CONTROL FOR BASIC OXYGEN STEELMAKING FURNACE

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Field of Search .......... 75/59, 60

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ABSTRACT

Method for controlling the refining of a molten bath of steel in a basic oxygen vessel by the steps of continually measuring the intensity of the flame at the mouth of the vessel and the flow rate of oxygen into the vessel, determining from a consideration of flame intensity drop-off a bench mark signaling that the oxygen blow and carbon removal processes are in the final stages, computing the amount of carbon remaining in the bath and the carbon removal rate at the bench mark, and thereafter periodically computing the amount of carbon left in the bath until computed carbon left matches the desired carbon content in the refined steel, whereupon the oxygen blow is terminated.

6 Claims, 3 Drawing Figures
FIG. 2A

FIG. 2B
CONTROL FOR BASIC OXYGEN STEELMAKING FURNACE

BACKGROUND OF THE INVENTION

As is known, the primary purpose of a basic oxygen steelmaking furnace operation is the elimination of carbon from the scrap and hot metal charged to thereby quickly and economically produce a mass of molten steel which may be alloyed and made into a specific product. Operational practices which increase the time required to produce a heat of steel or which reduce the overall yield from the furnace are detrimental to the economics of the operation. Operational practices which reduce heat time or increase yield are economically beneficial. One important consideration, particularly in a plant producing low carbon steels, is the determination of end-point carbon. If the blowing operation is discontinued prematurely (i.e., the end-point carbon level is higher than required) it is necessary to reblow the heat. In addition to extending the heat time, the reblow operation has been observed to reduce yields and influence certain quality factors. Overflowing the heat (i.e., discontinuing the blow at a carbon level significantly below the desired level) results in excessive oxidation of other materials and reduces yield. It is highly desirable, therefore, to provide a method which will respond to the dynamics of the basic oxygen furnace operation and predict the carbon content of the bath during the final seconds of the blow, in order that the blow can be stopped at the desired carbon end point.

SUMMARY OF THE INVENTION

In accordance with the present invention, end-point carbon is determined primarily from a consideration of the intensity of the flame at the mouth of the basic oxygen vessel, together with the flow rate of oxygen into the vessel and the total oxygen consumed at the point of bench mark recognition. The bench mark is defined as the point at which flame intensity with respect to time drops along a predetermined slope. Bench mark recognition is achieved by periodically sampling a signal proportional to flame intensity and comparing the samples with stored empirical data in a computer in accordance with pattern recognition techniques. Once the bench mark is detected, the computer computes the initial estimate of carbon in the bath in accordance with the equation:

\[ C_e = k_1 + k_2 \left( FR / O_2 C \right) \]

where:
- \( FL \) is the value of the flame intensity at the point of bench mark recognition;
- \( O_2 C \) is the total oxygen consumed from the beginning of the blow to the point of bench mark recognition;
- \( k_1 \) and \( k_2 \) are coefficients based on empirical data.

At the same time, (i.e., at the point of bench mark recognition) the base carbon removal rate is determined in accordance with the equation:

\[ XRM = k_3 \left( O_2 C \right) \]

where:
- \( k_3 \) is an empirically determined coefficient.

Having established these base conditions with the equations given above, a continuous prediction, once each second, is estimated by the computer from the relation:

\[ C_t = C_{t-1} - \Delta C_t \]

where:
- \( C_t \) is the instantaneous value of predicted carbon in the bath;
- \( C_{t-1} \) is the previous value of predicted carbon in the bath taken one second before; and
- \( \Delta C_t \) is the difference between \( C_t \) and \( C_{t-1} \).

\( \Delta C_t \), in turn, is determined once each second from the equation:

\[ \Delta C_t = \left( k_4 + k_5 \cdot C_{t-1} \right) \times \left( k_6 \times XRM \times \left( FL / FL_0 \right) / O_2 FR \right) \]

where:
- \( FL \) is the current flow intensity as measured by the smoothed signal;
- \( O_2 FR \) is the present oxygen flow rate; and
- \( k_4 \), \( k_5 \), \( k_6 \) are empirically derived coefficients.

As will appreciated, appreciated a vital part of the process is the initial recognition of the bench mark; and this is dependent upon a plot of flame intensity versus time or, more particularly, the slope of a curve defining flame intensity versus time. Since vessel additions may be made prior to the time of bench mark recognition which would give a false indication of the occurrence of a bench mark, means are provided to prevent initiation of the program for determining bench mark recognition until a short time before the end of the blow when a true bench mark recognition can occur. Usually this means comprises apparatus for determining total oxygen flow, the arrangement being such that if total oxygen flow has not exceeded a predetermined minimum, it is known that a true bench mark cannot occur since the refining process has not progressed far enough for this condition to occur.

Either a running indication of carbon content can be displayed to an operator such that he can terminate the blow when the indicated carbon content reaches that specified for the steel being blown, or the blow can be terminated automatically when the desired carbon content is reached.

The above and other objects and features of the invention will become apparent from the following detailed description taken in connection with the accompanying drawings which form a part of this specification, and in which:

FIG. 1 is a schematic diagram illustrating the process of the invention; and

FIGS. 2A and 2B are illustrations of flame intensity versus time before and after filtering, respectively, and showing the manner in which a bench mark is recognized.

With reference now to the drawings, and particularly to FIG. 1, a basic oxygen converter 10 is shown comprising an outer steel shell 12 provided with an inner refractory lining 14 and having an upper open mouth 16. Extending through the mouth 16 is a water-cooled lance 18 having a water inlet pipe 20, an interior cooling passage 22 and a water outlet pipe 24. The lance 18 is also connected to suitable lance-raising means, not shown.
3,719,469

3. The vessel 10 contains a bath 26 of molten metal, above which there may be a layer 28 of slag. The vessel 10 is adapted to be turned on trunnions 30 by conventional means, not shown. This permits the discharge of the finished steel through the mouth 16 or, if desired, through a suitable tap hole in the side of the vessel. Oxygen is fed from a supply means 32 through a line 34 containing a valve 36 such that when the refining is in progress, the bath 26 is impinged upon, as at 38, with the jet of oxygen issuing from the lance 18 penetrating the bath 26 more or less deeply, depending upon the position of the lance and the velocity of the oxygen jet. Those skilled in the art will understand that the apparatus thus far described is conventional.

A flame intensity sensing means 40 is trained upon an area of the side of the lance 18. Since the lance is water-cooled, this area of the lance will be essentially black and will emit no radiation. This is necessary to prevent radiation from the hot walls of the vessel, for example, from affecting flame intensity readings.

The flame intensity sensing means 40 may comprise any one of a number of suitable devices, as will be understood by those skilled in the art. For example, a bolometer might be used. It is preferred, however, to use a photovoltaic energy converter, and in particular, a semiconductor photovoltaic energy converter or solar cell. Satisfactory results have been obtained with a Land-type 60Q 35-50-48 Silicon Solar Cell with a 0.750 inch aperture. Although various physical arrangements are possible, satisfactory results have been obtained with such a cell, enclosed in a 2-foot pipe which serves to protect the lens of the cell from a buildup of dust particles, the pipe being attached to a swivel mount and this entire assembly being covered with a steel cage, in order to prevent accidental movement of the cell. The signals produced by the flame intensity sensing means 40 are filtered in a filter circuit 42 and applied to a digital computer, as described in Section 44 of 44. Other inputs to the digital computer 44 include a signal on lead 46 derived from a flow meter 48 proportional to the oxygen flow rate through the lance 18. The third input to the computer 44 is pulses from pulse generator 50 on lead 52, the number of which is indicative of the total oxygen consumed during a blow.

With reference now to FIG. 2A, the output signal derived from the intensity detector 40 during a typical oxygen blow is shown. The graphs of FIGS. 2A and 2B cover only the latter part of an oxygen blow, about seven minutes. The total blow takes about 20 to 25 minutes. Note that at the beginning of the last 7-minute period, the flame intensity is relatively high; however as the blow continues and the carbon and other impurities are burned out of the steel, the intensity gradually diminishes. In FIG. 2B, the output of the filter circuit 42 is shown. Note that between times t1 and t2, the curve 54 moves along a plateau. However, at time t2, it begins to move downwardly with decreasing flame intensity along a more or less constant slope. This is utilized in accordance with the invention in order to determine a bench mark 56, at which point an initial carbon prediction is made and carbon predictions are thereafter made at 1-second intervals until the termination of the blow. It is during the period between time t2 shown in FIG. 2B and the end of the blow that most of the carbon is burned out of the molten metal.

It may happen that because of additions to the ladle during a blow or for other reasons, the flame intensity may drop prematurely and before the true bench mark point is reached, indicating the final stages of the blow. For this reason, the pulses on lead 52 are counted within the computer 44, and if the count indicates that not enough oxygen has been blown onto the surface of the molten bath to justify a conclusion that the bench mark has been reached, then the computer program for determining the carbon remaining in the bath will not be initiated.

The computer 44 is provided with an input panel 58 which feeds signals to the computer 44 indicating that the oxygen is ON, that the oxygen is OFF, that additions are being made to the vessel 10, and that the vessel is being tapped. The "oxygen ON" signal initiates the computer program while the "oxygen OFF" signal terminates the program. Furthermore, the vessel addition signal interrupts the computer program such that a false indication of the bench mark 56 shown in FIG. 2B will not occur when additions are being made to the vessel. The vessel tap signal is necessary to indicate the end of the current heat and permits initialization of all software for the subsequent heat.

Once the "oxygen ON" signal from the input panel 58 is applied to the computer, a sampling circuit 60 samples the output of filter circuit 42, which is an analog signal, once each second. These samples are then compared in accordance with pattern recognition techniques in comparator 62 with stored data in a storage bank 64 in the computer. When the samples indicate that the bench mark has been reached, the comparator produces an output signal on lead 66 to initiate the program for determining the carbon content of the steel within the vessel 10. Note that the pulses on lead 52, the number of which is proportional to total oxygen flow into the vessel, are counted by counter 68. Until the count of counter 68 reaches a predetermined level, indicating that the blow is in the region where a bench mark can occur, a disabling signal is applied to the comparator 62 such that it cannot initiate the carbon removal program.

As was explained above, the carbon removal program initially determines the carbon remaining in the melt at the point of bench mark recognition and thereafter calculates, once each second, the carbon removed during that second. The carbon removed during the time period is then subtracted from the previously determined carbon content to derive the instantaneous carbon content in the bath.

The initial carbon content \( C_0 \) is determined in circuitry 70 within the computer in accordance with the equation:

\[
C_0 = k_1 + k_2 \left( \frac{F_t}{O_t} \right)
\]

where:

- \( C_0 \) = initial carbon content;
- \( F_t \) = the flame intensity at the point of bench mark recognition;
- \( O_t \) = the oxygen consumed at the point of recognition; and
- \( k_1 \) and \( k_2 \) are empirically derived coefficients.

Accordingly, it is necessary to apply to the circuit 70 a signal on lead 72 representative of the total oxygen consumed and a signal on lead 74 indicative of the flame intensity.
When the bench mark is recognized, it is also necessary to determine the carbon removal rate, \( XRM \), in accordance with the equation:

\[
XRM = k_2(O_2C)
\]

where:

\( O_2C \) is the oxygen consumed at the point of bench mark recognition; and

\( k_2 \) is an empirically derived coefficient.

This computation is performed in circuitry represented by the reference numeral 76 in FIG. 1 which has applied thereto the output of counter 68 representing \( O_2C \).

The constants \( k_1 \), \( k_2 \) and \( k_3 \) in Equations (1) and (2) above are determined from actual operating experience. The technique used is simple linear regression analysis which determines a "least squares" fit of a curve to the data points. In determining \( k_1 \) and \( k_2 \), for example, the quantity \( C_{n+1} \) determined by chemical analysis is plotted against the ratio \( FL'/O_2C \) for various samples. The resulting curve is defined by Equation (1) above and from this \( k_1 \) and \( k_2 \) can be determined. A similar technique is used to determine \( k_3 \).

Having thus determined the carbon content in the bath, \( C_n \), and the carbon removal rate, \( XRM \), at the point of bench mark recognition, the computer then computes, once each second, the difference in carbon content, \( \Delta C_t \), representative of the difference in carbon content between the reading just taken and the preceding reading. This is performed in circuitry represented by the reference numeral 78 in FIG. 1 in accordance with the equation:

\[
\Delta C_t = (k_4 + k_5 \cdot C_{n+1}) \times (k_6 \times XRM \times (FL'/FL))O_2FR
\]

where:

\( C_{n+1} \) is the previous estimate of carbon level;

\( FL' \) is the current flame intensity as measured by device 40;

\( FL \) is the flame intensity associated with the point of bench mark recognition;

\( O_2FR \) is the present oxygen flow rate as derived from lead 46 connected to flow meter 48; and

\( k_4, k_5 \) and \( k_6 \) are empirically derived coefficients.

\( k_4 \), \( k_5 \) and \( k_6 \) are again determined from actual operating data using the mathematical technique of multiple regression analysis.

Having determined \( \Delta C_t \), it is then necessary to determine \( C_t \), which is the instantaneous carbon level in accordance with the equation:

\[
C_t = C_{n+1} - \Delta C_t
\]

In order to do this, the value of \( C_t \) is stored in a moving table 82 during the next one-second sampling period. The previous value for \( C_t \) becomes \( C_{n+2} \) and is fed back into the circuit 80 for computation of a new value of \( C_t \) which, in turn, is fed back to the moving table 82.

Having determined \( C_t \), this can be displayed to an operator whereby he can terminate the oxygen flow when the indicated level of oxygen matches that required for a specific steel analysis. Alternatively, an electrical signal proportional to desired carbon content can be compared in comparator 84 with the calculated value of \( C_t \) from circuit 80. When the two are the same, a signal on lead 86 will cause oxygen flow control means 88 to shut off valve 24 and, hence, terminate the flow of oxygen to the bath.

The following table gives the ranges of constants \( k_1-k_6 \) for Equations (1-3) above:

<table>
<thead>
<tr>
<th>Constant</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>( k_1 )</td>
<td>0.06</td>
<td>0.10</td>
</tr>
<tr>
<td>( k_2 )</td>
<td>0.008</td>
<td>0.12</td>
</tr>
<tr>
<td>( k_3 )</td>
<td>1.70 ( \times 10^{-4} )</td>
<td>1.93 ( \times 10^{-4} )</td>
</tr>
<tr>
<td>( k_4 )</td>
<td>2.80</td>
<td>3.22</td>
</tr>
<tr>
<td>( k_5 )</td>
<td>3.50</td>
<td>4.50</td>
</tr>
<tr>
<td>( k_6 )</td>
<td>0.35</td>
<td>1.35</td>
</tr>
</tbody>
</table>

\( k_1, k_3 \) and \( k_4 \) are not actually constants but variables which are constant for a given blow only. Using feedback on actual performance, these parameters are evaluated after each heat and long range adaptive corrections made on actual performance. The manner in which these corrections are programmed into the computer is well within the skill of the art.

Although the invention has been shown in connection with a certain specific embodiment, it will be readily apparent to those skilled in the art that various changes in form and arrangement of parts may be made to suit requirements without departing from the spirit and scope of the invention.

I claim as my invention:

1. In the method for controlling the refining of a molten bath of steel in a basic oxygen vessel, the steps of continually measuring during an oxygen blow the intensity of the flame at the mouth of the vessel, continually measuring the flow rate of oxygen into the vessel and the total flow of oxygen into the vessel, determining from a consideration of measured flame intensity drop-off a bench mark signaling that the oxygen blow is in its final stages, periodically electrically computing carbon in the bath at the point of bench mark recognition from the equation:

\[
C_t = k_1 + k_2 (FL/O_2C)
\]

where \( C_t \) is the carbon in the bath at the point of bench mark recognition, \( k_1 \) and \( k_2 \) are constants determined by linear regression analysis, \( FL \) is the value of the flame intensity at the point of bench mark recognition and \( O_2C \) is the total oxygen consumed from the beginning of refining to the point of bench mark recognition, thereafter periodically computing from the point of bench mark recognition the amount of carbon left in the bath and stopping the oxygen blow when the computed amount of carbon left in the bath reaches a desired carbon level, and after each refining process computing the constants \( k_1 \) and \( k_2 \) based upon the values of \( C_t \) and \( (FL/O_2C) \) for the previous refining process and using the new computed values for a succeeding refining process.

2. The method of claim 1 including the step of determining the carbon removal rate at the point of bench mark recognition from a consideration of the total oxygen flow into the vessel at the point of bench mark recognition.

3. The method of claim 2 wherein the carbon removal rate at the point of bench mark recognition is determined from the equation:

\[
XRM = k_3 (O_2C)
\]

where \( XRM \) is the carbon removal rate at the point of bench mark recognition, \( k_3 \) is a constant determined by linear regression analysis from actual operating experience and \( O_2C \) is the total oxygen consumed from the beginning of refining to the point of bench mark recognition.
4. The method of claim 3 including the step of computing $k_2$ after each refining process based upon the values of $XRM$ and $(O_2C)$ for the previous refining process and using the new computed value of $k_2$ for the next refining process.

5. The method of claim 1 wherein the amount of carbon left in the bath at any point, $C_n$, is computed from the equation:

$$C_n = C_{n-1} - \Delta C_n$$

where $C_{n-1}$ is a previous value of predicted carbon as computed according to the method of claim 6 and $\Delta C_n$ is the difference between $C_n$ and $C_{n-1}$.

6. The method of claim 5 wherein $\Delta C_n$ is computed from the equation:

$$\Delta C_n = (k_1 + k_2 + k_3) \times (k_4 \times XRM \times (FL/FL) \times O_2FR)$$

where $k_1$, $k_2$, and $k_3$ are constants, $FL$ is the flame intensity at the point of bench mark recognition, $FL'$ is the current flame intensity, $O_2FR$ is the current oxygen flow rate and $XRM$ is the carbon removal rate at the point of bench mark recognition.

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