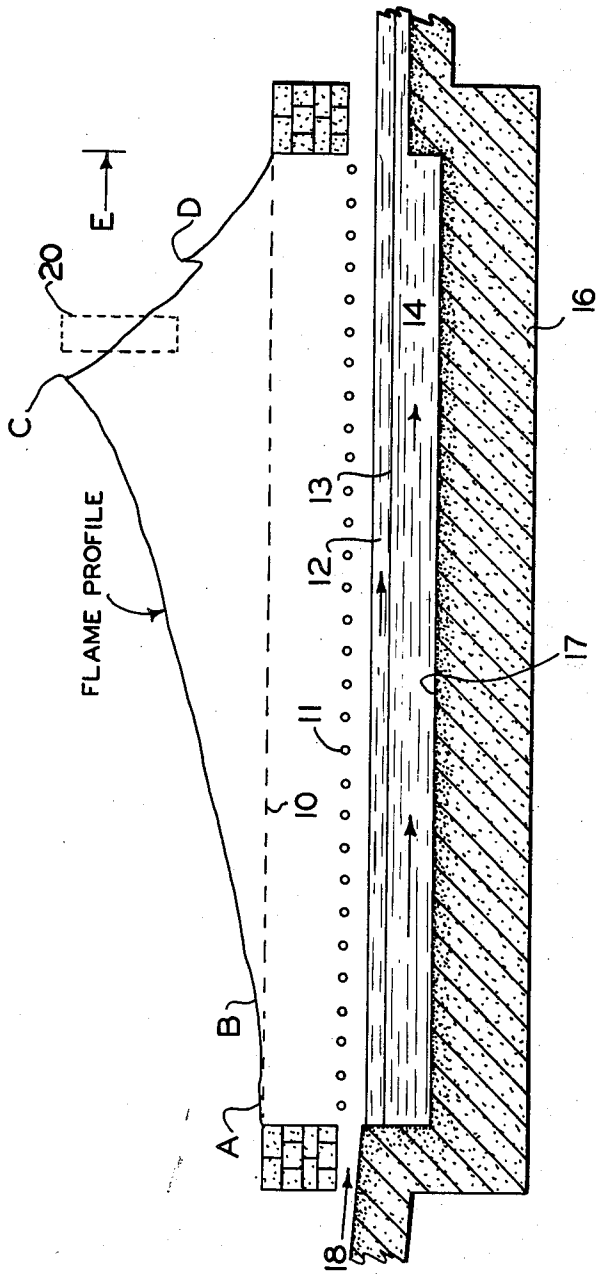
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PROFILE METHOD OF MAKING STEEL

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PROFILE METHOD OF MAKING STEEL

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7 Claims. (Cl. 75—60)

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My invention relates to metallurgy wherein molten iron containing carbon is bessemerized to yield a low-carbon iron.

This is a continuation-in-part of my application, Serial No. 745,853 of May 3, 1947, now abandoned, the continuation-in-part, Serial No. 29,029 of May 25, 1948, now abandoned, the continuation-in-part, Serial No. 152,650 of March 29, 1950, now abandoned, and my copending continuation-in-part, Serial No. 168,097 of June 14, 1950, now abandoned.

The principal objective of my invention is to provide the continuous bessemer process with a method of control; the lack of a method of control being a principal reason why steel metallurgists have never seriously undertaken to manufacture steel continuously. Other objects will be apparent in my specification and claims.

The expression "air" is employed to denote air, oxygen gas, concentrated oxygen gas, or air enriched with oxygen gas.

In a continuous bessemer process, the molten metal is confined to flow as a stream along a refractory trough as a series of air jets impinge into the flowing metal stream, said series of impinging jets being spread out sufficiently along said stream to resolve the refining reactions into a series of refining zones which gradually blend into each other, each of said refining zones being characterized by the substantially similar free energy of the reactions taking place therein. In general, the silicon and manganese are oxidized in the first of these zones, together with a certain amount of carbon. This first zone gradually blends into a second zone wherein the balance of the carbon is oxidized. If the process is being carried out under a basic slag, and under conditions wherein the iron oxide content of said basic slag is maintained at a relatively high level, the phosphorus and sulphur content of the flowing metal stream will pass into the basic slag stream as said metal stream flows thru zones one and two, so that, by the time that decarburization is essentially complete, the removal of the silicon, manganese, phosphorus and sulphur is essentially complete also. If, on the other hand, the iron oxide content of the basic slag stream is not maintained at a relatively high level, said decarburizing zone may be followed by a third zone wherein dephosphorization is achieved as the impinging air jets raise the oxygen level in the essentially-decarburized iron. In the event that the metal stream is flowing in contact with an acid slag stream, the refining process is divided into the mentioned zones one and two, dephosphorization and desulphurization not being a part of the process.

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Two methods of regulating this process are available: (1) by regulating the oxygen input into the flowing metal stream, and (2) by regulating the input of the raw iron into the process. Of these, the former is preferable. The input of oxygen into the flowing metal stream may be regulated by regulating the amount of oxygen being introduced by means of the impinging air jets, or by regulating the input of iron oxide into the flowing metal stream, or by regulating the iron oxide content of the molten slag stream in contact with which said metal stream is flowing, or by regulating several of these regulating means in combination. Of these, the simplest procedure is to form said air jets by means of orifices which are all connected to a common manifold, and then, by regulating the air pressure within said manifold, regulating the amount of oxygen being introduced into the metal stream. However, whichever method of regulating the process is to be used, it is first necessary to know just how the process is progressing.

The figure shows a refining trough in which my method of control is mounted. Trough 17 is formed by refractory body 16. Incoming raw metal 18 flows into trough 17 to form flowing metal stream 14, and stream 14 is refined as it flows along trough 17 by means of a series of impinging air jets which enter trough 17 thru ports 11, the refinement proceeding as said air jets impinge into contact with slag stream 12 and metal stream 14, the plane of contact between streams 14 and 12 being referred to as slag-metal interface 13.

I control the composition of the metal product by controlling the location of the flame profile that appears above datum line 10—datum line 10 being, at once, the top of trough 17 and the visible base of the flame profile appearing thereabove, as seen by an observer positioned to one side of trough 17, as in the figure. The flame profile appearing above any given position along the decarburizing phase of the process bears a simple and direct relationship to the progress of the reactions taking place therein and thereunder, for said flame profile arises from said reactions. Accordingly, I spread out the flame profile along stream 14 within trough 17 so that I may see a substantially continuous picture of the progress of the reactions which are taking place therealong. With the reactions spread out sufficiently to resolve the flame profile into discernible features which picture the progress of the process,

I act to control the composition of the metal product by fixing at least one of said discernible flame features at a predetermined location along stream 14 within trough 17.

Incoming raw iron 18 immediately comes under the oxidizing influence of the impinging air jets and slag stream 12 when said iron 18 enters trough 17 to form flowing metal stream 14. At the outset, the impinging air jets cause a short, intense flame to appear above datum line 10—the beginning of this short flame being represented as A. As stream 14 flows along trough 17, the silicon and manganese are oxidized, together with a certain amount of carbon—the progress of these reactions being represented by a flame profile that may assume the general shape shown between A and B. As the flow proceeds, and the temperature of stream 14 mounts, the height of the flame profile gradually mounts also—due, in the main, to an intensification of the decarburizing reaction. The progress of this intensification is shown by the flame profile and may take the general form shown between B and C—C representing the decarburizing reaction at the height of its intensity. As C is passed, the profile of flame falls into a rapid decline or break, represented between C and E. D represents an arrest that sometimes occurs in break C—E, particularly in an acid practice, being presumably the result of the sudden oxidation of some compound or element that yields a flame of high luminosity. Following arrest D, or in the absence of arrest D, the profile of flame continues to decline until E is reached. E represents the process end point or terminal point, insofar as the oxidation of carbon is concerned, and, as mentioned previously, E may be caused to represent the point whereat the elimination of carbon, silicon, manganese, phosphorus and sulphur is complete—that is, to the degree contemplated by the process.

The profile of flame arising from a continuous bessemer process may be resolved into the required discernible features by any method that will spread out the reactions along the metal stream within the refining trough. Thus, the profile may be spread out by increasing the distance between ports 11, and thereby increasing the length of said profile and the refining area by delaying the progress of the reactions, or said profile may be spread out by decreasing the input of air thru said ports 11 and then increasing the number of ports 11 at one, or both, ends of the refining area, thus lengthening the refining area and delaying the progress of the reactions.

It is essential to the success of my control process that incoming raw iron 18 be uniform with respect to temperature, chemical composition, and its rate of input into stream 14. This is not to say that changes cannot be tolerated, but only that such changes must be made gradually; for, the flame profile cannot be satisfactorily employed to control the process if sudden changes in temperature, chemical composition, and/or rate of raw metal input are being continually encountered. This uniformity requirement does not offer any serious handicap to my control process, for this uniformity problem has long since been solved in conventional steel plants by means of the hot-metal mixer. The rate of flow of raw iron 18 into stream 14 may be regulated in a number of ways. Thus, for example, the hot-metal mixer may be equipped with a replaceable carbon orifice that is submerged below the surface of the molten metal contained therein, and then, with the molten metal passing thru a weighing device as it emerges from said orifice and flows into stream 14, the rate of input into said stream 14 may be regulated by regulating the depth of immersion of said orifice. This method of regulating the rate of input of raw iron 18 into stream 14 was disclosed and claimed in my copending application, Serial No. 213,718 of March 3, 1951, now abandoned.

Whether the continuous bessemer process is operating under a basic or an acid slag, the procedure for placing my control method into operation may be substantially as follows: with stream 14 flowing along trough 17 at a uniform rate—the temperature and chemical composition of incoming raw iron 18 being uniform, the impinging air jets are brought to bear on the flowing metal stream, causing the erection of a profile of flame above datum line 10. The input of oxygen into stream 14 is increased until the metal that has passed the last impinging air jet conforms in composition to the desired product—presumably, but not necessarily, an iron containing about 0.05% carbon. With the process producing the desired product, the flame profile is examined for the flame feature that is to be employed for control purposes. In general, the flame feature should be selected from that portion of the profile of flame lying between C and the point along stream 14 whereat the profile of flame disappears below datum line 10. The nearer the selected flame feature is to the point whereat the profile disappears below datum line 10, the more accurate and responsive will be the controlling action. An arrest, D, may be the selected feature, or the point whereat the profile disappears below datum line 10 may be selected as a suitable feature, or the height of the flame profile at a selected position in the C—E break may be chosen as a suitable feature. In any case, with the process producing the desired product, the position of the selected flame feature along stream 14 within trough 17 is noted. With the location of the selected feature noted, the continued production of the desired product is assured so long as said selected feature remains at its noted location.

The selected flame feature may be held at its noted location by means of the previously-listed methods of regulating a continuous bessemer process; that is, by regulating the input of oxygen or raw iron 18 into stream 14. If, for example, in an acid bessemer process, the desired carbon content is, say 0.06%, and the selected flame feature is that point along stream 14 whereat the profile disappears below datum line 10, and, with the process producing the desired product when said profile disappears below datum line 10 at that point along stream 14 where the last of the impinging air jets is located, then said feature may be held at said last impinging air jet by increasing or decreasing the input of oxygen into stream 14, as may be required. Thus, if said feature moves upstream away from said last jet, then the carbon content of the metal product is falling below the desired 0.06% value, and said carbon content of the metal product may be restored to the desired 0.06% level by decreasing the input of oxygen into stream 14 until said selected feature returns to said last impinging jet, by decreasing the input of air into said stream of metal. If, on the other hand, said selected flame feature moves downstream from said last jet, then the carbon content of the metal product is rising above the desired 0.06% value, and the

carbon content may be restored to the desired 0.06% value by increasing the input of air into stream 14 until said selected feature is returned to said last jet.

The input of oxygen into stream 14 by means of the impinging air jets may be regulated by regulating each air jet independently, by regulating groups of said air jets together, by regulating the oxygen content of said air jets, or by regulating all jets together.

Another method of regulating the location of the selected flame feature is by varying the rate of input of raw iron 18 into stream 14. Thus, if the selected feature moves upstream, said feature may be returned to the desired location by increasing the rate of input of raw iron 18 into stream 14; and if, on the other hand, the selected feature moves downstream, said feature may be returned to the desired location by decreasing the input of raw iron 18 into stream 14.

When slag stream 12 contains iron oxide that was formed outside of the process, being added thereto in order to maintain the iron oxide content of stream 12 high and/or to increase the yield of the process, then a portion of the oxygen utilized in the process will be derived from said added iron oxide. While the process could, perhaps, be controlled in a crude sort of way by maintaining the oxygen input via the air jets at some constant level, while varying the iron oxide additions to slag stream 12 in order to hold the selected flame feature at its preselected location, such a procedure would be very sluggish in its action; however, if a powdered iron oxide is entrained in the air jets by the fluidized solids techniques, and the jets are impinging directly into or thru metal stream 14, then the process may be satisfactorily controlled by controlling the amount of iron oxide being introduced as fluidized solids entrained in said air jets.

Assuming all process variables to be substantially constant, the height of the flame profile immediately above a given carbon value in stream 14 will be substantially constant. Accordingly, the selected flame feature may be a selected flame height that is indicative of the attainment, in stream 14, of the carbon level that is a process objective. Thus, if the desired carbon level of the metal product is, say, 0.25%, then the height of the flame profile that represents 0.25% carbon may be held at the point where stream 14 leaves trough 17 to assure the production of a product containing 0.25% carbon.

While the shape of the profile of flame between A and C is not particularly important, the profile between C and E must conform to very definite requirements if my control method is to be firm. If the D point is being employed as the selected feature, the angle of slope of the C—E break must be gradual enough to permit the D point to be readily observed by the human eye; however, said slope should not be so gradual that the selected feature disappears by being spread out over too great a distance.

In tests which I made, I observed that the angle of slope of the profile of flame should be held in the range between 65° and 10° of datum line 19 as said flame profile approaches and reaches the end point of the process. I found that when the angle of slope was much above 65°, the end point was approached and passed so rapidly that little accurate control could be achieved, and the process yielded a product that varied as the end point swung back and forth around the selected location—this being particularly true when I attempted to cut off the process at about 0.25% carbon with a steep angle of decline, for in this case a comparatively-short length of the profile represented a very large change in the composition of stream 14, and as I moved the profile back and forth around the terminal point in an effort to hold my selected feature at said terminal point, the metal product varied seriously in composition—for example, while aiming at 0.25% carbon in one test, two samples of the metal product taken within one minute of each other varied from 0.19% to 0.35% carbon. When I operated the process with the angle of decline below 65°, however, I had little trouble holding the carbon content of the metal product close to the 0.25% value that I was aiming at. All things considered, I found that the best angle of decline was about 35°, and I found that when I desired to interrupt the process with the carbon level substantially above 0.06%, the more gradual the angle of decline, the better the control; however, I found that when the angle of decline was less than 10° off datum line 19, the profile of flame became quite indistinct and ragged, with the result that I had a very difficult time controlling the process. It was assumed that the indistinct character of the profile of flame when the angle of decline was below 10° was due to the fact that the process had been spread out so much along stream 14 that the decarburizing reaction no longer proceeded at a uniform rate towards the end point, but, rather, assumed the general character of the open-hearth type of decarburizing process wherein decarburization proceeds erratically—more specifically, the rate of oxygen input into the metal falls behind the requirements of the process, resulting in periods of process quiescence.

If my process is being employed to control a continuous bessemer process wherein dephosphorization is being carried out under a basic slag, my control process may be placed in operation by the previously-discussed procedure; the terminal point of the process being that position along stream 14 where the carbon content of said stream 14 has fallen to about 0.05%. Whether the attainment of this terminal point will indicate that the phosphorus has been removed also, depends upon the circumstances surrounding the operation. In general, dephosphorization will be essentially complete by the time that decarburization is essentially complete when the air jets are impinging into the basic slag and metal stream from a position that lies above said slag stream, especially when the slag and metal streams are flowing in counter-current contact with each other, for then the iron oxide content of the slag stream remains high and dephosphorization is achieved at the low temperature end of the trough—circumstances which favor dephosphorization. Dephosphorization will follow decarburization when the air jets are impinging into the metal stream from a position below the surface of said metal stream and when no particular attention is being paid to the maintenance of a high iron oxide content in the basic slag—by iron oxide additions thereto, for example.

The sequence of oxidation is also sensitive to the temperature of the flowing metal stream. Thus, with the temperature on the cold side, the silicon and manganese will tend to leave the metal well ahead of the carbon, while phosphorus will tend to leave the metal with the carbon if the composition of the slag favors phos-

phorus retention—a high V-ratio and iron oxide content. With the metal stream on the hot side, the oxidation of silicon and manganese and phosphorus will be delayed somewhat. However, whatever the oxidation sequence may be, by controlling the carbon terminal point at a preselected location along stream 14 I may control the overall process; for, in any given situation, said carbon terminal point will always bear a substantially-fixed relationship to the oxidation sequence being entertained.

Even tho the oxygen enters the flowing metal stream in a manner that concentrates the oxidizing action in the areas which comprise the points of impingement, the elimination of the carbon is not confined to these concentrated areas of air impingement, due to the fact that the decarburizing reaction does not take place at said points of impingement, but, rather, takes place in contact with the rough hearth and sidewalls of the refining trough. This delay between action and reaction spreads out the oxidizing effect of the jets so that the effect of each jet blends into the effect of the adjoining jets. While it might be convenient to have each jet feed the same amount of oxygen into the process, this is not essential to the success of my control process, due to the aforementioned spreading-out action of the decarburizing reaction. Furthermore, this spreading-out action tends to minimize the effect that might otherwise arise when orifices which feed air into the process become stopped-up with solidified slag and/or metal. The effect of stopped-up orifices may be offset, in part, by feeding said orifices with a common manifold wherein the air pressure rises when an orifice becomes clogged—an action that may be achieved by feeding the air into the manifold on a constant weight basis.

While I have described the use of the flame profile to observe the conversion of pig iron into steel, my control method may be employed in a refining process wherein a part of the decarburization is being carried out in a metallurgical vessel other than a trough as hereinbefore described. Thus, molten pig iron may be continuously introduced into an open-hearth furnace or into an electric-arc furnace, being permitted to continuously flow out of said furnace after the carbon content of the metal has been lowered to a point whereat continuous bessemerization in a refining trough will yield the declining flame profile wherein is located one of my flame features, and then, by continuously flowing said open-hearth/arc-furnace metal to a refining trough, completing the decarburization as herein described. The refining in the open-hearth/arc furnace may be carried out in manners conventional with this type of steel making, with the view of lowering the carbon content of the metal to, say, 1.00%, before flowing said metal to the refining trough for finishing.

My control process is concerned primarily with that portion of the flame profile immediately ahead of, or upstream from, the aforementioned point whereat the decarburizing process is to be terminated; for, as has been pointed out, it is within this section of the profile that the features employable for control are to be found. The flame above the metal stream wherein the carbon is still very high contributes very little to the control picture, and, accordingly, the carbon monoxide burned in forming this upstream flame is wasted, insofar as control is concerned. Accordingly, I may modify my previously-described process by providing this upstream portion of the trough with a cover or roof (not shown), so that only that portion of the evolved carbon monoxide which yields my selected flame feature is allowed to burn over the trough. Thus, for example, I may cover the flowing metal stream in the region between the aforementioned A and C points, so that the carbon monoxide evolved between said A and C points may be withdrawn from the trough without contacting the air lying thereover, so as to save said monoxide for more useful purposes, said monoxide being withdrawn from the covered trough via suitable ducts (not shown). Then, by allowing the monoxide evolved between C and E to burn freely over the uncovered portion of the trough, I may control the process. Obviously, if the air jets in the covered portion of the trough are impinging into the metal stream from a position located above said stream, a portion of the evolved monoxide will be burned in reaction with said jets.

The previously-described features of the profile of flame which may be employed to control a continuous bessemer process are all of the type that must ordinarily be observed by the human eye. As mentioned previously, the flame height may be employed as the selected feature, for the height of the flame over a given portion of the decarburizing process is related to the progress of said decarburizing process. By viewing a portion or section of the profile thru a viewing slit 20 in the region where the profile is rapidly declining as the process approaches the terminal point, by means of an electric eye that is connected to measuring means, movements of the flame profile upstream or downstream may be electrically detected and followed; for, as in the figure, when said profile moves downstream, the amount of light passing thru slit 20 increases, and when said profile moves upstream, the amount of light passing thru slit 20 decreases. Slit 20, in order to be fully responsive to profile movements, should be oriented with respect to the angle of decline so that profile movements are reflected by large changes in the amount of light passing thru slit 20. The amount of light passing thru slit 20 may be measured and/or recorded by conventional methods and means; that is, by a photoelectric cell that is connected to a suitable meter for measuring/recording the current that is generated/passed by said cell when said light passes thereinto. A further refinement involves the connection of electronic measuring means to control equipment, so that profile movements, detected and measured by an electric-eye measuring means, are immediately and automatically offset as said electronic measuring means actuates a control mechanism that adjusts the input of air into the refining process, said adjustment being in accordance with the degree that the process has departed from normal. It will be realized, accordingly, that that portion of the flame profile which is viewed thru slit 20 is but another flame feature that may be employed to control the continuous bessemer according to my method.

Still another flame feature that may be employed is the temperature attained by the gas at some selected distance above the profile, and this temperature feature may be employed to automatically control the position of the profile over the trough in the manner just mentioned in connection with slit 20. For example, one or more thermocouple(s) may be positioned over the profile of flame and over the position whereat it is

desired to terminate the decarburizing process, said thermocouple(s) being positioned above and, say, one foot away from the flame, said thermocouple(s) being connected to suitable measuring, recording and/or recording equipment. When, now, the profile of flame moves downstream, it approaches closer to said thermocouple, resulting in an immediate reaction on the part of the control equipment connected to said thermocouple—in this case, said control equipment will increase the oxygen input into the process until the profile of flame moves back to the position describable as the neutral point, and if, on the other hand, the profile of flame moves upstream away from said thermocouple, said thermocouple will record a lower temperature, and so act to actuate the connected control mechanism so as to decrease the input of oxygen until said profile returns to the desired position.

The molten metal being bessemerized will always contain carbon; however, said molten metal may or may not contain other oxidizable impurities. Accordingly, I refer in my claims to the molten raw iron whose refinement is to be controlled by my profile method of control as: molten high-carbon iron, and I refer to the product of the process controlled by my method as: molten low-carbon iron.

There are two basic reactants involved in my control process, namely, oxygen and molten iron containing carbon. The expression "oxygen" is employed in my claims to denote said reagent: oxygen. As mentioned previously, the continuous bessemer process may utilize oxygen derived from a number of sources; for example, the process may utilize the oxygen being introduced into the slag and/or metal thru the instrumentality of the impinging air jets, or said process may utilize the oxygen content of iron oxide being fed into said slag and/or metal, or said process may utilize the oxygen content of the molten slag stream in contact with which the metal stream flows, or the process may employ a combination of these oxygen sources at different, or the same, time.

Having now described several forms of my invention, I wish it to be understood that my invention is not to be limited to the specific form or arrangement of steps hereinbefore shown and described, or except insofar as such limitations are specified in the appended claims.

I claim as my invention:

1. In a continuous bessemer process wherein flame appears above and along a trough within which a stream of high-carbon iron is decarburized with the aid of a series of air jets, the method of controlling said decarburizing process, which comprises: introducing oxygen into the stream of molten metal within said trough so that the profile of the flame above the concluding portion of said decarburizing process declines as the carbon content of said metal stream declines, the angle of said decline being within the range between 10° and 65° from the surface of said stream of molten metal; and selectively increasing or decreasing the input of oxygen into said decarburizing process so that a discernible feature of said flame profile within said decline is maintained at a substantially-fixed position along the stream of molten metal within said trough.

2. The method according to claim 1 in which said discernible flame feature is the height of the profile of said flame above said position along said stream of molten metal within said trough.

3. The method according to claim 2 in which said flame height is measured by viewing a portion of said flame profile by means of a photoelectric cell positioned to view said flame profile at said position along said stream of molten metal within said trough.

4. The method according to claim 2 in which said flame height is measured by means of a thermocouple that is positioned above and normally out of direct contact with said flame at said position along said stream of molten metal within said trough.

5. The method according to claim 1 in which said discernible flame feature is the position along said trough where the profile of said flame essentially disappears below the top of said trough.

6. The method according to claim 1 in which said discernible flame feature is an arrest in the rate of decline of the profile of said flame as said process approaches its conclusion.

7. The method according to claim 1 in which carbon monoxide arising from said decarburizing prior to said concluding portion of said decarburizing process is withdrawn from said trough without being permitted to burn over said trough.

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