APPARATUS FOR CONTROL OF CARBON CONTENT IN STEEL PRODUCED IN BASIC OXYGEN FURNACE PROCESS

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References Cited

UNITED STATES PATENTS
3,372,023 3/1968 Kainer et al. 266/35 X
2,843,007 7/1958 Galey et al. 356/47


OTHER PUBLICATIONS


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ABSTRACT

This patent discloses an improvement in a basic oxygen furnace steelmaking process in accordance with which steel of desired carbon content is produced by observing the intensity of the flame at the mouth of the steelmaking vessel and controlling the supply of oxygen to the vessel in accordance with the above-mentioned observations. The control action taken as a result of the observations may be quite simple, e.g., termination of oxygen supply, or somewhat more complex, e.g., adjustment of lance position or oxygen-supply rate. As desired or needed, equipment of greater sophistication such as digital-computer means may be used to analyze the observations and determine the time of taking the necessary control action.

7 Claims, 5 Drawing Figures
FiG. 1

1. OXYGEN SUPPLY MEANS
   26
   27
   29
   16
   12
   10
   14
   18
   32
   8
   2
   24
   20
   22
   4
   6

2. FLAME INTENSITY SENSING MEANS: E.G. SOLAR CELL
   36
   38
   40
   42
   3

3. LANCE RAISING MEANS

4. ELECTRICAL FILTER CIRCUIT

5. DISPLAY MEANS: E.G. STRIP CHART RECORDER

FiG. 2

AREA VIEWED BY FLAME INTENSITY SENSING MEANS:
2d ≤ D; h ≥ 0

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By [Signatures]
APPARATUS FOR CONTROL OF CARBON CONTENT IN STEEL PRODUCED IN BASIC OXYGEN FURNACE PROCESS

This application is a continuation of Ser. No. 689,127, filed Dec. 8, 1967, now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to steelmaking processes and apparatus, and in particular, to processes and apparatus for determining the carbon endpoint in a basic oxygen furnace steelmaking operation.

2. Description of the Prior Art

It is known that steel can be made by applying to a bath of molten pig iron, alone or with scrap, contained in a converter vessel a substantially vertical jet of high-purity oxygen. The process is advantageous in comparison with the more usual open-hearth steelmaking process in that, for a particular amount of capital investment, a substantially greater steel-making capacity is obtained. In comparison with the known Bessemer steelmaking process, in which air is blown into the bottom of a converter vessel containing the molten pig iron, the above-mentioned oxygen process affords the advantage that nitrogen pickup is notably lessened. The high-nitrogen Bessemer steels tend to have a limited range of usefulness. The above-mentioned oxygen process also affords advantages, in certain instances, in comparison with the known electric-furnace steelmaking process, being faster and not requiring the availability of substantial quantities of electrical current.

One technical problem in connection with the above-mentioned oxygen process, however, has been the determination of the carbon endpoint. In the known open-hearth and electrical-furnace steelmaking processes, the reduction in carbon content of the bath proceeds in general at a rate so slow that it is feasible to extract small samples of the bath and analyze them for carbon content. With these processes, it is feasible to have the removal of carbon proceed sufficiently slowly, near the end of the refining operation, that the carbon content will not be reduced below the desired final value during the time that it takes to obtain a bath-sample carbon analysis.

With the somewhat faster moving Bessemer process, it has been known that steel of about the desired carbon content could be obtained by observing the flame issuing from the mouth of the converter and terminating the supply of air to the vessel in accordance therewith. For the most part, reliance has been placed upon the skill and judgment of the operator in determining when the process is to be stopped. As a result, this practice has not, in general, yielded a close control of the desired carbon content in the finished steel. In particular, steels having a carbon content of 0.05 percent plus or minus 0.005 percent have not been obtained reliably in this way; indeed, control of the carbon content to within 0.01 percent of the desired value, simply by observation of the flame issuing from the mouth of the vessel and without the use of the method and apparatus of the present invention, requires considerable attention, experience and skill on the part of the operator. Yet another factor is that, although it is usual with the Bessemer process to leave the converter vessel unhooded so that the flame may be readily observed, air-pollution considerations have generally dictated that oxygen-steelmaking vessels be provided with a hood, by means of which materials issuing from the mouth of the converter are gathered in order to prevent their discharge into the atmosphere. This has led those skilled in the art away from the observation of the flame at the mouth of the converter vessel, in the oxygen steelmaking process, as a means of determining the carbon endpoint.

To consider more specifically the practices that have been proposed for determining the carbon endpoint in an oxygen steelmaking process, prior to the present invention, there have been (1) the carbon balance approach, involving waste-gas analysis; (2) the hot-spot temperature analysis approach; and (3) the waste-gas component-analysis approach.

In accordance with the approach (1), the rate of removal of carbon dioxide from the bath is calculated by determining the percentage of carbon dioxide in the off gas and the off-gas flow rate. By integrating the product of these two values, the total carbon removed can be found, and by subtracting this from the total carbon charged, one can arrive at a value for the amount of carbon remaining in the vessel. Division of this value by the weight of ferrous material in the vessel yields the carbon percentage. The drawbacks of this approach are that it is difficult to obtain an accurate value of the total carbon charged to the vessel, since the hot-metal carbon measurements are seldom any better than plus or minus 0.02 percent, and inaccuracies of still larger magnitude occur in determining the percentage of carbon in the scrap. A further difficulty is that there is a substantial delay time, about 45 seconds, associated with the off-gas measurements.

The approach (2) involves having a radiation pyrometer positioned to view a portion of the bath. A procedure of this sort is taught in U.S. Pat. No. 3,080,755, issued to Percy. Although this approach apparently overcomes the time-lag problem, nothing in the prior art gives any assurance that it will yield carbon contents in the finished steels that approach those desired nearly so accurately as do values obtained with the present invention.

The approach (3) is essentially empirical, involving a presumed relationship between the observed carbon dioxide content of the waste gases (or the observed free oxygen content — see U.S. Pat. No. 2,236,630, issued to Stephan and assigned to U.S. Steel Corporation) and the carbon content of the steel in the vessel. Once again, a significant time lag is involved, and the prior art lacks any teaching that the quality of the control that can be obtained is as high as that obtained in accordance with the present invention.

SUMMARY OF THE INVENTION

This invention relates to an improvement in an oxygen steelmaking process in which steel of desired carbon content is obtained by monitoring the intensity of the flame issuing from the mouth of the converter vessel and taking suitable control actions in accordance therewith. A solar cell is trained upon a portion of the lance in the vicinity of the converter vessel mouth, and it emits signals that are suitably filtered to average out observed variations over a period of, for example, 16 seconds. The average values may be used in various ways. They may be displayed on a strip chart recorder, from which the operator may obtain the information necessary to initiate a desired control action (termination of oxygen supply, regulation of oxygen supply, or
change in the relative position of lance and vessel). Alternatively, or in addition, the filtered signals may be supplied to a voltage comparator, which will operate a suitable signal means such as a lamp. Still within the scope of the invention is the use of the filtered signals 10 themselves to operate control means to stop the oxygen supply or adjust its rate, or to change the relative position of the lance and the vessel. With some steelmaking practices, such as the late addition of lime or the late dissolution of scrap in the bath, the filtered signals may be fed to digital-computer means to analyze them using modern pattern-recognition techniques and thus allow for excursions in observed values that are attributable to such practices. The digital-computer means may then emit signals that either are used by the operator as indicated above or serve to operate control means as mentioned above. By means of the practices described herein, the carbon content at the end of blowing in an oxygen steelmaking process may be controlled within plus or minus 0.005 percent.

**BRIEF DESCRIPTION OF THE DRAWINGS**

A complete understanding of the invention may be obtained from the foregoing and following description thereof, taken together with the appended drawings, in which:

**FIG. 1** is a schematic diagram of apparatus of the present invention, used in practicing the method of the present invention;

**FIG. 2** is a view taken in line II—II of FIG. 1;

**FIG. 3** is a graph used in explaining the invention;

**FIG. 4** is a schematic view showing an alternative embodiment of equipment of the present invention, used in practicing an alternative method of the present invention; and

**FIG. 5** is a schematic view showing an alternative embodiment of equipment of the present invention, used in practicing an alternative method of the present invention.

**DESCRIPTION OF THE PREFERRED EMBODIMENTS**

As shown in **FIG. 1**, apparatus in accordance with the invention comprises a converter vessel 2 having an exterior steel shell 4 and an interior refractory lining 6. The vessel 2 has in its top a mouth 8, through which there is inserted a vertical lance 10, which is preferably adapted to be cooled by water, for example, by means of a water inlet pipe 12, interior passage 14, and water outlet passage 16. The lance 10 is also connected to suitable lance-raising means 18, which may be of conventional construction. The vessel 2 is adapted to contain a bath 20 of molten pig iron, above which there may be a layer 22 of slag. The vessel 2 is adapted to be turned upon trunnions 24 by conventional means (not shown). This permits discharge of the finished steel through the mouth 8 or, if desired, through a suitable tap hole (not shown). Oxygen is led from a supply means 28 of the lance 10 through a line 29 containing a valve 27, so that when the refining is in progress, the bath 20 is impinged upon, as at 30, the jet of oxygen issuing from the lance 10 penetrating the bath 20 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.

Also seen in **FIG. 1** is a schematic indication of additional apparatus used in accordance with one embodiment of the invention. This comprises a flame-intensity sensing means 32, which, as can be seen from **FIG. 2**, is trained upon an area 34 of the side of the lance 10. Referring further to **FIG. 2**, it will be seen that the area 34 viewed by the flame-intensity sensing means has a diameter d, and the diameter of the lance 10 is designated D. In accordance with the invention, the dimension d is preferably about one-half the dimension D, or slightly less. Also indicated on **FIG. 2** is the dimension h, which is the distance between the bottom of the area 34 and the top of the vessel 2 in the vicinity of the mouth 8. In accordance with the invention, the dimension h is quite small, preferably nil.

The flame-intensity sensing means may comprise any of a number of suitable devices, as will be understood by those skilled in the art. For example, a bolometer might be used. We prefer, 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 000 35/50/48 silicon solar cell with an 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 build-up of dust particles, the pipe being attached to a swivel mount and the entire assembly being covered with a steel cage, in order to prevent accidental movement of the cell.

Signals produced by the flame-intensity sensing means 32 are led by a line 36 to any electrical filter circuit 38 which may, for example, comprise a single-section resistance-capacitance filter. The filtering serves to convert the raw signals produced by the flame-intensity sensing means 32 to a value representative of the average flame intensity observed over a period of time. As is well understood by those skilled in the art, the averaging period will depend upon the values of resistance and capacitance used in the filter circuit 38. Satisfactory results have been obtained, using an averaging time of about 16 seconds. The output of the electrical filter circuit 38 appears on a line 40, by means of which it is led to a suitable display means 42, such as a strip chart recorder.

In operation, when thus described above as being conventional is operated in the usual manner until the start of the oxygen blow. At that point, the flame-intensity sensing means 32 and its associated equipment is activated, so that there is obtained upon the display means 42 an indication of flame intensity within the area 34 viewed by the means 32. It is important to note that the area 34 contains no part of the refractory lining 4 of the vessel 2; spurious readings are obtained if the sensing means 32 is not properly directed. It is important, moreover, that when practicing the invention with the embodiment thereof shown in FIGS. 1 and 2, certain practices such as the late addition of lime or the dissolving of scrap in the later stages of the melt, be avoided, as these also tend to give spurious readings. In a proper case, however, as for example when a 100 percent hot metal charge is used and late lime addition is not practiced, it is found that the values of flame intensity, as obtained and averaged and displayed by the apparatus of the invention, correspond quite well and closely with the carbon content of the steel in the bath 20. To be more specific, the observed flame intensity...
3,741,557

during a melt tends to exhibit a pattern such as that shown in FIG. 3. It will be seen that, toward the end of the blowing period, the flame intensity exhibits a smooth downward trend, as at 44, and it has been found that, with a little experience in the making of heats of steel of the kind involved, it becomes quite easy to tell, from the curve, at what point the blowing should be stopped in order to obtain steel having a desired carbon content. Results have indicated that control to within 0.005 percent of the desired carbon content can thus be obtained.

In FIG. 3, there is also shown the initial rapid rise in observed flame intensity that occurs upon ignition (this is indicated at 46), a decrease as at 48 during the period of the silicon blow, and a further rise as at 50 during the period of the carbon blow. The decrease during the blow-finishing period is smooth, and begins at levels of flame intensity about the same as that achieved immediately after ignition. In general, the shape of this curve is the same as that of the carbon-removal-rate curve obtained by the known gas-analysis method, but the time lag is considerably shorter, so that a more accurate control is obtained.

The possibility of using the flame-intensity readings thus obtained in other manners is not to be overlooked. It is desired, in order to obtain maximum production from the equipment, that the oxygen be blown at the maximum rate which will not produce slopping. A sharp increase in the observed flame intensity at the end of the silicon blow indicates that heavy slopping will occur when the carbon blow phase is reached, and this may be usually avoided by running the lance down closer to the bath surface.

As shown in FIG. 4, wherein components the same as used in the embodiment of FIG. 1 are designated with the same reference numerals, a second embodiment of the present invention, in accordance with which the signals emitted by the solar cell 32 are transmitted by a line 36 to the filter circuit 38, which comprises a resistor 52 and a capacitor 54. Signals emitted by the filter circuit 38 are conveyed by the line 40 to a display means 42, which is incorporated in the embodiment of FIG. 4 comprises a voltage comparator 54 connected by line 56 to the signal means 58, such as a lamp. Voltage comparator 54 is provided with power from a suitable source (not shown) and serves, whenever the voltage on the line 40 has dropped below a predetermined value, to activate the signal means 58.

In operation, the embodiment of FIG. 4 is substantially the same as that of FIGS. 1 and 2, in that it is left to the operator, whenever the signal means 58 is activated, to terminate the supply of oxygen to the vessel 2 or take other appropriate control action.

In the embodiment of the invention shown in FIG. 5, the equipment is essentially similar, except that there is provided an oxygen flow control means 60, which is operatively connected as at 62 with the valve 27 in the oxygen supply line 29, and a lance position control means 64, which is operatively connected as at 66 with the lance 10. The line 40 containing the output of the filter circuit 38 is connected to control means 68, which includes, if desired, digital-computer radiation. Control means 68 is operatively connected as at 70 with the oxygen flow control means 60 and as at 72 with the lance position control means 64. It is within the skill of the art to design suitable digital-computer means for use within the control means 68, in order that, to take a simple case, the valve 27 may be closed automatically at an appropriate time in order to obtain steel of a desired carbon content. It is also within the skill of the art to design control means 60 so as suitably to regulate the oxygen supplied by means of the valve 72 and/or adjust the position of the lance 10 by means of the lance position control means 64. With the aid of modern pattern-recognition techniques in the programming of the digital-computer means included within the control means 68, it is possible to cause the control means 68 to regulate the oxygen flow control means 60 and the lance position control means 64, despite the excursions in values of observed flame intensity that are occasioned by late time additions and/or the occurrence of scrap melting during the latter stages of the blowing period.

As specific examples of the practices above taught, the following data are presented. Nine heats were prepared, each with an aim carbon content of 0.025 percent and a specification of 0.020 to 0.028 percent. Equipment as depicted in FIG. 4 was used. The results were as given below in Table I.

<table>
<thead>
<tr>
<th>Heat No.</th>
<th>Observed Carbon Content, %</th>
<th>Deviation from Desired Carbon Content, %</th>
<th>Temp. at Turn Down, °F</th>
<th>Observed Flame Intensity at End of Blow</th>
</tr>
</thead>
<tbody>
<tr>
<td>200527</td>
<td>0.022/0.024 – 0.002</td>
<td>120,400</td>
<td>3005</td>
<td>18</td>
</tr>
<tr>
<td>200529</td>
<td>0.022</td>
<td>–0.003</td>
<td>122,400</td>
<td>29</td>
</tr>
<tr>
<td>200530</td>
<td>0.024</td>
<td>–0.001</td>
<td>122,500</td>
<td>25</td>
</tr>
<tr>
<td>200531</td>
<td>0.022</td>
<td>–0.003</td>
<td>121,100</td>
<td>29</td>
</tr>
<tr>
<td>200532</td>
<td>0.023</td>
<td>–0.002</td>
<td>119,300</td>
<td>35</td>
</tr>
<tr>
<td>200533</td>
<td>0.025</td>
<td>0</td>
<td>123,300</td>
<td>15</td>
</tr>
<tr>
<td>200534</td>
<td>0.025</td>
<td>0</td>
<td>120,600</td>
<td>20</td>
</tr>
<tr>
<td>200535</td>
<td>0.022</td>
<td>–0.003</td>
<td>121,600</td>
<td>17</td>
</tr>
<tr>
<td>200536</td>
<td>0.025</td>
<td>0</td>
<td>118,900</td>
<td>20</td>
</tr>
</tbody>
</table>

As will be seen from the above data, close control of carbon content of the finished steel was obtained. To be more specific, in none of the heats was there any deviation greater than 0.003 percent from the aim value of 0.025 percent.

While we have shown and described herein certain embodiments of our invention, we intend to cover as well any change or modification therein which may be made without departing from the spirit and scope of the invention.

We claim as our invention:

1. In apparatus for making steel of the type wherein a bath of molten carboniferous iron is disposed within a refractory-lined converter vessel having a mouth at its top and wherein oxygen is directed onto the surface of the bath by a lance extending into the vessel through said mouth to produce a flame above the surface of the bath, the improvement of means for producing an electrical signal which varies as a function of the intensity of the flame above the surface of the bath, comprising a device for converting light intensity into an electrical signal proportional to said signal, wall means above said surface of the bath and in the flame produced above said surface during an oxygen blow for providing for said light-converting device a field of view which contains no part of the refractory lining of said vessel such that radiation from the walls of said vessel will not substantially alter the magnitude of the electrical signal produced by said device, and electrical filter means connected to said device for producing an electrical signal proportional to the average flame intensity observed over a period of time.
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2. Apparatus as defined in claim 1, and including display means connected to the output of said filter means for displaying the magnitude of said electrical signal.

3. Apparatus as defined in claim 2 characterized in that said display means comprises a strip chart recorder.

4. Apparatus as defined in claim 2, characterized in that said display means comprises a voltage comparator connected to the output of said averaging means, and signal means connected to the output of said voltage comparator.

5. Apparatus as defined in claim 1 wherein said field of view is on said lance.

6. Apparatus as defined in claim 6 wherein said lance is water-cooled.

7. In apparatus for making steel of the type wherein a bath of molten carboniferous iron is disposed within a converter vessel having a mouth at its top and wherein oxygen is directed onto the surface of the bath by a lance extending into the vessel through said mouth to produce a flame above the surface of the bath; the improvement of means for producing an electrical signal which varies as a function of the intensity of the flame above the surface of the bath, comprising a device for converting light intensity into an electrical signal proportional to said intensity, said device being trained upon said lance whereby the field of view of said device contains no part of the refractory lining of said vessel such that radiation from the walls of said vessel will not substantially alter the magnitude of the electrical signal produced by said device, electrical filter means connected to said device for producing an electrical signal proportional to the average flame intensity observed over a period of time, and control means connected to the output of said filter means, said control means serving to terminate the supply of oxygen to said lance when during the blow-finishing period in the refining of said bath of molten iron a predetermined flame-intensity value is observed.

* * * * *