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(54) **Control of a melting process**

Kontrolle eines Schmelzprozesses

Contrôle d'un processus de fusion

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Description

[0001] The invention relates to a method to control a process for heating or melting a metal, in particular aluminium, comprising heating said metal in a fuel-fired furnace wherein a fuel is combusted with an oxygen containing gas, and measuring the concentrations of carbon dioxide and oxygen in the furnace atmosphere.

[0002] The invention relates to the field of heating or melting of metals in fuel-fired furnaces. Liquid or gaseous hydrocarbon containing fuels may be used. The heating or melting process is carried out in rotary or reverberatory furnaces. The process may be continuous or a batch process. The material to be melted, for example scrap or ingots, is charged through large doors into the furnace. Typically a furnace is charged two or more times during a process cycle.

[0003] During melting of aluminium, metal losses occur essentially due to the following phenomena: A part of the losses originates from direct oxidation of the metal with the furnace atmosphere. A second part of the metal losses comes from metal that is entrapped between the metal oxides formed through direct oxidation.

[0004] The oxidation of aluminium is temperature dependent. The rate of oxidation increases with increasing temperature, especially at temperatures above 780 °C the oxidation increases rapidly.

[0005] The heat introduced into the melting furnace by burners is not uniformly distributed over the whole metal surface and thus local overheating may occur. Such local overheating leads to a local increase in the metal oxidation. Local overheating is more likely to occur in reverberatory furnaces owing to the heat transfer characteristics of reverberatory furnaces. But the problem of hot spots also exists in rotary furnaces.

[0006] There are various means used in industry to minimize the metal losses:

For example, in rotary furnaces the temperature of the metal charge and of the metal melt is homogenized by rotation of the furnace in order to avoid overheating. In reverberatory furnaces mechanical or electromagnetic stirrers are installed to get a more uniform heat distribution within the furnace.

[0007] Another example for reverberatory furnaces is to optimise the timing for removal of the dross layer on the metal melt by skimming. The dross layer comprises aluminium oxide which has a high melting point. The dross layer will not melt further, but functions as a heat insulator. If it is allowed to grow too much, it will insulate the metal melt from the burner flame. The dross will be more heated and more metal will be oxidized.

[0008] Various attempts have been made to find control parameters to monitor how the oxidation of the metal proceeds without opening the furnace door. Such a parameter would allow to determine the correct time for skimming the dross, for stirring the metal melt or for changing the burner power.

[0009] For reverberatory furnaces it is state of the art to measure the temperature in the furnace or the temperature of the flue gases so that the burner power can be reduced or other measures can be taken when a critical temperature is reached. Such measuring devices are mainly used to protect the refractory, but they do not indicate the formation of local hot spots where oxidation takes place.

[0010] An alternative is to submerge a thermocouple into the melted metal. However, this is only a local indication and it does not give any information as to hot spots on other locations. Monitoring of the temperature is thus not a sufficient means to monitor how the metal oxidation proceeds.

[0011] In US 2005/0103159 A1 it is suggested that in an aluminium melting process the measurement of the temperature of the flue gases in combination with the determination of the concentration of carbon monoxide or hydrogen in the flue gases gives an indication of the formation of aluminium oxides.

[0012] FR 2824130 A1 discloses a method for controlling the quality of a product treated at a temperature and under an atmosphere generated by burners arranged at certain locations of the furnace. A laser beam passes through the atmosphere of the furnace and the optical characteristics of the beam being modified after passing through the furnace. The analysis of the modifications of the beam enables to act immediately on the fluid (oxidant/fuel) injections in the burners to modify said atmosphere and thereby control the quality of the products.

[0013] However, there are disadvantages with that method. In a melting furnace carbon monoxide and hydrogen are formed in an uncontrolled manner by gasification of organic contaminations on the metal charge. Also, carbon monoxide and hydrogen are oxidized by air leaking into the furnace. This makes the interpretation of the carbon monoxide concentration uncertain.

[0014] Further, an industrial furnace can never be perfectly sealed. Thus, a significant amount of air is always leaking into a furnace causing an excess of oxygen which may oxidize any carbon monoxide or hydrogen formed in the furnace. The oxygen from the leak air may also oxidize metal. This makes the use of the carbon monoxide concentration even more uncertain.

[0015] The authors of US 2005/0103159 A1 consider various interactions between the components of the furnace atmosphere and the metal charge. The various modes of heat transfer do not lend themselves to an easy solution by modeling, but a learning procedure, for example based on neural networks, is proposed.

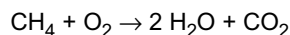
[0016] Thus, it is an object of the invention to provide a more simple method for monitoring the metal oxidation in melting furnaces, in particular in aluminium melting furnaces.

[0017] This object is achieved by a method to control a process for heating or melting a metal, in particular aluminium,

comprising:

- heating said metal in a fuel-fired furnace wherein a fuel is combusted with an oxygen containing gas,
- measuring the concentrations of carbon dioxide and oxygen in the furnace atmosphere,
- wherein
- the theoretical concentration of oxygen in the furnace atmosphere is calculated on the basis of said concentration of carbon dioxide,
- the difference between said theoretical concentration of oxygen and said detected concentration of oxygen is determined and
- said process is controlled depending on said difference.

[0018] When oxygen and methane are combusted the following reaction will take place:



If methane and oxygen react at stoichiometric amounts in an absolute tight furnace without any leak air, the flue gases will contain only water and carbon dioxide. Thus only CO_2 and H_2O would be analysed and the oxygen concentration would be 0 %.

[0019] This is an ideal situation. In an industrial furnace there is always air leaking into the furnace diluting the furnace atmosphere and thus the CO_2 and H_2O concentration will be lower. On the other hand, since leak air contains 21 % oxygen the oxygen content in the flue gases will be higher.

[0020] The concentrations of oxygen and carbon dioxide in the atmosphere of a combustion process in an inert furnace where a hydrocarbon fuel is combusted with oxygen and wherein leak air may introduce into the furnace, can be described by a straight line. In case of a stoichiometric combustion and that an analysing equipment analysing dry gases is used this relation is given by

$$(1) \% \text{O}_2 = k \cdot \% \text{CO}_2 + m$$

wherein $\% \text{O}_2$ = the oxygen content in the furnace atmosphere

$\% \text{CO}_2$ = the carbon dioxide content in the furnace atmosphere

k = constant, depending on the composition of the fuel and on the CO_2 content in the furnace atmosphere without any leak air (in the case of combustion of CH_4 with pure O_2 : $k = -0,21$)

m = the oxygen content of the leak air, that is $m = 0,21$

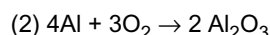
[0021] For a man skilled in the art it is clear that what has been explained by using the combustion of methane with oxygen as an example can be easily transferred to the use of other fuels and other oxygen containing gas mixtures. Deviation from stoichiometric combustion will shift the line. Analysing wet gases, for example by using a laser will also shift the line.

[0022] According to the invention the CO_2 concentration in the furnace atmosphere is measured. Then equation (1) allows to calculate the theoretical O_2 concentration in the furnace atmosphere.

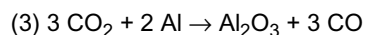
[0023] If a reducing substance, such as a metal or an organic material, is added to the furnace some oxygen will be consumed and the oxygen content in the furnace will be reduced. The O_2 concentration in the furnace atmosphere is measured and compared to the theoretical O_2 concentration. The difference between both values is an indicator for the amount of metal or material that has been oxidized.

[0024] The O_2 concentration and the CO_2 concentration can be determined by direct measurement or detection of the respective concentrations within the furnace or, according to a preferred embodiment, the O_2 concentration and the CO_2 concentration are measured in the flue gas stream. More preferred a sample is taken from the flue gas stream and then analyzed in order to determine the O_2 concentration and the CO_2 concentration.

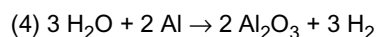
[0025] If the reducing substance is aluminium it will react with oxygen according to the following reaction



[0026] Carbon dioxide will also react with aluminium according to



and the reaction

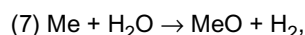
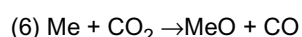
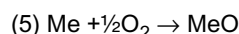


will also occur.

[0027] By simultaneous analysis of the concentrations of carbon dioxide, carbon monoxide, and hydrogen the inventors could show that reactions (3) and (4) can be neglected compared to reaction (2). It can be concluded that in case aluminium is charged into the furnace the amount of oxygen deviating from the oxygen concentration calculated from equation (1) is mainly consumed by reaction (2). Thus, the amount of aluminium oxidized is proportional to the deviation of the measured oxygen content from the oxygen content given by equation (1).

[0028] In a preferred embodiment the invention utilizes this insight to control an aluminium melting process. The content of oxygen in the furnace atmosphere is detected several times and the relative amount of aluminium oxide is determined from the difference between the detected oxygen concentration and the theoretical oxygen concentration. This information is used to regulate and / or control the melting process, for example by changing the burner power.

[0029] What has been described above with respect to the melting of aluminium can be generalized to the heating and / or melting of other metals. The oxidation reactions (2), (3) and (4) could then be formulated as:



[0030] Reaction (5) would be dominating as long as free O_2 is present in the furnace atmosphere. For example the invention could be applicable for the heating of steel or steel alloys..

[0031] According to the invention there is no need to detect the concentration of carbon monoxide or hydrogen in the furnace atmosphere or in the flue gases or to measure the flue gas temperature. Preferably the heating or melting process is controlled without using the temperature of the flue gases or the temperature in the furnace. It is further preferred that the control of the melting process is not based on carbon monoxide measurements or on measurements of the hydrogen content in the furnace atmosphere or in the flue gases. It is especially advantageous to base the control of the heating or melting process on the difference between the theoretical O_2 concentration and the measured O_2 concentration, only.

[0032] In a preferred embodiment the oxygen concentration and the carbon dioxide concentration are continuously detected. In the beginning when the temperature in the furnace is low so that no metal is oxidized the measured oxygen concentration will be essentially equal to the theoretical oxygen concentration calculated from the measured CO_2 concentration. With increasing temperature, at least at some local spots metal will be oxidized.

[0033] Preferably said furnace is heated by one or more burners. Further it is preferred to measure the amount of fuel supplied to the burner(s). If the fuel flow is measured the absolute amount of CO_2 , for example the mass of CO_2 in kg, can be calculated from the chemical reaction equation. Further, that information allows to calculate the absolute amount of O_2 which has been consumed by oxidation of the metal in the furnace. That is, the absolute difference, for example in kg, between the theoretical oxygen content and the measured oxygen content can be given.

[0034] Preferably the amount of oxidized metal, for example aluminium, is calculated using the absolute amount of oxygen consumed in that oxidation reaction and the formula weight of the metal oxide, for example the formula weight of aluminium oxide Al_2O_3 . As described above the metal may also be oxidized by H_2O and CO_2 but the inventors could show that the oxidation with oxygen is dominating in an industrial furnace.

[0035] Preferably the oxygen and the carbon dioxide concentration are detected in the flue gases. A flue gas analysis provides a direct information on the composition of the atmosphere within the furnace. For practical reasons it is preferred to determine the oxygen and the carbon dioxide content in the furnace atmosphere from a measurement in the flue gas duct.

[0036] The measurement of the oxygen concentration can be carried out by any equipment for analyzing oxygen. In a preferred embodiment a laser, especially a diode-laser, is used to analyze the oxygen concentration.

[0037] When a deviation between the theoretical and the measured oxygen concentration is monitored some metal must have been oxidized. According to the invention the so determined metal oxidation rate is used to control the heating or melting process. In a preferred embodiment the heating or melting process is controlled by changing the power of the burner or of the burners which are used to heat the furnace and its charge.

[0038] According to another preferred embodiment the amount of oxygen supplied to the burner is changed in order to influence the heating or melting process. For example, it may be switched from oxygen burners to air burners or vice versa.

[0039] In a further embodiment several charges of metal are melted in said melting furnace and for each charge the difference between the theoretical and the measured oxygen concentration is determined. These data are then stored,

for example in a computer memory. By varying different process parameters or exchanging part of the furnace equipment and recording new curves, these new curves can be compared to the stored curves. The comparison of the new curves with the stored curves allows to further optimize the heating or melting process. In addition these data can be used for training of personnel operating the furnace.

[0040] According to another embodiment the invention is used to monitor the combustion of organic contaminants on the metal charge. For example, if the metal charged into the furnace is contaminated by organic matter, such as oil, lacquer, or plastics, these materials are evaporated and combusted and oxidized inside the furnace. This oxidation will also create a difference between the calculated and the measured oxygen in the flue gas or in the furnace atmosphere. The oxidation of the organic matter can then be studied in the same way as the oxidation of the metal. When oxidation of organic matter is detected, it can be controlled by adding excess oxygen to the furnace.

[0041] The evaporation of organic matter dominates at the beginning of the process at temperatures below 500 °C, especially between 400 and 500 °C. The oxidation of the metal dominates later in the process when the metal is at higher temperatures, especially above the melting point of the metal. In case of aluminium the oxidation increases at temperatures above the melting point at 660 °C and it may increase rapidly at temperatures above about 780 °C. In case of iron, the oxidation starts to be significant above 900 °C.

[0042] Therefore, the invention shows either oxidation of organic matter or oxidation of metal, but not the two at the same time. For the man skilled in the art it is obvious at what part of the process it is of interest to study oxidation of organic matter and at what part of the process it is of interest to study oxidation of the metal.

[0043] The invention has several advantages compared to the state of the art technology. The inventive method provides a signal showing the oxidation rate of a metal, in particular of aluminium, that is independent from the amount of leak air entering the furnace. Thus the inventive method is more reliable than methods based on flue gas temperature measurements or based on carbon monoxide measurements. The invention provides a method which is very appropriate for industrial furnaces, in particular for rotary furnaces and reverberatory furnaces used for heating or melting of metals. The user of the invention will be able to have a better process control and hence will be able to decrease the aluminium losses and to get a higher metal yield. Further, the inventive method is easy to implement. The invention is in particular useful to control a process for melting aluminium.

[0044] The invention as well as further details and preferred embodiments of the invention are disclosed in the following description and illustrated in the accompanying drawings in which the figures show:

figure 1 an aluminium melting furnace with the equipment to carry out the inventive control method and
figure 2 the on-line flue gas analysis measured with the arrangement according to figure 1.

[0045] Figure 1 shows an aluminium melting furnace 1 of the rotary type. The aluminium melting furnace 1 has been charged with aluminium scrap 2. Melting furnace 1 is heated with an oxy-fuel burner 3 which can be supplied with fuel, oxygen and / or air. The amount of fuel, oxygen and air provided to burner 3 is regulated by flow control valves 4 and can be measured by flow measurement means 5.

[0046] Burner 3 generates a burner flame 6 which heats the aluminium charge 2. The flue gases 7 which are produced during the heating and melting of charge 2 leave the furnace 1 through a flue gas duct 8.

[0047] Flue gas duct 8 is provided with an oxygen analyzer 9 and a carbon dioxide analyzer 10. Oxygen analyzer 9 and CO₂ analyzer 10 provide signals 11, 12 which are proportional to the concentration of oxygen and carbon dioxide in the flue gases 7. These signals are sent as input to a process computer 13.

[0048] From the flow measurement means 5 process computer 13 further receives input signals 14, 15, 16 proportional to the measured flow of fuel, oxygen and air, respectively. Any of the data 11, 12, 14, 15, 16 can be shown on a computer monitor 17. Computer monitor 17 is also used to visualize the analysis of the data 11, 12, 14, 15, 16.

[0049] Process computer 17 calculates from the data 11, 12, 14, 15, 16 a signal 18 which is used to control the melting process by varying the flow of fuel, oxygen, and / or air supplied to burner 3. These calculations are made on-line and can be shown on computer monitor 17 in a real time graph.

[0050] By variations of the pressure within aluminium melting furnace 1 or by opening the door of aluminium melting furnace 1 the amount of leak air entering the furnace 1 will change. CO₂ analyzer 10 continuously measures the CO₂ concentration in the flue gas stream 7. The measured values are sent to process computer 13 and are recorded. For example, every minute one measured value is recorded. By using equation (1) process computer 13 calculates the theoretical oxygen concentration for every measured CO₂ value. Thus, for every minute a measured CO₂ concentration and the corresponding theoretical O₂ concentration is recorded.

[0051] Oxygen analyzer 9 continuously measures the O₂ concentration in the flue gases. The measured values are also stored every minute in the process computer 13.

[0052] If there is no oxidation in the furnace 1 the measured oxygen value and the theoretical oxygen value should be equal. However, the furnace 1 contains aluminium and when this aluminium starts to oxidize, the oxidation of aluminium will consume some of the oxygen in the furnace atmosphere. The measured oxygen concentration will then be lower

than the theoretical oxygen concentration. The difference between both values is an indication of aluminium oxidation. This difference is also calculated and stored in process computer 13.

[0053] With flow measurement means 5 the fuel flow to burner 3 is determined and stored in the same process computer 13. Using the fuel flow data the difference between the measured and the theoretical oxygen concentration can be calculated into mass units, that is into kg oxygen. The amount of consumed oxygen in kg is also stored in the same computer program 13.

[0054] Assuming that this amount of oxygen has reacted with aluminium to form aluminium oxide the mass of aluminium that is oxidized can be calculated. These data are also stored in process computer 13.

[0055] All these data - CO₂ concentration, measured and theoretical O₂ concentration, difference between measured and theoretical O₂ concentration, amount of oxidized aluminium - can be visualized during the melting process by computer screen 17 (see figure 2). Computer screen 17 displays the measured and calculated values as value versus time graphs. From the screen 17 the operator can thus see how many aluminium is oxidized every minute and he can use this information to optimize the melting process.

[0056] Figure 2 shows a typical graph recorded by process computer 13. At 14:50 a rapid increase in aluminium oxidation is detected and this information is used to control the melting process by changing the burner power.

[0057] The inventive method is independent of leak air into the furnace, since the influence of leak air variations is compensated by repeating the calculation according to equation (1) for every measurement - in the example above, every minute. Of course the data can be calculated more or less frequent than every minute.

Claims

1. Method to control a process for heating or melting a metal (2), in particular aluminium, comprising:

- heating said metal (2) in a fuel-fired furnace (1) wherein a fuel is combusted with an oxygen containing gas,
- measuring (9, 10) the concentrations of carbon dioxide and oxygen in the furnace atmosphere,

characterized in that

- the theoretical concentration of oxygen %O₂ in the furnace atmosphere is calculated by using the equation

$$\%O_2 = k \cdot \%CO_2 + m$$

wherein %CO₂ is the measured carbon dioxide concentration in the furnace,
k is a constant, depending on the composition of the fuel and on the CO₂ content in the furnace atmosphere without any leak air and
m is the oxygen content of the leak air,

- the difference between said theoretical concentration of oxygen and said detected concentration of oxygen is determined and
- said process is controlled depending on said difference.

2. Method according to claim 1, **characterized in that** said oxygen and said carbon dioxide concentration are continuously measured.

3. Method according to any of claims 1 or 2, **characterized in that** said furnace (1) is heated by one or more burners (3) and that the amount of fuel supplied to the burner(s) (3) is measured.

4. Method according to claim 3, **characterized in that** the absolute value of said difference between said theoretical concentration of oxygen and said measured concentration of oxygen is calculated based on said measured concentrations of oxygen and carbon dioxide and on said measured amount of fuel.

5. Method according to claim 4, **characterized in that** the amount of oxidized metal is calculated.

6. Method according to any of claims 1 to 5, **characterized in that** said measured oxygen concentration and / or said measured carbon dioxide concentration are detected by means of a laser.

7. Method according to any of claims 1 to 6, **characterized in that** said fuel is combusted with a gas containing more than 21 % oxygen, preferably more than 50 % oxygen, preferably more than 90% oxygen.
8. Method according to any of claims 1 to 7, **characterized in that** said process is controlled by changing the power of said burner(s) (3).
9. Method according to any of claims 1 to 8, **characterized in that** several charges of metal (2) are melted in said furnace (1) and that for each charge the difference between said theoretical concentration of oxygen and said measured concentration of oxygen is determined.
10. Method according to claim 9, **characterized in that** for at least two different charges the respective differences between said theoretical concentration of oxygen and said measured concentration of oxygen are compared.
11. Method according to any of claims 1 to 10, **characterized in that** said metal is contaminated with organic substances, that said organic substances are at least partly oxidized with said oxygen and that the amount of oxidized substances is monitored.

Patentansprüche

1. Verfahren zur Kontrolle eines Prozesses zum Erhitzen oder Schmelzen eines Metalls (2), insbesondere Aluminium, wobei das Verfahren Folgendes umfasst:

- Erhitzen des Metalls (2) in einem brennstoffbefeuerten Ofen (1), in dem ein Brennstoff mit einem sauerstoffhaltigen Gas verbrannt wird,
- Messen (9, 10) der Konzentrationen von Kohlendioxid und Sauerstoff in der Ofenatmosphäre,

dadurch gekennzeichnet, dass

- die theoretische Konzentration von Sauerstoff (%O₂) in der Ofenatmosphäre nach folgender Gleichung berechnet wird:

$$\%O_2 = k \cdot \%CO_2 + m$$

wobei %CO₂ die gemessene Kohlendioxidkonzentration im Ofen, k eine Konstante, abhängig von der Zusammensetzung des Brennstoffs und vom CO₂-Gehalt in der Ofenatmosphäre ohne jegliche Falschluf, und m der Sauerstoffgehalt der Falschluf ist,

- die Differenz zwischen der theoretischen Konzentration von Sauerstoff und der ermittelten Konzentration von Sauerstoff bestimmt wird und
- der Prozess in Abhängigkeit von der Differenz kontrolliert wird.

2. Verfahren nach Anspruch 1, **dadurch gekennzeichnet, dass** die Sauerstoff- und die Kohlendioxidkonzentrationen kontinuierlich gemessen werden.
3. Verfahren nach Anspruch 1 oder Anspruch 2, **dadurch gekennzeichnet, dass** der Ofen (1) durch einen oder mehrere Brenner (3) beheizt und die Menge des den Brennern (3) zugeführten Brennstoffs gemessen wird.
4. Verfahren nach Anspruch 3, **dadurch gekennzeichnet, dass** der absolute Wert der Differenz zwischen der theoretischen Konzentration von Sauerstoff und der gemessenen Konzentration von Sauerstoff auf der Basis der gemessenen Konzentrationen von Sauerstoff und Kohlendioxid und der gemessenen Brennstoffmenge berechnet wird.
5. Verfahren nach Anspruch 4, **dadurch gekennzeichnet, dass** die Menge oxidierten Metalls berechnet wird.
6. Verfahren nach einem der Ansprüche 1 bis 5, **dadurch gekennzeichnet, dass** die gemessene Sauerstoffkonzentration und/oder die gemessene Kohlendioxidkonzentration mittels eines Lasers ermittelt werden.

7. Verfahren nach einem der Ansprüche 1 bis 6, **dadurch gekennzeichnet, dass** der Brennstoff mit einem Gas verbrannt wird, das mehr als 21% Sauerstoff, vorzugsweise mehr als 50% Sauerstoff, vorzugsweise mehr als 90% Sauerstoff enthält.
8. Verfahren nach einem der Ansprüche 1 bis 7, **dadurch gekennzeichnet, dass** der Prozess durch Ändern der Leistung des Brenners/der Brenner (3) kontrolliert wird.
9. Verfahren nach einem der Ansprüche 1 bis 8, **dadurch gekennzeichnet, dass** mehrere Chargen von Metall (2) im Ofen (1) geschmolzen werden und dass für jede Charge die Differenz zwischen der theoretischen Konzentration von Sauerstoff und der gemessenen Konzentration von Sauerstoff bestimmt wird.
10. Verfahren nach Anspruch 9, **dadurch gekennzeichnet, dass** für mindestens zwei verschiedene Chargen die jeweiligen Differenzen zwischen der theoretischen Konzentration von Sauerstoff und der gemessenen Konzentration von Sauerstoff verglichen werden.
11. Verfahren nach einem der Ansprüche 1 bis 10, **dadurch gekennzeichnet, dass** das Metall mit organischen Substanzen verunreinigt ist, dass die organischen Substanzen mindestens teilweise mit dem Sauerstoff oxidiert sind und dass die Menge oxidiertter Substanzen überwacht wird.

Revendications

1. Procédé de contrôle d'un processus de chauffage ou de fusion d'un métal (2), en particulier l'aluminium, comprenant les opérations consistant à :

- chauffer ledit métal (2) dans un four (1) chauffé par un carburant qui brûle avec un gaz contenant de l'oxygène,
- mesurer (9, 10) les concentrations en anhydride carbonique et en oxygène dans l'atmosphère du four,

caractérisé en ce que

- on calcule la concentration théorique d'oxygène %O₂ dans l'atmosphère du four en utilisant l'équation

$$\%O_2 = k * \%CO_2 + m$$

dans laquelle %CO₂ est la concentration en anhydride carbonique mesurée dans le four ;
 k est une constante dépendant de la composition du carburant et de la teneur en CO₂ de l'atmosphère du four en l'absence de tout air de fuite et
 m est la teneur en oxygène de l'air de fuite,

- on détermine la différence entre ladite concentration théorique d'oxygène et ladite concentration d'oxygène détectée et
- on contrôle ledit processus en fonction de ladite différence.

2. Procédé selon la revendication 1, **caractérisé en ce que** lesdites concentrations en oxygène et en anhydride carbonique sont mesurées en continu.
3. Procédé selon l'une quelconque des revendications 1 et 2, **caractérisé en ce que** ledit four (1) est chauffé par un ou plusieurs brûleurs (3) et que l'on mesure la quantité de carburant fournie au(x) brûleur(s) (3).
4. Procédé selon la revendication 3, **caractérisé en ce que** l'on calcule la valeur absolue de ladite différence entre ladite concentration théorique d'oxygène et ladite concentration d'oxygène mesurée sur la base desdites concentrations mesurées d'oxygène et d'anhydride carbonique et de ladite quantité mesurée de carburant.
5. Procédé selon la revendication 4, **caractérisé en ce que** l'on calcule la quantité de métal oxydé.
6. Procédé selon l'une quelconque des revendications 1 à 5, **caractérisé en ce que** l'on détecte ladite concentration d'oxygène mesurée et/ou ladite concentration d'anhydride carbonique mesurée au moyen d'un laser.

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7. Procédé selon l'une quelconque des revendications 1 à 6, **caractérisé en ce que** ledit carburant est brûlé avec un gaz contenant plus de 21% d'oxygène, de préférence plus de 50% d'oxygène, mieux encore plus de 90% d'oxygène.
8. Procédé selon l'une quelconque des revendications 1 à 7, **caractérisé en ce que** l'on contrôle ledit processus en faisant varier la puissance dudit/desdits brûleur(s) (3).
9. Procédé selon l'une quelconque des revendications 1 à 8, **caractérisé en ce que** plusieurs charges de métal (2) sont fondues dans ledit four (1) et que pour chaque charge on détermine la différence entre ladite concentration théorique d'oxygène et ladite concentration d'oxygène mesurée.
10. Procédé selon la revendication 9, **caractérisé en ce que** pour au moins deux charges différentes on compare les différences respectives entre ladite concentration théorique d'oxygène et ladite concentration d'oxygène mesurée.
11. Procédé selon l'une quelconque des revendications 1 à 10, **caractérisé en ce que** ledit métal est contaminé par des substances organiques, que lesdites substances organiques sont au moins en partie oxydées par ledit oxygène et que l'on surveille la quantité de substances oxydées.

Fig. 1

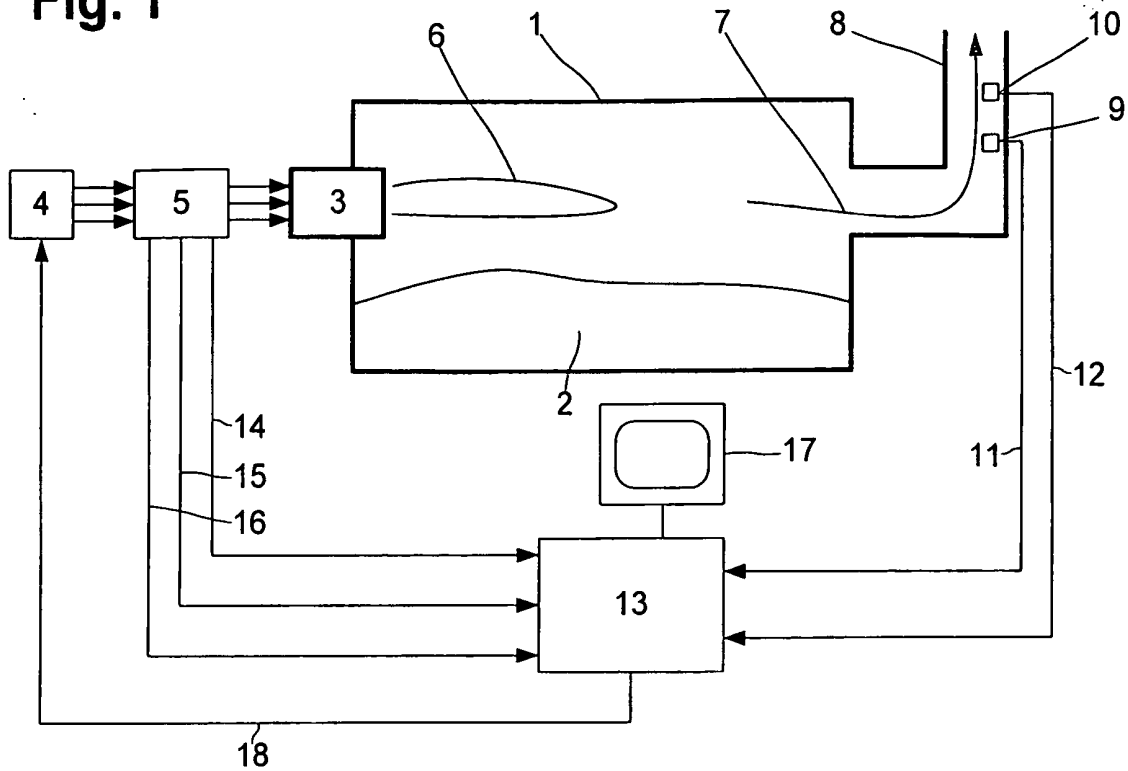
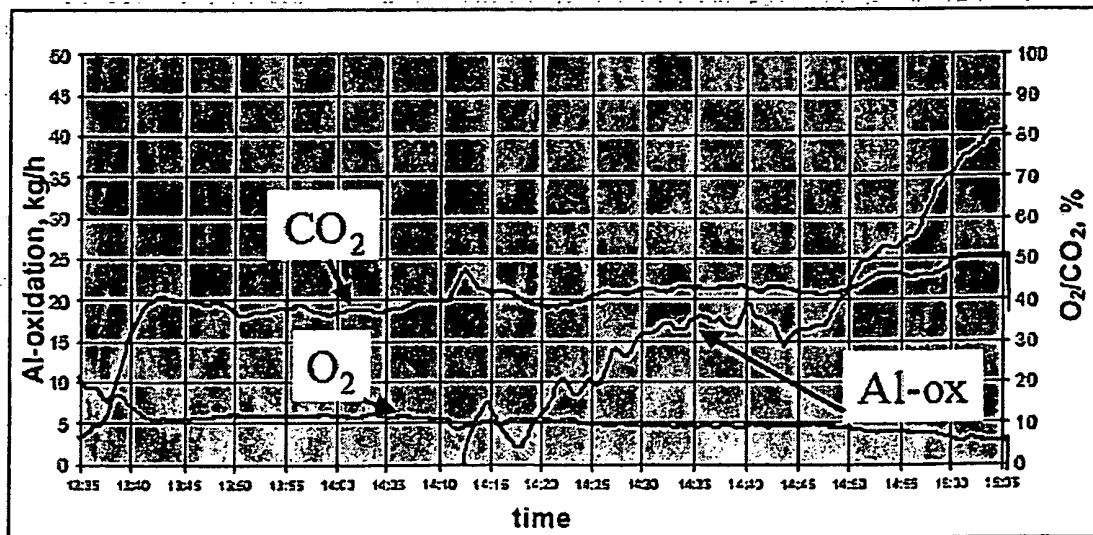


Fig. 2



REFERENCES CITED IN THE DESCRIPTION

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