

[54] MONITORING AND CONTROL OF PIG IRON REFINING

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Foreign Application Priority Data

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[51] Int. Cl..... C21c 5/30, B21d 28/00, G01n 21/26

[58] Field of Search..... 73/357, 339 A, 194 A; 75/60; 250/43.5 R, 71 R

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ABSTRACT

In the refining operation taking place under regulable refining conditions, oxygen-containing gas is blown from above onto a bath of molten pig iron in a vessel; the gases leaving the vessel are withdrawn through a hood. The following three parameters are determined by making measurements of only the physical properties of the gases at one position in the hood upstream of where the CO in the gases has burnt to CO₂: the mean speed of the gases, their carbon content, and their temperature. From these three parameters the decarburisation rate is calculated and is compared with a predetermined optimum value. If the calculated rate differs from the predetermined value, one or more of the regulable refining conditions are adjusted to reduce or annul this difference.

13 Claims, 6 Drawing Figures

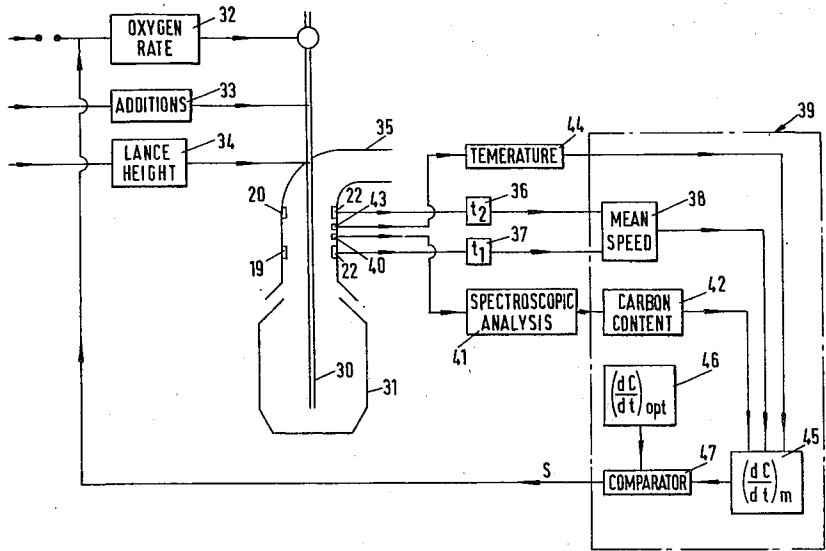


FIG.1.

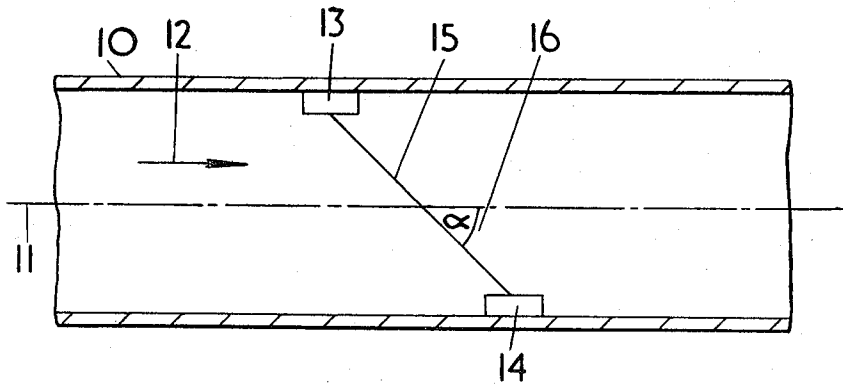


FIG.2.

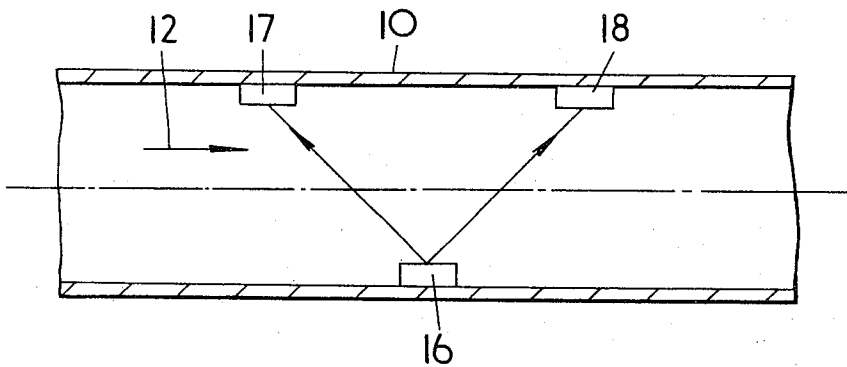
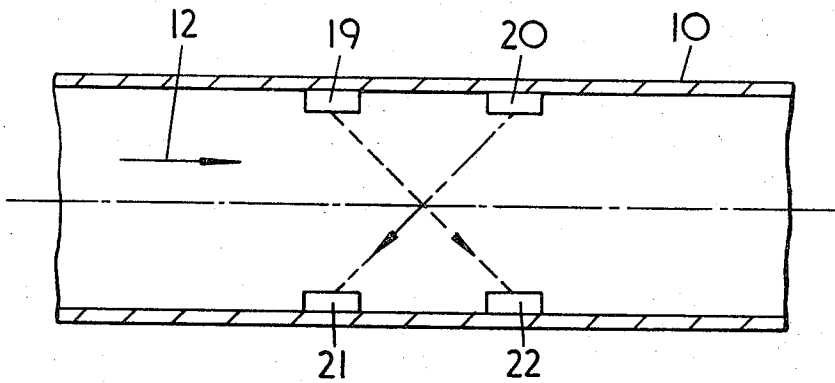


FIG.3.



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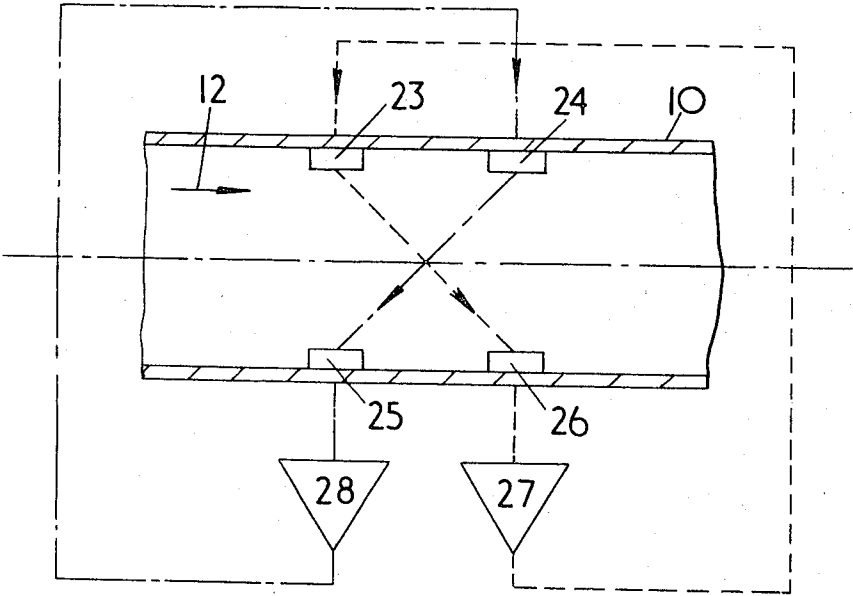


FIG.4.

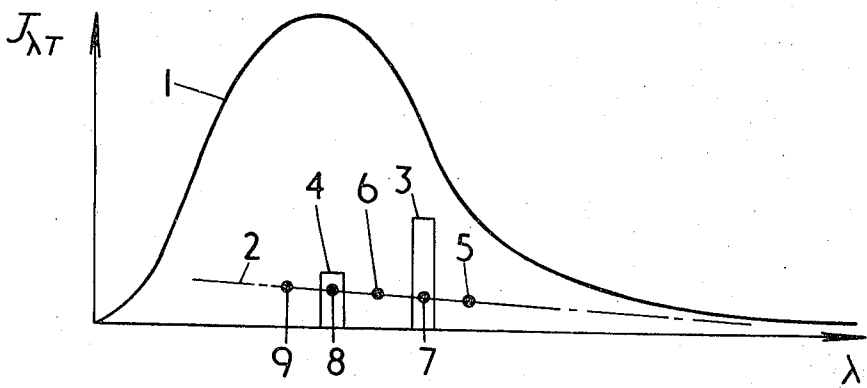


FIG.5.

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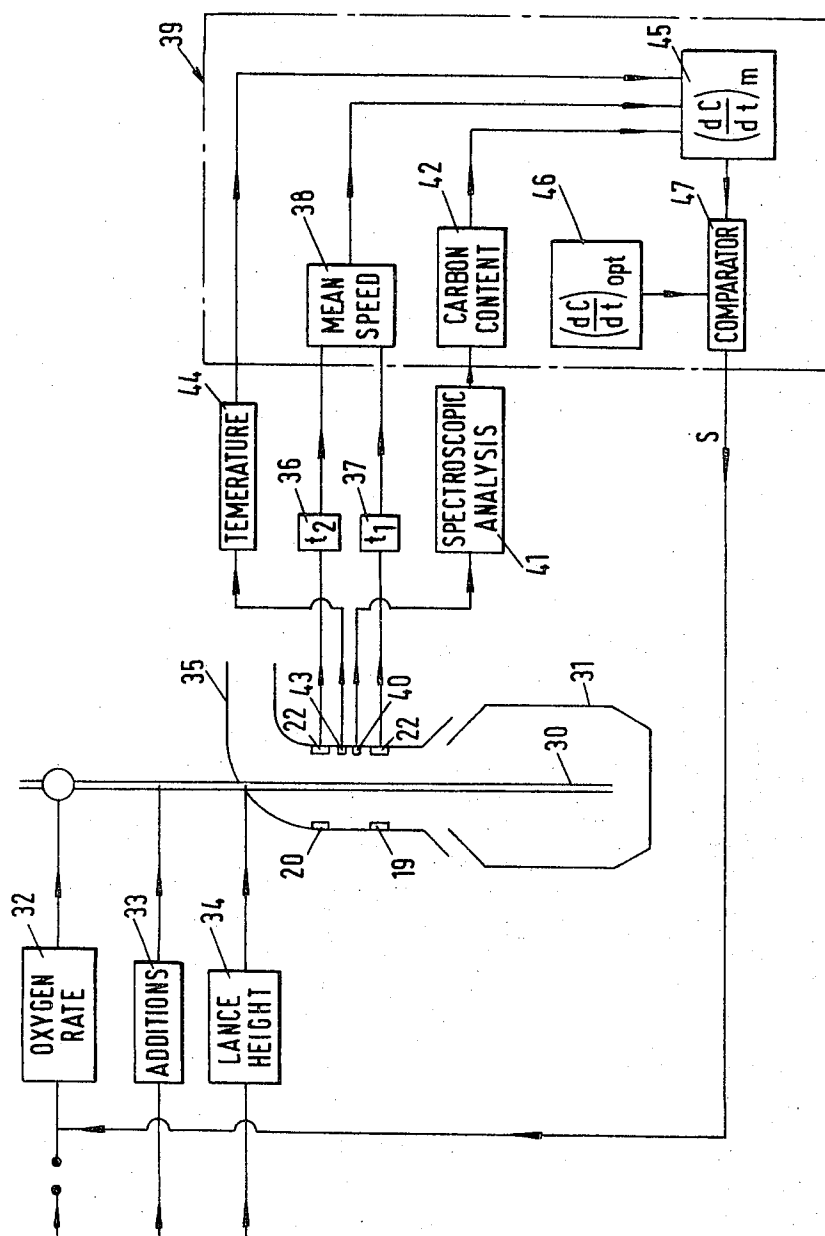


FIG. 6

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MONITORING AND CONTROL OF PIG IRON REFINING

The present invention is a continuation-in-part of application Ser. No. 782,032 filed Dec. 9, 1968, and now abandoned, and relates to a method for monitoring and regulating the refining of pig iron; it has particular reference to the case in which an oxygen-containing gas, which is most frequently commercially pure oxygen, is blown from above onto or into the bath of molten metal to be refined. The vessels in which the refining operation is carried out may be rotated during the whole or part of the refining operation.

The variables in the problem set in carrying out a customary refining operation may be itemised as follows: molten pig iron, lime, oxygen, additives, and their amounts, chemical compositions, and physical characteristics.

It is desired to obtain a given weight of steel of specified composition, at a given temperature.

Starting out from these data, the steelmaker has to determine the necessary charges which are to be put into the furnace; calculate the rate of flow of oxygen to be supplied during the phase or phases of the refining operation; and fix all the conditions to be fulfilled in order to reach in the best possible way the target which has been set. The optimum evolution of the carbon content of the bath during the refining operation is one of the most important of these conditions.

When these preliminary operations have been carried out and the optimum development curves have been determined from the above calculations, the steelmaker still has the important task of checking whether the refining process is developing in accordance with the pre-arranged plan, and if need be, of taking any measures considered necessary to keep the development of the refining operation in conformity with specifications, or to bring it back to these.

Numerous methods have already been proposed or utilised for carrying out this control in the course of the refining operation. Based on the observation of the evolution of the decarburisation of the bath of molten metal, most of these methods include the steps of chemically analysing the gases issuing from the refining installation (converter gases) and in measuring their rate of flow. By this means it is possible to know, at least theoretically, the amount of carbon leaving the refining installation at a given moment. By carrying out these methods continuously it is possible to plot the curve of decarburisation rate against time and by comparing this with the optimum curve, it is possible to determine the state of affairs and make the necessary corrective arrangements which may be found to be necessary.

Some disadvantages are found to be inherent in carrying out this program, one of these being the delay between the moment when analysis of converter gases is started and the moment when, after all calculations have been made, the appropriate corrective measures may be carried out. This delay, which in industrial practice is often 15 seconds or more, is too long for truly efficient operation. The result is that corrections made may be insufficient or may partially be inadequate because there is too much delay, as the evolution of the refining operation is, of course, very rapid.

There is another disadvantage inherent in the customary methods of measuring the rate of flow of gases

escaping from the refining vessel. These measurements are carried out most often by means of a device producing a pressure reduction, such as a venturi tube, which may for instance be placed in the fumes suction hood, which means that no great accuracy can be obtained in particular because of the presence of dust in the fumes. It is in fact known that measurement of the rate of flow of a gas, if carried out by means of a venturi tube, can only lead to accurate results if the gas is free from any disturbing components such as dust or foreign particles of any type.

Moreover, in numerous existing installations, the local configuration means that only very infrequently can a venturi tube or the like be set up in conditions which are anything like satisfactory.

In order to overcome this disadvantage, it has already been proposed to omit the venturi tube and to calculate the rate of flow of the gases in accordance with the power absorbed by the fumes suction fan. There is however a disadvantage attendant on this solution in that the rate of flow measured in this way represents, over and above the rate of flow of the converter gases, the rates of flows of all the air or steam, accidental or intended, from the refining vessel to the fan. As a result the accuracy of the measurement carried out is not improved. Other disadvantages include the considerable drift in the measurements themselves in the course of time, the inevitable variations in the pressure drops in the conduits and so on.

The aim of the present invention is to produce a method by which it is possible to eliminate to a considerable extent the major part of these disadvantages.

The present invention provides a method for monitoring and controlling a pig iron refining operation taking place under regulable refining conditions, in which oxygen-containing gas is blown from above onto a bath of molten pig iron in a vessel, and the gases leaving the vessel are withdrawn through a hood, comprising the steps of:

- i. determining the mean speed of said gases at a given position in the hood upstream of the position at which the CO in said gases has burnt to CO₂;
- ii. determining the carbon content of said gases at said given position;
- iii. determining the temperature of said gases at said given position; these three determinations being carried out by making measurements of only the physical properties of said gases within the hood;
- iv. calculating the rate of decarburisation of said bath from said mean gas speed, said carbon content, and said temperature;
- v. comparing the calculated decarburisation rate with a predetermined optimum value of said rate; and, if said calculated decarburisation rate differs from said predetermined optimum rate,
- vi. adjusting at least one of said regulable refining conditions to reduce or annul the difference between said calculated rate and said optimum rate.

The measurements leading to the said determinations may be carried out continuously throughout the refining process, which makes possible continuous calculation of the decarburisation rate by introduction of the results of the measurements into a suitably programmed electronic computer, which supplies continuously such corrective data as may be needed. These corrective data can themselves be transmitted continuously to a regulator or to an automatic control device.

Since measurements of the physical properties of the gases within the hood can be obtained practically instantaneously, there need only be a short delay before the regulable refining conditions are altered, as compared with chemical analysis of the gases.

The method of the invention has the important advantage that it can be put into operation with rapid response apparatus having little bulk, which can be installed in practically all existing installations, without the necessity for large scale modifications.

The invention will be described further, by way of example only, with reference to the accompanying drawings, in which:

FIGS. 1 to 4 are diagrammatic sections of different arrangements for determining the speed of the gases;

FIG. 5 shows curves of spectral distribution plotted against wavelengths; and

FIG. 6 is a block diagram illustrating the control of the refining operation.

1 DETERMINATION OF THE SPEED OF THE GASES ESCAPING FROM THE REFINING VESSEL.

The principle made use of for determining the speed of the refining gases is based on the well known influence which a gaseous fluid has on the speed of an acoustic wave, sonic or ultra-sonic, passing through the gaseous fluid. The sound wave is made to pass through the hood, or its extension through which the fumes pass, at or near the place where the measurements (described below) are carried out for the determination of the amount (ΔC) of carbon which escapes with the fumes in a given time interval.

As an example (see FIG. 1) the hood will be considered as a cylindrical channel 10, having an axis 11, through which the gases flow at a speed V (taken to be uniform to facilitate reasoning) in the direction of the arrow 12. On opposite sides of the channel 10 two apparatuses 13, 14 are mounted, which can be used alternately as sound emitter and sound receiver. If α is the angle which the axis 11 makes with the line 15 of length L joining the apparatuses 13 and 14 and ϵ is the speed of an acoustic wave in the fluid at rest, at the temperature T and at the pressure considered (speed of sound in the case of sonic frequencies), one will have:

a. In the direction 13 $\rightarrow$ 14

$$L = (\epsilon + V \cos \alpha) t_1$$

(t_1 = time taken by the wave to travel along the path 13 $\rightarrow$ 14);

b. In the direction 14 $\rightarrow$ 13

$$L = (\epsilon - V \cos \alpha) t_2$$

(t_2 = time taken by the wave to travel the path 14 $\rightarrow$ 13);

or

$$t = L/(\epsilon \pm V \cos \alpha)$$

(1)

where the sign in the denominator depends on the direction of travel.

A measurement of this type means then, in effect, the measurement of a time of travel t of a sound wave between two well determined points in a channel carrying the gases whose speed it is desired to determine.

In order to increase the accuracy which can be obtained by means of this method, the two measurements indicated above are combined by arranging an acoustic emitter 16 (FIG. 2) facing two receivers 17 and 18

which are in symmetrical arrangement. One thus obtains a differential measurement whose accuracy is substantially increased. In actual fact the difference of the time of travel of the same acoustic wave between the emitter 16 and the receivers 17, 18 will be given by the equation

$$t_1 - t_2 = [L/(\epsilon - V \cos \alpha)] - [L/(\epsilon + V \cos \alpha)] = 2LV \cos \alpha / \epsilon^2$$

(2)

ignoring $V^2 \cos^2 \alpha$, which is small in relation to ϵ^2 .

It follows that the error in V is substantially directly proportional to that in $(t_1 - t_2)$, i.e. the accuracy obtained for $(t_1 - t_2)$ is proportional to that obtained for V , which was not the case for the single measurement.

The choice of the acoustic frequency to be used depends on conditions of absorption, by the gases, of the wave emitted; these conditions are in related to the temperature, composition, pressure etc. of the gases.

In a method of operation which is of particular interest from the viewpoint of this type of measurement, the acoustic wave emitted is constituted by a carrier wave of relatively high frequency (for instance 100kHz), which makes it possible to obtain sufficient accuracy in measurement with acceptable attenuation, the carrier wave being modulated with a train of low frequency pulses which ensures continuity in practice of the transmission of information and, consequently, continuity of the corresponding measurement operation.

FIG. 3 shows another arrangement, well known per se, of emitters and receivers, leading to Equation (2) given above. The directional emitters 19, 20 are arranged on one side of the channel 10, whilst two directional receivers 21, 22 are arranged on the opposite side. The travel times t_1 and t_2 correspond respectively to the directions 20/21 and 19/22, the length of the paths 20/21 and 19/22 being substantially the same.

However, it would not be going beyond the scope of the invention to arrange the directional sound emitters and receivers in such a way that the two sound paths are substantially parallel and adjacent to each other, which makes it possible to eliminate the influence of any local lack of symmetry in the temperature distribution and the speed of the gases.

Equation (2) above can be put in a more directly utilisable form by defining

$$\Delta t = t_1 - t_2$$

and

$$\Delta \phi = \omega \Delta t,$$

ω being the frequency of the acoustic wave.

It follows that

$$\Delta \phi = 2 \omega LV \cos \alpha / \epsilon^2$$

(3)

This equation, as well as Equation (2), shows that the value Δt , or $\Delta \phi$, depends directly on the value of ϵ , which is well known to be a function of temperature (T) and of the composition of the medium considered.

In order to eliminate ϵ from the calculation, if necessary, or in order to know ϵ in a way that is as permanent as it is automatic, use may advantageously be made of the arrangement of FIG. 4.

Here again there are two directional acoustic emitters 23 and 24 exactly opposite two directional receivers 25 and 16. Each receiver is return looped to its associated emitter. The wave received by the receiver 25 or 26 passes through an amplifier 28 or 27 and is re-injected into the emitter 24 or 23. The looping across the gas transforms the amplifier circuit into an oscillator the frequency of which is determined by the actual relaxation time of the acoustic circuit concerned.

One will accordingly have

$$t_1 (= 1/f_1) = L(\epsilon - V \cos \alpha)$$

$$t_2 (= 1/f_2) = L/(\epsilon + V \cos \alpha)$$

hence

$$f_1 = (\epsilon - V \cos \alpha)/L$$

(4)

$$f_2 = (\epsilon + V \cos \alpha)/L$$

(4')

This system (4,4') gives rise to two relationships

$$f_2 - f_1 (= \Delta f) = 2 V \cos \alpha / L$$

(5)

$$f_2 + f_1 (= \Sigma f) = 2\epsilon/L$$

(6)

Equation (5) enables the determination of V to be made independently of ϵ , whereas Equation (6) makes it possible to obtain the permanent determination of ϵ from the frequencies f_1 and f_2 .

A particularly important advantage of the methods given above, and characteristic of them all, consists in the fact that they are applicable even when the gases contain materials in suspension. An advantage of this type is not to be found in the venturi tube or like systems customarily used.

As can be seen above, the determination of V can be reduced to a measurement of sound frequencies, the influence of the temperature accordingly being automatically included in the result.

Moreover, Equation (6) supplies a permanent value of ϵ , which itself supplies the value of the temperature T in accordance with a well known standard relationship (see below). This value may contribute a checking of the values obtained by other methods, and has the advantage of being particularly accurate and of showing very little variation as a function of the variations of the composition of the gases which may be met with in the channel. By means of the permanent value of ϵ , it is accordingly possible immediately to determine the values $J \gamma \tau$ introduced into Equation (8) given below.

It should be noted that the considerations given above include the simplifying hypothesis that the speed V of the gases is practically uniform over the cross-section of the channel. In actual fact, this hypothesis is very seldom realised, the flow of the gases being either laminar or turbulent, or, when the Reynolds number is in the vicinity of the critical number, the gases may be in an intermediate state between these states.

It is, however, an easy matter to introduce into the above equations the necessary corrective terms for enabling the mean effective speed of the gases to be determined, whatever may be the state of flow. These cor-

rective terms are well known, and their use does not pose any special difficulty.

In order to avoid any doubt on the nature of the gas flow it is possible to carry out a preliminary check of the flow by means of a Pitot tube displaced systematically across one diameter of the channel wherein the gases are circulating. In the event that the observations carried out in this way indicate that one is in what has been called the intermediate state, it is possible to disturb the flow of gas artificially, so as to make it turbulent, or to increase the speed of the gases by restricting the passage section of a portion of their path; it is known that such restriction favours the establishment of a turbulent system or state in the portion concerned.

It is possible to carry out this check by measuring the rate of flow of the gases by the well known method of tracers, which may or may not be radioactive.

II DETERMINATION OF THE CARBON CONTENT OF THE GASES.

The rate of decarburisation of the pig iron, i.e. the instantaneous value of variation of the carbon content of the bath, can be found by determining the amount of carbon which is escaping at any moment in the fumes.

In order to evaluate this amount, a section of length Δx of the hood or its extension is taken, through which the fumes pass after issuing from the refining vessel. The amount of carbon ΔC contained in this section at a given time t is proportional to the mean value (calculated from the time $\Delta t'$ which the gases take to pass through the section Δx) of the decarburisation rate dC/dt calculated at the time $(t - \tau)$, τ being the time necessary for the gases to move from the level of the bath to the beginning of the section Δx :

$$\Delta C / \Delta t' = (dC/dt)_{t-\tau}$$

Now if V is the speed of displacement of the gases in the section Δx — to facilitate reasoning this speed is taken to be constant for all the gas streams — one has likewise

$$\Delta t' = \Delta x / V.$$

It follows that

$$\Delta C = (dC/dt)_{t-\tau} \cdot \Delta x / V \quad (7)$$

In order to know dC/dt it is accordingly sufficient to measure ΔC and V .

The measurement of ΔC can be carried out by means of a radiation receiver arranged in such a way as to include the section Δx in its field of observation.

One way of determining ΔC consists in measuring in a particular way the energy radiated by the fumes located in the section Δx at the time t .

It is known that the elementary thermal energy dW radiated by a body raised to a high temperature is given by the standard equation:

$$dW = a\lambda \cdot J_{\lambda \tau} \cdot d\lambda \cdot d\Omega \cdot dS \cdot \cos \beta \quad (8)$$

in which

$a\lambda$ = absorption coefficient of the body considered, for the wavelength λ considered;

$J_{\lambda T}$ = Specific intensity of radiation of a black body for the wavelength λ and at the temperature T (this value $J_{\lambda T}$ is supplied by the Planck equation);

$d\lambda$ = Elementary interval of the length of wave considered;

$d\Omega dS \cos \beta$ = Differential factors of geometric nature, constant for a given installation.

Moreover, it is known that

$$a\lambda = 1 - \exp\{-E \cdot D \cdot (C_p K_p + C_g K_g)\} \quad (9)$$

where:

E and D are constants depending on local geometrical conditions;

C_p = volumetric concentration of dust in the gases passing through the channel, in p.p.m. i.e. parts per million;

C_g = volumetric concentration of (CO and CO₂) in the gases in p.p.m.;

K_p = constant of absorption of the dust, in % per p.p.m. and per unit of length of optical path;

K_g = constant of absorption of the CO and the CO₂, in % per p.p.m. and per unit of length of optical path.

The value of ΔC , which should make it possible to calculate dC/dt , is in fact proportional to the product of C_g by the elementary volume corresponding to the sighting along the solid angle d and integrated over the whole volume of the section.

It should be noted that C_g is in fact the sum of two terms i.e. C'_g corresponding to the carbon due to the presence of the CO₂ and C''_g corresponding to the carbon due to the presence of the CO. This value of C_g may in accordance with the invention be obtained in the following novel way.

In FIG. 5, the standard curve 1 represents the spectral distribution $J_{\lambda T}$ relative to the emission of energy by a black body at a given temperature T . This curve 1, is given by the well known equation, known as Planck's equation. The curve 2 represents the spectral distribution of the energy emitted by the dust and other bodies present in the gases and which are likewise at a substantially equal temperature T . From this viewpoint, the particles and dust play the role substantially of a grey body in the wavelengths considered. This curve 2 is substantially linear, at least in a restricted region of the infra-red spectrum. The graph also shows diagrammatically the emission bands 3 or 4 of 2.7μ and 2.35μ relative to the gases CO₂ and CO. Measurements of $W = \int dW$ are carried out in the area defined by the section Δx , and for the following wavelengths:

a. At reference 5, where the measurement supplies only the value of $C_p K_p$, since CO and CO₂ are not emitting. In actual fact the right-hand side of the equation $W = \int dW$ contains in practice only one term ($a\lambda$) which is not directly known. (The value of the temperature T is permanently known, as has been shown above.) This value of $a\lambda$, which is now determined by virtue of the measurement of W which has been carried out, enables the value of $(C_p K_p + C_g K_g)$ to be found from Equation (9). As at these frequencies the CO and the CO₂ do not emit the corresponding product $C_g K_g$ is zero and one can accordingly isolate and know the value of $C_p K_p$.

b. At reference 6, located between the bands 3 and 4, where another measurement of W supplies another isolated value of $C_p K_p$, which makes it possible to de-

termine very roughly by interpolation the value of $C_p K_p$ at 7 in the band 3 where the CO₂ is emitting and where the CO is not emitting. A measurement of W at this wavelength makes it possible to know the value of the sum $(C_p K_p + C_g K_g)$ whence, by difference, one can deduce $C_g K_g$ relative to the CO₂ and consequently the value of C'_g , since K_g is a known constant, both for CO and CO₂.

Measurements are made at 8 and/or at 9 by the same method, at a wavelength less than 2.35μ to determine the value of $C_p K_p$ at 8 in the band of emission of CO, where CO₂ is not emitting. A measurement undertaken at 8 accordingly makes it possible to calculate C''_g relative to CO.

The knowledge of C''_g (CO) and C'_g (CO₂) makes it possible, by addition and after integration over the whole of the volume of the section, know known ΔC at the moment considered, and consequently to determine $C(t)$ and dC/dt at any moment.

The above method has the advantage that all the measurements can be carried out simultaneously; all that has to be done is to have available as many radiation receivers as there are measurements to be carried out at different frequencies, each receiver being provided with a suitable filter. All the values of the measurements carried out in this way can be introduced simultaneously and without delay into an electronic computer programmed to solve the equations involved, and the results of the operations may be known practically immediately.

In the description of the above method, the bands of emission of 2.7μ of the CO₂ and of 2.35μ of the CO have been sketched at 3 and 4, and it is necessary to bear in mind that the measurement carried out at 6 only makes sense if at this wavelength there is, as a matter of actual fact, virtually no emission on the part of the CO or of the CO₂. If there is some difficulty in finding a wavelength which satisfies this condition the measurement at 6 can make do with measurements taken at 5 and 9, the sole inconvenience being a linear interpolation to determine $C_p K_p$ at 8 and at 7. The principle of the method used however remains the same.

Another version of this method of determining the value of ΔC consists in directing through the section Δx , in which the instantaneous value of ΔC is to be evaluated, an electromagnetic radiation of energy J_i with a predetermined intensity and wavelength, and in measuring the intensity of the portion of this radiation which passes through the gases contained in the section. Since the gases play the part of an absorbing medium, one is in this case utilising a method by absorption.

The measurement to be carried out consists on the one hand of measuring the incident energy J_i and the transmitted energy J_t , their difference representing the energy absorbed J_a .

One accordingly has

$$J_i = J_t + J_a$$

$$1 = (J_t/J_i) + (J_a/J_i)$$

J_a/J_i being precisely the absorption coefficient of the medium for the radiation considered i.e. $a\lambda$, and

J_t/J_i being the transmission coefficient of this medium for this same radiation. i.e. $\delta\lambda$; from which one deduces

$$a\lambda = 1 - \delta\lambda,$$

$\delta\lambda$ being determined by the measurements of J_i and of J_e , the value of $a\lambda$ being accordingly itself determined. As on has Equation (9) which connects $a\lambda$ to the values C'_p and C'_g , it suffices to carry out as above the measurements of J_i at the wavelength corresponding to references 5, 6, 7, 8, 9 already mentioned, to be able to calculate the value of dC/dt sought (note that $J_i = W$).

All these measurements, as has already been pointed out, can be carried out in a systematic and automatic way within a very short space of time and can be utilised without delay in a suitable electronic computer which immediately supplies the results sought.

Here it should be mentioned that the radiation from the "internal wall" of the section Δx considered has no influence on the result of the measurements and can be ignored in these measurements. In fact, at a point such as 5, the measurement carried out does not in fact make it possible to obtain the isolated value of $C_p K_p$, but the sum $(C_p K_p + C'_p K'_p)$ the last term of which corresponds to the influence of the radiation of the wall. At a place such as 7, the real measurement supplies $C_p K_p + C'_p K'_p + C_g K_g$, and it can be seen that $C'_p K'_p$ eliminates itself automatically, by virtue of the subtraction carried out, which leaves only $C_g K_g$ sought.

The electromagnetic radiations to be used for this method by absorption can be obtained by making use of a suitably filtered grey body, or by selecting from among all the spectra of emission at the known bodies those which include bands with frequency ranges which fall exactly in the zones where the reference 5 to 9 are located. Moreover, all radiation of this latter type is all the more interesting in that it can be obtained with a greater energy density, which obviously facilitates the measurements facilitates be carried out. In this respect the radiations of the energy stimulated type, for instance LASER or MASER, are especially useful.

A second way of evaluating ΔC consists in measuring the energy radiated by chemiluminescence at the outlet of the refining vessel, from the chemical reaction $CO + \frac{1}{2} O_2 = CO_2$. This reaction brings about an electromagnetic radiation having a continuous spectrum the intensity of which can be measured by means of a suitable selective receiver which is substantially in proximity to 0.43μ . This intensity is in direct relationship with the amount of CO entering into reaction, which is a practically constant proportion of the total amount of CO leaving the refining apparatus at that moment. It follows that this measurement of intensity supplies a direct indication of the value of ΔC and consequently of dC/dt .

This method has the special advantage of being very accurate, since the results of the measurements are little influenced by considerable variation in the temperature in the usual range of gas temperature met with at the outlet of the refining vessel.

A third way of determining the value of dC/dt involves measuring the intensity of radiation emitted by the particles and dust present in the gases in a definite frequency range.

It has in actual fact being observed that, in an absolutely unexpected way, a measurement of the radiation emitted by the particles, dust and so on, in suspension in the gases, in a range of wavelength less than 1.6μ , and preferably between 0.8μ and 1.6μ supplies a value

of W which is closely proportional to dC/dt . The value of the coefficient of proportionality can easily be determined by comparison with statistical data.

It is to be noted that this spectrum range does not include any corresponding corresponding to emissions coming from CO, CO₂ or from chemical reactions between the constituents of the gases.

In order to increase the accuracy of this method, by eliminating the influence of the radiation from the portion of the wall of the section Δx which influences the receiver, this portion is provided with an internal coating having a high heat conductivity coefficient, for instance copper, which is cooled energetically. The considerable drop in the temperature of this portion makes negligible the influence of the value of its radiation on the result of the measurement carried out on the dust.

III DETERMINATION OF THE TEMPERATURE OF THE CONVERTER GASES.

Among the numerous methods which can be envisaged for carrying out the instantaneous and continuous measurement of the temperature T of the converter gases, choice is preferably made of the method already mentioned in section I of this description, i.e. the method where the value of T is deduced instantaneously from that of which is known in permanence through the measurement of the frequencies f_1 and f_2 mentioned.

Another particularly interesting method has been developed, and consists in measuring the frequency of a stationary acoustic wave set up in a guide of known length placed in the converter gases, the guide being inserted in a sound circuit which is oscillating and self-maintained, the excitation of which is established as a function of this frequency itself, which makes possible accurate and instantaneous measurements of the temperature ruling in the guide (Belgian Pat. No. 699,762).

EXAMPLE

A total combustion hood is considered. It should be noted that, whatever the type of hood, the pressure p at the place where the measurement is taken is practically constant and very slightly lower than the atmospheric pressure. The pressure must remain approximately constant to ensure suitable combustion in the combustion hood. (In non combustion hoods the pressure must likewise remain constant to avoid backflow).

Variations in application of the process described in the application differ from one installation to another, the principle remaining always the same. It is for this reason that the example is limited to a given installation.

1. DETERMINATION OF THE CO AND CO₂ CONCENTRATIONS IN THE CONVERTER GASES.

To simplify matters, it is supposed that this measurement is made where radiation from dust and from the walls of the hood is negligible. Where this is so, it suffices to use two radiation receivers, fitted with suitable optic filters. It is supposed that the two receivers are directed towards the same part of the flame and that the geometric factors are the same for the two positionings.

$$d\Omega \delta d \cos \beta = \alpha.$$

The bands 8(CO) and 7(CO₂) of FIG. 1 are aimed at;

$$dW_8 = \alpha(1 - \exp\{-E \cdot D \cdot K(\text{CO}) \cdot [\text{CO}]\}) J_{\lambda(8)T} d\lambda_8 \quad (8')$$

$$dW_7 = \alpha(1 - \exp\{-E \cdot D \cdot K(\text{CO}_2) \cdot [\text{CO}_2]\}) J_{\lambda(7)T} d\lambda_7 \quad (8'')$$

$[\text{CO}] = C_{\theta''}$, and $[\text{CO}_2] = C_{\theta'}$;
 dW_8 and dW_7 are measured by the radiation receivers;
 $d\lambda_8$ and $d\lambda_7$ are the data from the optic filter;

$$J\lambda_T = C_1 \lambda^{-5} / \exp(C_2 / \lambda T) - 1 \quad (10)$$

where C_1 and C_2 are physical constants.

For the purpose of calculation the means $J\lambda_T$ within the given band is used.

To facilitate understanding, it is supposed that discrete calculations are made with regard to time, i.e. that calculations are made every Δt seconds, and Δt is very small in relation to the speed at which the phenomena develop.

If $(T)_{t-\Delta t}$ is the temperature measured at time $t-\Delta t$, then $(J\lambda_T)_{t-\Delta t}$ is calculated, $(dW)_t$ is measured and by means of the calculation, Equations (8') and (8'') give the values of

$$E \cdot D \cdot K(\text{CO}) \cdot [\text{CO}] \text{ and } E \cdot D \cdot K(\text{CO}_2) \cdot [\text{CO}_2].$$

EDK (CO) and EDK (CO₂) may be obtained partly by calculation and partly from known statistical data. Since these factors vary from installation to installation, the simplest method is to measure them once and for all by comparison with gas analyses carried out by any known method. When these factors are established once and for all for any given installation, $[\text{CO}]$ and $[\text{CO}_2]$ may be calculated from Equations (8') and (8''). If $[\text{CO}]$ and $[\text{CO}_2]$ are expressed in mols per unit volume and if the gas in question is for example a cylinder with a cross-sectional area A and height dx , the number ΔC of gramme atoms of carbon in the volume studied at time t , would be

$$(\Delta C)_t = A \cdot dx \{ [\text{CO}] + [\text{CO}_2] \}_t \quad (11)$$

2. COMBINATION OF MEASUREMENTS.

The acoustic measurements described in section I enable the average fluid speed V and the average speed of sound in the fluid to be obtained at the instant.

$$\text{For a perfect gas } \epsilon^2 = (YR/M) \cdot T$$

$$\text{and } \gamma = C_p/C_v,$$

where

C_p = specific heat at constant pressure,

C_v = specific heat at constant volume,

R = the gas constant,

M = mass of one mole the gas under consideration.

If ϵ_n is the speed under normalised conditions T_n, P_n , then (recalling that the pressure is constant in the present case)

$$\epsilon = \epsilon_n \sqrt{(T/T_n)} \quad (12)$$

For a mixture of gases each having a sound propagation speed $\epsilon_{n,i}$ and a volume concentration a_i , under normalised conditions:

$$\epsilon_n = \sum_i a_i \epsilon_{n,i} \dots \dots \dots (13)$$

5 In our case there are four gases, for which the sound propagation speeds at 0°C and 760 mmHg are:

$$\epsilon_n(\text{N}_2) = 336.6 \text{ m/s;}$$

$$\epsilon_n(\text{CO}) = 336.8 \text{ m/s;}$$

$$\epsilon_n(\text{O}_2) = 315.1 \text{ m/s;}$$

$$\epsilon_n(\text{CO}_2) = 259.6 \text{ m/s.}$$

As an approximation, $\epsilon_n(\text{N}_2) = \epsilon_n(\text{CO})$; therefore in our case Equation (13) may be written;

$$\epsilon_n = \epsilon_n(\text{N}_2) \{ [\text{N}_2] + [\text{CO}] \} + \epsilon_n(\text{O}_2) \cdot [\text{O}_2] + \epsilon_n(\text{CO}_2) \cdot [\text{CO}_2]$$

$[\text{N}_2] = a(\text{N}_2) = \text{volume concentration of N}_2, \text{ etc.}$

For a given type of hood (air excess known), $[\text{N}_2]$ and $[\text{O}_2]$ may be calculated, with considerable precision and following a known method, from the knowledge of $[\text{CO}]$ and $[\text{CO}_2]$. By way of example, we give below such an equation obtained experimentally for a given zone in a given hood;

$$[\text{N}_2] = 0.75 - [\text{CO}]$$

$$[\text{O}_2] = 0.20 - \frac{1}{2} [\text{CO}_2]$$

In this case, therefore

$$\epsilon_n = 0.75 \epsilon_n(\text{N}_2) + 0.20 \epsilon_n(\text{O}_2) + [\text{CO}_2] \{ \epsilon_n(\text{CO}_2) - \frac{1}{2} \epsilon_n(\text{O}_2) \}$$

(14)

35 The examination of Equations (12) and (14) shows that, by means of the knowledge of $[\text{CO}_2]$, measurement of ϵ enables T to be calculated in a simple manner.

To show clearly that the combined solution of equation (8) and (12) is not a vicious circle, but the solution of a system of two equations with two unknowns, we shown schematically how the series of calculations may be made in the particular case where the time is divided into short intervals Δt , and where an iterative method is applied:

at time t

We have $(T)_{t-\Delta t}$.

Measurement is made of: $(\epsilon)_t$, $(dW_7)_t$, and $(dW_8)_t$.

From $(dW_7)_t$, $(dW_8)_t$, and $(T)_{t-\Delta t}$ one calculates

$[\text{CO}]_t$ and $[\text{CO}_2]_t$ as explained above.

50 From $[\text{CO}_2]_t$ and $(\epsilon)_t$, Equations (12) and (14) give $(T)_t$.

at time $t + \Delta t$

We have $(T)_t$

55 Measurement is made of:

$$(\epsilon)_{t+\Delta t}, (dW_7)_{t+\Delta t}, \text{ and } (dW_8)_{t+\Delta t}$$

and so on.

Iteration may therefore be begun if $(T)_{t=0}$ is known.

60 This is possible since when $t=0$, $[\text{CO}_2]=0$ and the composition of the gas is therefore well known. It should be noted that at $t=0$ Equation (14) leads to a slight error, since at this moment it should be written:

$$\epsilon_n = 0.79 \epsilon_n(\text{N}_2) + 0.21 \epsilon_n(\text{O}_2).$$

65 This is of little importance, however, since at this moment $[\text{CO}]$ and $[\text{CO}_2]$ are zero or rather very small, and the absolute error is therefore negligible.

At this stage of the calculation we have $(\Delta C)_t$ from Equation (11), and we have the gas speed $(V)_t$. These values will now be introduced into Equation (7), and we obtain:

$$(\Delta C)_t = A \cdot dx \{ [CO] + [CO_2] \}_t = (dC/dt)_{t-\tau} \cdot \Delta x / (V)_t$$

from which we get:

$$(dC/dt)_{t-\tau} = A \cdot (V)_t \{ [CO] + [CO_2] \}_t$$

which gives the decarburisation rate.

3. PROCESS CONTROL

It is known that different means exist for the control of the development of the refining process. For example: the height of the lance, the flow of oxygen, and the flow and nature of the additions. Each of these means allows control of the decarburisation rate, and also of other values which characterise the refining process (height of the foam, quality of the foam, etc.). The steel technologist may define (as a function of the grade of steel to be processed, and of the type of pig-iron and additions used) the developments considered to be optimum with regard to these characteristic values during the refining process. These optimum developments will, therefore, differ from steelworks to steelworks, because each has a different manufacturing programme, and each installation is affected by particular limitations which must be respected, for example the maximum and minimum flow of oxygen, and the maximum rate of heat dissipation in the hood. The aim here is not to describe the optimum developments, nor to state how they must be attained.

In parts 1) and 2) above the calculation of the decarburisation rate from the various measurements made in the hood, has been described; these measurements and calculations will be performed throughout the refining process, by a computer programmed to solve the various equations.

Let $(dC/dt)_m$ be the value of dC/dt calculated from the measurements at any given instant t . The steel technologist has previously calculated the optimum curve of the decarburisation rate, i.e.

$$(dC/dt)_{opt} = f(t).$$

By subtraction the deviation Δ from the optimum is obtained;

$$\Delta = (dC/dt)_m - (dC/dt)_{opt}.$$

The aim of the control is to make $\int |\Delta| \cdot dt$ a minimum (the integral being over the whole process time). The bases of control may vary from one steelworks to another, according to the value or values which the steel technologist wishes to use in order to correct the error.

Let us suppose that it has been decided to compensate for the error by acting upon the oxygen flow rate. In this case, the technologist foresees for the other parameters (which are well known) a sequential development compatible with the attainment of the optimum decarburisation curve; this means, for example, that if he carries out the additions in a certain manner and at given times during the process, he has programmed the change of position of the lance in such a way that the optimal decarburisation curve will effectively be $(dC/dt)_{opt} = f(t)$. All modifications to be carried out with regard to the variables with the exception of the oxygen flow rate, are therefore programmed in a com-

puter which will sequentially impose all the necessary controls. It will also calculate the decarburisation rate and Δ , and modify the oxygen flow rate by means of a suitable controller. The direction of the modification is well known, and is such that if the oxygen flow rate is increased, the speed of decarburisation is also increased.

Such a flow rate controller may operate as follows on the process to be controlled. The computer which issues, at the required time, commands intended to impose the required controls, calculates the decarburisation rate at a given instant, and compares this with the optimum rate which corresponds. The difference which results from this comparison serves as a parameter for the modification of the oxygen flow rate and is used to generate a control signal S.

In order to ensure that the refining process is not subjected to large disturbances, the control signal S which acts upon the rate of flow of oxygen, is the sum of three terms, namely:

$$S = A \Delta + B \int_0^t \Delta \cdot dt + C \cdot \frac{d\Delta}{dt},$$

the three constants A, B, C being experimentally determined constants obtained from the known transfer functions of the refining process, to minimise the value

$$\int_0^t |\Delta| \cdot dt$$

(whole process) which represents the error to be eliminated. This value S is supplied continuously to the controller, and determines the modification to be made to the rate of flow of oxygen.

The control process is illustrated in FIG. 6. Commercially pure oxygen is blown through a lance 30 onto a bath of molten pig iron in a converter vessel 31. Additions of powdered refining agents (lime, iron ore) are also made through the lance 30. The blocks 32, 33, 34 represent the oxygen rate regulator, the additions regulator, and the lance height regulator, respectively. The regulators 32 to 34 are normally controlled by predetermined sequential control programs in a computer (not shown) but in this process the oxygen rate is not controlled by a sequential program.

The converter gases are withdrawn through a combustion hood 35, in which apparatus is arranged for making the three determinations described in sections I to III of part 1) of this description. The apparatus is upstream of the position at which the CO has burnt to CO₂. Sound waves from two directional emitters 19, 20 (see also FIG. 3) are received by two directional receivers 22, 21 respectively. The respective times of travel t_2, t_1 of the sound waves are measured by two timing modules 36, 37. The block 38 represents the calculation of the mean speed of the gases in the hood from t_1 and t_2 , in a computer 39.

A pair of radiation receivers 40 in the hood 35 is connected to a module 41 for spectrographic analysis of the gases in the hood; the block 42 represents the calculation of the carbon content of the gases from this spectral analysis, in the computer 30. A temperature detecting element 43 in the hood is connected to a temperature measuring module 44.

In the computer 39, block 45 represents the calculation of the decarburisation rate $dC/dt)_m$ from the mean speed, carbon content, and temperature of the gases in the hood. Block 46 represents a program which continuously supplies the instantaneous value of the optimum decarburisation rate $(dC/dt)_{opt}$. Block 47 represents the continuous comparison of $(dC/dt)_m$ with $(dC/dt)_{opt}$ and generation of the control signal S.

The signal S is fed to the oxygen flow rate regulator 32 to control the decarburisation rate: if $(dC/dt)_m$ is too high, S is positive and controls the regulator 32 so as to reduce the oxygen flow rate; if $(dC/dt)_m$ is too low, S is negative and controls the regulator 32 so as to increase the oxygen flow rate.

If the signal S were to be used to control the lance height, the lance would be raised when S is positive and lowered when S is negative. For control by means of the additions, if S were positive the rate of addition of lime or iron ore would be decreased.

The marked advantage of the control process described above is that it only uses measurements which are rapid. It therefore follows that the control itself may be brought to bear on disturbances of high frequency and short duration, which enables the final values

$$\int_0^t |\Delta| dt$$

to be greatly reduced.

We claim:

1. A method of monitoring and controlling a pig iron refining operation in which an oxygen-containing gas is blown from above by means of a lance onto a bath of molten pig iron in a vessel, refining agents are fed into the vessel, and the gases leaving the vessel are withdrawn through a hood; the refining operation taking place under regulable refining conditions comprising the height of the lance above the bath, the rate of flow of gas through the lance, and the rate at which refining agents are fed in; the method comprising the steps of

- i. automatically determining the means speed of said gases at a given position in the hood at which the CO in said gases has burnt to CO_2 and prior to dust removal or drying of said gases, by
 - a. automatically measuring the time taken by an acoustic wave to travel through said gases from an emitter to a receiver upstream of the emitter,
 - b. automatically measuring the time taken by an acoustic wave to travel through said gases from an emitter to a receiver downstream of the emitter, and
 - c. transmitting said time measurements to a computing device adapted to calculate said mean speed from said time measurements;
- ii. automatically determining the carbon content of said gases at said given position by spectrographic analysis;
- iii. automatically measuring the temperature of said gases at said given position;
- iv. transmitting the calculated value of the means speed, the determined value of the carbon content, and the measured value of the temperature to a computing device adapted to calculate the rate of decarburisation of said bath from said values;

v. automatically comparing the calculated value of the decarburisation rate with a predetermined instantaneous optimum value;

vi. automatically generating a signal representative of the difference, if any, between said calculated value and said predetermined instantaneous optimum value; and

vii. automatically regulating at least one of said regulable refining conditions in accordance with said signal so as to reduce or annul said difference.

2. A method as claimed in claim 1 comprising

i. automatically measuring the time taken by an acoustic wave emitted from a first element to travel to a second element upstream of the first element; and

ii. automatically measuring the time taken by an acoustic wave emitted from the second element to travel to the first element.

3. A method as claimed in claim 1, comprising

i. emitting an acoustic wave into said gas by means of an emitter;

ii. automatically measuring the time taken by the wave to travel from said emitter to a receiver upstream of said emitter; and

iii. automatically measuring the time taken by the wave to travel from said emitter to a receiver downstream of said emitter.

4. A method as claimed in claim 1, comprising

i. automatically measuring the time taken by an acoustic wave to travel from a first emitter to a first receiver upstream of said first emitter; and simultaneously

ii. automatically measuring the time taken by an acoustic wave to travel from a second emitter to a second receiver downstream of said second emitter.

5. A method as claimed in claim 1, further comprising

i. setting up first and second self maintaining acoustic oscillating circuits; the first circuit comprising a first emitter in the hood, a first receiver in the hood, upstream of the emitter and adapted to receive acoustic waves from the emitter, and a first amplifier connecting the receiver and the emitter; the second circuit comprising a second emitter in the hood, a second receiver in the hood downstream of the second emitter and adapted to receive acoustic waves from the second emitter, and a second amplifier connecting the second receiver and the second emitter, the first emitter being diametrically opposite the second receiver; and the second emitter being diametrically opposite the first receiver;

ii. inducing oscillations in the first and second circuits;

iii. automatically measuring the frequency of oscillation of the first circuit;

iv. automatically measuring the frequency of oscillation of the second circuit;

v. automatically measuring the difference between said frequencies;

vi. automatically measuring the sum of said frequencies;

vii. transmitting said measured difference to a computing device adapted to calculate said mean speed from said difference; and

- viii. transmitting said measured sum to a computing device adapted to calculate said temperature from said sum.
6. A method as claimed in claim 1, wherein said step of determining the carbon content of said gases comprises determining the concentration of CO and CO₂ in said gases. 5
7. A method as claimed in claim 6, comprising
- automatically measuring the intensity of thermal radiation emitted by said gases in a wavelength range lying within a CO emission band; 10
 - automatically measuring the intensity of thermal radiation emitted by said gases in a wavelength range lying within a CO₂ emission band;
 - automatically measuring the intensity of thermal radiation emitted by said gases in each of at least two wavelength ranges near said bands but where the contribution of the CO and CO₂ emission spectra is practically negligible; and 15
 - transmitting said measured intensities to a computing device adapted to calculate the concentration of CO and CO₂ from said measurements. 20
8. A method as claimed in claim 6, comprising
- automatically measuring the coefficient of absorption of electromagnetic radiation for said gases in a wavelength range lying within a CO absorption band; 25
 - automatically measuring the coefficient of absorption of electromagnetic radiation for said gases in a wavelength range lying within a CO₂ absorption band; 30
 - automatically measuring the coefficient of absorption of electromagnetic radiation for said gases in 35

- each of at least two wavelength ranges near said bands but where the effect of the CO and CO₂ absorption spectrum is practically negligible; and
- iv. transmitting said measured coefficients to a computing device adapted to calculate the concentration of CO and CO₂ from said measurements.
9. A method as claimed in claim 1, wherein said step of determining the carbon content of said gases comprises automatically measuring the intensity of radiation due to chemiluminescence from the reaction $\text{CO} + \frac{1}{2}\text{O}_2 = \text{CO}_2$.
10. A method as claimed in claim 9, wherein the measurement is carried out in proximity to 0.43 μ .
11. A method as claimed in claim 1, further comprising automatically measuring the intensity of radiation emitted by dust and other particles in said gases, the radiation being in a wavelength range lying below 1.6 μ , whereby a measurement is obtained proportional to the decarburisation rate.
12. A method as claimed in claim 11, wherein the wavelength range lies between 0.8 μ and 1.6 μ .
13. A method as claimed in claim 1, wherein said step of determining the temperature of said gases comprises
- setting up a stationary acoustic wave in an acoustic guide of given length positioned in the hood, the guide being part of a self maintaining oscillating circuit;
 - automatically measuring the frequency of said wave; and
 - transmitting said measured frequency to a computing device adapted to calculate said temperature from said frequency. 65

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