United States Patent

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[33] **Japan**
[31] **40/73041**
Continuation-in-part of application Ser. No. 592,830, Nov. 8, 1966, now abandoned.

[56] **References Cited**

UNITED STATES PATENTS

3,181,343	5/1965	Fillon	73/23
3,329,495	7/1967	Ohta et al.	75/60
3,372,023	3/1968	Krainer et al.	75/60
3,377,158	4/1968	Meyer et al.	75/60
3,432,288	3/1969	Ardito et al.	75/60
3,455,164	7/1969	Boyle	75/60 UX
3,463,631	8/1969	Vayssiere et al.	75/60

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[54] **METHOD FOR CONTROLLING THE CARBON CONTENT IN AND/OR THE TEMPERATURE OF THE STEEL**
2 Claims, 3 Drawing Figs.

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

ABSTRACT: On the basis the experimental data, constants are predetermined to establish the decarburizing rate of a ferrous metal bath in a refining vessel in three successive oxygen blowing periods constituting the refining cycle. The model provided by the three equations determining the decarburizing rates is then used to control the refining time so as to obtain a steel of the desired carbon content from the charge of a given carbon content.

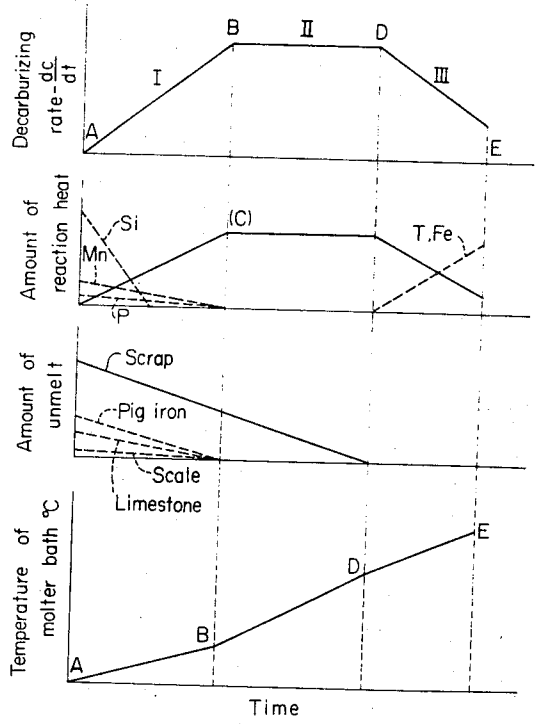
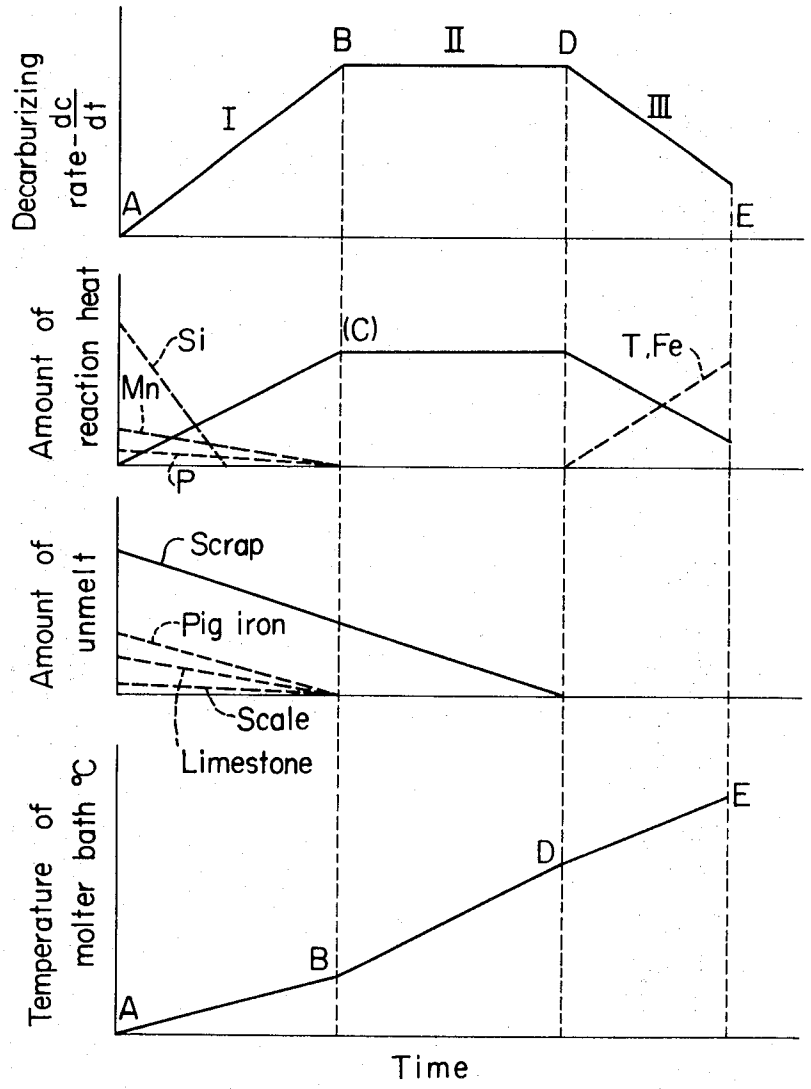


FIG. 1



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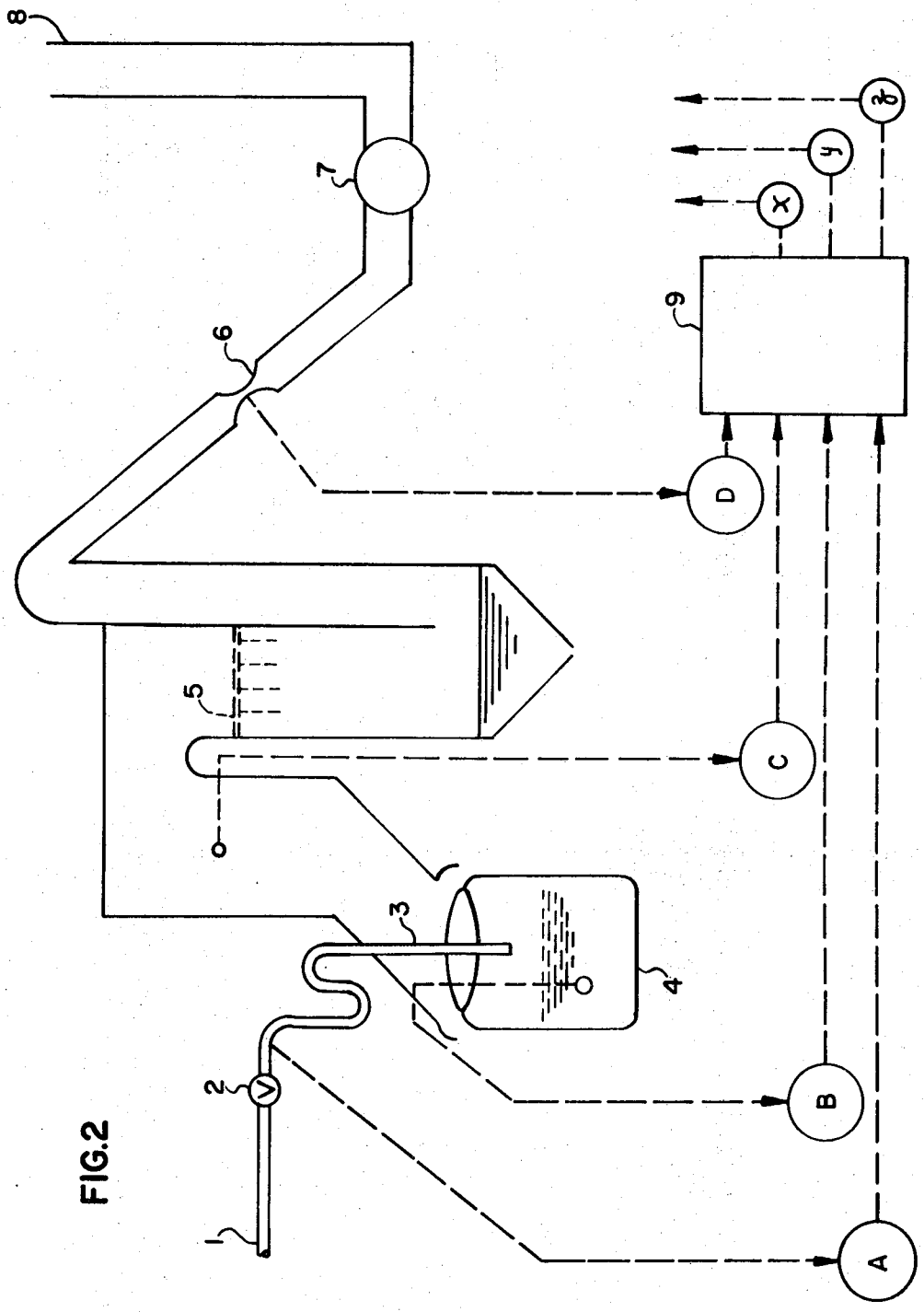
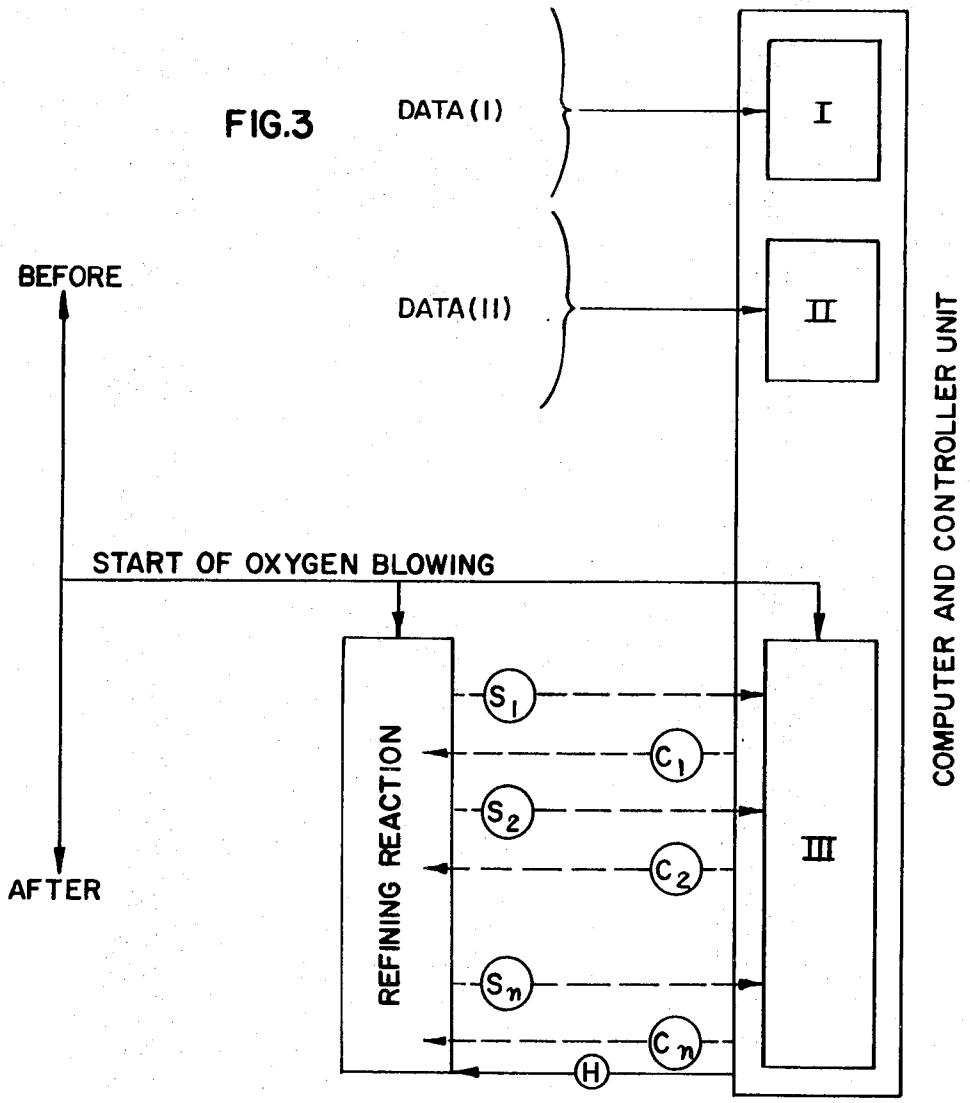


FIG.2

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FIG.3



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METHOD FOR CONTROLLING THE CARBON CONTENT IN AND/OR THE TEMPERATURE OF THE STEEL

REFERENCE TO RELATED APPLICATIONS

The present application is a continuation-in-part of our application Ser. No. 592,830, filed Nov. 8, 1966, now abandoned.

This invention relates to a method for controlling the refining of steel in order to obtain molten steel having the desired carbon content, and/or to a method for controlling the temperature at the end point of refining steel.

The refining of steel comprises a decarburizing reaction in which the carbon in the molten steel is separated in the form of CO or CO_2 by combining with oxygen in the atmosphere and simultaneously the temperature of the molten steel is raised in order to remove any impurities. Therefore, it is possible to control the carbon content in the molten steel and/or the temperature of the molten metal during and/or at the end point of refining the steel by studying the decarburizing reaction during the refining process and the mechanism of the refining process.

After having studied the decarburizing reaction, it has been found that, in the process of refining steel using an oxygen blown converter, the refining process may be divided into three blowing periods, the first blowing period being the period in which the rate of the decarburizing reaction is mainly influenced by the temperature in the converter and the silicon content of the material charged into the converter, the second blowing period being the period in which the rate of the decarburizing reaction is mainly influenced by the quantity of oxygen supplied which is independent of the carbon content, and the third blowing period being the period in which the rate of the decarburizing reaction is mainly influenced by the carbon content.

It has further been found that the carbon content in the molten steel and/or the temperature of the molten steel during the refining process can be calculated theoretically by setting up a model of the decarburizing rate, as hereinafter defined, by making the temperature increase in the refining process correspond exactly to the decarburizing condition and by making a model of the temperature increase of the molten steel, as hereinafter defined, corresponding to the model of the decarburizing rate. The temperature model is of secondary importance and depends on the model of the decarburizing rate.

Therefore, an object of this invention is to provide a method in which the refining time determines the desired value of the carbon content during the refining process and/or the carbon content at the end of the refining process, using predetermined formulas concerning the decarburizing rate.

The predetermined model of the decarburizing rate and of the temperature of the molten steel, or the refining conditions of the material to be charged into the converter is accordingly modified.

In the present invention, a model of the decarburizing rate is defined as a combination of variations of the decarburizing rates represented by the formulas in the said three blowing periods and a model of the temperature is defined as a combination of variations of the temperature of the molten steel represented by the formulas on the basis of the model of the decarburizing rate.

For a better understanding of the present invention and to show how the same may be carried into effect, reference will now be made to the accompanying drawing, in which

FIG. 1 shows four relations between the blowing time and, respectively, the decarburizing rate, the amount of reaction heat, the amount of solid material charged, and the temperature of the molten metal;

FIG. 2 is a schematic showing of a steel-making plant incorporating a computer control according to a preferred embodiment of the invention; and

FIG. 3 is a simplified flow chart depicting the method of this invention.

Referring now to the drawing and first to FIG. 2, a ferrous metal charge is placed into converter vessel 4 and the molten metal in the converter is converted to steel by blowing oxygen into the converter from the lance 3 which receives oxygen from supply line 1, the oxygen supply being controlled by valve 2 in the line. The exhaust gases from the converter are removed through a hood placed over the mouth of the converter and leading to an exhaust conduit in which the exhaust gases are sprayed at 5 and then led through a Venturi tube 6, the exhaust gases being sucked through the exhaust pipe by blower 7 whose output leads to stack 8. All of this structure and operation is substantially conventional.

While this is not essential, as will be explained hereinafter, the present method is practiced in the illustrated embodiment by means of a computer 9 programmed according to the invention. As is shown in FIG. 2, the flow rate, pressure and temperature of the oxygen supplied to vessel 4 is measured and the resultant signal is fed to the input of the computer through line A. The composition and temperature of the molten bath in the vessel is sampled and the signal from this measurement is fed to the computer input through line B. The CO, CO_2 and O_2 contents of the exhaust gas coming from the hood above the converter are sampled and measured, and the resultant signals are fed to the computer input through line C. Finally, at Venturi 6, the flow rate, pressure, temperature and dew point of the exhaust gas are measured, and the resultant signals are fed to the computer input through line D.

The output of the computer, exemplified by lines x, y and z, controls the operation in dependence on the input signals. As a minimum, the output controls the oxygen supply and stops the same upon completion of the refining reaction. It preferably also controls the oxygen flow rate by operating valve 2, the height of the lance, the addition of cooling and/or slag making agents to the molten bath, etc.

As used throughout this specification and the claims, the term "model" refers to a set of equations mathematically expressing relevant refining reaction conditions. Thus, a model of the decarburizing rate is a set of equations representing the known relationships between the decarburizing rate and such factors as the refining time, the carbon and silicon content of the charge being refined, the amount of oxygen blown into the charge, the refining temperature, the furnace configuration, and the like.

Once, on the basis of experience, the coefficients sr constants of the equations of the model were set up for producing steel of a desired carbon content from a ferrous melt of given composition under predetermined refining conditions, any refining reaction following this model and/or controlled to reflect the model will produce such steel.

In producing a model or prototype refining reaction, we have found that the reaction must be divided into three blowing periods.

FIG. 1 shows blowing periods I, II and III corresponding to $\overline{AB}$, $\overline{BD}$ and $\overline{DE}$.

In the first, blowing period I, the decarburizing rate ($-dc/dt$) varies with the refining time and depends on the silicon content and the temperature of the molten material. In other words,

$$-\frac{dc}{dt}(1)=K_4 t \qquad (1)$$

where K_4 is a constant determined by the initial values of the silicon content and the temperature of the material in the converter, t is the refining time.

In the second blowing period II, the decarburizing rate is a function of the oxygen flow blown into the converter, or, if the oxygen flow is kept constant during this period, is a fixed valve, i.e.

$$-\frac{dc}{dt}(2)=K_5 \qquad (2)$$

where K_5 is a constant determined by the oxygen flow.

In the third blowing period III, the decarburizing rate is a function of the carbon content or the velocity of the carbon arriving at the reaction surface, i.e. approximately

$$-\frac{dc}{dt}(3) = K_6 C \qquad (3)$$

where K_6 is a constant determined by the oxygen flow, the lance height, etc. and

C is the carbon content of the molten steel bath.

The constants in the above equations, which form the prototype or model of the decarburizing rate, are obtained experimentally by running a series of tests and averaging the results into a constant of desired accuracy. Obviously, this accuracy will increase with the number of test runs and the relevant data collected. The constants K_4, K_5 and K_6 are so selected as best to fit the refining vessel and the ferrous charge to be refined, the other parameters depending on the known refining conditions of the reaction to be controlled by application of the model.

Apparatus and instruments for measuring and analyzing the oxygen flow, the amount and composition of the exhaust gas, the carbon content, the temperature, the decarburizing rate and the like are well known, and any suitable means of this type may be used in carrying out the method of the present invention. The total refining time and the duration of each blowing period necessary to obtain a desired carbon content in the steel may be calculated by suitable computers, also well known in the art. An electronic computer may be programmed with the models of the decarburizing rate and the temperature, and the furnace operation is then controlled in a known manner by the computer output to conform to the models, as shown in FIG. 2.

FIG. 3 shows the sequential steps of the method. Computer 9 calculates the values of constants K_4, K_5 and K_6, and the refining time, and after the refining operation has started, it controls the oxygen blowing periods. Before the refining operation starts, the computer effectuates stages I and II.

The values of the constants are calculated on the basis of Data (*i*) which includes the predetermined oxygen flow rate, the silicon content and the temperature of the ferrous metal to be refined, general converter factors, all based on the experimental data of past refining test runs.

In stage II, also before the refining begins, Data (*ii*) such as the original carbon content of the ferrous metal charge, the desired carbon content in the steel to be produced, and the values of the calculated constants, are substituted in the three equations setting up the constants, to determine the total refining time needed to obtain the desired carbon content in the steel. This is stored in the computer to operate its control unit.

After stages I and II have been completed, the refining operation is started by blowing oxygen into the converter and the programmed computer is simultaneously set into operation to compare the stored "model" with the actual operating conditions.

In its simplest form, the control unit of the computer simply produces a stop signal H for halting the oxygen flow when the refining time calculated in stage II has elapsed.

In the preferred procedure, sampling operations are performed at given points throughout the refining reaction (S_1, $S_2 \ldots S_n$) to supply data to the computer in stage III. The computer calculates the difference between the actual values sampled and the estimates derived from the stored model, and provides control signals as functions of these differences to the control unit of the computer to provide control commands C_1, $C_2 \ldots C_n$ to change the refining conditions accordingly, until the stop command H is produced.

In a simpler and less expensive way, the method of the present invention may also be carried out by (1) experimentally determining the three constants in the above equations covering each blowing period, (2) setting the desired carbon content of the steel to be obtained, (3) preparing a chart depicting the decarburizing rate model, as seen on top of FIG. 1, (4) calculating the total refining time from the chart, (5) setting a timer to stop the refining reaction in the furnace at the calculated time, (6) start the refining operation, and (7) stop blowing oxygen under control of the timer to terminate refining.

On the basis of experimental data, the three constants K_4, K_5 and K_6 are determined with respect to the refining vessel to be operated and the ferrous melt to be refined in the following manner for any given point P in the first blowing period I (see top of FIG. 1), successive points R and Q in blowing period II, and any point S in blowing period III.

In the following equations, the decarburizing rate at a given point on the curve on top of FIG. 1 is indicated as $(-dc/dt)P$, $(-dc/dt)B$, etc. The refining time counted from the start of oxygen blowing at each point of refining on this curve is indicated by t_p, t_b, etc. The time elapsed between two successive refining points on the curve is indicated by t_{PB}, t_{BR}, etc. The carbon content of the melt at any refining point is indicated by C_A, C_P, etc.

(A) t_{PB}=?

At the transition point B

$(-dc/dt)_B = K_4 t_B$ the end of period I

$(-dc/dt_B = K_5$ the start of period II

By equating the above two equations

$(-dc/dt)_B = K_4 t_B = K_5$

$t_B = K_5/K_4$

Therefore,

$t_{PB} = t_B - t_P$

$= K_5/K_4 - t_P \quad (5)$

(B) t_{BD}=?

From the equation 2

$-dc/dt = K_5$

$-dc = K_5\, dt$; By integration $\int -dc = K_5 \int dt$

$t = -1/C$

The definite integral from R to Q

$t_{RQ} = 1/K_5(C_R - C_Q) \quad (6)$

The definite integral from B to D

$t_{BD} = 1/K_5(C_B - C_D) \quad (7)$

(C) t_{DS}=?

From the equation 3

$-dc/dt = K_6 C$

$-dc/C = K_6\, dt$

By integration $\int -\frac{dc}{C} = K_6 \int dt$

$-1/K_6 \log_e C = t$

The definite integral from D to S

$t_{DS} = 1/K_6 (\ln C_D - \ln C_S) \quad (8)$

(D) At the transition point D

$(-dc/dt)\ K_5$ the end of period II

$(-dc/dt)_D = K_6 C_D$ the start of period III

Therefore,

$C_D = K_5/K_6 \quad (9)$

(E) C_B=?

From the equation 1

$-dc/dt = K_4 t$

$-dc = K_4\, t\, dt$

By integration

$-\int dc = K_4 \int t dt$

$C = -K_4 t^2/2$

The definite integral from P to B

$$C_P - C_B = \frac{K_4}{2}(t_B^2 - t_P^2)$$

$$C_B = C_P - \frac{K_4}{2}(t_B + t_P)(t_B - t_P)$$

$$= C_P - \frac{1}{2}(K_4 t_B + K_4 t_P)(t_B - t_P)$$

By considering the equation 4

$$C_B = C_P - \frac{1}{2}(K_5 + K_4 t_P)\left(\frac{K_5}{K_4} - t_P\right) \quad (10)$$

(F) By adding equations 5, 7 and 8, one can obtain the refining time from P to S

$$t_{PS} = t_{PB} + t_{BD} t_{DS}$$
$$= \frac{K_5}{K_4} - t_P$$
$$+ \frac{1}{K_5}(C_B - C_D)$$
$$+ \frac{1}{K_6}(1nC_D - 1nC_S) \quad (11)$$

(G) Accordingly, if the values of t_p, C_B and C_D are measured by any conventional means, and since the value C_S is a set value or a desired carbon value, the total refining time from point P to point B is easily calculated from the equation 11.

However, if the values C_P and t_P are obtained, the value C_B is calculated by the equation 10, and the value C_D is also obtained by the equation 9.

In summary, if the values C_P and t_P are obtained, the total refining time t_{PS} is easily calculated by the above equations.

Further, if the point P is shifted back to the point A, that is, the starting point of the oxygen blowing, "t_P" becomes "t_A" or zero and "C_P" becomes "C_A" or the carbon value of the material charged which is measurable before the start of the refining operation.

Thus, equation (10), above, becomes

$$C_B = C_A - \frac{K^5}{2}\frac{K_5}{K_4}$$

The above-detailed explanation or mathematical operation relates to the model of the decarburizing rate. However, since the model of the temperature is also represented by a combination of the three first order equations between the temperature and the refining time for the respective blowing period, an analogous mathematical operation is applicable to the model of the temperature.

Generally speaking, the relationship between the temperature and the refining time or the carbon content in the molten steel is not controlling so that from the model of the temperature we could not obtain the total refining time or the carbon content in the molten steel. The purpose of the temperature model is merely to assure whether the thermal reaction in the furnace is in the order or not.

The reaction heat accompanying the decarburizing reaction, and the oxidation of the silicon and the iron effect a temperature rise of the molten steel. However, as the reaction of the silicon and the iron in the molten metal bath proceeds in quite intimate relation with the decarburizing rate, it is necessary to monitor accurately the decarburizing reaction mechanism in order to control the temperature of the molten bath.

In the first blowing period I, the decarburizing rate does not reach its highest level since the temperature of the molten bath is still low and many impurities, such as silicon, manganese and phosphorus which are more easily oxidizable than the carbon, exist in the molten steel. Therefore, almost all the oxygen blown into the molten metal bath is used to oxidize the silicon, manganese and phosphorus, which oxidation generates a reaction heat. In the second blowing period II, substantially all of the blown oxygen is used for decarburizing and the temperature of the bath rises due to the decarburizing reaction heat. In the third blowing period III, the carbon content decreased. Therefore, the blown oxygen exceeds the required amount due to the decrease in the amount of the carbon arriving and diffusing at the reaction surface. Accordingly, blown oxygen begins to oxidize the iron and the amount of the decarburizing reaction heat decreases whilst the amount of the iron oxidation heat increases.

As to the thermic reaction in the molten steel bath, if the exothermic reaction and the endothermic reaction correspond to the model of the decarburizing rate, in the first blowing period I the pig iron, lime stone and scale, etc. greater substantially with absorbing the heat of fusion, and the greater part of the scrap melts till the end of the second blowing period II. Some thermal dissipation through the brick of the furnace trunk and from the exhausted gas can be observed during the refining reaction. However, with the same furnace life, amount of charge, lance height and oxygen flow, the thermal dissipation can be taken as substantially invariable. Therefore, if this thermal dissipation was previously measured by applying a standard charge into the furnace and the result was substituted into the temperature model as a standard heat, the thermal dissipation can be neglected in considering the model of practical use.

As stated above, in the refining process of steel, the main factors dominating the decarburizing rates are different from period to period and the decarburizing rates naturally vary in accordance with the auxiliary factors, such as the oxygen flow blown in, the oxygen pressure or the reaction area, and the agitation effect of the molten steel due to the lance position. Therefore, the decarburizing rate in each blowing period can be obtained more accurately by considering the auxiliary factors as well as the main factors. In table 1 the factors dominating the decarburizing rates in the blowing periods are shown.

TABLE 1

Periods	Main factors	Auxiliary factors
I	Si content in molten pig iron, temperature of molten pig iron.	Scale, solvent such as slaked lime, limestone, O_2 flow, lance height, nozzle configuration, etc.
II	O_2 flow	Temperature of molten steel, lance height, nozzle configuration, etc.
III	C content	Temperature of molten steel, lance height, nozzle configuration, O_2 flow, etc.

Generally speaking, the method of the present invention is carried out in the following sequence of steps:

1. the constants K_4, K_5 and K_6 in the model or prototype of the decarburizing rate are predetermined experimentally.
2. The desired carbon content of the steel at the end of the refining period is inserted in the equation 3.
3. Since the values or coefficients for the total refining time are thus determined, the values t_{PS} or t_{AS} are calculated.
4. The refining operation is started.
5. The refining operation is continued for the duration t_{AS}, i.e. oxygen blowing is stopped at the calculated time.

In determining the constants K_4, K_5 and K_6, the experimental data concerning the main factors listed in table 1 are primarily considered as mainly determinative of these constants. However, the above sequence of steps does not take into consideration the auxiliary factors listed in table 1, such as the distance of the lance from the molten bath or the nozzle configuration. If these are changed during refining, the initially calculated time t_{AS} becomes incorrect and must be adjusted. Therefore, greater accuracy will be achieved, if an additional step is inserted between steps (4) and (5), above to modify the constants in the light of changed refining conditions and thus to change the total blowing time, or to modify the refining conditions in the light of a continuous comparison between the refining state at any given point calculated from the model of the decarburizing rate and an analysis of the actual refining state of the bath, i.e. its carbon content at such given point. The carbon content at any point may be readily measured by sampling the molten bath, and the refining times and/or decarburizing rate may also be readily measured at such point.

Under many conditions, it will be necessary to take into consideration only the enumerated main factors since the auxiliary factors influence the refining reaction only minimally.

Particularly if the constant have been predetermined on the basis of a large number of experimental runs, the model will usually serve adequately without taking into account the auxiliary factors, and the latter are not critical.

In the present invention, the model of the decarburizing rate in the three blowing periods is prepared for the predetermined refining conditions and the model of the variation of the temperature in the molten steel converter is prepared on the basis of the model of the decarburizing rate. The model of the decarburizing rate is compared with the actual decarburizing rate obtained continuously from the exhaust gas flow and the CO and CO_2 contents in the exhaust gas or from the sampling of the carbon quantity of the steel converter during the refining operation till the end of the first or second blowing period or the model of the decarburizing rate is compared with the decarburizing rate obtained during the second blowing period II. The model of the variation of the temperature in the molten converter is compared with the actual temperature in the molten converter at an arbitrary point during the refining operation by measuring the temperature several times. Any difference between the model and the actual value is used to control the carbon content in and/or the temperature of the steel converter during the refining of the charge or at the end of the refining, by modifying the model of the decarburizing rate of the charge, by modifying the refining condition so as to meet with the model of the temperature variation in the steel bath of the charge corresponding to modification or coincidence of the model of the decarburizing rate, or by modifying the refining condition so as to meet the modification or coincidence of the model of the decarburizing rate.

Hereinafter, the method for modifying the refining condition in order to modify the model of the decarburizing rate is explained precisely with reference to FIG. 1.

The model of the decarburizing rate is obtained on the basis of the silicon quantity in the molten material charged into the converter and the temperature of the material.

1. The time $\overline{AB}$ is read from a chart when the refining process proceeds beyond point B, said chart being the record of the decarburizing rate of the exhaust gas. The refining condition is modified by the deviation between the actual time measured and the set time calculated, and the predetermined total time for refining is modified.

2. The modification on the maximum decarburizing rate in the chart during the second blowing period II is effected by changing the refining time and the oxygen flow in order to obtain the desired carbon quantity in the molten steel to the effect that the proper refining condition is obtained after considering the propriety of the oxygen flow and the oxygen content.

3. If the time $\overline{AD}$ calculated from the model differs from the actual time due to the inaccuracy in the carbon charge or the slopping under, the refining condition is modified by the difference so that the predetermined refining time is modified or the carbon content at the end of refining can be assumed without actual analysis from the actual refining time read after the blowing period III is over.

The refining conditions are so modified that the decarburizing rate actually calculated from the exhaust gas flow and the CO and CO_2 quantity in the exhaust gas or the sampling of the carbon content in the molten steel converter during the refining equals the set decarburizing rate in the model, according to the following procedures:

1. If the actual increasing decarburizing rate in the blowing period I of the charge increases over the set increasing decarburizing rate in the model, the oxygen flow is decreased, and/or additional silicon or limestone is charged as cooling agent. If the actual increasing decarburizing rate decreases below the set increasing decarburizing rate, the oxygen flow is increased, and/or an oxygen source, such as iron ore, or an exothermic agent is charged into the converter.
2. If the actual decarburizing rate in the second blowing period II of the charge increases over the set decarburizing rate in the model, the oxygen flow is decreased, the oxygen lance height is increased, or the slag quantity is increased by adding a slag producing agent, such as limestone. If the actual decarburizing rate decreases below the set decarburizing rate, the oxygen flow is increased, the oxygen lance height is decreased, or an oxygen source such as iron ore is charged.
3. If the actual decreasing decarburizing rate in the third blowing period III of the charge decreases below the set decreasing decarburizing rate in the model, the oxygen flow is increased, the oxygen lance height is decreased, or an oxygen source, such as iron ore, is charged. If the actual decreasing decarburizing rate increases over the set decreasing decarburizing rate, the oxygen flow is decreased, the oxygen lance height is increased, or the slag quantity is increased by adding slag producing agents, such as limestone.

In steel refining plants, the steel is tapped from the furnace after the carbon content and the temperature of the steel converter at the end of refining have reached the desired values. Therefore, the control of the carbon content should be effected in addition to the control of the temperature in order to control the refining process.

In the present invention, the total refining time and the respective times in the blowing periods, I, II and III are calculated in accordance with the system controlling the carbon content in the steel bath, the factors of the control being the main material charged, the quantity of the material charged, the carbon content in the material charged, the oxygen flow and the lance height. Therefore, the model for the temperature of the steel bath in each blowing period can be calculated from the times referred to above and the process in which the temperature of the steel bath increases is made clear. In conclusion, the finished carbon content in and the temperature of the steel converter can be controlled easily and accurately by measuring the temperature of the steel converter during refining.

The following examples further illustrate the present invention without limiting the same thereto:

EXAMPLE I tz

a. Desired carbon content at the end of refining			0.07%
Desired steel temperature at the end of refining			1,630° C.
b. Measured values:			
Oxygen flow			23,000 Nm.³/Hr.
Main charge: Molten pig iron		128 tons	
Cold pig iron		7 tons	
Scrap		32 tons	167 tons
Auxiliary charge:	Limestone	7.0 tons	
	Scale	0.8 tons	7.8 tons
Components of the molten pig iron:			
C			4.45%
Si			0.30%
Mn			0.62%
P			0.194%
Molten pig iron temperature at start			1,212° C.
c. Time calculated on the basis of the model of the decarburizing rate			
Refining time of blowing period I			7.00 min.
Refining time of blowing period II			9.26 min.
Refining time of blowing period III			5.06 min.
Total refining time			21.32 min.
d. Temperature calculated from the refining time above			
Point B			1,252° C.
Point D			1,575° C.
Point E (desired)			1,630° C.

The above calculations were performed prior to the actual refining operation.

e. The refining proceeded as follows:

1. After start, the recording of the decarburizing rate rate chart was started.
2. Blowing period I coincided with the model so that no adjustment was needed.

3. Actual time to point D exceeded the calculated time by 0.35 minutes. So the total refining time of the model was extended by 0.35 min. and the temperature model was changed accordinghy.
4. 1.5 tons of limestone was charged at 17.05 min. after start.
5. Analyzed carbon content of the finished steel 0.7%
6. Temperature at the end of refining 1632° C.

EXAMPLE 2.

a. Desired carbon content at the end of refining		0.18%
Desired steel temperature at the end of refining		percent 1,620° C.
b. Measured values:		
Oxygen flow		21,000 Nm.³/Hr.
Main charge: Molten pig iron	121 tons	
Cold pig iron	7 tons	
Scrap	41 tons	169 tons
Auxiliary charge: Limestone	7.9 tons	
Scale	1.3 tons	9.2 tons
Components of the molten pig iron.		
C		4.38%
Si		0.47%
Mn		0.69%
P		0.198%
Molten pig iron temperature at start		1,324° C.
c. Time calculated on the basis of the model of the decarburizing rate		
Refining time of blowing period I		9.50 min.
Refining time of blowing period II		7.40 min.
Refining time of blowing period III		4.83 min.
Total refining time		21.73 min.
d. Temperature calculated from the refining time above		
Point B		1,265° C.
Point D		1,568° C.
Point E (desired) th		
1,620° C.		
The above calculations were performed prior to the actual refining operation.		
e. The refining proceeded as follows:		
1. After start, the recording of the decarburizing rate chart was started.		
2. Actual time to point D was 0.20 min. less than calculated. So the total refining time of the model was shortened by 0.20 min.		
3. Temperature measured after refining of 17 min. 1,567° C.		
4. Substituted the temperatures at 17 min. and at 4.53 min. after the former measurement into the model of the temperature.		
5. During 20 seconds after refining of 18.5 min., the refining was done with increased lance height.		
6. Actual refining time was extended by 10 seconds from that of the model.		
7. Analyzed carbon content of the finished steel		0.17
8. Temperature at the end of refining		1,624° C.

As will be clear from the above description, in the present invention the carbon content in the molten steel individually and/or simultaneously during refining.

We claim:

1. A method of producing steel of a desired carbon content, comprising the steps of

a. charging a refining vessel with a ferrous metal having a known silicon content and a known carbon content C_A,

b. blowing oxygen into bath of the molten ferrous metal at a flow rate in successive first, second the third oxygen blowing periods;

c. establishing said flow rate in the respective and successive blowing periods by the following equations:

$$-\frac{dc}{dt}(1) = K_4 t$$

$$-\frac{dc}{dt}(2) = K_5$$

$$-\frac{dc}{dt}(3) = K_6 C$$

wherein K_4, K_5 and K_6 are constants obtained on the basis of experimental data of past refining runs at said oxygen flow rate, the silicon content and the temperature of the ferrous metal bath, and operating factors of the vessel, t is the refining time, C is the carbon content of the molten bath at any given point, dc/dt being the decarburizing rate;

d. sampling the carbon content C_P in the first blowing period at a time t_P from the start of the oxygen blowing;

e. limiting the oxygen blowing time in the successive blowing periods to respective and successive times t_{PD}, t_{BD} and t_{DS}, totaling refining time t_{PS} from point P, these times being derived from the following equations, wherein the desired carbon content of the steel is C_S C_B being the carbon content at a transition point B between the first and second blowing periods, and C_D being the carbon content at a transition point D between the second and third blowing periods: :

$$[t_{AB}]t_{PD} = \frac{K_5}{K_4} - t_P$$

$$t_{BD} = \frac{1}{K_5}(C_B - C_D)$$

$$t_{DS} = \frac{1}{K_6}(1nC_D - 1nC_S)$$

wherein

$$C_B = C_P - \frac{1}{2}(K_5 + K_4 t_P)\left(\frac{K_5}{K_4} - t_P\right)$$

and

$$C_D = \frac{K_5}{K_6}$$

and

f. discontinuing refining when the end of time t_{PS} has been reached.

2. The method of claim 1, wherein the time t_P of sampling the carbon content C_P is the start of the oxygen blowing whereby t_P becomes zero in said equations.

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