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[45] Nov. 20, 1973

[54] PROCESS FOR THE AUTOMATIC CONTROL OF THE PIG IRON REFINING OPERATION

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Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 835,521, June 23, 1969, abandoned.

[30] **Foreign Application Priority Data**

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[52] **U.S. Cl.** **75/60**
[51] **Int. Cl.** **C21c 5/32**
[58] **Field of Search** 75/60

[56] **References Cited**

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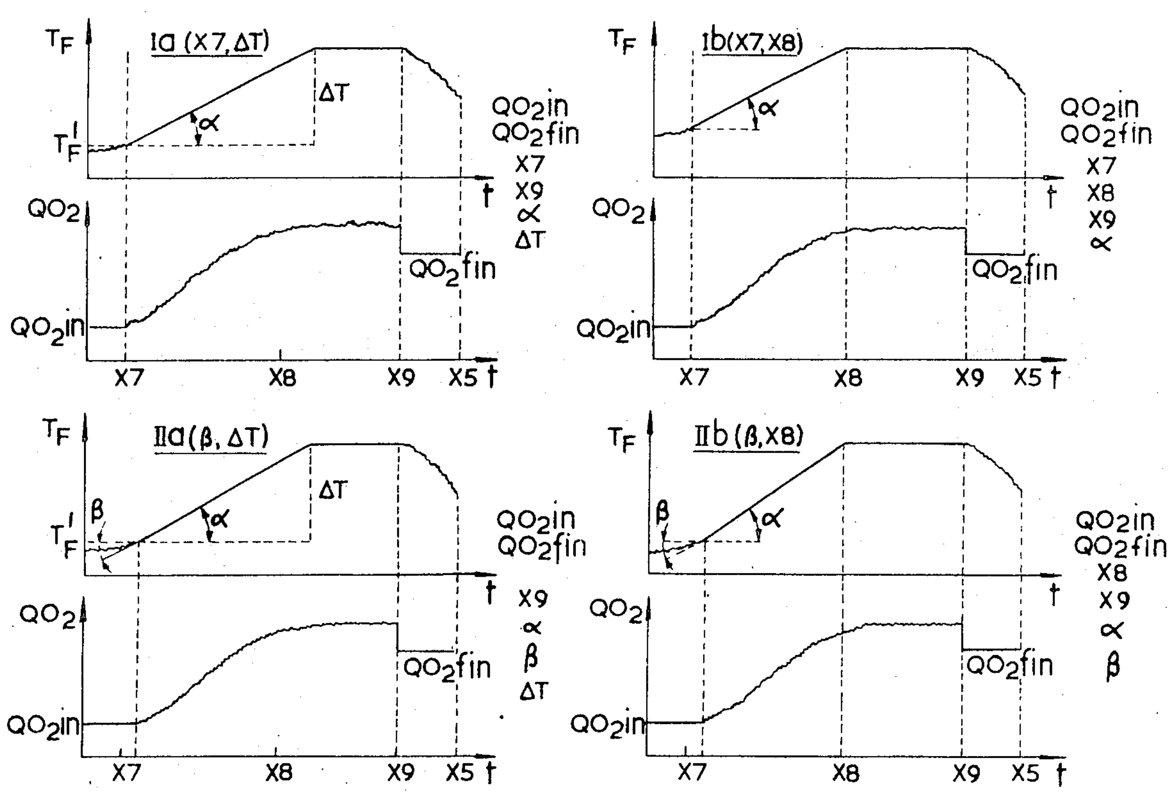
[57] **ABSTRACT**

In the pig iron refining operation in a converter working on the top blowing principle, the invention concerns an automatic control process in which the rate of blowing of oxygen into the converter and the temperature of the refining fumes are measured. The lance height is regulated relative to the bath of molten metal according to a predetermined program based on the amount of oxygen blown in. Simultaneously, the blowing rate is regulated in such a manner that the temperature of the fumes follows a predetermined path.

5 Claims, 4 Drawing Figures



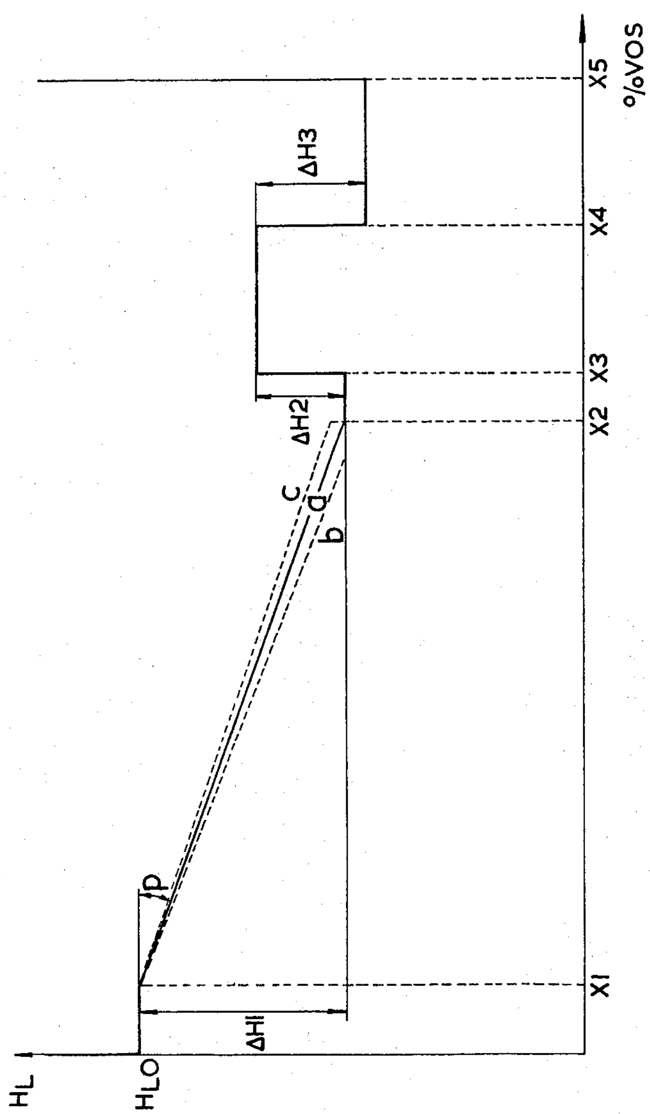


FIG. 1.

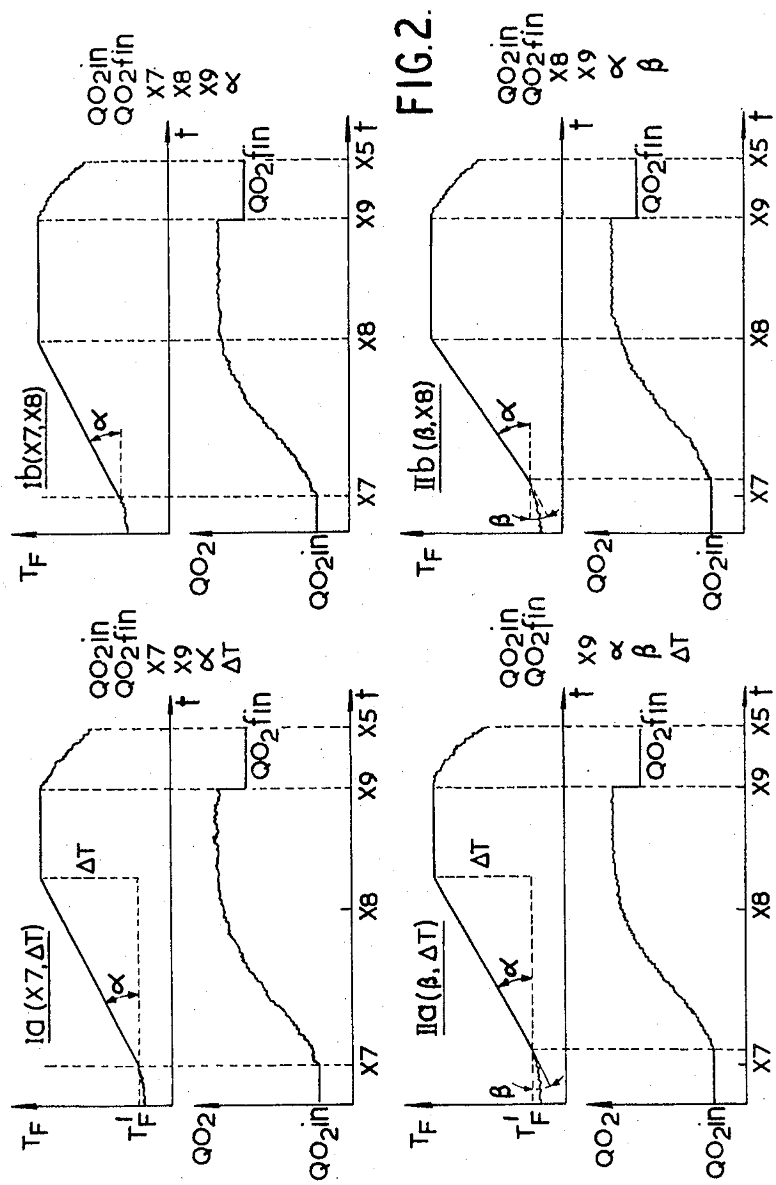


FIG. 2.

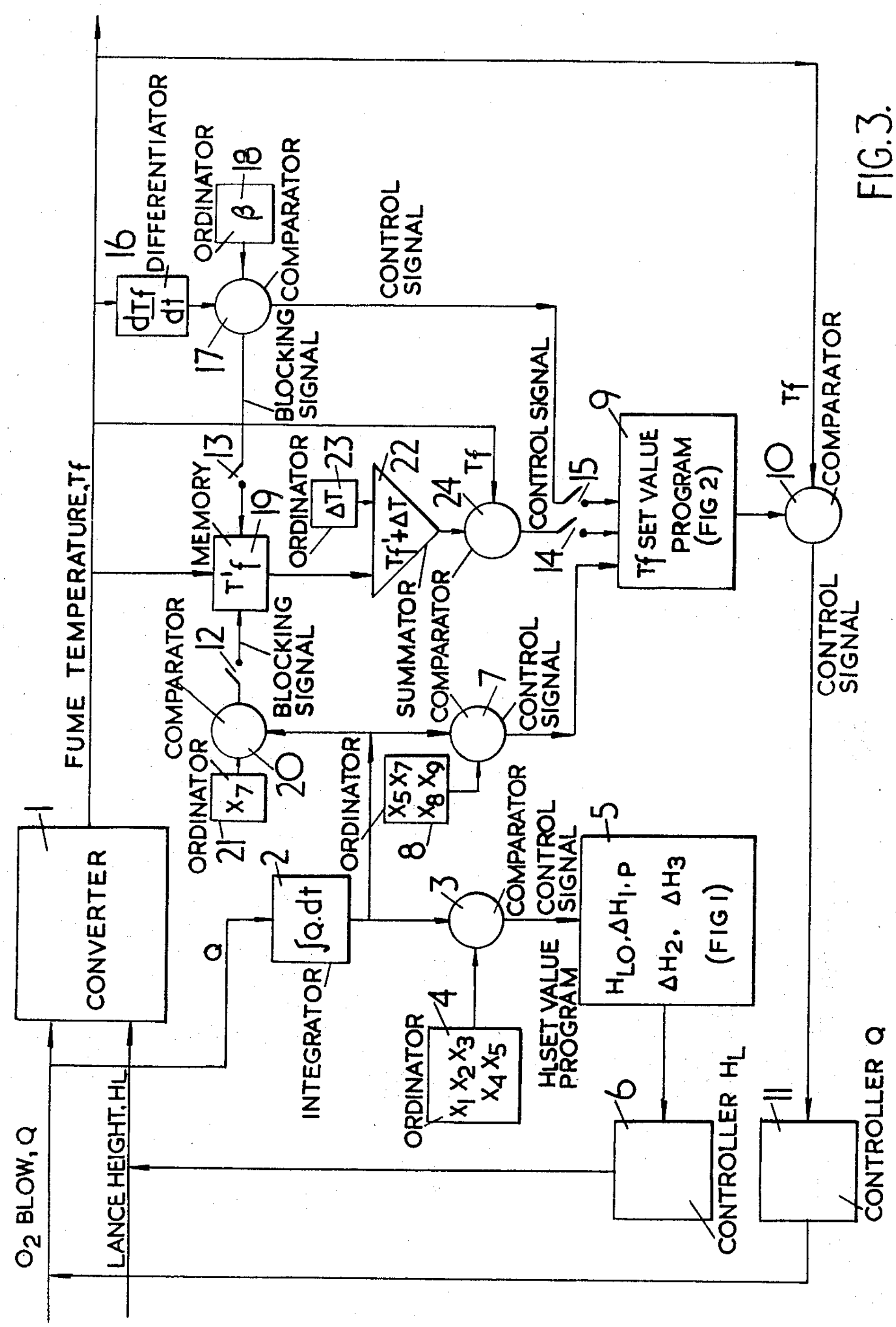

CONVERTER
FUME TEMPERATURE, Tf
O_2 BLOW, Q
LANCE HEIGHT, HL
Q
INTEGRATOR
∫Q.dt
ORDINATOR
COMPARATOR
CONTROL SIGNAL
HLSET VALUE PROGRAM
$H_{LO}, \Delta H_1, P$
$\Delta H_2, \Delta H_3$
(FIG 1)
CONTROLLER H_L
CONTROLLER Q
$X_1 X_2 X_3$
$X_4 X_5$
$X_5 X_7$
$X_8 X_9$
X_7
BLOCKING SIGNAL
MEMORY
T'_f
ΔT
$T_f' + \Delta T$
SUMMATOR
T_f
$\frac{dT_f}{dt}$
DIFFERENTIATOR
β
Tf SET VALUE PROGRAM (FIG 2)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

FIG. 3.

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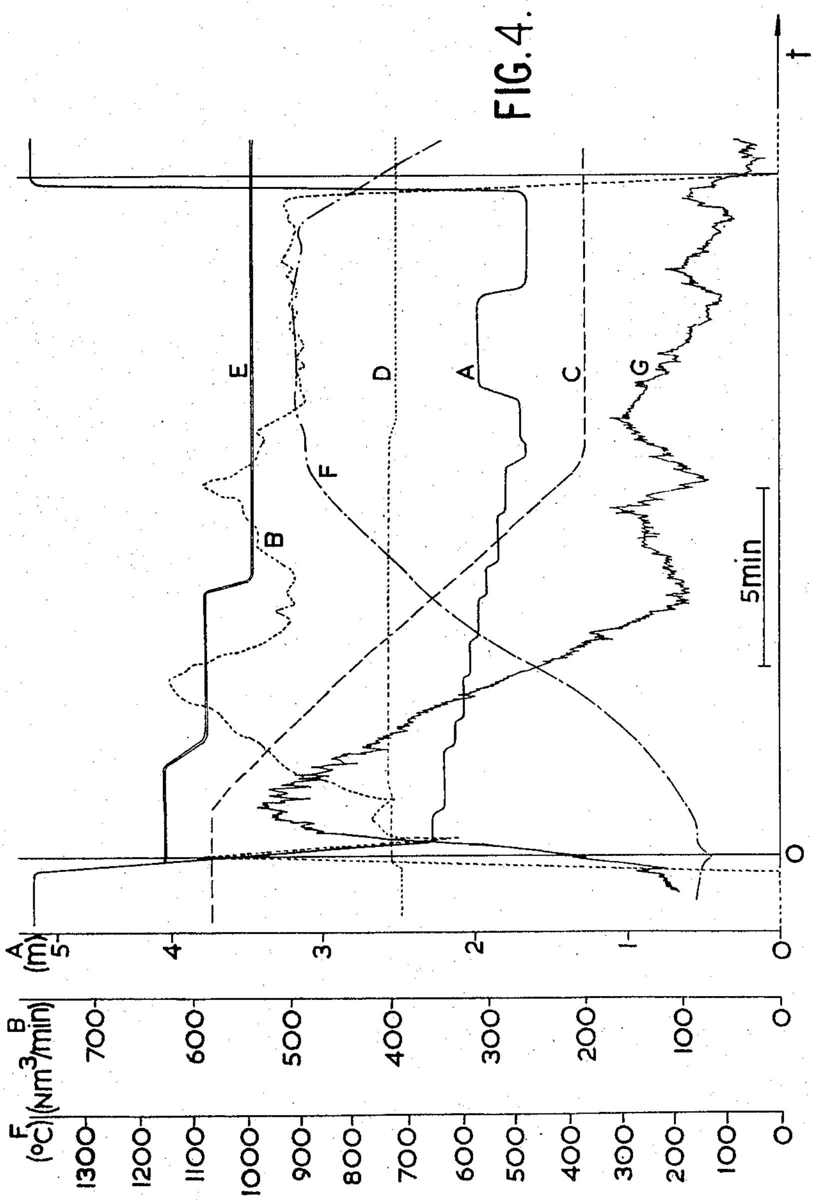

FIG. 4.

PROCESS FOR THE AUTOMATIC CONTROL OF THE PIG IRON REFINING OPERATION

This application is a continuation-in-part of now abandoned application Ser. No. 835 521, "Process for the automatic control of the pig iron refining operation" of Paul-Emile Nilles and Yvon-Paul Noël, filed June 23, 1969. The benefit of the filing date of the parent application is hereby claimed.

The invention relates to processes for the automatic control of the pig iron refining operation in a converter using the top blowing method.

Up to the present, the majority of research workers concerned with the automatic control of the blow in oxygen steel plants have considered the fume analysis as an essential datum for solving this problem. However, sampling difficulties, rather long response times and problems in obtaining the required accuracies from the analysers constitute obstacles to this method of operating.

The relationships existing — at least in a hood ensuring complete combustion — between the temperature of the fumes in the collecting hood and the metallurgical reactions in the converter have, moreover, already been established.

The simplicity of the fume temperature measurement and the fact that thermometers with very short response times can be developed, are important factors pointing to the advantages of automatic control of the blow. Moreover, by measuring the temperature of the fumes it is possible to calculate with accuracy and at any moment during the blow, the decarburization rate and the degree of oxidation of the slag.

In such a control of the blow, it has already been proposed to vary the height of the lance; the position of the lance is altered in relation to the bath of molten metal in such a manner as to control the temperature of the fumes evacuated in the hood to cause the graph of this temperature against time to follow as far as possible a curve set up empirically in advance.

The invention is based on the discovery that better correlations exist between the oxygen flow and the metallurgical reactions (decarburization rate, degree of oxidation of the slag and so on) than between the latter and the lance height.

Moreover, acting on the oxygen flow rate offers the advantage of making it possible to allow automatically for the oxygen supplied by the ore and contributing to decarburization.

The present invention provides a process for automatically controlling pig iron refining in an oxygen top-blown converter wherein the oxygen is blown through a lance, comprising the steps of:

a. introducing into an analog device the value for the initial lance height from the surface of the melt and the total amount of oxygen to be blown into the converter;

b. measuring the rate of oxygen blown into the converter;

c. introducing said oxygen blowing rate into an analog device which performs integration of said oxygen blowing rate to obtain the total amount of oxygen blown in up to each moment of time and which compares said total amount at each moment of time with a series of pre-set values of the amount of oxygen based on the total amount of oxygen to be blown into the converter;

d. measuring the temperature of the refining fumes;

e. introducing said fume temperature into an analog device which compares said temperature, at each moment of time, with a predetermined fume temperature curve;

f. adjusting said oxygen blowing rate so that said fume temperature follows said predetermined curve; and

g. adjusting the height of the lance above the melt in accordance with a predetermined curve of lance height based on said pre-set values of the amount of oxygen blown in.

This control process covers in itself a large variety of possible steel making practices. For instance, it suffices to raise the predetermined values of the fume temperature to increase the oxygen flow required and speed up the refining operation, all other factors being constant, or again, it suffices to raise the level of the lance during the first part of the operation to speed up the formation of the slag without incurring risks of accident. Indeed, the oxygen flow rate will be increased in order that the predetermined decarburization rate be achieved, without consequent increase in the rate of oxygen transferred to the slag.

Consequently, by means of a very simple change in the order, the process for the control of refining may be adapted to a given analysis of pig iron or to obtaining a given steel.

The control provided by the invention enables inter alia wear on the lance to be compensated. It is moreover possible to operate with a lance height program in which the lance height at any instant is set at a mean value determined from oxygen flow rates normally found, so that the desired metallurgical conditions will be approximately realised.

Purely by way of example, an application of the process of automatic control of the pig iron refining operation forming the subject of the invention is described below, with reference to the accompanying drawings. In the drawings:

FIG. 1 shows a program for controlling the lance height;

FIG. 2 shows various relationships between the graph of fume temperature against time and the graph of blowing rate against time;

FIG. 3 is a block diagram of an automatic control installation; and

FIG. 4 shows a graph of various values recorded during a blow, against time.

The process was carried out on the two 180 metric ton converters of an LD steel plant; the automated blowing installation monitors four operations;

position of the lance;
oxygen rate;
fume temperature;
additions time.

The principle on which the process is based is that of regulating the lance height in relation to the bath of molten metal in accordance with a predetermined program based on the amount of oxygen blown in, while regulating the flow of oxygen blown in, in such a manner that the temperature of the fumes follows a predetermined course.

FIG. 1 represents a program for controlling the lance height; it can be seen that the lance height program is a curve imposed as a function of the percentage

Oxygen blown/total oxygen to be blown

and not as a function of time. One can distinguish the following phases:

1. Start (operator): the lance is lowered at maximum speed, then reduced progressively, down to the initial lance level HL_o imposed by an off-line computer and manually introduced by the operator.

2. The lance stays at this HL_o level until a volume of oxygen equal to x_1 percent of the total volume to be blown (x_1 VOS Nm^3 O_2) has passed through.

3. The lance is lowered at a constant speed (corresponding to the gradient p if the oxygen flow rate is constant) down to the $HL_o - \Delta H_1$ level. Supposing there is a steady oxygen flow and the adjustments are correct, this lance height must in principle be reached for x_2 VOS Nm^3 O_2 (line a in FIG. 1). If the $HL_o - \Delta H_1$ level is reached a little before the moment corresponding to x_2 VOS, the lance is kept at the $HL_o - \Delta H_1$, line b. If x_2 VOS is reached before the ΔH_1 step is totally performed, the lowering of the lance is immediately completed, line c.

4. The lance is maintained at a steady level up to x_3 VOS.

5. The lance is raised by a height equal to ΔH_2 and is kept at the value $HL_o - \Delta H_1 + \Delta H_2$, up to x_4 VOS. This operation makes foaming easier.

6. The lance is lowered by ΔH_3 and stays at the height $HL_o - \Delta H_1 + \Delta H_2 - \Delta H_3$ until the end of the blowing operation represented by x_5 VOS ($x_5 = 100\%$).

7. When the predetermined amount of oxygen has been blown, the installation automatically gives the signal for upward movement of the lance to a top limit switch, and gives the oxygen valve the closing signal.

For the purpose of realising the program of variation of lance height just described, the automatic installation performs the following functions:

- integration of the blown oxygen rate;
- comparison, at any moment, of the volume blown with the predetermined values x_1 VOS, x_2 VOS . . . x_5 VOS;
- when passing through these values, initiation of a signal constituting the order for the next lance height adjustment;
- carrying out successive lance height orders as a function on the one hand of the above determined moments and on the other hand of the values selected for HL_o, ΔH_1, p, etc.

A certain number of auxiliary functions, such as resetting of the integrator after blowing, starting the integrator, and resetting of the slope p generator, must also be added to these functions.

In the installation used, these different functions are carried out by analog devices and by relays; the lance height order is constituted by means of potentiometers and servo-mechanisms.

The initial lance height HL_o and the total volume of oxygen to be blown VOS must be introduced into the automatic installation by the operator, before blowing. In the present example, these values are determined by a computer on the basis of a program used for calculating the charge.

The adjustment of the variables x_1, x_2, x_3, x_4, ΔH_1, ΔH_2, ΔH_3 and the speed at which the lance is lowered, must be imposed by the responsible steel plant authority each time a modification to the lance height program is to be made. The following figures are given purely by way of example:

$$x_1 : 7\%,\ x_2 : 65\%,\ x_3 : 70\%,\ x_4 : 85\%,$$
$$\Delta H_1 : 60 \text{ cm},\ \Delta H_2 : 30 \text{ cm},\ \Delta H_3 : 30 \text{ cm},$$
$$p : 7 \text{ cm/min}.$$

The variables can be adjusted over a very wide range and this results in a great flexibility in the choice of the lance height program.

The second characteristic of the process is to regulate the flow of oxygen blown in, in such a manner that the temperature of the fumes will follow a predetermined curve. This latter measurement is carried out by means of a thermocouple arranged in the hood at the optimum level. The blow is divided into four sections or phases:

1. Start; during this first part, which should comprise the ignition, the oxygen rate is maintained at a constant predetermined value QO_{2in}; then the temperature of the fumes slowly rises.

2. Temperature rise: from a given moment, the fume temperature regulator comes into action and imposes on the oxygen flow regulator a variable command signal such that the temperature will follow a linear path of predetermined slope (α °C/min). The oxygen flow is, however, permitted to vary only between two extreme limits, upper and lower, consistent with normal running of the installation and with safety regulations.

3. Temperature level: from a second given moment, the temperature of the fumes is kept constant and the oxygen flow regulator receives the command signal necessary for this. The temperature remains constant up to the moment when x_9 VOS Nm^3 of oxygen have been blown.

4. Temperature drop: from the moment determined by the value of x_9, the oxygen flow is kept constant (QO_{2fin}) and the temperature of the fumes of course follows a descending curve until the end of the blow.

The determination of the beginning of the phases 2 and 3 is effected as follows:

second phase starts:

either at the moment when x_7 VOS Nm^3 of oxygen have been blown;

or when the normal rate of increase of fume temperature (phase 1) reaches a fixed threshold value of β °C/min.

third phase starts:

either when the temperature has increased by ΔT°C since the start of regulation; or when x_8 VOS Nm^3 of oxygen have been blown.

The two alternatives may be combined; we are confronted accordingly with four possibilities illustrated in FIG. 2. In the case of Ia for instance, the starting of the temperature regulation takes place at the moment corresponding to x_7 VOS and the temperature level starts after an increase of ΔT°C. In the right-hand margin of each Figure, there are found the parameters to be fixed for determining the type of blowing illustrated (example: for Ia: QO_{2in}, QO_{2fin}, x_7, x_9, α, ΔT).

To ensure the regulating of the oxygen flow which has just been described the following functions must be realised:

integration of the oxygen flow rate and comparison with the adjustable threshold values x_7, x_8, x_9;

differentiation of the fume temperature with respect to time and comparison with the regulable threshold value β;

determination of the temperature increase and comparison with the regulable threshold value ΔT;

initiation of the operations provided for when passing through these various threshold values;

production of the command signal to maintain the constant following of the predetermined path of the temperature of the fumes;

realisation of the set temperature by action on the oxygen rate.

The following parameters must be supplied to the installation to allow the "fume temperature-oxygen flow" loop to function:

fume temperature (supplied by suitable measuring devices),

initial oxygen flow, QO_{2in}, (laid down by the operator),

ultimate oxygen flow, QO_{2fin},

x_7 or β, x_8 or ΔT, x_9.

The following values are given purely by way of example:

x_7 : 7%, β : 40°C/min, x_8 : 50%, ΔT : 600°C, x_9 : 85%.

FIG. 3 is a block diagram of an automatic installation applying the lance height program and "fume temperature-oxygen flow" loop described above. The analog circuit as illustrated is set up to apply the lance height program of FIG. 1 and the fume temperature program of FIG. 2 I*b*, but the elements necessary to follow the programs of FIG. 2 I*a*, II*a*, and II*b* are also included.

The input variables to the converter **1** are the rate of oxygen blown in, Q, and the lance height, H_L; the only output variable considered here is the fume temperature, T_f.

The lance height H_L, is controlled as follows: the measured oxygen blowing rate Q is transmitted to an integrator **2** whose output signal represents the total amount of oxygen blown in up to each moment of time, $\int Q.dt$. This signal is transmitted to the first input of a comparator **3**, which at a second input receives signals representing x_1, x_2, x_3, x_4, and x_5 (see FIG. 1) from an ordinator **4**, e.g., a series of potentiometers. As the oxygen amount coincides with x_1 to x_5 successively, the comparator **3** emits a control signal to a program unit **5** in which the program of the pre-set values of H_L represented by FIG. 1 are set up. The output of the unit **5** is transmitted to a controller **6** which adjusts the lance height H_L accordingly.

The fume temperature program of FIG. 2 I*b* is controlled as follows: the output of the integrator **2** is transmitted to the first input of a comparator **7**, which at a second input receives signals representing x_5, x_7, x_8, and x_9, from an ordinator **8**, e.g., a series of potentiometers. As the oxygen amount coincides with x_7, x_8, x_9, and x_5, successively, the comparator **7** emits a control signal to a program unit **9** in which the program of the pre-set values of T_f represented by FIG. 2 I*b* are set up. Each control signal initiates and terminates successive phases of the fume temperature curve, as indicated by the vertical broken lines in FIG. 2 I*b*. The unit **9** continuously transmits a signal, representing the instantaneous set value of fume temperature, to the first input of a comparator **10**, which at a second input receives a signal representing T_f.

The resulting control signal, representing any deviation of T_f from the instantaneous set value, is fed to a controller **11** which adjusts the oxygen blowing rate, Q, so as to reduce the deviation.

The other units illustrated in FIG. **3** relate to the determination of the other two control factors, β, ΔT, shown in FIG. **2**, which have been rendered inoperative by the opening of switches **12, 13, 14, 15.**

A control signal representing the factor β, used to control the program unit **9** in the mode shown in FIG. 2 II*a* or *b*, is generated as follows: the measured fume temperature, T_f, is fed to a differentiator **16** whose output signal represents dT_f/dt. This signal is transmitted to the first input of a comparator **17**, which at a second input receives a signal representing β from an ordinator **18**, e.g., a potentiometer. When dT_f/dt becomes equal to β the comparator **17** emits a control signal which can be fed to the program unit **9** through the switch **15** to initiate the second phase of the fume temperature curve.

A control signal derived from T, used to control the unit **9** in the mode shown in FIG. **2** I*a* or II*a*, is generated as follows: the measured fume temperature, T_f is fed to a memory unit **19** which, when supplied with a blocking signal, retains the last value T_f' of fume temperature received. The memory **19** is blocked at the end of the first phase of the fume temperature curve either by a blocking signal from the comparator **17** when $dT_f/dt = \beta$, or by a blocking signal from a comparator **20**, supplied at respective inputs by an ordinator **21** representing x_7 and the integrator **2**, the blocking signal being emitted when the oxygen amount coincides with x_7. The particular blocking signal used is selected by the switches **12, 13.**

The output of the memory **19** is fed to one input of a summator **22**, which at a second input receives a signal representing ΔT (FIG. 2), the desired rise in fume temperature during the second phase, from an ordinator **23**. The output, $T_f' + \Delta T$, of the summator **22** is transmitted to the input of a comparator **24**, which at a second input receives the measured fume temperature, T_f. When T_f becomes equal to $T_f' + \Delta T$ the comparator **24** emits a control signal which can be fed to the program unit **9** through the switch **14** to initiate the third phase of the fume temperature curve.

FIG. 4 shows the simultaneous recording of various values, carried out during a blow taking place in accordance with the automatic control process forming the subject of the invention. The values shown as a function of time are:

A: lance height (meters);

B: oxygen rate: (Nm^3/min);

C: weight of lime added;

D: weight of ore added;

E: weight of fluor-spar added;

F: the fumes temperature (°C);

G: the noise level emitted by the converter.

As far as the oxygen flow regulation is concerned, phase 2 was defined by means of the pair of parameters $x_7 - \Delta T$ (FIG. 2, I*a*).

One can observe the variations of oxygen flow necessary to make the fume temperature follow the desired curve.

We claim:

1. A process for automatically controlling pig iron refining in an oxygen top-blown converter wherein the oxygen is blown through a lance, comprising the steps of:

a. introducing into an analog device the value for the initial lance height from the surface of the melt and the total amount of oxygen to be blown into the converter;

b. measuring the rate of oxygen blown into the converter;

c. introducing said oxygen blowing rate into an analog device which performs integration of said oxygen blowing rate to obtain the total amount of oxygen blown in up to each moment of time and which compares said total amount at each moment of time with a series of pre-set values of the amount of oxygen based on the total amount of oxygen to be blown into the converter;

d. measuring the temperature of the refining fumes;

e. introducing said fume temperature into an analog device which compares said temperature, at each moment of time, with a predetermined fume temperature curve;

f. adjusting said oxygen blowing rate so that said fume temperature follows said predetermined curve; and

g. adjusting the height of the lance above the melt in accordance with a predetermined curve of lance height based on said pre-set values of the amount of oxygen blown in.

2. A process as claimed in claim **1**, further comprising, before the comparison of the fume temperature with the predetermined fume temperature curve of step (e), introducing said oxygen amount into an analog device which compares said amount with a pre-set value of the amount, and initiating said comparison of step (e) when said oxygen amount becomes equal to said pre-set value.

3. A process as claimed in claim **1**, further comprising, before the comparison of the fume temperature with the predetermined fume temperature curve of step (e), introducing said fume temperature into an analog device which differentiates the fume temperature with respect to time and which compares said time differential with a pre-set threshold value and initiating said comparison of step (e) when said time differential becomes equal to said pre-set threshold value.

4. A process as claimed in claim **1**, wherein said predetermined fume temperature curve comprises two distinct contiguous sections, the process further comprising introducing said oxygen amount into an analog device which compares said amount with a pre-set value of said amount, adjusting said oxygen blowing rate so that the fume temperature follows the first of said sections until said oxygen amount becomes equal to said pre-set value, and then adjusting said oxygen blowing rate so that the fume temperature follows the second of said sections.

5. A process as claimed in claim **1**, wherein said predetermined fume temperature curve comprises two distinct contiguous sections, the process further comprising introducing said fume temperature into an analog device which compares the rise in temperature with a pre-set value, adjusting said oxygen blowing rate so that the fume temperature follows the first of said sections until said temperature rise becomes equal to said pre-set value, and then adjusting said oxygen blowing rate so that the fume temperature follows the second of said sections.

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