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(54) CONTROL OF A MELTING PROCESS

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(57) **ABSTRACT**

The invention relates to a method to control a process for heating or melting a metal, in particular aluminium, which includes: 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, calculating the theoretical concentration of oxygen in the furnace atmosphere on the basis of said concentration of carbon dioxide, determining the difference between said theoretical concentration of oxygen and said detected concentration of oxygen and controlling said process depending on said difference.

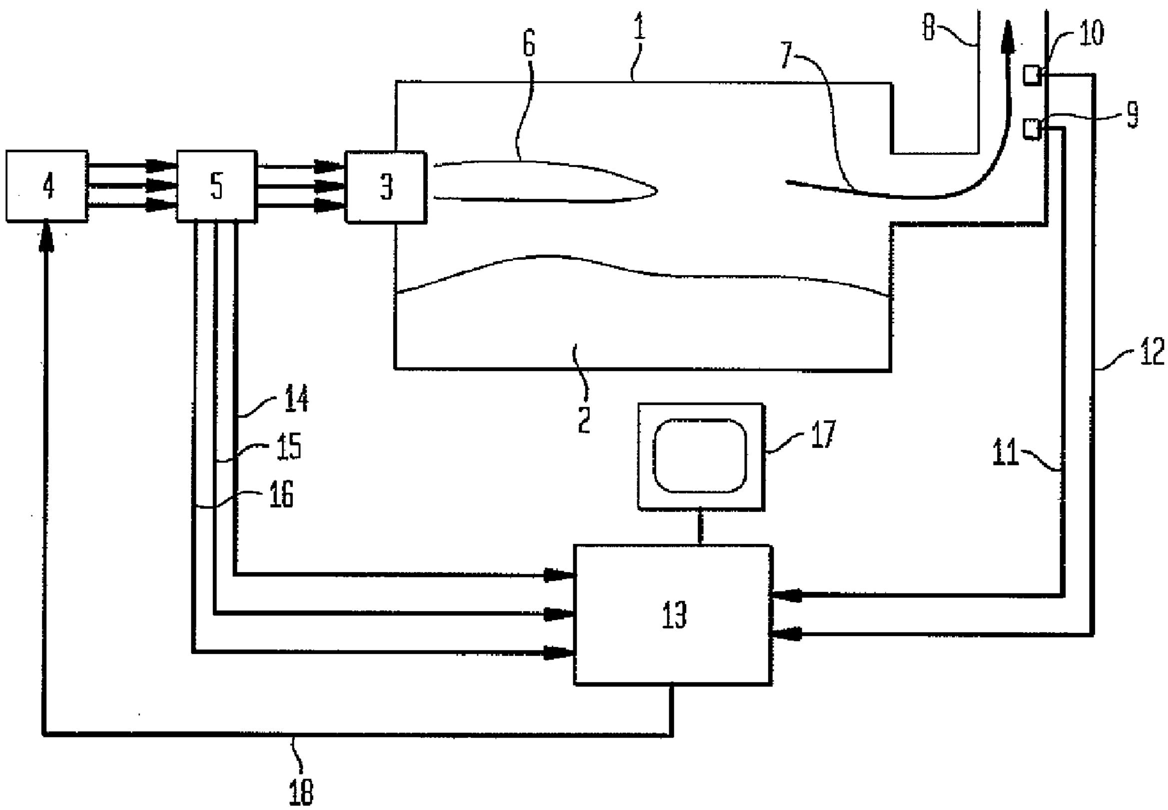

FIG. 1

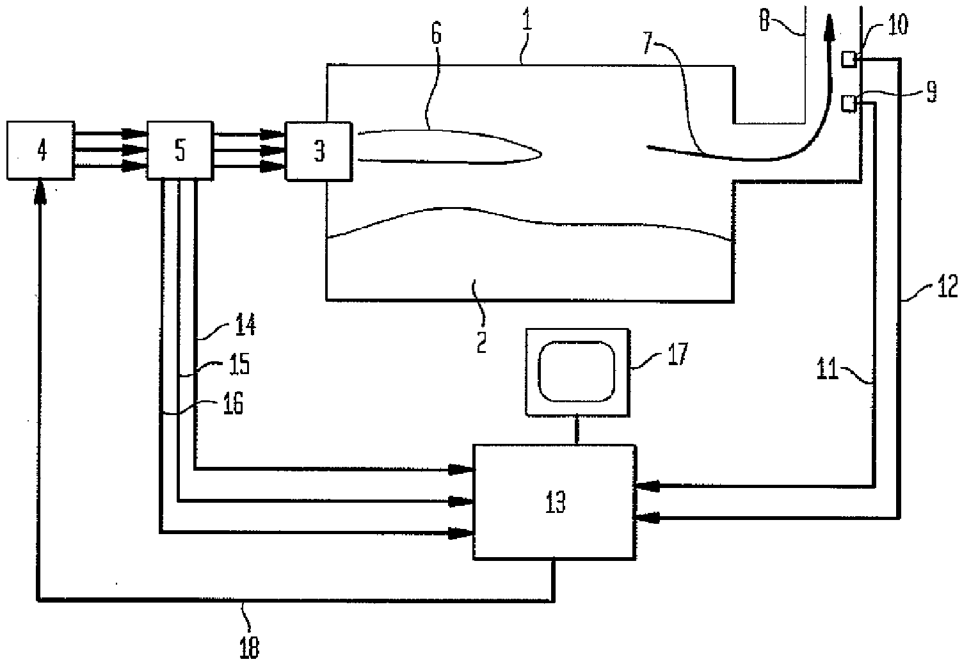
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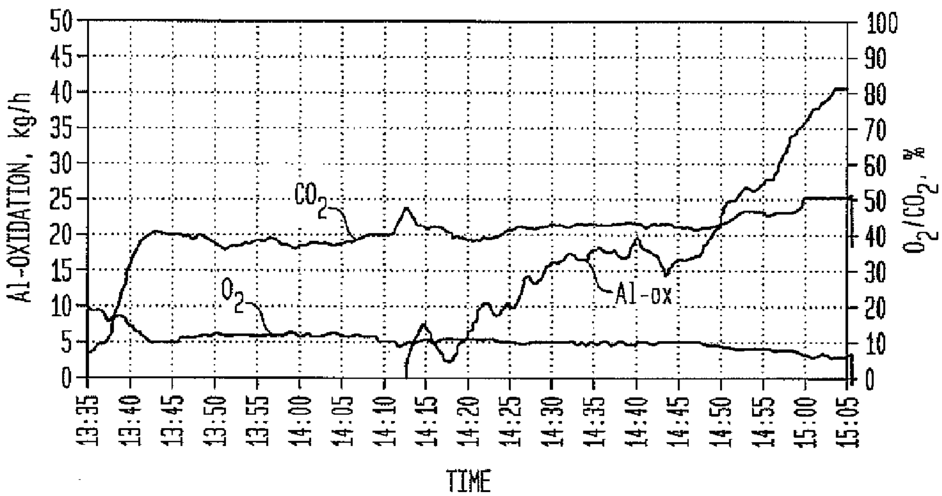
FIG. 2


Al-OXIDATION, kg/h
O_2/CO_2, %
CO_2
O_2
Al-ox
TIME
50
45
40
35
30
25
20
15
10
5
0
100
90
80
70
60
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CONTROL OF A MELTING PROCESS

[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:

[0007] 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.

[0008] 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.

[0009] 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.

[0010] 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.

[0011] 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.

[0012] 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.

[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:

[0018] heating said metal in a fuel-fired furnace wherein a fuel is combusted with an oxygen containing gas,

[0019] measuring the concentrations of carbon dioxide and oxygen in the furnace atmosphere,

wherein

[0020] the theoretical concentration of oxygen in the furnace atmosphere is calculated on the basis of said concentration of carbon dioxide,

[0021] the difference between said theoretical concentration of oxygen and said detected concentration of oxygen is determined and

[0022] said process is controlled depending on said difference.

[0023] When oxygen and methane are combusted the following reaction will take place:

$$CH_4+O_2\rightarrow 2H_2O+CO_2$$

[0024] 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%.

[0025] 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.

[0026] 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

$$\%O_2=k*\%CO_2+m \quad (1)$$

wherein

[0027] % O_2=the oxygen content in the furnace atmosphere

[0028] % CO_2=the carbon dioxide content in the furnace atmosphere

[0029] 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

[0030] m=the oxygen content of the leak air, that is m=0, 21

[0031] 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.

[0032] 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.

[0033] 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.

[0034] 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.

[0035] If the reducing substance is aluminium it will react with oxygen according to the following reaction

$$4Al+3O_2\rightarrow 2Al_2O_3 \quad (2)$$

[0036] Carbon dioxide will also react with aluminium according to

$$3CO_2+2Al\rightarrow Al_2O_3+3CO \quad (3)$$

and the reaction

$$3H_2O+2Al\rightarrow Al_2O_3+3H_2 \quad (4)$$

will also occur.

[0037] 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).

[0038] 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.

[0039] 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:

$$Me+\frac{1}{2}O2\rightarrow MeO \quad (5)$$

$$Me+CO_2\rightarrow MeO+CO \quad (6)$$

$$Me+H_2O\rightarrow MeO+H_2, \quad (7)$$

[0040] 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.

[0041] 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.

[0042] 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.

[0043] 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.

[0044] 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.

[0045] 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.

[0046] 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.

[0047] 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.

[0048] 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.

[0049] 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.

[0050] 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.

[0051] 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.

[0052] 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.

[0053] 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.

[0054] 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.

[0055] 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:

[0056] FIG. **1** an aluminium melting furnace with the equipment to carry out the inventive control method and

[0057] FIG. **2** the on-line flue gas analysis measured with the arrangement according to FIG. **1**.

[0058] FIG. **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**.

[0059] 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**.

[0060] Flue gas duct **8** is provided with an oxygen analyzer **9** and a carbon dioxide analyzer **10**. Oxygen analyzer **9** and CO_2 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**.

[0061] 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**.

[0062] 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.

[0063] 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. CO_2 analyzer **10** continuously measures the CO_2 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 CO_2 value. Thus, for every minute a measured CO_2 concentration and the corresponding theoretical O_2 concentration is recorded.

[0064] Oxygen analyzer **9** continuously measures the O_2 concentration in the flue gases. The measured values are also stored every minute in the process computer **13**.

[0065] 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**.

[0066] 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**.

[0067] 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**.

[0068] All these data —CO_2 concentration, measured and theoretical O_2 concentration, difference between measured and theoretical O_2 concentration, amount of oxidized aluminium—can be visualized during the melting process by computer screen **17** (see FIG. **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.

[0069] FIG. **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.

[0070] 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.

1. 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 an atmosphere of the furnace,

calculating a theoretical concentration of oxygen in the furnace atmosphere on the basis of said concentration of carbon dioxide,

determining a difference between said theoretical concentration of oxygen and said concentration of oxygen detected and

controlling said process depending on said difference.

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

3. Method according to claim **1**, wherein said fuel-fired furnace is heated by at least one burner and an amount of the fuel supplied to the at least one burner is measured.

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

5. Method according to claim **4**, further comprising calculating an amount of oxidized metal.

6. Method according to claim **1**, wherein said measuring of at least one of said oxygen concentration and said measured carbon dioxide concentration is by means of a laser.

7. Method according to claim **1**, wherein said fuel is combusted with the gas containing more than 21% oxygen.

8. Method according to claim **3**, wherein said process is controlled by changing power of said at least one burner.

9. Method according to claim **1**, further comprising melting a plurality of charges of metal in said furnace, and determining for each charge the difference between said theoretical concentration of oxygen and said measured concentration of oxygen.

10. Method according to claim **9**, further comprising comparing the differences between said theoretical concentration of oxygen and said measured concentration of oxygen of at least two charges of the plurality of charges of metal.

11. Method according to claim **1**, wherein said metal is contaminated with organic substances, and further comprising partly oxidizing said organic substances with said oxygen and monitoring an amount of oxidized substances.

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