United States Patent [19]
Kraemer et al.

[11] **3,785,632**
[45] **Jan. 15, 1974**

[54] APPARATUS FOR ACCELERATING METALLURGICAL REACTIONS

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[22] Filed: **Mar. 9, 1972**

[21] Appl. No.: **233,237**

Related U.S. Application Data

[62] Division of Ser. No. 843,868, March 17, 1969, Pat. No. 3,664,826.

[52] **U.S. Cl.** .... **266/34 A**
[51] **Int. Cl.** **C21c 7/00**
[58] **Field of Search** .... 266/34 T, 34 A, 34 V; 75/55, 61

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Attorney—Burgess, Dinklage & Sprung

[57] ABSTRACT

Apparatus including means for adjusting vertically the level of a mechanical stirring member with respect to the vertical level of a melt, e.g. the vertical level of the interface between the top surface of an iron melt and slagging or the like ingredients floating on such iron melt surface especially in a circular upright ladle with a discharge aperture, and method of using such stirring member, e.g. to enhance or accelerate contact and reaction between such melt and floating ingredients, to carry out metallurgical reactions, as well as tough cast iron containing spherical graphite producible thereby.

7 Claims, 7 Drawing Figures

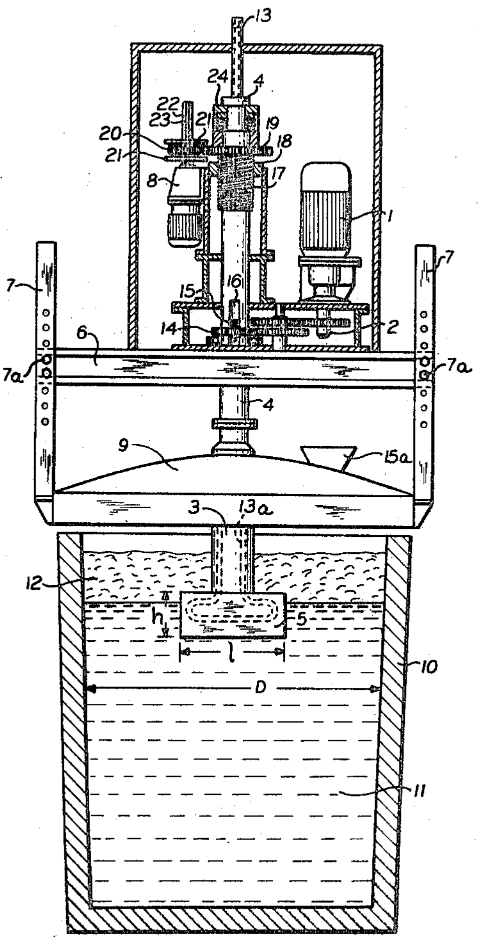

FIG. 1.

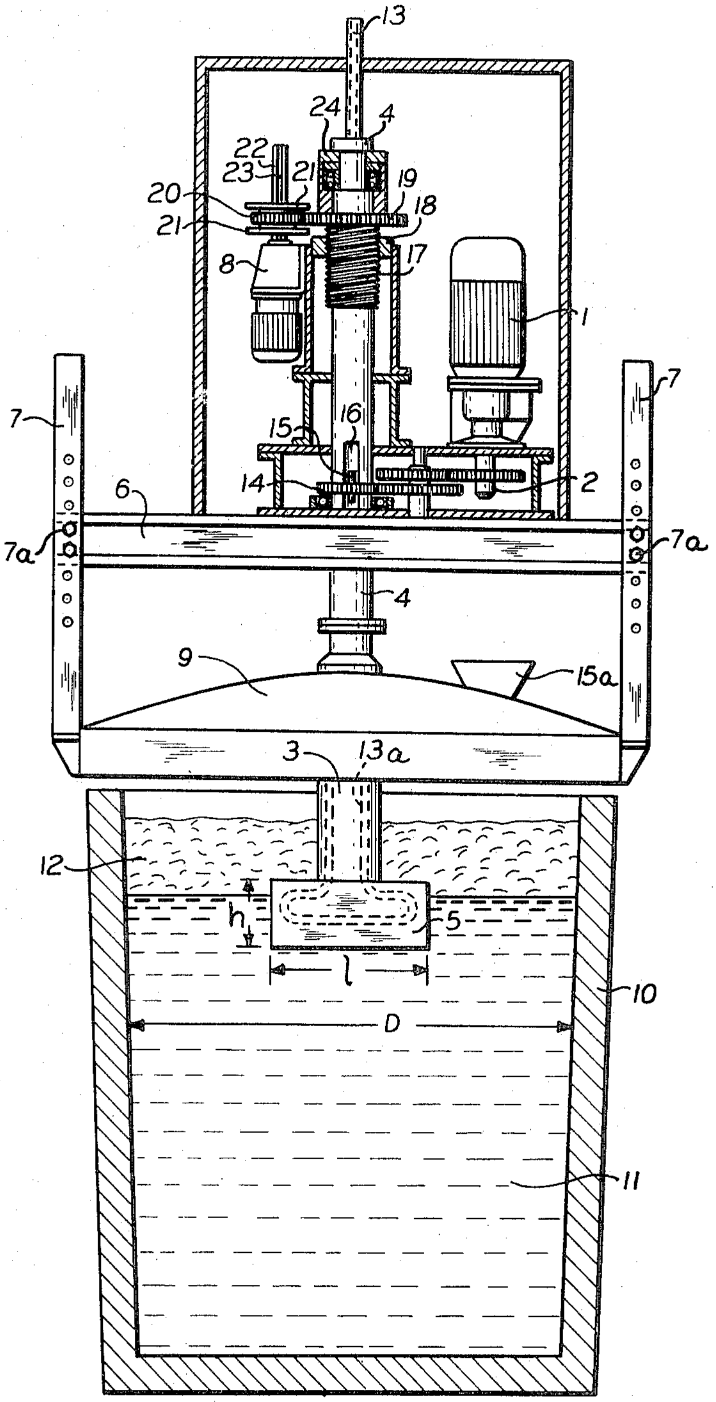
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FIG. 2.

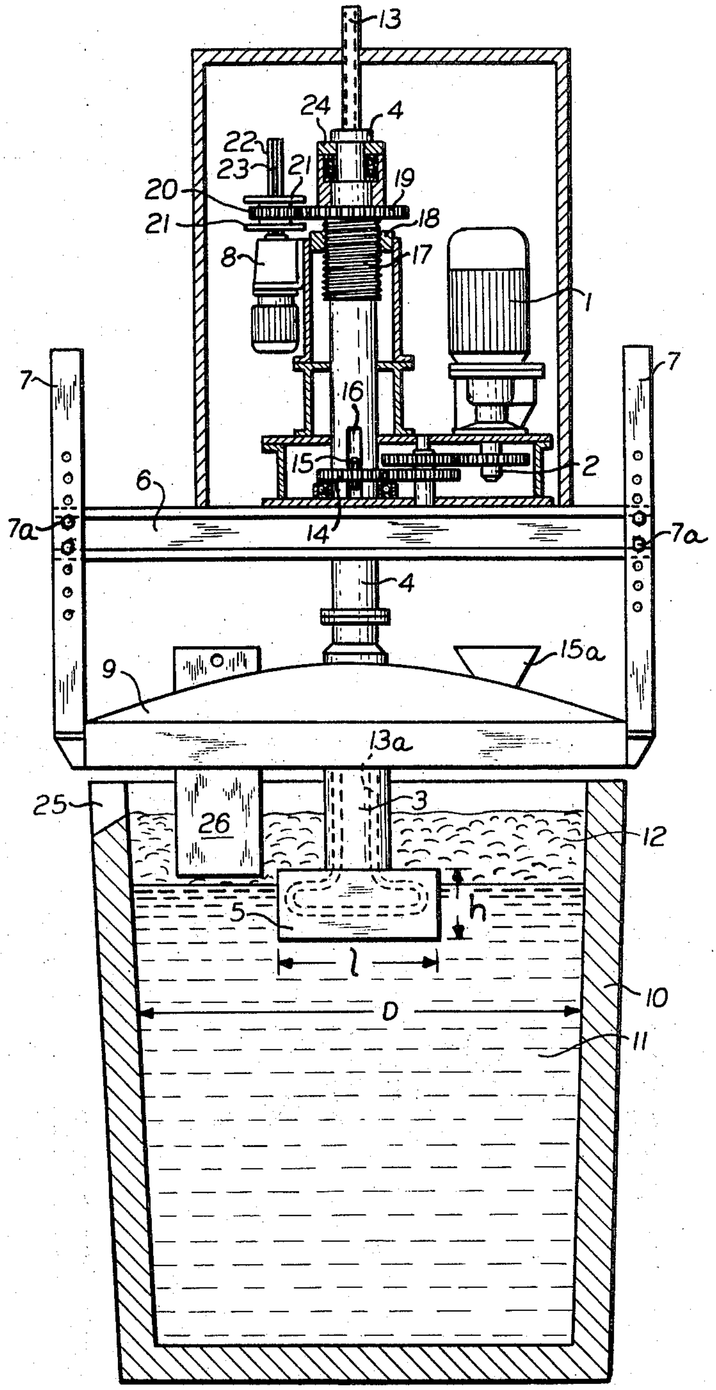
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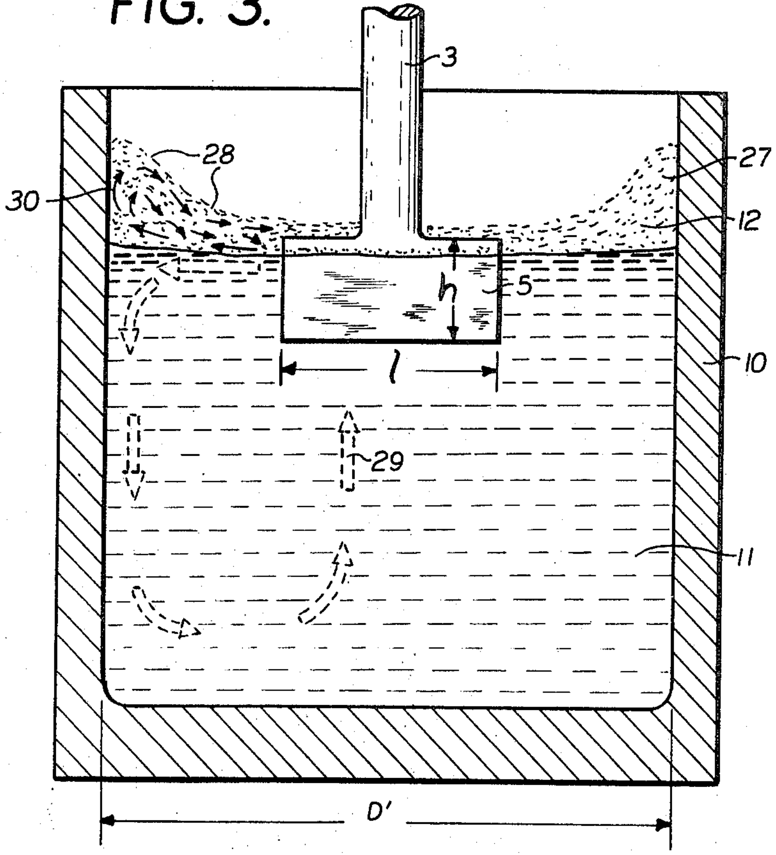
FIG. 3.



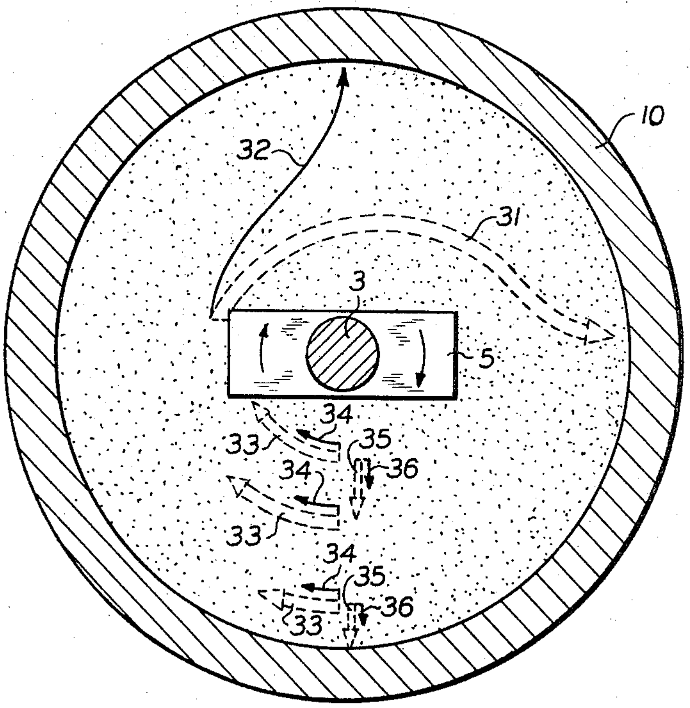


FIG. 4.

FIG. 5.

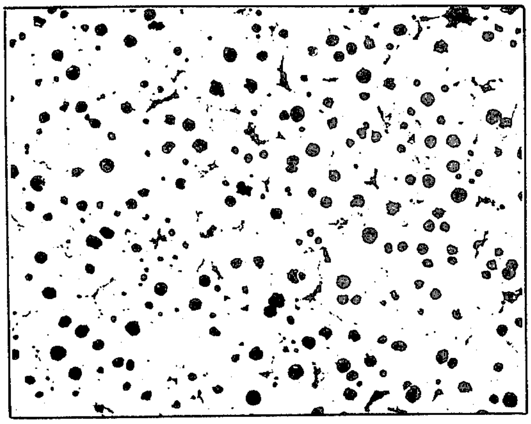


FIG. 6.

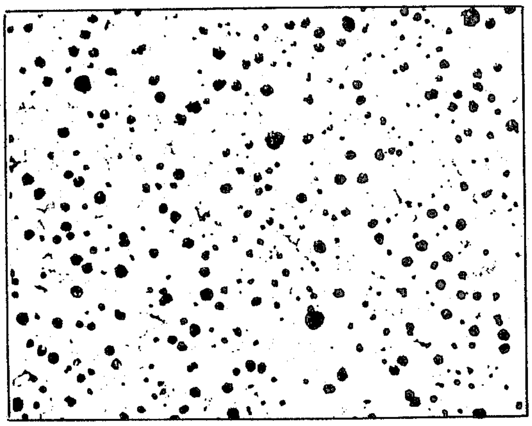
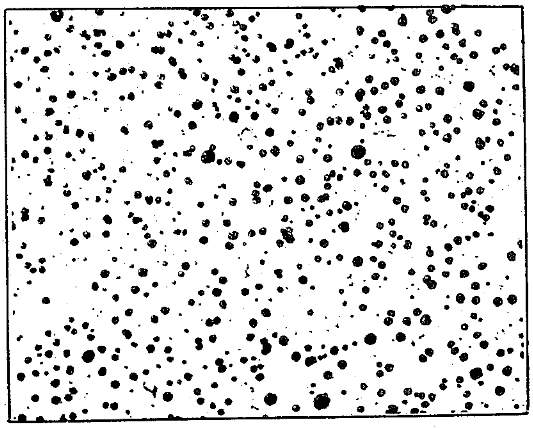


FIG. 7.



APPARATUS FOR ACCELERATING METALLURGICAL REACTIONS

This is a division, of application Ser. No. 843,868 filed Mar. 17, 1969 and now U.S. Pat. No. 3,664,826.

The present invention relates to and has among its objects an apparatus for adjusting vertically the level of a mechanical stirring member with respect to the vertical level of a melt, and especially the level of the interface between the top surface of an iron melt and slagging or the like ingredients floating on such surface in an upright substantially cylindrical ladle having a discharge aperture, and methods of using such stirring member to carry out metallurgical reactions, as well cast iron producible thereby.

Numerous known metallurgical reactions of various kinds have in common the fact that the reaction components lack sufficient natural flow capability. Hence, frequently additional means are employed in an attempt to achieve rapid, intimate, and thorough mixing at least of the molten bath constituents and, as far as possible, an intermixing thereof with the other reaction materials which may be present.

A known type of such means or apparatus chiefly consists of a ladle or vessel which receives the metal bath or melt and which undergoes corresponding accelerations owing to translatory or rotational, partly also periodically direction-reversing, motion of such vessel, said accelerations causing the thorough mixing of the reactants involved owing to the inertia of such reactants as compared with the movement of the ladle. It is true that quite good results can be achieved with these types of apparatus, but the high costs of setting up and operating the equipment and the complicated manipulations necessary are considered decisive disadvantages.

No doubt, arrangements where the vessel containing the molten bath remains stationary and intermixing of the reactants is brought about by an agitating motion of the bath or melt are obviously more advantageous. Various embodiments of agitating devices are known for accelerated and/or improved carrying out of metallurgical reactions.

However, to the extent that electrodynamic forces are utilized for these agitating devices, the metallurgical vessel requires a special shape. Also, no sufficient movement of the molten bath can be achieved where the device makes use of the injection of gases by means of known types of blowing lances. On the other hand, where injections of gases are carried out through porous hearth bottoms, the durability of the bricks of this type apparatus is insuffcient.

German Patent 1,190,479 discloses a mechanical agitating and pumping arrangement for accelerating physical-chemical processes in molten baths, said arrangement consisting of a lower vertical suction pipe and at least one essentially horizontal discharge pipe arranged laterally above and flow-communicating with the suction pipe. The arrangement rotates within the molten bath so that the melt is drawn from the lower portion of the ladle into the opening of the vertical suction pipe located in the lower portion of the ladle and is forced out again through the horizontal discharge pipes. Owing to this pumping action, a circulation flow of the molten bath takes place in the ladle. At the same time, there is a certain amount of agitating motion on

account of the horizontal discharge pipes, but, as one can gather from the details stated, an obviously lesser significance is attached to said agitating motion.

Good results can be achieved with the arrangement of said German Patent as regards acceleration of metallurgical reactions. The treatment takes place in a normal ladle so that additional re-ladling operations necessarily involving temperature losses are obviated. The light and portable device can be taken to the individual ladles. That is why it is very convenient in use and has a relatively low energy requirement.

The essential disadvantage of this German patent arrangement resides in the fact that the agitating and pumping elements are made of pipes, thus constituting a hollow body heavily washed by the melt on the inside and on the outside. The rather high operating temperatures of the device in conjunction with the abrupt temperature changes in treatment intervals severely shorten its life so that the costs of repair and renewal represent a considerable portion of the total operating cost.

A similar arrangement is shown in U.S. Pat. No. 2,290,961, in which a tank car-mounted pivotable vacuum vessel in the form of a horizontal cylinder with pointed longitudinal ends is provided with air introduction nozzles for agitating treatment of an iron melt or with a rotary mixing member in the form of an inverted T-beam or impeller for the same purpose. In the case of the impeller, either a solid horizontal beam or one containing pumping passages therein for pumping the melt, may be used, the beam being carried by a vertical shaft or supporting extension. To adjust the level of the beam, for example with respect to the level of the interface of the melt and slag floating thereon, this arrangement has the disadvantage that the beam must be physically replaced by another beam having the desired different length of vertical shaft or supporting extension. Especially where vacuum treatment of the melt is intended, the replacement of one beam by another of a different length of vertical shaft or supporting extension obviously will cause costly interruptions in terms of energy loss and time loss. Because of the very shape of the ladle and its normally sealed condition, efficient mixing is limited and problems arise because of the confined space above the melt to accommodate the voluminous slag constituents and volatile slag reaction products.

In Japanese Published Utility Patent No. Sho 40-26 248, published Sept. 7, 1965, a similar rotary impller or inverted T-beam is shown for use with iron melts. Here, however, the impeller is extended into the melt well below the surface of such melt and not at any interface between the melt and slag which might float on top of the melt. No means for adjusting the vertical level of the impeller with respect to the body of the melt or of accommodating voluminous slag constituents are shown.

It has been found, in accordance with the present invention, that an agitating device may be provided, having a drive motor and a vertically adjustable vertical drive shaft on which a beam-shaped agitating element consisting of reinforced refractory material is arranged transversely or horizontally, for accelerated and/or improved carrying out of metallurgical reactions.

The mixing device according to the invention is especially effective for carrying out the most varied types of metallurgical reactions, particularly reactions taking place in metal melts in stationary ladles although also in other metallurgical vessels such as hearth furnaces or crucible furnaces. While the main mixing movement, corresponding to the height of the beam-shaped mixing member which rotates in the horizontal plane, is carried out only in a relatively narrow zone, based on the depth of the bath, a vigorous circulatory flow movement is nevertheless imparted to the entire bath which in a short time leads to complete homogenization of the metal melt. The mixing device is thus advantageously able to be used for example for the addition of alloying metals, for deoxidation, for carburization and similar procedures wherein it is of primary importance to obtain a uniform distribution in the metal melt.

The mixing device, however, also causes a significant horizontal flow so that the device is also very suitable for reactions between the metal melt and solid or liquid reactants which rest on the surface of the metal melt.

The mixing device is particularly suitable for reactions with slags which rest on the surface of the metal melt, during the removal of undesired secondary elements from the melt.

The mixing device may be modified and embodied in various specific forms. Generally, it is advantageous to envelop the lower part of the vertical driving shaft with a refractory material, such as where the lower part forms a structural unit with the horizontal beam-shaped mixing member, the unit being connected with the upper portion of the drive shaft in exchangeable or replaceable manner. The beam-shaped mixing member should preferably have a compact configuration which, in its longitudinal axial cross section, has a ratio of length to height between 2.5 : 1 and 1 : 1, e.g. 2.3 or 2.5 : 1, and in which appropriate cross sections at right angles to the longitudinal axis have a circular or rectangular form with rounded edges.

The usual refractory materials which may be selected on the basis of known principles depending upon the individual application are usable for the agitating element, thereby attaining high resistance to wear and appropriate resistance to temperature changes. It is preferable to provide for reinforcement of the refractory material of the agitating element in the form of a cooling line, e.g. for special cases involving very high bath temperatures and/or relatively long periods of treatment with short intervening rest periods.

The agitating device is, in particular, employed for treating molten baths contained in stationary ladles. For this purpose, it will be suitable to select the length of the beam-shaped agitating element so that it is between the 0.25-fold and 0.65-fold value, preferably between the 0.35-fold and 0.50 fold value, of the inside ladle diameter (at the level of the agitating element). In this case, the agitating device will be especially easy to operate when mounted on a cap piece centering the ladle, the drive shaft with agitating element of course extending through the cap piece and being vertically adjustable.

It may be suitable in special cases, for instance with very large steel ladles, to keep the length of the agitator beam or paddle as short as possible so that the aforesaid proportioning to the ladle diameter need not be observed. In this case, the agitating device and especially the agitating beam or element is used to impart an additional translatory motion on a horizontal plane corresponding to the molten bath surface.

A further surprising advantage of the invention lies in the fact that the above-described agitating device enables, to a completely unexpected extent, acceleration and improvement in the effectuating of such metallurgical reactions to be carried out, due to material exchange at the boundary layer or interface between the molten bath surface and the superimposed solid or liquid reactants, in particular slags or fine-grained buoyant compounds, floating on the melt surface. For optimum attainment of this end, a further feature of the invention is to lower the agitating device into the ladle only to the point at which the beam-shaped agitating element is immersed during the agitating operation to at least half its own height, but not more than just complete immersion into the molten bath. Considerable relative motions between the two phases are brought about by such agitation in the boundary zone or interface between the liquid molten bath and the adjoining reactant floating on the surface thereof.

Although the agitating element rotates practically in the surface zone only, the molten bath becomes homogeneous throughout. It has been found in accordance with the invention that the efficiency of the agitating element decreases with increasing depth of immersion. For this reason it is preferred that the depth of immersion of the beam-shaped agitating element should not be more than **1.5**-fold its own height, measured from its bottom edge, during the agitating operation.

In the drawing,

FIG. **1** is a schematic side view, partially in section, of a ladle containing a metal melt having slagging ingredients or the like floating thereon, provided with a stirring member in the form of a horizontal beam-shaped element carried by a vertical shaft operatively mounted on a cover above the ladle for independent rotational as well as vertical displacement, in accordance with one embodiment of the invention;

FIG. **2** is a schematic side view similar to that of FIG. **1** of a modified arrangement in accordance with the invention provided with an adjustable slag baffle depending from the cover and a slag overflow aperture at the upper end of the ladle;

FIG. **3** is a schematic side view, partially in section, of a portion of an arrangement similar to that shown in FIG. **1**, illustrating flow paths and flow directions of the melt and slag or the like ingredients in the ladle during rotation of the beam-shaped element located in the vicinity of the melt surface;

FIG. **4** is a schematic top view, partially in section of the embodiment of FIG. **3**, showing the flow path trajectories and velocities of the melt and slag or the like ingredients during rotation of the beam-shaped element; and

FIG. **5** to **7** are photomicrographs of sections of cast iron produced in accordance with the invention, at an enlargement of 100 times, showing clearly the presence of spherical graphite.

The following is a detailed description of the invention by way of a practical embodiment in connection with FIG. **1** of the drawing.

The agitating device has a drive motor **1** driving a vertical shaft **3, 4** via a gear unit **2**. Transversely arranged on this shaft is a horizontal beam-shaped agitating element **5** composed of refractory material provided with internal reinforcement, e.g. in the form of a metal tube **13***a* (shown in phantom) which may also serve to conduct via shaft 3,4 a cooling fluid therethrough for cooling the shaft and the element.

A preferred refractory material which may be cast to form the element may consist of 33 per cent of SiO_2, 60 per cent of Al_2O_3, 3.5 per cent of CaO, 1.5 per cent of Fe_2O_3, and 1.3 per cent of alkalies. This material is mixed with water until it is just flowable and cast into a formwork in which the reinforcement, e.g. tube, is positioned. Then the case is air-dried for approximately one day.

A chemically binding refractory material, optionally preferred, consists of 26 per cent of SiO_2, 69 per cent of Al_2O_3, 0.9 per cent of P_2O_5, 1.3 per cent of Fe_2O_3, 1.5 per cent of TiO_2, and 1.2 per cent of alkalies. This material is tamped into a mold containing the reinforcement together with 5 to 6 per cent of a chemical binding agent, e.g, monoaluminum phosphate $[AlH_2(PO_4)_3]$ or phosphoric acid $[H_3PO_4]$.

In certain cases, the agitating element can also be made of graphite.

The lower portion 3 of the drive shaft has a refractory coating and forms a constructional unit with the beam-shaped agitating element 5, said constructional unit being interchangeably connected to the upper portion 4 of the drive shaft for replacement if and when necessary. The agitating element 5 may be so designed that the ratio of the length l to the height h is 2 : 1, i.e., in terms of a section taken along the longitudinal axis ; the cross sections at right angles to the longitudinal axis preferably have a circular form. The rotational speed of the drive shaft 3,4 should be adjustable to provide, for example, speed rates of 49, 74, and 99 r.p.m.

If the duration of an individual melt treatment considerably exceeds about 45 minutes, or if the time interval between the individual treatments is less than about half an hour and if high bath temperatures are involved, it may be desirable to cool the reinforcement, e.g. tube 13*a*, with air. For this purpose, a pair of concentric tubes in the form of connecting piece 13 leading from a cooling air source (not shown) may be provided, which flow communicates as a double cooling line with tube 13*a* (shown in phantom) which in turn extends into the beam-shaped agitating element 5 through the drive shaft 3, 4, the cooling air flowing via one of said concentric tubes into and through the reinforcement, e.g. tube 13*a*, of the agitating element 5 and being exhausted via the other of said concentric tubes.

The agitating device is mounted on a cross plate 6 of a supporting structure in the form of vertical supports 7. The cross plate can be vertically adjusted via main adjustment means 7*a*, e.g. connecting bolts for attaching plate 6 to bolt seats or holes provided on supports 7. A reversible drive motor 8 provided with appropriate gearing acts on the upper portion 4 of the drive shaft for vertical fine adjustment of the beam-shaped agitating element 5 independently of the rotational movement of shaft 4.

In this regard, gear wheel 20 provided with appropriate disc guides 21 is mounted on vertical shaft 22 for rotation therewith yet is appropriately keyed, by means not shown, in slot 23 to permit vertical displacement of wheel 20 axially along slot 23 independently of the rotation of shaft 22. Gear wheel 20 meshes operatively with gear wheel 19 fixed to the rotable collar 17 having external threads along the lower portion thereof. Collar 17 is mounted in stationary nut 18 provided with internal threads matching the external threads on collar 17. The upper end of shaft 4 is operatively mounted on the pressure bearing 24 situated at the upper portion of collar 17. Thus, as wheel 20 drives wheel 19 in response to the rotational direction of reversible drive motor 8 transmitted via shaft 22, collar 17 will be rotated correspondingly within fixed nut 18. This will cause upward or downward axial movement of collar 17, as the case may be, with respect to nut 18 and in turn upward or downward axial movement of shaft 4, carried thereby via bearing 24, independently of the rotational movement of shaft 4. Furthermore, as wheel 19 is displaced axially with collar 17 so also will wheel 20 be displaced along shaft 22 due to the guiding relation between disc guides 21 and the adjacent periphery of gear wheel 19.

In a manner similar to the axial displacement of wheel 20 along shaft 22, shaft 4 is displaceable vertically with respect to the gearing 2 of motor 1 due to the provision for the slot 16 in shaft 4 to which the gear wheel 14 is keyed via key 15. Therefore, as shaft 4 is raised or lowered axially along with collar 17, key 15 will ride in slot 16 and permit rotational movement of gear wheel 14 to be transmitted to shaft 4 without interruption regardless of the axial position of shaft 4 and slot 16 with respect to the axially fixed gear wheel 14, i.e., within the longitudinal limits of slot 16.

Alternate means for effecting the raising and lowering of shaft 4 will occur to the artisan aware of the invention.

Hence, nut 18 can remain fixed from axial displacement by suitable guides yet be provided with an external gearing meshing with gear wheel 20 while a portion of collar 17 can be provided with a key riding in a stationary vertical slot mounted on the framework for motor 8. In this way, as nut 18 is rotated collar 17 will be displaced axially without being rotated.

On the other hand, a rack and pinion connection can be similarly provided.

Such rack and pinion can even be provided to raise and lower the entire assembly on plate 6 in lieu of the bolts or the like 7*a*.

Also, supports 7 can carry appropriate pulleys and cables, and contain vertical tracks in which plate 6 can ride while the pulleys are rotated to raise and lower plate 6 via the cables in the manner of a conventional elevator.

An additional feature is to provide vertical worm gears along supports 7, so as to coact with appropriate threaded apertures in plate 6 whereby to obtain vertical displacement of plate 6 by suitable rotation of such vertical worm gears.

All of these means for achieving vertical displacement are appropriately able to raise and lower either plate 6 or collar 17 and in turn shaft 4 in a more or less infinitely variable manner within the limits of displacement intended, whereby to obtain fine adjustment of the vertical level of shaft 4 and consequently of shaft 3 and element 5 with respect to the melt to be treated. On the other hand, the bolt means or the like, 7*a*, used for adjustment of plate 6 with respect to supports 7 can only achieve step-wise changes in the vertical level in question.

The step-wise adjustment means 7*a*, or the like, may be designated coarse or main adjustment means while the infinite adjustment means 17, 18, 19 or the like, may be designated fine adjustment means.

The supporting structure carrying the agitating device is mounted on the cap piece or ladle cover **9** such that the drive shaft portion having the agitating element **5** connected thereto extends through the cover **9**, e.g. in an axially slidable yet independently rotatable manner. The cap piece **9** covers the ladle **10** and keeps temperature losses to a minimum. The cover **9** may be provided with a feed hopper **15***a* if desired. The ladle **10** contains the molten bath **11** and the reactant **12,** for instance some slag, which float on the melt or bath surface. The agitating element **5** is arranged in the boundary zone or interface between the two phases by reason of appropriate axial displacement of shaft **4** and/or plate **6** and is immersed into the molten bath up to approximately three-fourth of its own height *h*. The inside diameter of ladle **10** at about the level of the element **5** is designated D.

The above-described agitating device can be used for the most varied metallurgical reactions. Some examples are set forth hereinafter.

For the purpose of carburizing a cast-iron heat, coke breeze is fed to the ladle and the cap piece carrying the agitating device is placed on the ladle after the iron has been tapped. It is preferred in this connection to work with a low speed first, for instance at 49 revolutions per minute, to avoid too turbulent an evolution of gas and too heavy a generation of dust. The speed can be increased later on, as the artisan wil appreciate.

Similarly, the usual alloying constituents can be quickly charged with good results, for instance pure nickel into liquid copper, silicon into liquid aluminum, ferro-silicon, ferro-manganese or ferro-chromium into molten iron, etc. Good results are obtained with precipitation deoxidations in molten iron baths, for instance by adding shot aluminum, ferro-silicon, and the like, since, on the one hand, a quick and uniform distribution of the melting bath is achieved and, on the other hand, the agitating device highly favors the rise of deoxidation products to the bath surface.

Especially good results are obtained with reactions between a molten iron bath and superimposed liquid slags.

Starting with a blast-furnace pig iron having 0.27 per cent of manganese, 0.052 per cent of phosphorus, 0.008 per cent of sulfur, and 0.035 per cent of titanium, it has been possible to produce a cast-iron premelting bath having a composition of less than 0.08 per cent of manganese, less than 0.035 per cent of phosphorus, less than 0.008 per cent sulfur, less than 0.015 per cent of titanium, and less than 0.008 per cent vanadium. In this case, a total of 86.2 kg of hematite fine ore and 24.8 kg of sodium carbonate were added to each (metric) ton of pig iron. The procedure for adding was such that first 60 per cent of the fine-ore quantity was batched with constant agitation, thereby converting the silicon and manganese into slag. After that, sodium carbonate and fine ore were alternately added in batches for the purpose of dephosphorization with agitation continuing so that the phosphorus also reached the aforesaid low value after completion of the slag reaction. This was followed by another addition of sodium carbonate for desulfurization. The desired final silicon content of the cast-iron premelting bath was determined by an addition of ferro-silicon. All aforesaid process cycles can be carried out continuously and consecutively within a period of approximately 60 minutes, the temperature losses amounting to approximately 150° C. The finished cast-iron premelting bath is especially well suited for the production of nodular cast iron having a vastly ferritic structure already in as-cast condition even in the case of thin-walled castings.

For the purpose of desulfurizing open-hearth pig iron, pulverous calcium carbide was charged onto a pig-iron melting bath. The agitating element **5** was immersed into the pig-iron melting bath up to approximately half its height.

a. with an initial sulfur content of 0.1 per cent, a final content of 0.009 per cent is reached after an agitating period of approximately 6 to 8 minutes, corresponding to a desulfurization degree of approximately 90 per cent. The amount of calcium carbide consumed was approximately 1 per cent of the amount of pig iron. During the treatment, the temperature of the pig iron only dropped from 1,390° C to 1,380° C.

b. with an initial sulfur content of the pig iron of 0.05 per cent, a sulfur content of 0.009 per cent is reached after an agitating period of approximately 6 to 8 minutes, corresponding to a desulfurization degree of 82 per cent. The amount of calcium carbide consumed was 0.52 per cent of the amount of pig iron.

In the embodiment shown in FIG. **2** which is basically the same as that of FIG. **1** the vertical adjustment means, cover and beam-shaped mixing element are present, but in addition thereto a slag overflow aperture **25** is provided in the upper edge of the wall of the ladle **10** as well as a vertically adjustable slag baffle or guide member **26** which is disposed operatively in cover **9** in the vicinity of aperture **25** to guide slag **12**, or the like, outwardly through aperture **25** as may be necessary depending upon the particular reactions intended with respect to the melt or bath **11** and the desired control of quantities of slagging ingredients which develop during the mixing. The ratio of the length l to the height *h* in this embodiment may be 2.3=1.

Slag baffle or guide member **26** may be mounted on cover **9** to permit vertical displacement from an upper position out of contact with the slag **12** to the lower position shown in FIG. **2**, for operative guiding of the adjacent portion of slag **12** toward the overflow aperture **25** whereupon under the flowing movement of the slag in consequence of the rotation of element **5** such slag will pass through aperture **25** and leave the ladle **10.** Any suitable means may be used to control the vertical displacement of the slag baffle **26** as the artisan will appreciate, such as a rack and pinion assembly or one of the other arrangements described above for vertical displacement of shaft **4** or plate **6.**

The embodiment of FIG. **2** of the invention is particularly applicable for carrying out a process for the production of a pig iron having especially low percentages of manganese, phosphorus, sulfur, titanium and vanadium, and whose composition ranges from 3.5 to 4.6 percent carbon, 0 to 3 percent silicon, less than 0.10 percent manganese, less than 0.040 percent phosphorus, less than 0.010 percent sulfur, less than 0.015 percent titanium and less than 0.008 percent vanadium. Such a pig iron offers distinct advantages, especially in the production of cast iron containing spherical graphite and having a substantially ferritic structure.

In cast iron containing spherical graphite, a ferritic structure used to be obtained by the heat treatment of the finished castings. More recently the practice has been to produce spherical graphite cast iron, which has a ferritic structure in the cast state, and which thus does not require expensive heat treatment, by setting out from types of pig iron having low contents of manganese and other pearlitizing impurities (Jurgen Motz and Kurt Orths in "Giessereiforschung" 1967, pp. 109–124). Additional requirements are a low phosphorus content to improve the notch impact toughness, a low sulfur content to lower the magnesium consumption and improve the notch impact toughness, and a low titanium content to prevent interference with the formation of spherical graphite.

In the production of pig iron for the above-mentioned purpose it is thus necessary for the contents of manganese, phosphorus, sulfur, titanium, vanadium and other accompanying elements to be kept as low as possible. Accordingly, pig iron grades are being offered which have a gradated maximum manganese content, e.g., less than 0.14 percent Mn, or less than 0.10 percent Mn, or less than 0.05 percent Mn. The phosphorus content and the sulfur content are also similarly gradated in these known types of pig iron.

Pig iron grades having the composition in question cannot be produced directly in the blast furnace, even when smelted from extremely pure and expensive ores.

In one known process, the blast furnace pig iron is placed in a converter and there purified with gaseous oxygen, using a blowing lance. In this process, silicon and manganese are first slagged, and then phosphorus and, inevitably, carbon too, are removed. Accordingly, the iron has to be recarburized by the addition of carbon.

In another known process, the Sorel process, high-grade iron ore is reduced in the electric furnace with anthracite coal. Pure titanium oxide is won from the slag and the pig iron is then deoxidized in the induction furnace, recarburized, and then desulfurized.

The known processes suffer from the main disadvantage that they involve a plurality of steps, and that different treatment apparatus and working means are successively needed, which entail a correspondingly high cost of installation and operation.

This particular embodiment of the invention achieves the production of a pig iron having the above-stated composition starting from a blast-furnace iron, by using a beam-shaped mixing element and ladle arrangement of the foregoing type.

In this embodiment first fine ore is added to the molten iron tapped from the blast furnace into a static ladle, with stirring via the mixing element in the boundary zone between the bath and the slag, until the desired manganese content is reached, then, with continued stirring in the boundary zone, the phosphorus is removed by the addition of soda and fine ore, and then, with continued stirring in the boundary zone, the bath is desulfurized by the addition of a known desulfurating agent, such as soda.

Advantageously, by mere stirring in a zone extending only partially into the slag area, and especially extending only slightly percentagewise (with reference to the bath depth) into the molten iron, an extremely effective exchange of material can be achieved between all of the iron and the slag, in all steps of the process. Although very large quantities of slag develop in the process, i.e., according to this embodiment of the invention, the speed of reaction is high and the utilization of the slag is very good. The carbon content is not appreciably affected by the treatment, so that recarburization of the treated iron is not necessary.

The process of this embodiment can be improved in various ways. As a rule, a siliceous alloying agent, such as ferrosilicon, is added immediately after the desulfuration, preferably before any removal of slag, so as to adjust the required silicon content. Even without removing any of the oxidizing slag a surprisingly high silicon yield is achieved.

Even in the slagging of the manganese a considerable amount of slag develops, which is preferably drawn off automatically when a certain level in the ladle is reached, i.e., via the conjoint use of the slag aperture 25 and baffle 26 of the apparatus of FIG. 2. This quantity can be controlled by the controlled addition of the fine ore so that the removal of the manganese will be accomplished with certainty down to the desired final content, whereupon the titanium and vanadium present will also have been removed or slagged as well. In like manner, it is preferably to control the amount of slag developing in the phosphorus slagging by the controlled addition of the fine ore and/or soda, and to cause excess amounts rising above a certain level to run off automatically as noted above.

The instant process embodiment of the invention becomes especially simple if, even between the individual steps in the process (silicon and manganese slagging, phosphorus slagging, desulfuration, resiliconizing), there be no complete removal of the slag that is present. At the same time the ladle can be closed with the cover on which the necessary stirring apparatus and the feed aperture are provided, so that the temperature losses can be kept low. The entire process is then continuous, and can be performed with a correspondingly small consumption of time, yet with controlled removal of slag quantities by reason of the slag baffle and ladle aperture used conjointly with the beam-shaped stirring element of the invention.

By use of the stirring apparatus contemplated herein, therefore, a rapid exchange of material between the phases involved is achieved as well as a homogeneous molten metal, with such apparatus being of the simplest possible construction and having a long service life.

In the following Table 1 a comparison is made of four different heats from the blast furnace in connection with this embodiment of the invention.

TABLE 1

Amount of Raw Iron (t)	Amount of Fine Ore (kg/t of raw iron)	Amount of Soda (kg/t of raw iron)	In starting melt (percent)				
			Mn	P	S	Ti	V
46.5	95.8	25.8	0.17	0.052	0.010	0.037	0.015
48.3	86.2	24.8	0.27	0.052	0.008	0.035	0.018
52.4	87.8	31.5	0.12	0.055	0.010	0.031	0.015
52.6	87.5	31.4	0.12	0.059	0.013	0.027	0.016
Average analysis after treatment			< 0.08	< 0.035	< 0.008	< 0.015	< 0.008

Table 1 gives the total amount of ore and soda added during the stirring treatment, as well as the starting contents of manganese, phosphorus, sulfur, titanium and vanadium. From the bottom line it can be seen that the final contents are below the required maximum values for these elements.

In the case of a heat having the 48.3 metric tons weight, the procedure in detail was as follows using an arrangement analogous to that of FIG. **2**. First about 2.5 metric tons of hematitic iron ore having an Fe content (total) of about 67 percent was added gradually, portion by portion, to the heat tapped from the blast furnace into a static ladle, while the heat was being stirred. This addition amounts to about 60 percent of the total amount of iron ore added. The ore was added in the form of a fine ore having a grain size of at most about 10mm. Shortly after the beginning of the addition of ore, a voluminous slag formed, which automatically ran off through an aperture in the ladle when it rose above a certain level in the ladle. This slag first removes the silicon, and other highly oxygen - refining attendant elements, particularly titanium and vanadium, from the iron. As the addition of ore continues, at a rate determined by the amount of slag forming, the slag also carries off the manganese, so that by the end of this stage of the process the heat has attained a manganese content below 0.08 percent. During this treatment the heat has been constantly stirred in the boundary zone between the bath and the slag by the beam-like stirring element rotating while immersed to about ½ to ⅔ of its thickness into the metal. The length of the stirring element amounted in this case to 800 mm, at a ladle diameter of 2200 mm. At the beginning of the treatment the stirrer was driven at 30 rpm. After the liquefaction of the iron ore the speed was raised to 70 rpm.

Then, while stirring continued in the boundary zone, soda and fine ore were added portion by portion, alternately, for the purpose of dephosphorization. The amount of soda was 75 percent of the total shown in the table, sub-divided into three individual additions of about 6.2 kg/ton of raw iron each, alternated with additions of ore of about two times 8.6 kg/ton of raw iron each (2X 10 percent of the total quantity). The last addition of soda was followed by the addition of 17 kg of ore/ton of raw iron (about 20 percent of the total amount). After each, addition there was a period of waiting until the fluid slag resulting from the exchange of material had formed, when then ran off in part.

While the stirring in the boundary zone continued, another batch of soda weighing 6.2 kg/ton of raw iron was put in for desulfuration, and then, at increased rotary speed (100 rpm) of the stirring element, and without any special removal of slag, an appropriate quantity of ferrosilicon (75 percent Si) was added to adjust the desired silicon content. The silicon yield amounted to 92 percent. With a treatment time of about 60 minutes, the temperature losses amounted to only 150° C.

The embodiment of FIGS. **3** and **4** of the invention is best illustrated in terms of a process for the desulfuration and deoxidation of carbon-containing iron heats in a ladle, in which a circulatory flow is produced in the hot metal, which is directed downwardly at the wall of the ladle and upwardly at the center of the ladle.

Mechanically driven ladle units of the type noted heretofore have in recent years acquired what is no doubt chief importance in the desulfuration of iron. The ladles are set in motion in such a manner that the accelerations which occur, and which vary to some extent in degree and direction, cause the metal and the desulfurating agent to blend together due to the mass inertia of the bath and of the desulfurating agent. If the degree of utilization of the desulfurating agent is good, such driven ladles permit the achievement of final sulfur contents of 0.01 percent or less, setting out from initial sulfur contents between 0.08 percent and 0.12 percent, depending on the method of melting in the acid cupola furnace. Important disadvantages, of course, are the high cost of the erection of the equipment, the complicated handling in connection with a particular location, and considerable power requirements.

In other known processes, the expense is lower because the ladle and its contents are stationary and a circulatory flow is induced in the bath by introducing a gas through a blowing lance or through porous bricks disposed in the bottom of the ladle as discussed above, occasionally with the desulfurating agent being also blown in with the gas. Aside from the fact, however, that the gas introduced produces an undesirable cooling action, either the bath movement that could be induced proved to be inadequate or the service life was too short.

Although the mechanical stirring and pumping apparatus of the above-mentioned German Patent 1,190,479 is able to induce a circulatory flow of the hot metal in the ladle, such that desulfuration can be performed in a regular teeming ladle, the pumping device has the disadvantage of short service life discussed previously.

The arrangement shown in said U.S. Pat. No. 2,290,961, because of the peculiar tank orientation and non-uniform shape in horizontal cross-section, is unfitted for efficient flow of the melt and slag and is unable to attain convenient manipulation of the ingredients, controlled removal of slag during the operation. etc.

All the prior-art processes and apparatus have tried to achieve an intensive blending of the desulfurating agent with the hot metal, evidently based upon the theory that the stronger the agitation, the better will be the desulfuration.

In connection with the particular embodiment of the invention in question, it has been found that desulfurating and deoxidizing of carbon-containing iron heats can be carried out extremely effectively in a static ladle or other such vessel for ferrometallurgical purposes, i.e., of the type contemplated for instance, in FIGS. **1–4**. The treatment can thus be performed either in the melting unit itself, e.g., in the crucible of an induction furnace or in the forehearth of a cupola furnace, or preferably in the teeming ladle. The invention provides not only an inducing of a circulatory flow in the molten iron, but also the producing of an appropriate flow in the desulfurating agent, without producing a turbulent blending of the desulfurating agent with the hot metal. It has been found in fact that intensive blending of the desulfurating agent with the hot metal is by no means necessary for the achievement of a high degree of desulfuration. Instead, it is quite sufficient for both of the reactants to remain separate from one another and for each to undergo a separate pronounced circulatory movement, so that the reaction is restricted to a boundary surface or interface, but it is nevertheless very intense.

Thus, the desulfuration and deoxidation of carbon-containing iron heats may be carried out in a static ladle or other such vessel for metallurgical purposes, in which a circulatory flow of the hot metal is provided which is directed downwardly at the ladle wall and upwardly at the center of the ladle. The instant process differs from the prior art in that a charge of a finely granular material containing calcium and carbon is placed on the surface of the bath, and in that a stirring movement takes place in the boundary zone and is so chosen that the hot metal at the surface has a flow which propels the particles of finely granular material on the bottom of the charge toward the edge of the ladle and there causes the accumulation of a heap of particles along the very slope of which the particles slowly move back to the stirring center individually or in the form of coarser aggregations.

The finely granular material used can be, for example, calcium carbide or other known finely granular desulfurating agent such as lime nitrogen (technical $CaCN_2$ containing some CaO, regarded in Germany as Kalkstickstoff) or mixtures of fine limestone and coke breeze.

This embodiment of the process of the invention is preferably performed so that the stirring in the boundary zone produces such a flow of the individual units of volume of the iron at the bath surface that the trajectory of the units of volume of the iron, which is sharply curved in the area of the stirrer, has a constantly diminishing curvature which causes a centrifugal thrust at the ladle margin, and furthermore so that the trajectory of the units of volume of the top charge is similar as regards the change of curvature. At the same time the velocity of the units of volume of the iron and the velocity of the units of volume of the top charge are preferably maintained in a value ratio that is greater than 2:1 and is preferably greater than 5:1.

The stirring movement should be produced insofar as possible so that the top charge of finely granular material forms a continuous blanket so as to avoid loss of heat by radiation and prevent oxidation of the metal.

In order to achieve the desired flow in the iron bath and in the desulfurating agent, the beam-shaped stirring element is best adjusted to such a height that, during the stirring, it is immersed into the metal at least to the extent of half of its own thickness, but is not more than barely completely immersed therein. In this manner, although the desulfurating agent is moved in the stirring center, it nevertheless forms advantageously a continuous blanket on the surface of the hot metal. In order to obtain an optimum desulfurating and deoxidation, it is preferable to proportion the length of the beam-like stirrer to the diameter of the ladle. In this regard, it is best for the length of the stirrer to amount to between 0.25 and 0.65, and preferably to between 0.35 and 0.50, times the ladle diameter, as noted previously. The rotary speed of the stirrer or beam-shaped element is preferably adjustable so that the extremities of the stirrer will assume peripheral velocities ranging from 1.8 to 3.5 m/sec, and preferably between 2.0 and 2.8 m/sec.

With specific reference to the embodiment of FIGS. 3 and 4, the beam-shaped element or stirrer 5 is 460 mm long, 350 mm thick and 250 mm wide, so that the ratio of its length l to its thickness or height h is 1.3 : 1. The beam-shaped stirrer is immersed to a depth of 340 mm into the molten iron and extends 10 mm into the top charge of for instance powdered calcium carbide. The length l of the beam-shaped stirrer 5 is equal to 0.42 times the ladle diameter D'. The ladle **10** has a vertical axis and a corresponding continuous upright confining wall of substantially constant radius of curvature at any given axial level and the stirrer **5** is centered for rotation substantially about the vertical axis of the ladle. The rotary speed of the drive shaft 3 of the stirrer is adjustable to preferred values in such a manner that the extremities of the stirrer **5** can assume peripheral velocities ranging from 1.8 to 3.5 m/sec, and preferably from 2.0 to 2.8 m/sec., as aforesaid.

When the described stirring device is composed of reinforced fire clay, approximately 60 desulfuration treatments lasting from 8 to 12 minutes were regularly performed at iron bath temperatures between 1,380° and 1420° C.

According to this embodiment of the invention, a top charge **12** of a finely granulated material containing calcium and carbon, e.g., calcium carbide, is placed on the surface of the molten metal **11**, and a stirring movement is executed in the boundary zone. This movement is so adjusted that the molten iron at the surface of the bath has such a flow that it propels the calcium carbide particles towards the margin of the ladle **10** and there builds up a pile **27** of particles along the slope **28** of which the calcium carbide particles move back individually or as coarser aggregations towards the stirring center. The calcium carbide top charge **12** forms advantageously a continuous blanket over the hot metal, thereby minimizing temperature losses, which amount to about 10° to 30° C under the conditions stated above, on the basis of experiments actually performed.

FIG. 3 also indicates diagrammatically the conditions of flow in the hot metal and in the calcium carbide top charge. According to the wide arrows **29**, the flow of iron is directed downwardly at the ladle walls and upwardly in the middle of the ladle. On the other hand, as a result of the pileup **87** of particles and slope **28**, a circulatory flow takes place as indicated by the thin arrows **30**, which is an important requirement for the obtaining of the outstanding results actually achieved in the desulfuration, which will be clear from a consideration of Table **2**. A blending together of the two reactants does not take place throughout; the reaction takes place instead entirely in a boundary layer or interface therebetween.

FIG. 4 illustrates, by flow arrows in the top view shown, the trajectory **31** of a unit of volume of iron and the trajectory **32** of a unit of volume of the top charge, as well as the corresponding rotational and centrifugal velocity vectors **33, 34** and **35, 36**, respectively. As to the trajectory **31** (iron), the curvature which is strong in the area of the stirrer **5** diminishes constantly towards the margin of the ladle **10**, so that a centrifugal force component is created, and the slowed propulsion of the calcium carbide particles produces a pileup in the area of the margin of the ladle. Trajectory **32** (calcium carbide) is similar in its basic form (flow pattern). FIG. 4 is intended to show, of course, only on a fundamental basis, the nature and magnitude of the motional actions in question.

From FIGS. 3 and 4 can be appreciated the considerable relative velocities of the two reactants which prevail in the boundary layer. This factor, together with the circulatory flow in the iron and in the top charge, tends to optimize the exchange of material as desired. This is particularly true because the ladle is more or less of uniform diameter throughout its height while being of substantially round or circular configuration in horizontal cross-section, in relation to the centrally disposed beam-shaped stirring element.

Some of the results of desulfuration treatments performed on cast-iron heats are compiled in the following Table 2:

Table 2

Exp. No.	No. of treatments	Initial Sulfur content percent	Final Sulfur content percent	Stirring time (min.)	Quantity of iron (in metric tons)	Percent of CaC_2 added	Rotary speed (rpm)	Peripheral velocity (m/sec)	Depth of immersion (mm)	I/D (ratio of length of stirrer to ladle diameter)	Starting Temp. (°C)	Loss in Temp. (°C)
1	5	0.086–0.112	0.003–0.004	10	6.1	1.2	74	1.78	340	0.41	1410–1420	25–30
2	2	0.106–0.118	0.003–0.005	4	8.0	1.0	72	1.74	340	0.41	1380–1390	15–20
3	4	0.100–0.120	0.007–0.009	2	8.0	1.2	86	2.07	350	0.41	1400–1410	10–15
4	2	0.082	0.003	10	20.7	0.97	70	2.35	320	0.39	1420–1425	15–20
5	2	0.086	0.045	12	9.5	1.2	55	0.84	330	0.25	1400–1420	25–35

A further embodiment of the invention as covered by FIGS. 5 to 7 relates to a cast iron containing spherical graphite, which is tough in the cast state, and which contains from 3.0 to 4.2 percent carbon, 2.0 to 3.0 percent silicon, less than 0.1 percent manganese, less than 0.04 percent phosphorus, less than 0.01 percent sulfur and 0.02 to 0.07 percent magnesium.

For many applications a cast iron containing spherical graphite is desired which has sufficiently high ductility to assure good forming qualities in the castings. It is known that a perfect forming of spherical graphite and a substantially ferritic structure is necessary for this purpose. A ferritic structure is increasingly more difficult to achieve as the wall thickness of the castings decreases. Consequently, the finished castings have previously been subjected to a ferritizing heat treatment, usually in two stages, but this entails an increase in the risk of reject due to distortion, scaling and the like, in addition to the heat treatment costs.

In former times, efforts were made to produce pig iron types of select composition from which a cast iron containing spherical graphite could be produced, which in the cast state exhibits a substantially ferritic structure, even in thin-walled castings. Such types of pig iron must be as free as possible from accompanying elements other than the carbon and silicon they contain, since such elements interfere with the formation of spherical graphite or have a pearlite-stabilizing effect, even in low concentration, or they diminish toughness due to solution embrittlement of the ferrite.

Low-manganese types of pig iron having graded maximum manganese contents, graded maximum phosphorus contents and graded maximum sulfur contents are available commercially, which are characterized also by very low concentrations of other accompanying elements. Manufacturers of cast iron containing spherical graphite can thus select the types of iron that meet their particular requirements.

Furthermore, it is known quantitatively (see the aforementioned Jurgen Motz and Kurt Orths in "Giessereiforschung" 1967, pp. 109–24) what weight per percentage unit of certain impurities adversely affects the toughness of cast iron in the cast state. Important in this regard are not only the above-mentioned manganese and phosphorus, but particularly the contents of copper, lead, antimony, tin and arsenic.

Although types of pig iron that are low in accompanying elements are available as starting material, and although, as stated, the relationships are to a great extent undersood, hitherto the only types of industrially manufactured types of cast iron that have been known are those which produce in castings having a wall thickness of 5 mm in the cast state (sand molds) a pearlite content that is definitely above 20 percent, and usually runs even around 50 percent.

The cast iron containing spherical graphite which is tough in the cast state, as provided in accordance with this particular embodiment of the present invention, is distinguished from the prior art in that the following contents of the specified impurities are present: lead under 0.002 percent, titanium under 0.04 percent, chromium under 0.01 percent, arsenic under 0.002 percent, copper under 0.01 percent, tin under 0.002 percent, vanadium under 0.01 percent, and antimony under 0.002 percent, and in that the cast iron in castings made in sand molds and having a wall thickness of 5 mm has a pearlite content in the cast state of less than 10 percent.

In accordance with the instant embodiment of the invention, it has been surprisingly found that the production of a cast iron containing spherical graphite, whose castings are to have a virtually entirely ferritic structure and hence a high toughness in the cast state, even in the case of slight wall thicknesses, is not assured by the mere fact that the concentration of the impurities interfering with spherical graphite formation and of the impurities hitherto regarded as pearlite stabilizers is kept low. Evidently still other, hitherto unrecognized, influences are at work.

Using an apparatus of the type known in FIG. 2, the manufacture of a cast iron according to the instant embodiment of the invention, is set forth below by way of example:

A blast-furnace pig iron (about 50 tons) containing 4.4 percent C, 1.35 percent Si, 0.17 percent, Mn, 0.067 percent P, 0.022 percent S, 0.037 percent Ti, 0.015 percent V, 0.0015 percent Pb, 0.008 percent Cr, 0.001 percentAs, 0.008 percent Cu, 0.001 percent Sn, and 0.001 percent Sb, is tapped (1,350–1450° C) into a ladle, and at first fine ore is added with stirring in the boundary zone between the pig iron (at about 1,300–1350° C) and the slag until the desired manganese content is achieved. Then, with continued agitation in the boundary zone, soda and fine ore are added to flux out the phosphorus. While stirring in the boundary zone between the pig iron and the slag continues, the molten pig iron is desulfurized by the addition of a known desulfurizing agent, such as soda. The treatments to this point take a total of only about 60–85 minutes and the temperature drop is only about 100°–150° C. Thereafter, ferrosilicon is added to adjust the silicon content to the desired higher level, requiring only an additional 5–20 minutes.

In detail the procedure is such that, to a pig-iron quantity of 48.3 metric tons (1,340° C), a total of 86.2 kg of fine ore (grain size equal to or less than 10 mm) and 24.8 kg of soda per ton of pig iron are added.

To remove the manganese, approximately 60 percent of the total quantity of fine ore is added portion by portion, and the slag thus produced is allowed to run off through an overflow trough (see FIG. 2) to the extent that it rises above the top level.

To remove phosphorus, about 75 percent of the total amount of soda is added in portions alternating with the balance of the fine ore. Here, again, some of the slag is to be allowed to overflow from the ladle.

To remove sulfur, about 25 percent of the total amount of soda is added.

The treatments to this point actually take only about 70 minutes and the temperature drop is only about 125° C.

Immediately thereafter ferrosilicon (75 percent Si) is added, with stirring, in order to adjust a silicon content of 1.3 percent. This step only takes an additional 8 minutes but no further temperature drop occurs since the solution heat of ferrosilicon counteracts radiation and conduction heat losses.

For the stirring in the boundary zone between the pig iron and the slag, the stirrer or beam-shaped element is adjusted in height so that the same extends partially into the pig iron bath and to a slighter extent into the fluid slag.

As a result, a preliminary cast iron is obtained containing the following elements: 4.3 percent C, 1.26 percent Si, 0.07 percent Mn, 0.038 percent P, 0.007 percent S, 0.013 percent Ti, 0.008 percent V, 0.0015 percent Pb, 0.008 percent Cr, 0.001 percent As, 0.008 percent Cu, 0.001 percent Sn, amd 0.001 percent Sb.

From this preliminary cast iron, a starting iron for case iron containing spherical graphite was prepared by remelting in a medium-frequency induction furnace with the addition of ferrosilicon. This starting iron was treated with an iron-magnesium-silicon alloy (about 30 percent Mg) by dipping process, and it was then inoculated with 0.8 percent ferrosilicon (75 percent Si).

The chemical composition of the iron before casting was the following: 3.86 percent carbon, 2.48 percent silicon, 0.08 percent manganese, 0.034 percent phosphorus, 0.006 percent sulfur and 0.051 percent magnesium. The rest of the elements were contained in the same percentages as they were in the preliminary cast iron. With the iron at a temperature between 1,390° and 1360° C, plates having a wall thickness of 5, 12 and 30 mm were case in an oil sand mold. The pearlite content in the 5 mm plate amounted to 3–5 percent, while the 12 and 30 mm plates contained only traces of pearlite. The rest of the ground mass consisted of ferrite. The pearlite content of these three plates was estimated under the microscope at a 100× enlargement, using fully planimetered test rows (see FIGS. 5 to 7, respectively, of the drawing). According to the formula given by said J. Motz and K. Orths, an average ferrite content of 59 percent over all three plates would be computed on the basis of the chemical composition. The actual value for the average pearlite content of the cast iron according to the invention, however, amounts to only 2 percent. The mechanical characteristics were determined to be the following:

Notch impact toughness (at 20°C, specimen from 30 mm plate)	2–2.5 Kp/m/cm^2
Transition temperature	−38° to −43°C
0.2% elastic limit $\delta_{0.2}$	= 25 to 30 Kp/mm^2
Tensile strength σ_B	= 40 to 45 Kp/mm^2
Elongation at rupture δ_5	= 20 – 25%
Brinell Hardness BH$_{30}$	= 150 Kp/mm^2

A. Generally, in connection with all of the embodiments of the invention, the starting blast furnace iron may contain in percent by weight:

carbon	4.40–4.86
silicon	less than 1.5
manganese	less than 0.30
phosphorous	less than 0.1
sulfur	less than 0.030
titanium	less than 0.060
vanadium	less than 0.025
remainder substantially iron	

and where the usual other impurities are also present, such iron may further contain:

lead	less than 0.001
chromium	0.010
arsenic	0.001
copper	less than 0.01
tin	less than 0.002
antimony	less than 0.002

B. A conventional range of ingredients in a starting blast furnace iron, in connection with all of the embodiments of the invention, may include in percent by weight:

carbon	4.40–4.86
silicon	0.86–1.50
manganese	0.08–0.12
phosphorus	0.041–0.056
sulfur	0.012–0.030
titanium	0.025–0.038
vanadium	0.010–0.012
remainder substantially iron	

and optionally the immediately above amounts of said other impurities (see A above), such that the final pig iron, before addition of ferrosilicon to adjust the silicon content, for example in the case of the embodiments discussed above in connection with FIGS. 2, and 5–7, respectively, may contain in percent by weight:

carbon	3.95–4.35
silicon	0.01–0.07
manganese	0.04–0.06
phosphorus	0.024–0.035
sulfur	0.006–0.010
titanium	0.004–0.008
vanadium	0.003–0.005
remainder substantially iron	

and optionally the same amounts of said other impurities as in the starting blast furnace iron (see A above), possibly with the chromium content being reduced to 0.008 percent.

In this regard, the amount of fine ore (e.g. hematite) added as contemplated for the various treatment steps = (the starting Si content in percent minus the final Si content in percent) times 100 kg per ton of melt weight. Generally, the final Si content (before the alloying addition of ferrosilicon) is adjusted to less than 0.10 percent. The amount of soda added is between about 25–30 kg per ton of raw iron, yet at smaller starting Si contents, e.g. less than 0.08 percent, correspondingly smaller amounts of soda will be needed, as the artisan will appreciate. Upon such treatment, the immediately aforementioned final contents of carbon, silicon, manganese, phosphorus, sulfur, titanium and vanadium (see B above) can be obtained in the final pig iron produced.

It will be realized that the starting raw iron or blast furnace iron will preferably have less than 1.5 percent silicon content since higher silicon contents require higher amounts of fine ore to refine the silicon content down to the mentioned 0.10 percent silicon content and this entails temperature control difficulties. Of course, by reducing the silicon content to below 0.10 percent the titanium and vanadium contents are also reduced, and thus the manganese slagging is readily carried out.

Especially important in accordance with the invention is the use of the foregoing starting blast furnace iron (see A above) to produce the aforementioned cast iron containing nodular or spherical graphite with a vastly ferritic structure, tough in the case state and having less than **10%** pearlite (see FIGS. 5–7).

The advantages of uniform, thorough and efficient boundary layer or interface mixing of the melt and slag within very short treatment times and with simple removal of slagging ingredients are achieved in accordance with the invention because of the flow paths and trajectories of the two phases (see FIGS. **3** and **4**) made possible by the use of the beam-shaped mixing element in coaction with a ladle of substantially uniform diameter throughout its axial height and having walls of substantially circular configuration in horizontal section, such that the mixing element is positioned substantially coincidentally with the main vertical axis of the ladle (see FIG. **1**). With the provision for a vertically adjustable baffle and ladle aperture (FIG. **2**), the slagging materials can be run off conveniently and with a minimum of manipulation, i.e., merely by lowering the adjustable baffle into the slag phase to guide the slag, under the flow path conditions generated by the mixing element, out through the ladle aperture.

In particular, the vertically adjustable mixing element permits much more accurate as well as continuous adjustment of the mixing element position with respect to the interface between the two phases (FIGS. **1** and **2**) while the adjustable baffle and the ladle aperture (FIG. **2**) usable in conjunction therewith attain full control and simple manipulation of the slag level under the existing operating conditions and flow paths (FIGS. **3** and **4**), all without interruption of the overall multiple step slagging operation. The prior art devices are devoid of these structural conjoint features and thus inherently cannot attain these advantages, nor does the prior art suggest the make-up of the cast iron containing spherical graphite which is tough in the cast state and essentially completely ferritic in nature, with less than 10 percent pearlite.

It will be appreciated that the instant specification, drawings and examples are set forth by way of illustration and not limitation, and that various modifications and changes may be made without departing from the spirit and scope of the present invention.

What is claimed:

1. Heat retaining mixing assembly for accelerating as well as enhancing metallurgical reactions by mechanical stirring of a melt in a container, which comprises an independently transportable cover adapted to be removably positioned in substantial closing relation with the upper end of such container to minimize heat losses from the melt, shaft support means disposed on said cover, an upright driving shaft rotatably mounted on said support means and having a lower portion extending downwardly through said cover, a relatively elongated mixing member in the form of a solid beam-shaped mass of refractory material secured to the lower end of said lower portion of the shaft and extending substantially perpendicular to said shaft for contact with the melt to promote flow and rapid and intimate mixing of the contents thereof upon rotation in turn of said shaft, and adjustment means on said support means operatively connected to said shaft to adjust the vertical disposition of said shaft and in turn said mixing member with respect to said cover and such melt, said adjustment means including main adjustment means interconnecting said shaft support means and shaft for step-wise vertical adjustment of said shaft with respect to said cover.

2. Assembly according to claim **1** wherein said cover is provided with a vertically displaceable guide member, extending downwardly, therefrom, and arranged to be lowered into the container to conduct a portion of the flowing contents at the upper end of said container peripherally outwardly for discharge thereof from the container upper end.

3. Assembly according to claim **2** wherein said cover is disposed above such a container and said container is provided with an aperture at the upper edge thereof in the vicinity of said guide member to discharge said portion of the flowing contents conducted peripherally outwardly by said guide member.

4. Assembly according to claim **1**, said adjustment means further including fine adjustment means disposed on said support means operatively connected to said shaft independently of said main adjustment means, for infinite fine adjustment of the vertical disposition of said shaft and in turn said mixing member with respect to said cover.

5. Assembly according to claim **4** wherein said support means include opposed upright support members attached to said cover and a cross-plate vertically adjustably connected therewith via said main adjustment means, said shaft being rotatably mounted on and extending through said cross-plate and in turn therebelow through said cover and being controlled via said main adjustment means to cause vertical displacement of said shaft with respect to said upright support members and said cover.

6. Assembly according to claim **5** wherein said fine adjustment means are fixedly mounted on said cross-plate and control the vertical displacement of said shaft with respect to said cross-plate and in turn said cover.

7. Assembly according to claim **6** wherein drive means operatively connected to rotate said shaft and in turn said mixing member are mounted on said cross-plate.

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