April 18, 1967 F. K. E. JOHANSSON ETAL 3,314,781

METHOD FOR THE CONTROL OF BLAST REFINING OF CARBON-CONTAINING METAL MELTS

Filed Dec. 7, 1965

2 Sheets-Sheet 1

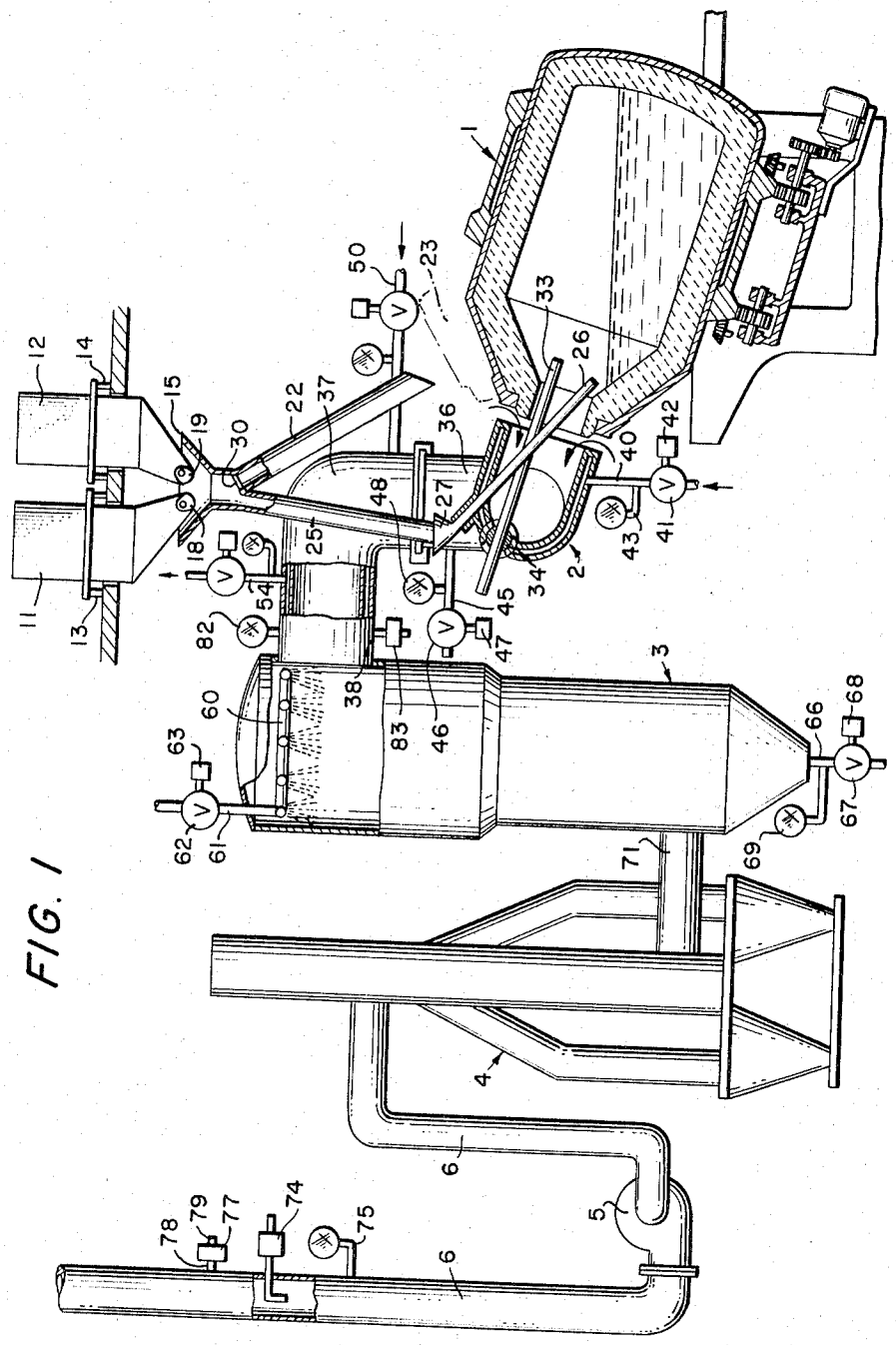


FIG. 1

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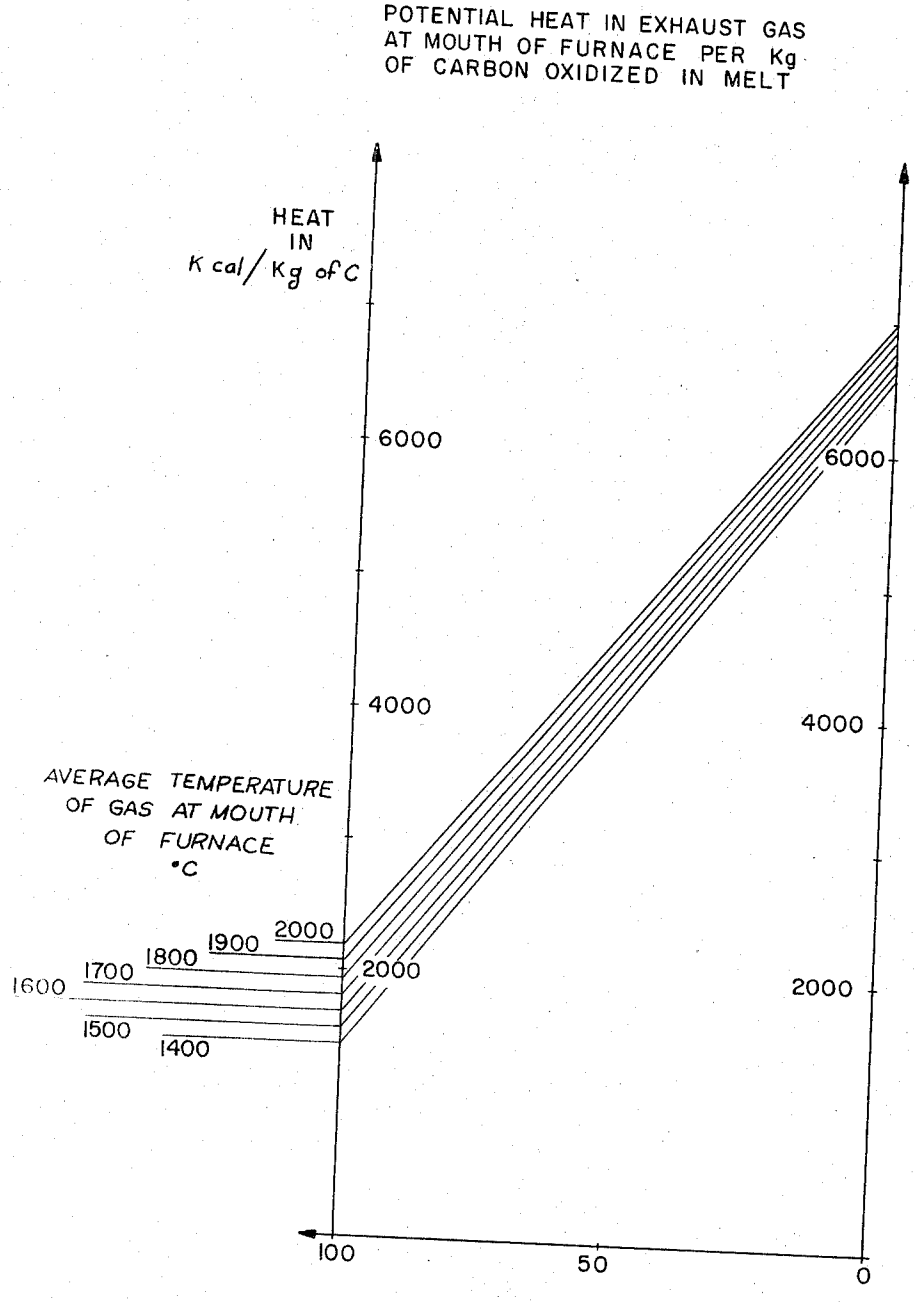
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2 Sheets-Sheet 2

FIG. 2



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METHOD FOR THE CONTROL OF BLAST REFINING OF CARBON-CONTAINING METAL MELTS

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12 Claims. (Cl. 75—52)

The present invention relates to a method used in the refining of molten carbon-containing ferrous metal to produce a melt having a predetermined temperature and carbon content. This application is a continuation-in-part of our prior application Ser. No. 266,758 filed Mar. 20, 1963, now abandoned, and relates back to said prior application for all common subject matter.

In the manufacture of steel it is essential that the refined melt has the right carbon content to produce the kind of steel desired as well as the right temperature at the time it is poured to produce a steel in accordance with predetermined specifications. If the melt has too high a carbon content when it is poured the resulting steel would be harder than desired and if it has too little carbon the resulting steel would be too soft. Therefore, if either of these conditions exists the refining of the metal is either continued to further reduce the carbon content if too much carbon is present, or carbon is added to the melt if too little carbon is present. The melt should not be poured until the temperature as well as the carbon content is correct which may require continued refining or addition of carbon. It is desirable, however, to refine the melt to the desired carbon content and temperature as quickly as possible as refining to first obtain one condition and then adding carbon to obtain the other condition with interruptions to take and analyze samples requires additional time and reduces the output from the equipment in a given period of time. Also, such interruptions are apt to introduce undesirable materials into the melt as, for example, nitrogen when interruptions are made for sampling and sulfur when carbonaceous materials are added to the melt.

Obtaining a predetermined temperature in the melt at the same time that the desired carbon content is attained is essential and critical. If the melt is too hot at the time it is poured, it is apt to adversely effect the quality of the product by segregating impurities therein and also by producing a porous core and/or cracks due to additions of hydrogen or other gases as impurities as well as eroding the lining of the furnace, ladle and/or mold. If the melt is too cold at the time it is poured the components of the melt do not properly mix; the melt is difficult to pour and is apt to freeze, at least in part, in the ladle and solidifies too fast with resulting defects in its surface. As stated above the proper pouring temperature of the melt is critical and in many cases must be restricted to $\pm 6°$ C.

It has long been desired to provide a method for more or less automatically controlling refining processes so as to eliminate or reduce the number of interruptions in the processes necessary in conventional controls for taking and analyzing the contents of samples. This is especially true for Basic Oxygen (pneumatic high speed blast) refining processes in which a large part of the tap to tap time is used for sampling and analyzing samples. It follows, therefore, that the production capacity of these blast refining processes cannot be fully utilized in present practice.

One of the objects of the present invention is to provide a reliable method of controlling such a refining process so as to obtain a final product having a preselected carbon content and temperature at the same time without, or with only a few, interruptions for sampling and analysis.

Another object is to control the percentage of carbon and temperature of the melt by controlling the supply of oxygen to reduce the carbon content and the supply of cooling medium to the melt in accordance with the carbon containing gases produced to simultaneously arrive at the desired composition and temperature.

A further object is to provide reliable methods of determining the ratio or degree of combustion of the carbon that occurs in the refining furnace as represented by the quotient of the carbon dioxide produced by combustion within the furnace divided by the sum of the carbon monoxide and carbon dioxide produced within the furnace.

These and other objects will become more apparent from the following description and drawings. It is to be understood, however, that the drawings are for the purpose of illustration only and are not a definition of the limits of the invention, reference being had for this purpose to the appended claims.

In the drawings:

FIGURE 1 is a diagrammatic view of an apparatus for carrying out the method of the present invention; and

FIGURE 2 is a chart showing the potential heat of gas, exhausted from the mouth of the furnace in relation to actual degree of carbon combustion.

The invention is particularly applicable to the manufacture of steel by refining molten pig iron and reference will now be made to conventional methods used in such manufacture. It is to be understood, however, that the method of refining of the present invention may be used with other ferrous metal alloys containing carbon such as nickel, cobalt and chromium. Pig iron in addition to its main constituents, iron and up to 5% by weight of carbon, also usually contains a relatively small percentage of silicon, manganese and phosphorus. These impurities, together with a relatively small portion of iron, are oxidized and removed from the melt as slag during refining and are herein below referred to as slag-transferable elements and after conversion to slag constituents are referred to as slag-transferred elements. The molten pig iron is treated in a furnace, as shown in FIGURE 1, having a gas space above the melt. The refining is performed by supplying a refining gas containing free oxygen to the space above the melt and supplying solid ferrous metal, oxidic compounds thereof, slag-formers, or a combination thereof to the melt as cooling agents. The refining gas and cooling agents are supplied in such balanced quantities as to supply sufficient oxygen for the oxidation of (a) all the carbon to be removed to carbon monoxide, (b) said slag-transferable elements in said metal, and (c) a portion of said carbon monoxide to carbon dioxide. Such oxidation of carbon, slag-transferable elements and carbon monoxide as well as slag forming reactions, generate a quantity of heat sufficient to raise the temperature of the melt, i.e. metal and slag, including said cooling agents, to said preselected temperature. As the slag-formers usually exert a cooling action, it is desirable to include them as part of the cooling agent although they are mainly added for chemically combining the oxides of said slag-transferable elements. Exhaust gas emerging from the furnace mouth contains all carbon monoxide and carbon dioxide formed in the furnace, any nitrogen from air used for charging solids or partly as a refining gas, excess oxygen, if any is present, and usually some iron dust or fumes as iron oxide inadvertently formed in the refining process.

The temperature, quantity and composition of pig iron, scrap iron and cooling agents initially charged to the

furnace are measured. The theoretical amount of oxygen required may then be calculated from the amount of slag-transferable elements in the pig iron and the difference between the initial carbon content of the pig iron and the preselected carbon content of the steel to be produced, both of which materials must be oxidized. All carbon removed from the melt occurs as carbon monoxide and a portion of this carbon monoxide is converted to carbon dioxide within the furnace. Thus, the initial determination of the oxygen required presupposes an assumed average degree of combustion of the carbon monoxide formed in the refining process to carbon dioxide in the gas space of the furnace. The degree of combustion is defined as

$$\frac{CO_2}{CO+CO_2}$$

i.e. the quotient obtained from the amount of the CO_2 divided by the sum of the amount of CO plus CO_2 in the exhaust gas, and the quantities of CO and CO_2 are calculated as standard volumes such as moles (gram molecules). The oxygen is supplied as free oxygen injected into the gas space and metal oxides such as ore which is supplied to the melt as a cooling agent. If carbonates, supplied as iron bearing compounds or slag-formers, are used, corresponding correction must be made of the carbon dioxide content of the exhaust gas. In order to allow large additions of iron bearing coolants, it is advantageous to operate with a high degree of combustion, e.g. at least 70% and preferably at about 80–100% thereby producing considerable excess heat over that required to attain the preselected temperature of the final melt. By supplying ferrous metals as a coolant the quantity of ferrous metal, i.e. steel, produced at the end of the process may increase over the metal initially supplied. Some iron, it is true, is lost as oxides in the slag and as dust in the exhaust gas, and consideration must be given to such losses of iron, which are estimated by experience.

With knowledge of the heat losses from the furnace, the theoretical amounts of free oxygen and cooling agents, including metal oxides, required for obtaining the preselected temperature and carbon content can be determined by calculating heat and material (particularly oxygen) balances.

More specifically, the sensible heat content of the pig iron and cooling agents as well as refining gas charged plus the heat developed by oxidation of carbon, carbon monoxide (according to the presumed average degree of combustion) and slag-transferable elements as well as slag-forming reactions are balanced by the sensible heat content of the resulting steel and slag (at preselected temperature) and of the exhaust gas (at a measured or estimated average temperature), plus the heat required for endothermic reactions, e.g. ore reduction and decomposition of carbonates, plus heat losses from the furnace for the period of time of a refining operation.

Similarly the amount of oxygen supplied to the furnace as free oxygen, i.e. the amount of oxygen in the refining gas plus the amount of oxygen in the air or the like entering the furnace during the feed of solids thereto, and as oxidic oxygen, i.e. iron oxide or the like in the cooling agent, shall be balanced by the amounts of oxygen in the exhaust gas as carbon monoxide, carbon dioxide, possibly free oxygen and iron oxide (as dust) plus the oxygen in oxides of slag-transferable elements.

It will be understood that such theoretical calculations although accurate and based on long experience cannot reliably suffice by themselves in attaining the preselected temperature and carbon content simultaneously. Therefore, the process must be interrupted for sampling, which extends the time required to process a melt, and even then does not always produce the desired carbon content and temperature because the results of the analyses can only be obtained after some delay.

It has been suggested that the carbon content of the exhaust gases be utilized for determining the carbon content of the metal melt in the furnace by integrating the quantities of carbon monoxide and carbon dioxide of the exhaust gas from the beginning of the process. It is true that the reduction of the carbon content of the liquid pig iron can be closely followed, and the process can be terminated at the preselected carbon content of the melt. But, to our knowledge, in no conventional pneumatic refining process has the temperature of the melt been controlled so as in a convenient way to reach a preselected temperature simultaneously with a preselected carbon content with any degree of accuracy.

With the method of directing the refining of a molten carbon—containing ferrous metal in a furnace in accordance with the present invention it is possible to produce a metal melt having a preselected temperature and a preselected carbon content by continuously measuring the quantity of carbon monoxide and the quantity of carbon dioxide in the exhaust gas removed from the furnace, and controlling the refining process at one or more instants during the process, and at least at one late instant near the end of the refining, by separately measuring as from the start of the refining through each one of said instants the accumulated molar amount of carbon monoxide and the accumulated molar amount of carbon dioxide in said exhaust gas and determining from these measurements the actual average degree of combustion up to said instant. Such actual average degree of combustion is defined as the quotient of the accumulated molar amount of carbon dioxide by the sum of the accumulated molar amounts of carbon monoxide and carbon dioxide, i.e.

$$\frac{CO_2}{(CO+CO_2)}$$

as from the start of refining through said instant. The method also comprises supplying after each of said instants an amount of cooling agent that together with previously supplied amounts thereof lies within and approaches, and in case of said late instant substantially equals to, the quantity necessary for absorbing that portion of the heat developed by the oxidation at said actual average degree of combustion of all carbon to be removed and by the oxidation and combining of said slag-transferable elements, which exceeds the heat required for attaining said preselected temperature of the final melt; and further supplying after each of said instants an amount of refining gas that together with previously supplied amounts thereof lies within and approaches, and in case of said late instant substantially equals to, the quantity necessary for oxidizing said slag-transferable elements and for oxidizing at said actual average degree of combustion all carbon to be removed; and thereafter terminating the refining operation, thereby obtaining refined molten metal with said preselected temperature and carbon content.

The continual measuring and separate accumulation (or integration) of the amounts of carbon monoxide and carbon dioxide from the very start of the refining is fundamental for carrying out the invention. The measuring is best carried out by automatic flow measuring and analyzing equipment as will be described more in detail hereinbelow. The values obtained may be delivered to a computing apparatus which accumulates the values and can give at any checking instant the totals of the individual values of CO_2 and CO fed to it from the start (s) up to said instant (i), i.e.

$$\sum_{s}^{i} CO_2 \text{ and } \sum_{s}^{i} CO$$

respectively.

The degree of combustion is denominated F. For the refining period from the start (*s*) to an actual checking instant (*i*) the average degree of combustion F_{av} is:

$$F_{av_i} = \frac{\sum_{s}^{i} CO_2}{\sum_{s}^{i} CO + \sum_{s}^{i} CO_2}$$

which is readily obtained from the values of the individual totals of the formula.

Knowing this average degree of combustion up to a certain instant and assuming it to be representative for the entire refining operation, the heat and material (oxygen) balances up to the desired end condition, referred to above, can be determined at the instant in question and from such determination the amounts of cooling agent and gaseous oxygen still to be added also can be determined. These determinations are intended to be made automatically by an analog or digital computer from measured amounts of CO, CO_2 and other materials, such as O_2, continually supplied thereto, but can be made with the aid of a slide rule, or taken from nomogram charts if allowance is made for certain approximations.

In making the heat balance on the refining furnace the input comprises the heat content of the metal (pig iron) and possibly slag initially charged, the reaction heat of the oxidation of slag-transferable elements, usually silicon, manganese, phosphorus and to some estimated extent iron, into their oxides, the reaction heat of the forming of slag from these oxides, and the combustion heat of the oxidation of all carbon to be removed from the melt into carbon monoxide and, further, the combustion heat produced by oxidizing part of said carbon monoxide into carbon dioxide as determined from the average degree of combustion, as assumed F_{av} or obtained at the checking instant F_{av_i}. The particular values to be used in this calculation are obtained from measuring the quantities and temperatures of initially charged and later added metal, slag, metal oxides and slag-formers. Preferably, the sensible heat contents are reckoned as above room temperature, whereby the temperature of said materials need not be taken into consideration when added at about room temperature. The refining gas is usually injected at about room temperature and does not then contribute to the heat balance by its sensible heat. The total of all these input items constitute the heat input of the entire heat balance at a particular instant of checking F_{av_i}.

In order to determine the excess heat to be absorbed by cooling agents the total heat input is compared with the total heat output both considered up to the end of the process. The heat output comprises the sensible heat of the metal and slag in the furnace and emerging dust, the sensible heat of the exhaust gases, the decomposition heat of the slag forming carbonates and the inevitable furnace heat losses, all calculated on the presumption that the metal and slag in the furnace have the preselected temperature and the steel the preselected carbon content, and that all the carbon to be removed has escaped as monoxide and dioxide in the exhaust gases at a proportion defined by the f_{av_i} at the instant when the balance is made. The amount of steel obtained equals the initially charged pig iron minus the slag transferred elements and carbon to be removed, plus iron added as coolant minus the iron occuring as oxide in the slag and dust in the exhaust gas. The amount of slag is the sum of initially charged and added slag and slag formers and chemically combined oxides of the slag-transferable elements. The sensible heat content of the exhaust gases may be calculated from the amount thereof measured, the value of the actual average degree of combustion at the said instant, the specific sensible heat content of CO and CO_2 and possibly other constituents of the exhaust gas at an assumed or measured average exhaust gas temperature for the entire

refining operation. The heat losses from the furnace mainly through radiation and convection may be estimated with great accuracy from previous refining periods of the furnace and enters the calculation as a factor per unit of time.

Knowing the cooling effect per unit of the different cooling agents used, the balance between the input and output heat will indicate how much cooling agent will have to be added as a total, and knowing the amount already supplied the remaining amount to be added can be easily determined. The amount of slag-formers will be mainly determined by the percentage of slag-transferable elements in the pig iron.

In making the oxygen balance the total oxygen to be supplied is that required for oxidizing the slag-transferred elements to their respective oxides and for oxidizing all the carbon to be removed, i.e. in order to attain the preselected carbon content, into carbon monoxide, and further oxidize a portion of said monoxide into carbon dioxide as determined by the average degree of combustion F_{av_i} at the instant a heat balance is made. From this total amount of oxygen required a subtraction is made of oxidic oxygen, held by the above calculated total amounts of coolants, and the amount of free oxygen supplied in air, or the like, used for feeding solids to the furnace.

The difference between the amount of free oxygen required and the amount supplied up to a particular instant when a balance is measured is the free oxygen which must be supplied after the balance is made.

In calculating heat and oxygen balances the F_{av} assumed or true for the particular instant is used. This means an approximation as the true value at the end of the process should be used. However, this value is not known, but if the successively measured F_{av} is used for new balances up to and near the end of the refining operation, the corresponding balances become more and more accurate so that nearly true values for the end of the process can be predicted. Thus, at the start of the process an assumed value of F_{av} may be used in the balances, or the process can be started at random and after some time when a significant F_{av_i} is obtainable, this value can be used to direct the operation toward the desired end conditions.

As the heat and oxygen balances decide the proportions of the total amounts of free oxygen and oxidic oxygen to be supplied, they will also give information as to the supplementary amounts of cooling agent and free oxygen, respectively, to be added before the termination of the refining operation and the time when termination shall occur.

An important factor in controlling a refining operation in accordance with the present invention is the fact that the amounts of oxygen and cooling agent, whether a metal or an oxide thereof, to be supplied after each instant when a measurement is made is determined by applying the accumulated average of combustion of the carbon monoxide at said instant to predict the requirements at the end of the refining process, when all carbon to be removed will have been removed. Since these determinations can be made within a few seconds or at least within a minute, the determinations can be and ought to be made frequently, at least near the end of the process. Such successive determinations project requirements near the end of the process very accurate so that the exact amounts of materials may be supplied adjacent the end of the refining period and thus attain the preselected temperature and carbon content at the same time. Preferably, the materials are added automatically as controlled by a computer, or the information may be supplied to an operator who, after some experience, can master the refining process with only a few or even a single correction near the end of the process.

It will be understood that in view of the great importance of the measurements of the amounts of carbon

monoxide and dioxide for obtaining the average degree of combustion, and for obtaining it without delay, it is imperative to use high speed measuring methods that are sufficiently accurate. Therefore, the invention, according to certain aspects thereof, also comprises such methods.

In order to obtain good results when controlling a melt according to the present invention it is important that the quantity of carbon removed and the degree of combustion of this carbon to carbon dioxide in the refining chamber or furnace be determined with accuracy. The most obvious method of determining the amount of refined carbon and the degree of combustion in the furnace is, of course, to measure directly the amounts of carbon dioxide and carbon monoxide in the exhaust gas from the furnace where it leaves the furnace mouth, and to calculate the amount of carbon and the degree of combustion from the measured amounts. However, accurate measurements are not practical at the furnace mouth where dust, slag splashes and non-uniformity of the gas stream occur which make sampling difficult and jeopardize the significance of any such measurements. In accordance with the invention, a new way has been found to determine accurately the degree of combustion of the carbon to be removed from the melt within the refining furnace when practicing the new control method.

In general the method of determining the degree of combustion comprises, collecting all exhaust gas from the furnace, supplying thereto air in excess of that required for complete oxidation of all carbon monoxide of the exhaust gas into carbon dioxide and thereby completely burning the exhaust gas to form a flue gas which contains substantially only carbon dioxide, oxygen and nitrogen. The completely burnt flue gas will have a quantity of heat in addition to the sensible heat which the exhaust gas had when leaving the furnace which is substantially equal to the combustion heat of said carbon monoxide to carbon dioxide. The accumulated molar amount of carbon dioxide in said flue gas is continuously determined by measuring the content at intervals e.g. continuously, and integrating the value against time. Any changes in the status, i.e. composition and heat content of said flue gas caused by said burning of carbon monoxide, which changes correspond to the molar amount of carbon monoxide of the exhaust gas, also are measured to obtain the actual average degree combustion. The change in status of said flue gas can be ascertained in various ways. In all these methods, however, it is necessary to measure the flow of flue gas and the molar amount of carbon dioxide therein. Therefore, the flue gas has to be analyzed, preferably in dry state, at least with regard to carbon dioxide, and according to certain methods also with regard to oxygen.

According to one of these methods for determining the average degree of combustion based upon an oxygen balance on the gas collecting hood, the dry flue gas is continuously analyzed to determine the molar amounts of carbon dioxide and oxygen. The remainder of the flue gas is assumed to be nitrogen. The air used for burning the exhaust gas contains 79% by volume of nitrogen and 21% of oxygen. Therefore, the molar amount of said nitrogen corresponds to 79/21 moles of oxygen admitted with the air to the exhaust gas. The difference between the molar amount of the oxygen admitted and the molar amount of oxygen found in the flue gas is the molar amount of oxygen consumed in oxidizing the carbon monoxide of the exhaust gas into carbon dioxide. As one mole of oxygen can oxidize 2 moles of carbon monoxide ($O_2+2CO=2CO_2$), the said molar amount of oxygen consumed corresponds to the double molar amount of carbon monoxide in the exhaust gas. The degree of combustion at a particular instant is now obtained by dividing the difference between the molar amount of carbon dioxide found in the flue gas by analysis and flow measurement and said molar amount of carbon monoxide determined from the oxygen removed from the air with said amount of carbon dioxide analyzed. This degree of combustion is obtained for a short moment or an arbitrarily long interval and all successive values can be integrated to obtain the average degree of combustion, the integration being made with regard to the molar amount of analyzed carbon dioxide, being equal to the molar amount of concurrently oxidized carbon removed from the metal being refined.

This method can be modified so as to render directly the average degree of combustion at any instant, by separately integrating the molar amount of the oxygen admitted with the combustion air (obtained from the nitrogen in the flue gas) and the molar amount of the analyzed oxygen as from the start of the refining up to the actual instant. The difference between these oxygen amounts being that consumed by the oxidation of the integrated amount of carbon monoxide of the exhaust gas. Said carbon monoxide is equal to double said difference (O_2 diff$+2CO=2CO_2$). The integrated amount of carbon dioxide in the exhaust gas (at the outlet mouth of the furnace) is obtained as the difference between the accumulated molar amounts of carbon dioxide in the flue gas (stack) and said carbon monoxide, and the average degree of combustion is the quotient between said accumulated amounts of carbon dioxide in the exhaust gas and in the flue gas, respectively.

According to another method for determining the average degree of combustion the sensible heat content, in, for instance, kilo calories, of the flue gas and the amount of carbon dioxide in the flue gas are continuously measured. The heat content of the flue gas comprises two terms, the sensible heat of the exhaust gas supplied to the hood at the mouth of the furnace and the potential heat of combustion produced by burning carbon monoxide in the hood. The sensible heat of the flue gas cannot be ascertained directly in an easy way. Therefore, according to this invention an approximate procedure will be resorted to. Said sensible heat content may be determined from the heat absorbed by a cooling medium in the flue system, the heat losses from said system and the remaining sensible heat in flue gas leaving said flue system. Said losses are mainly due to radiation and convection from the flue system. The amount of carbon dioxide may be obtained as a molar amount and then be recalculated as kilograms of carbon oxidized from the ferrous metal being refined in the furnace. From these values the heat content per kilogram of carbon removed from the metal will easily be obtained as a quotient of the accumulated amounts of kcals. and kg. of carbon. The temperature of the exhaust gas prevailing at the mouth of the furnace can be estimated with reasonable accuracy from experience from previous similar refining operations (heats). Moreover, it is a fact that at each temperature that normally prevails in the exhaust gas the degree of combustion varies linearly with the potential heat content (in kilo calories) per kilogram of carbon refined away from the molten ferrous metal. Thus, for instance, at 1800° C. the degree of combustion increases linearly from 0% to 100% as the potential heat content per kilogram of carbon oxidized away from the metal decreases from about 6815 kcal. to about 1910 kcal., and at 1400° C. from about 6525 kcal. to about 1430 kcal. The degree of combustion for intermediate or extraneous temperatures can easily be obtained by interpolation or extrapolation, respectively. Such a relationship is illustrated in the chart in FIGURE 2 of the drawings.

According to a third method, based upon an oxygen balance on the refining furnace, of determining the average degree of combustion up to any instant the molar amount of carbon dioxide in the flue gas and the molar amount of free and oxidic oxygen supplied to the furnace are separately and continuously measured and accumulated from the start of the refining operation up to said instant. The oxygen so supplied to the furnace is, on the

one hand, consumed therein for oxidizing carbon of the metal into carbon monoxide and the slag-transferable elements (Si, Mn, P, and some Fe) to respective oxides, and, on the other hand, for oxidizing a portion of said carbon monoxide into carbon dioxide (according to the prevailing degree of combustion as defined above. Occasionally some oxygen escapes with the exhaust gas, especially in a case where all carbon monoxide is oxidized to carbon dioxide in the furnace. The rate and amount of oxygen consumed by the slag-transferable elements can be calculated by experience from the percentages of said elements in the pig iron. The amount of oxygen consumed by the carbon removed for oxidation into carbon monoxide is derived from the measured accumulated molar amount of carbon dioxide in the flue gas which is equal to the accumulated molar amount of carbon monoxide formed of all carbon refined away up to said instant. One mole of oxygen being required for oxidizing two moles of carbon into carbon monoxide, said amount of oxygen consumed by the carbon is equal to half of the molar amount of carbon dioxide in the flue gas. From this consideration it is clear that the molar amount of oxygen supplied to the furnace minus the portions thereof consumed by the slag-transferred elements and the carbon by its primary oxidation into carbon monoxide is oxygen available for oxidizing carbon monoxide in the gas space of the furnace into carbon dioxide, and the molar amount of said available oxygen oxidizes twice as much carbon monoxide into carbon dioxide. Thus twice the accumulated molar amount of said available oxygen, equal to the accumulated molar amount of carbon dioxide in the emerging exhaust gas, divided by the accumulated molar amount of carbon dioxide in the flue gas constitutes the average degree of combustion at said instant.

According to this third method the net amount of oxygen supplied to the furnace as oxygen gas and cooling agent, i.e. oxygen supplied in addition to the amount of oxygen consumed by the slag-transferred elements is used in determining the degree of combustion.

Said net amount of oxygen supplied to the refining furnace is continuously and accumulatively recorded. The amount of carbon refined away and thus the oxygen required for transferring it into carbon monoxide is determined from the molar amount of carbon dioxide, accumulatively measured, in the flue gas. This demand of oxygen is subtracted from the recorded net amount of oxygen supplied to the furnace. The remainder of oxygen is that available for the combustion of carbon monoxide to carbon dioxide in the furnace. The amount of available oxygen stoichiometrically compared with the theoretical amount of oxygen required for 100% combustion of the carbon monoxide to carbon dioxide makes it possible to calculate directly the (average) degree of combustion of the carbon in the furnace, namely by the aid from the above net amount of oxygen supplied and the amount of carbon dioxide in the flue gas.

The above described methods of measuring the degree of combustion of the carbon in the furnace may be used as a check against the others and are applicable when excess oxygen is supplied to the furnace, i.e. the gas leaves the latter with a content of unreacted oxygen and the degree of combustion of carbon equal to 100% ($F=1.0$).

In case the carbon combustion degree, arrived at through computation according to either of above described methods, exceeds the value 1.0 with a certain fraction, said excess oxygen may be quantitatively calculated as directly proportional to said fraction. It is to be observed that this will not affect the result of the method according to the invention, since in the heat balance one calculates with the maximally possible F value (1.0) while in the oxygen balance the theoretically derived F value will be used, thereby ensuring an agreement with prevailing operating conditions.

The invention can be carried out in different types of oxygen blast refining furnaces, in which the refining gas can be readily injected and the exhaust gas collected. The furnace may be stationary or movable by shaking, but the present method is best carried out in a rotary furnace having an axis of rotation which may be vertical, horizontal or, preferably, more or less inclined to the horizontal. By varying the motion of the furnace it is possible to regulate the contacting action of the metal and slag phases and thus influence the development of carbon monoxide from the melt during the refining.

The oxygen can be injected onto the furnace in measured quantities through one or more oxygen lances which direct the oxygen stream at a right or oblique angle against the surface of the metal melt.

The formation of carbon monoxide, rapidly influenced upon by said lance positions and/or furnace motions, will reflect upon the composition of the exhaust gas emerging from the furnace mouth. Changes in this composition correspond to the instantaneous relationship between the main constituents CO_2 and CO, i.e. instantaneous degree of combustion of carbon within the furnace or possibly a transient degree of combustion of carbon for a short period. This momentary, or temporary degree of carbon combustion can be used to control the supply of oxygen and coolant or may be indicated or recorded on the panel of a computing instrument to assist an operator in controlling the process and indicate the effect of his adjustments of the lance position and/or furnace movement.

Typical examples of the operating conditions during a refining operation controlled in accordance with the present invention are as follows:

Example No. 1

A rotary furnace was charged with 110,250 kgs. of pig iron of the following analysis:

4.26% C, 0.77% Si, 0.70% Mn

The temperature of the pig iron measured in the ladle before charging was 1280° C. After charging 5000 kgs. burnt lime, CaO, the oxygen refining process was started. Based on experiences from previous heats 1800 nm.^{3} (normal or standard cubic meters) of oxygen gas were supplied during 15 minutes whereafter the temperature of the melt was 1480° C.

Sample was taken for analysis and the determination of the percentages of C, Si and Mn and the oxygen blowing was continued with 100 nm.^{3} per minute under continuous supply of about 325 kgs. of ore concentrate per minute. The exhaust gases from the furnace were collected in the hood and completely burnt with air in excess. They were cooled to 300° C. with a measured amount of atomized water which was completely evaporated. The gases were then passed into an electrofilter after which the gas flow and the percentages of CO_2 and O_2 after drying were measured. Based upon the amount of flue gas, the gas temperature at the place where the amount of gas was measured and the known amount of steam in the flue gases calculation was made every thirty-two seconds to determine the amount of dry flue gas volume per unit of time and, by the aid of the percentage of carbon dioxide of the gas per unit of time, the amount of carbon removed (refined away) per unit of time as well as the integrated value thereof from the beginning of the blowing period.

From the percentages of CO_2 and O_2 of the continuously analyzed gas (after drying) it was furthermore calculated, under the presumption that the gas in addition contained only N_2, the amount of carbon monoxide that was oxidized in the gas collecting hood, i.e. after the gas had left the furnace, or in the case where the gas was completely burnt in the furnace, how much of free oxygen the gas contained when it left the furnace. Also these calculations were performed every thirty-two seconds. The integrated average degree of combustion of the carbon was calculated from the beginning of the blowing operation.

The analysis of the sample taken before the blowing period was reported after 8 minutes of blowing and was 3.65% C, 0.32% Si and 0.70% Mn. Ordered analysis after the termination of the blowing was about 0.18% C, and the steel temperature was 1620° C. In order to obtain these values and under the presumption that 65% of the carbon was burnt to CO_2 in the furnace and on the basis of stoichiometric, thermodynamic and empiric data the required total oxygen demand was calculated and found to be 8970 kgs., 5790 kgs. as oxygen gas and 13,120 kgs. of ore containing 24.3% oxygen.

During the blowing period, however, the calculated average degree of combustion fell below 65% and as a consequence thereof new calculations repeated every thirty-two seconds showed lower value for the required amount of oxygen gas and ore concentrate. The supplies of gaseous oxygen and concentrate were accommodated mutually so that the require amount of concentrate had been supplied when further 400 kgs. of oxygen gas had still to be supplied. The average degree of combustion of the carbon from the beginning of the period was then only 57% and as a consequence thereof and in accordance with the calculations based upon the analysis of the flue gas only 12,000 kgs. of concentrate and 5660 kgs. oxygen gas, or in total 8570 kgs. oxygen, were supplied during the period.

The integrated percentage of carbon calculated from the volume of flue gas showed that when the blowing period was interrupted the percentage of carbon had fallen to 0.22%.

After the blowing the temperature of the melt was found to be 1625° and a check analysis before tapping showed 0.22% C. Without the adjustment of the first calculated demand of oxygen gas and concentrate, the percentage of carbon and the temperature would have become too low for rendering the desired steel to be tapped. An additional blowing period with inferior yield of steel and an addition of carbon would then have been necessary.

Example No. 2

Steel is to be made by refining molten pig iron in a furnace.

32,500 kg. of molten pig iron containing 3.3% C, 0.3% Si, 0.80% Mn, and 1.85% P (C as Fe_3C and Si as Fe_3Si) and having a temperature of 1275° C. is charged into the furnace and by reacting it with commercial oxygen and burnt lime as a slag former. The steel to be made is to contain 0.50% C, less than 0.01% Si, 0.20% Mn, and 0.08% P and have a temperature of 1570° C.

Ore concentrate is used as a cooling agent for absorbing excess heat. The ore concentrate had the composition of 61% Fe, 23.3% O_2, and 15.7% gangue. Assuming a percentage of 10% Fe as oxides in the slag the ore has 22.6% O_2 available for refining. The cooling effect is 1230 kcal./kg. of ore.

The specific demand of lime for slagging oxides of Si and P and the gangue of the ore is 7.0 kg. per kg. Si, 5.0 kg. per kg. P, and 8.0 kg. per 100 kg. of ore.

The process is performed by supplying oxygen and ore, more or less continuously, in proportions to produce the desired steel from the raw materials.

From previous heats it has been found that the following values can be used with satisfactory accuracy as starting conditions:

Average degree of combustion (assumed), (F_a =0.75), percent	75
Average temperature of exhaust gas, ° C.	1700
Quantity of slag at end of period, kg.	7000
Fe-content of slag (Fe_xO=13.4%), percent	10
Furnace losses, mcal. (mcal.=million cal.)	300

The amount of steel obtained from the charged pig iron is equal to the weight of pig iron, 32,500 kg., less the oxidized elements, namely

C, 2.80% of 32,500=910 kg.; Si, 0.31% of 32,500=101 kg.; Mn (0.80–0.20)% of 32,500=195 kg.; P (1.85–0.80)% of 32,500=575 kg.; Fe to the slag 10% of 7000 =700 kg.; Total, 2481 kg.

thus steel from pig iron 32,500–2480=30,020 kg.

The ore concentrate required for cooling is estimated from the following heat balance

Heat input

Pig iron (1275° C.)	32,500×0.274=8905 mcal.
Reaction heat:	
$Fe_3C \rightarrow CO$	910×2.697=2454 mcal.
$CO \rightarrow CO_2$	0.75×910×5.631=3843 mcal.
$Fe_3Si \rightarrow 2CaO \cdot SiO_2$	101×7.860=794 mcal.
$Mn \rightarrow MnO$	195×1.675=327 mcal.
$P \rightarrow 3CaO \cdot P_2O_5$	575×7.317=4207 mcal.
$Fe \rightarrow Fe_xO$	700×1.340=938 mcal.
Total input	21,468 mcal.

Heat output

Steel (1580° C.)	30,020×0.325=9756 mcal.
Slag (1580° C.)	7000×0.455=3185 mcal.
Exhaust gases (1700° C.):	
CO	0.25×910×1.110=253 mcal.
CO_2	0.75×910×1.787=1220 mcal.
Furnace losses	300 mcal.
Total output	14,714 mcal.

The difference between input and output gives an excess heat of 6754 mcal., which shall be absorbed by the ore concentrate to be added, the cooling capacity of which is 1.23 mcal. per kg. Thus,

$$\frac{6754}{1.23}=5490 \text{ kg.}$$

ore has to be supplied.

Oxygen

The oxygen required is obtained from the amounts of the elements to be oxidized multiplied by the ratio of the atomic weights of the oxygen required and the respective element.

$C \rightarrow CO$	910×1.33=1210 kg.
$CO \rightarrow CO_2$	0.75×910×1.33=908 kg.
$Si \rightarrow SiO_2$	101×1.14=115 kg.
$Mn \rightarrow MnO$	195×0.29=57 kg.
$P \rightarrow P_2O_5$	575×1.29=742 kg.
$Fe \rightarrow Fe_xO$	700×0.34=238 kg.
Total oxygen demand	3270 kg.
Oxygen supplied by ore 22.6% of 5490	1241 kg.
Free oxygen to be supplied by lance	2029 kg.

Lime

The lime required is determined as follows:

Si	101×7.0=707 kg.
P	575×5.0=2875 kg.
Ore	5490×0.08=439 kg.
Total lime demand	4021 kg.

The refining process is started (prior to determination of the actual balance) in a hot furnace charged with 32,500 kg. molten pig iron and 3600 kg. cold burnt lime, by injecting 80 kg. free oxygen per minute through the oxygen lance and supplying successively 250 kg. of ore concentrate per minute through the lance for solid additions. The deficit of lime (4020—3600=420 kg.) also is supplied through the latter lance as required.

The above information may be supplied to a computer for a standard when the refining process is to be automatically controlled and the additions and exhaust gases are measured continuously and accumulatively, the corresponding values being supplied to the computer. Thus, the amounts of free (lance) oxygen supplied, carbon monoxide and carbon dioxide occurring in the exhaust

gas are all measured individually and the measured amounts are integrated. From this information the average degree of combustion (F_{av}) as determined in accordance with this invention is recorded from the start s and after i seconds it is

$$F_{av_i}=\frac{\sum_{s}^{i}CO_2}{\sum_{s}^{i}CO+\sum_{s}^{i}CO_2}$$

The amount of ore concentrate added is continuously measured accumulatively and the rate at which the ore concentrate is supplied may be varied in accordance with changes in the F_{av_i}.

The ore concentrate, calculated to 5490 kg. has to be supplied well in advance of the moment when the demand of free oxygen 2018 kg. will have been supplied. The ore concentrate need not be supplied at a constant rate but should be supplied at a rate to prevent too violent a reaction.

For controlling the process according to the invention it is imperative that the average degree of combustion F_{av} be continuously measured and recorded. This degree is usually high at the early periods of the process and can be varied by varying the amount of ore concentrate supplied. For example, if the degree of combustion tends to decrease it can be corrected by decreasing the amount of ore concentrate supplied.

If the measured average degree of combustion (F_{av}) decreases below the assumed degree 75% ($F_a=0.75$) the supply of ore is reduced to maintain the temperature high enough at the end of the refining, i.e. when the total amount of free oxygen will have been supplied. Suppose that at a checking instant the value of $F_{av_i}=0.70$, which is 0.05 below the assumed value, and being an average from the start, it indicates that the combustion heat available has been reduced by the heat that would otherwise have been obtained by combustion of the deficiency amount of 5% CO to CO_2. However, all this heat is not lost, because the sensible heat content per mole of CO_2 is higher than the heat content per mole of CO. The actual loss of heat is therefore:

$$(0.05\times910\times5.631)-0.05\times910\times(1.787-1.110)$$
$$=0.05\times910\times4.954=2.25 \text{ mcal.}$$

(5.631 being reaction heat $CO\rightarrow CO_2$ and 1.787 and 1.110 being sensible heats of CO_2 and CO, respectively, per kilogram of carbon).

The cooling effect of 1 kg. ore being 1.23 mcal. the deficit heat quantity 225 mcal. corresponds to

$$225:1.23=180 \text{ kg.}$$

ore, which must deducted from previously calculated ore demand 5490 kg. The supply of ore concentrate is then stopped when 5490—180=5310 kg. ore have been supplied.

Consequently the oxygen demand decreases correspondingly, namely by $0.05\times910\times910\times1.33$ (which is the difference in oxygen in CO_2 and CO) less 180×0.226 (which is the reduction already determined for the reduction in the supply of ore concentrate by 180 kg. containing 22.6% oxygen) making 20 kg. The previously determined oxygen requirement of 2029 kg. is corrected and reduced to 2009 kg.

All of the 5310 kgs. of ore concentrate are supplied early so that there will be time for them to melt and react before all the 2009 kg. oxygen have been supplied through the oxygen lance or lances, and the process is interrupted when this amount of oxygen has been supplied.

Then slag was tapped. A sample of steel was taken and analyzed and the temperature measured. The resulting steel had 0.48% C, no Si, 0.075% P, 0.18% Mn; 1575° C., which is very near the preselected values.

Instead of automatically controlling the entire refining operation, the information obtained such as the degree of combustion, the amounts of oxygen and coolant supplied up to any particular instant may be used by an operator of the furnace to predict the future requirements to simultaneously arrive at the desired carbon content and temperature in the refined product.

An apparatus for performing the method of the present invention and as illustrated in the accompanying drawing will now be described.

In the drawing **1** indicates a rotary furnace for pneumatic (high speed blast) refining and **2** a hood for collecting the exhaust gas leaving the furnace during the refining. From the hood **2** the flue gas is conducted through a cooler **3** and a gas cleaner **4** to a fan **5** which exhausts the gas through a conduit **6** from the refining apparatus. Various measurements are made in the conduit **6**, the hood **2**, cooler **3** and cleaner **4** and these elements should be so dimensioned so as to pass the flue gas through them relatively quickly, in order to facilitate a rapid reproduction of measured values obtained at various positions in the gas flow.

The furnace **1** is charged with molten pig iron in a conventional way, not illustrated, and cooling agents are charged through weighing bins **11** for oxidic material, usually ore concentrate, and **12** for slag formers, usually burnt lime. The feed from these bins is measured by means of weighing equipments **13** and **14**, respectively, and the materials to be charged to the furnace from the bins are admitted to a funnel **15** by opening shutters **18** and **19**, respectively. From the funnel **15** the material may be passed to the furnace either through conduit **22** to the charging position **23** of the furnace or through conduit **25** to a water cooled lance **26** having a receiving funnel **27**, the lance opening into the furnace in operating position. By means of a damper **30** the funnel **15** can be connected to the conduits **22** and **25**, one at a time.

Air may be used for facilitating the charging of the solids through lance **26**, which is not illustrated. The refining gas proper is supplied through a water cooled oxygen lance **33** movably mounted in a holder **34** permitting the lance to be moved in its longitudinal direction and pivotally about at least a horizontal axis. Air in excess of that required for complete oxidation of all CO of the exhaust gas into CO_2 is supplied to the exhaust gas through the opening between the outlet from the furnace **1** and the hood **2** as shown by arrows in FIGURE 1, and such excess air is caused to flow into the exhaust gas by the action of the fan **5**.

The exhaust gas leaving the furnace is completely collected by hood **2** having a side conduit **36** connected to gas conduit **37** which opens at **38** in the cooler **3**. Both the hood and its side conduit **36**, on the one hand, and the gas conduit **37**, on the other hand, are jacketed for water cooling, the water being admitted to the hood through conduit **40**, equipped with a valve **41** with flow meter **42** and a thermometer **43** and removed from the side conduit through pipe **45**, equipped with a valve **46** with flow meter **47** and a thermometer **48**. Likewise the gas conduit **37** is provided with water inlet pipe **50** and water outlet pipe **54**, both pipes being provided with valves with flow meters and thermometers.

The cooling tower has a spray device **60** at the top connected to an inlet pipe **61** for cooling water. The pipe **61** is provided with a valve **62** with flow meter **63**. Since the cooling water is usually of room temperature no thermometer is shown. At the bottom of the tower non-evaporated water accumulates and can be removed through pipe **66** provided with thermometer **69** and a valve **67** with flow meter **68**.

Having been cooled in cooler **3** the flue gas is passed to the electrostatic cleaner **4** through conduit **71** and from the cleaner through exhaust conduit **6** containing fan **5**.

Conduit **6** is provided with a gas flow meter **74** that can be a pitot-meter or, alternatively, a Venturi-meter. The conduit is also provided with a thermometer **75** for meas-

uring the gas temperature. A gas analyzer **77** is connected by pipe **78** to the conduit **6** and has a gas outlet **79**. The analyzer **77** can provide analysis, in the first hand, on carbon dioxide and also on oxygen. The water content of the gas can be determined or the gas can be analyzed after drying in the analyzing apparatus. The balance between the total of dry flue gas and its contents of carbon dioxide and oxygen is considered as nitrogen.

Even though the flue gas is dirty, the gas temperature and composition may advantageously be investigated at the exit portion of the hood arrangement by the aid of thermometer **82** and analyzer **83**, thereby avoiding the effect of CO_2 absorption by water in i.e. a wet cleaning system.

While a method and apparatus for carrying out the method are described herein, it will be understood that various changes may be made in the steps of the method and form of the apparatus shown without departing from the spirit or scope of the invention. Therefore, without limitation in this respect the invention is defined by the following claims.

We claim:

1. In a method of refining a melt of ferrous metal containing carbon in a furnace to produce a melt having a predetermined temperature at a predetermined carbon content comprising the steps of determining the initial temperature, amount and carbon content of the melt, continuously contacting the melt with a stream of gas containing free oxygen to produce carbon monoxide, convert at least a portion of the carbon monoxide to carbon dioxide by combustion and generate heat sufficient to exceed the desired predetermined temperature of the final melt, measuring the average degree of combustion of carbon removed from the melt by determining the relative amounts of carbon monoxide and carbon dioxode produced in the furnace, utilizing the average degree of combustion for determining the amount of heat developed and absorbed by the melt to raise its temperature, continuing to supply oxygen for a period of time required to produce the desired carbon content of said melt by combustion of carbon, introducing a coolant into the melt during the refining operation in amounts sufficient to absorb excess heat and approach the required temperature simultaneously with the approach of the desired carbon content in the melt, stopping said refining operation by stopping the supply of oxygen when the melt has the predetermined temperature and carbon content and then pouring the melt.

2. The method in accordance with claim **1** in which the amount of coolant supplied is varied in accordance with the heat produced by the combustion of carbon to carbon monoxide and carbon dioxide to absorb said excess heat at a rate related to its generation to produce the required temperature when the proper carbon content is attained.

3. The method in accordance with claim **1** in which the carbon content of the melt and temperature of the melt are both determined by the average degree of combustion of removed carbon to carbon monoxide and carbon dioxide, measuring the average degree of combustion during the refining operation, and intermittently varying the supply of coolant to simultaneously produce the desired carbon content and temperature.

4. In a method of refining a molten, carbon containing ferrous metal in a furnace having a gas space above the melt to produce a metal melt having a preselected temperature and a preselected carbon content, the improvement which comprises, directing the refining process towards said preselected temperature and carbon content at least at one instant before the end of the process by measuring from the start (s) of the refining operation the separate accumulated amounts of carbon monoxide and carbon dioxide in the exhaust gas and obtaining therefrom at said instant (i) the actual average degree of combustion from the beginning of the refining process:

$$F_{av_i} = \frac{\sum_{s}^{i} CO_2}{\sum_{s}^{i} CO + \sum_{s}^{i} CO_2}$$

utilizing the average degree of combustion for determining the amount of heat developed and absorbed by the melt up to said instant to raise its temperature, supplying after said instant an amount of cooling agent which, together with previously supplied amounts thereof, approaches the quantity necessary for absorbing that portion of the heat developed during the entire refining operation at said actual average degree of combustion which exceeds the heat required for attaining said preselected temperature of the final melt, supplying after said instant an amount of refining gas which, together with previously supplied amounts thereof, will oxidize the slag-transferable elements and approach that amount required to oxidize all carbon to be removed at said actual average degree of combustion, and terminating the refining process when the refined molten metal simultaneously has said preselected temperature and carbon content.

5. In a method of refining a molten, carbon containing ferrous metal in a furnace having a gas space above the melt to produce a metal melt having a preselected temperature and a preselected carbon content, comprising, supplying into the furnace a refining gas which contains free oxygen and a solid material of the group consisting of ferrous metal, oxidic compounds thereof and slag-formers and combinations thereof as cooling agent, in such programmed quantities so as to supply approximately that quantity of free and oxidic oxygen that is required for the oxidation of all the carbon to be removed by refining to carbon monoxide, oxidation of any slag-transferable elements in said ferrous metal oxidizable during refining, and oxidation of a portion of said carbon monoxide to carbon dioxide to produce an estimated degree of combustion, comprising the ratio of the amount of carbon dioxide and the sum of said amount and the amount of carbon monoxide formed in said furnace, to generate approximately the quantity of heat required for raising the temperature of the melt, including said cooling agent, to said preselected temperature, measuring the quantities of carbon monoxide and carbon dioxide in the exhaust gas from the furnace to determine at least at one instant near the end of the refining operation the actual average degree of combustion of carbon removed from the melt, utilizing the average degree of combustion for determining the amount of heat developed and absorbed by the melt up to said instant to raise its temperature, varying the program by supplying after said instant and before terminating the refining process an amount of cooling agent which, together with previously supplied amounts thereof, substantially equals the quantity necessary for absorbing excess heat developed by oxidation at said actual average degree of combustion of all carbon to be removed and by oxidation of said slag-transferable elements to produce the desired temperature at the particular time when the melt has the preselected carbon content, and terminating the refining process when the preselected carbon content and temperature have been reached.

6. A method as claimed in claim **5** characterized in supplying after said instant an amount of supplementary refining gas that together with previously supplied amounts thereof is substantially equal to the quantity required for oxidizing said slag-transferable elements and for oxidizing all carbon to be removed and converted into carbon monoxide and carbon dioxide in the proportions of said actual average degree of combustion at said instant, and terminating said supply of refining gas as soon as the supplementary gas has been supplied.

7. A method in accordance with claim **1** in which the

average degree of combustion is measured by collecting all exhaust gas from the furnace, supplying air to the collected gases in an amount in excess of that required for complete oxidation of all carbon monoxide of the exhaust gas into carbon dioxide and thereby completely burning the exhaust gas to form a flue gas containing substantially only carbon dioxide, oxygen, and nitrogen and a quantity of sensible heat in addition to that of the exhaust gas substantially equal to the combustion heat of said carbon monoxide, continuously measuring and integrating the amount of carbon dioxide in said flue gas, continuously measuring the change in said gas caused by said burning of carbon monoxide to carbon dioxide which change corresponds to the amount of carbon monoxide in the exhaust gas, and continuously integrating the measured amount of carbon monoxide so determined, whereby to obtain the actual average degree of combustion.

8. A method as claimed in claim 7 comprising the steps of continuously measuring and integrating the quantity of said flue gas in dry state, continuously analyzing said flue gas with regard to oxygen as well as carbon dioxide, the balance being considered as nitrogen, the molar amount of said nitrogen corresponding to 79/21 moles of oxygen admitted with said air to said exhaust gas, the difference between the molar amount of said oxygen admitted as determined by the molar amount of nitrogen and the molar amount of said oxygen analyzed representing the double molar amount of carbon monoxide in said exhaust gas, determining the degree of combustion in said exhaust gas from the ratio between said carbon monoxide and said analyzed carbon dioxide, and determining the actual average degree of combustion by integrating said degree of combustion with regard to accumulated amount of analyzed carbon dioxide.

9. A method as claimed in claim 7 comprising, the steps of continuously measuring and integrating the quantity of said flue gas in dry state, continuously analyzing said flue gas with regard to oxygen as well as carbon dioxide, the balance being considered as nitrogen, separately accumulating the molar amount of said admitted oxygen supplied as air as determined by the amount of nitrogen and the molar amount of said analyzed oxygen as from the start of the refining operation, the difference

therebetween being equal to the accumulated amounts of oxygen used in converting carbon monoxide of the exhaust gas to carbon dioxide, thereby obtaining the average degree of combustion.

10. A method as claimed in claim 7, comprising the steps of continuously measuring and integrating the quantity of said flue gas in dry state, continuously measuring and accumulating the sensible heat and the amount of carbon dioxide in said flue gas to determine the heat content per unit of weight of carbon oxidized from said ferrous metal, and determining from the given linear relationship of the degree of combustion relative to heat content per unit of weight of oxidized carbon which exists for any given temperature, the average degree of combustion at the prevailing average exhaust gas temperature.

11. A method as claimed in claim 10, in which the heat content of the flue gas is measured by cooling the gas and measuring the heat absorbed by the cooling medium, the heat lost through radiation and convection and the remaining heat content of the thus cooled gas.

12. A method as claimed in claim 7, comprising continuously measuring and integrating the quantity of said flue gas in dry state, continuously measuring the accumulated molar amount of carbon dioxide in the flue gas and the molar amount of free and oxidic oxygen supplied to the furnace, the double amount of said oxygen in addition to oxygen required for oxidizing slag-transferable elements of said ferrous metal and for primary oxidation of the carbon of said ferrous metal into carbon monoxide representing the molar amount of carbon dioxide in the exhaust gas, and determining the average degree of combustion as the quotient between said amount of carbon dioxide in the exhaust gas and said amount of carbon dioxide in the flue gas.

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