floating charge by the heat imparted to the charge by the slag.

3. The method of smelting an iron-bearing oxidic zinciferous material with solid carbonaceous reducing material in an electric arc furnace with the resulting production of a molten iron product, a molten slag and metallic zinc vapor substantially free from dust-forming impurities which comprises charging to the furnace the zinciferous material and an amount of the carbonaceous reducing material exceeding but not more than about 125% of the amount of said reducing material stoichiometrically required for reduction of the zinc and other oxides in the charge readily reduced by carbonaceous material and thereby precluding the presence in the molten slag of more than 6% by weight of iron oxide (calculated as Fe), further incorporating in the charge an amount of an extraneous fluxing material selected from the class consisting of lime and silica such that upon smelting of the zinciferous material the resulting molten slag derived from calcareous and siliceous components of the zinciferous material and from said extraneous fluxing material will contain not more than 85% by weight of lime (CaO) and silica (SiO_2) in a ratio between 0.9:1 and 1.2:1 and not exceeding, with respect to the total amount of the other constituents of the slag, the ratio represented by the line AB in Fig. 1 of the drawing, whereby the fluidity of the slag within the temperature range of 1250° to 1450° C. is sufficient to permit heating of the slag by an elec-

tric arc without local overheating of the charge in contact therewith to a temperature in excess of 1450° C., heating said body of slag by electric arc heating to a temperature within the range of 1250° to 1450° C., and delivering the charge to the furnace in such manner as to provide a mass of the charge floating on the slag, smelting of the charge thus taking place primarily at the interface between the fluid slag and the floating charge by the heat imparted to the charge by the slag.

4. The method of smelting an iron-bearing oxidic zinciferous material with solid carbonaceous reducing material in an electric arm furnace with the resulting production of a molten iron product, a molten slag and metallic zinc vapor substantially free from dust-forming impurities which comprises charging to the furnace the zinciferous material and an amount of the carbonaceous reducing material exceeding but not more than about 125% of the amount of said reducing material stoichiometrically required for reduction of the zinc and other oxides in the charge readily reduced by carbonaceous material and thereby precluding the presence in the molten slag of more than 6% by weight of iron oxide (calculated as Fe), further incorporating in the charge an amount of an extraneous fluxing material selected from the class consisting of lime and silica such that upon smelting of the zinciferous material the resulting molten slag derived from calcareous and siliceous components of the zinciferous material and from said extraneous fluxing material will contain not more than 83% by weight of lime (CaO) and silica (SiO_2) in a ratio between 1.05:1 and 1.15:1 and not exceeding, with respect to the total amount of the other constituents of the slag, the ratio represented by the line CD in Fig. 1 of the drawing, whereby the fluidity of the slag within the temperature range of 1250° to 1450° C. is sufficient to permit heating of the slag by an electric arc without local overheating of the charge in contact therewith to a temperature in excess of 1450° C., heating said body of slag by electric arc heating to a temperature within the range of 1250° to 1450° C., and delivering the charge to the furnace in such manner as to provide a mass of the charge floating on the slag, smelting of the charge thus taking place primarily at the interface between the fluid slag and the floating charge by the heat imparted to the charge by the slag.

5. The method of smelting an iron-bearing oxidic zinciferous material with solid carbonaceous reducing material in an electric arm furnace with the resulting production of a molten iron product, a molten slag and metallic zinc vapor substantially free from dust-forming impurities which comprises charging to the furnace the zinciferous material and an amount of the carbonaceous reducing material exceeding but not more than about 125% of the amount of said reducing material stoichiometrically required for reduction of the zinc and other oxides in the charge readily reduced by carbonaceous material and thereby precluding the presence in the molten slag of more than 6% by weight of iron oxide (calculated as Fe), further incorporating in the charge an amount of an extraneous fluxing material selected from the class consisting of lime and silica such that upon smelting of the zinciferous material the resulting molten slag derived from calcareous and siliceous components of the zinciferous material and from said extraneous fluxing material will contain not more than 83% by weight of lime (CaO) and silica (SiO_2) in a ratio between 1.05:1 and 1.15:1 and not exceeding, with respect to the total amount of the other constituents of the slag, the ratio represented by the line CD in Fig. 1 of the drawing, whereby the fluidity of the slag within the temperature range of 1250° to 1450° C. is sufficient to permit heating of the slag by an electric arc without local overheating of the charge in contact therewith to a temperature in excess of 1450° C., heating said body of slag by electric arc heating to a temperature within the range of 1250° to 1450° C., delivering the charge to the furnace in such manner as to provide a mass of the charge floating on the slag, smelting of the charge thus taking place primarily at the interface between the fluid slag and the floating charge by the heat imparted to the charge by the slag, and condensing the resulting zinc vapor-bearing gases in a condensing zone by subjecting them to intimate contact with a relatively large freshly exposed surface of molten zinc metal.

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REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
834,644	Snyder	Oct. 30, 1906
859,132	Snyder	July 2, 1907
933,133	Snyder	Sept. 7, 1909
1,738,910	Lepsoe	Dec. 10, 1929
2,457,544	Handwerk et al.	Dec. 28, 1948
2,509,326	Weaton et al.	May 30, 1950

OTHER REFERENCES

The Art of Electric Zinc Smelting by Johnson, published 1913 by Continuous Zinc Furnace Co., Hartford, Conn.