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(54) **SYSTEM FOR MEASURING TEMPERATURE IN A FURNACE AND METHOD FOR CONTROLLING COMBUSTION INSIDE THE SAME**

(57) The invention refers to a system for measuring the temperature inside a furnace and to a method for controlling the combustion in the furnace. The combustion comprises a vessel that defines a heating chamber in which a material is to be heated, an openable door, at least one burner configured to burn a fuel and a gaseous oxidant, each burner generating a flame inside the heating chamber that heats the material and a flue through which an exhaust flame extends out of the heating cham-

ber. The system comprises at least one multi-wavelength pyrometer coupled to the furnace wherein the multi-wavelength pyrometer is oriented towards a portion of a refractory lining of the heating chamber not in direct contact with the heated material. The multi-wavelength pyrometer is configured to measure the temperature of the corresponding portion of the refractory lining during operation of the furnace.

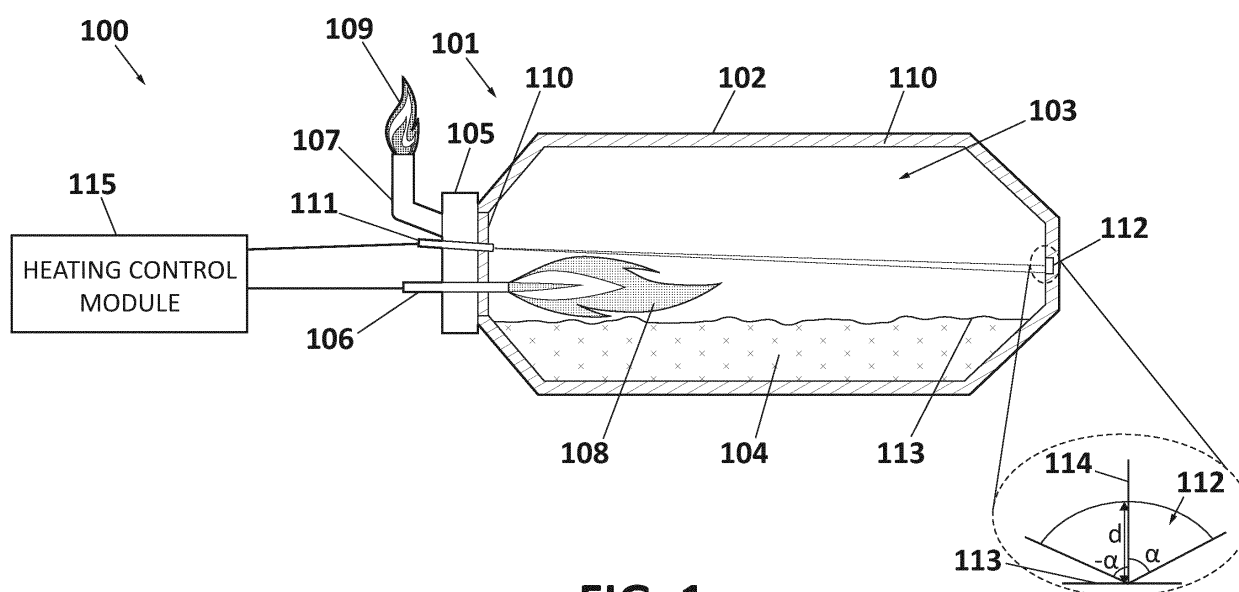


FIG. 1

Description

TECHNICAL FIELD

[0001] The present invention generally refers to systems for measuring the temperature inside furnaces, e.g., in rotary furnaces, tilting rotary furnaces or reverberatory furnaces, among others, that makes use of at least one multi-wavelength pyrometer and to methods for controlling combustion inside such furnaces that are based on at least the temperature measured inside the furnace by the multi-wavelength pyrometers. The present invention is to be used, preferably, in the ferrous and nonferrous metal manufacturing sectors.

STATE OF THE ART

[0002] Furnaces in which material is heated, preferably, until its melting temperature, consume high amounts of energy. Besides, the temperature at which the material is heated inside the furnaces is a critical factor to the quality of the resulting product and the life of the refractory lining covering the inner surface of the heating chamber of the furnaces (by which is meant an enclosed space defined by the vessel of the furnace in which the material is heated). Some attempts have been made to measure the temperature inside the furnaces to have a better control on the heating process. Some solutions use thermocouples that are attached to the outer surface of the vessels of the furnaces. However, the temperature measured by these thermocouples is not exactly the temperature inside the vessels but an approximation. Some other solutions include drilled holes in the vessel's walls and in the refractory lining in which different heating measuring devices such as thermocouples or thermometers are inserted to be closer to the material inside the heating chamber. However, these solutions are also capable of obtaining just an approximation of the temperature of the material since these temperature measuring devices are never in direct contact with the material that is being heated but with interposition of at least a layer of refractory material. In addition, in such solutions the drilled holes made in the vessel significantly weaken the refractory lining which may lead to catastrophic failures and unnecessary or premature refurbishment of the entire vessel's refractory lining.

[0003] Some other solutions carry out measures of the temperature of the refractory lining from the outside of the vessel and through its mouth during the downtime periods of the vessels, in other words, when the vessel is empty. From that measure, the temperature reached by the material during the operation of the furnace can be estimated. Again, the temperature obtained can only be considered as an approximation of the temperature that reaches the refractory material. Besides, these solutions are time consuming since the measurement must be performed when the vessel is empty and reduce the productivity of the overall process insofar as the down-

time periods are extended to carry out the temperature measurements.

[0004] This lack of accurate control on the temperature that reaches the refractory material and thus, the material that is being heated inside the furnaces does not allow to have real control over the final properties and quality of the manufactured product, contributing as well to increase the percentage of material oxidized (dross) due to the very high temperature reached.

[0005] Additionally, this lack of control on the temperature inside the furnaces may also generate a lack of control on the combustion of the fuel and oxidants taking place inside the heating chamber which may lead to formation of great amounts of carbon monoxide, and other undesirable gases such as methane or hydrogen, in the furnace. Carbon monoxide is a colourless, odourless, and tasteless flammable gas that is slightly less dense than air and that is highly toxic for humans and animals. Mechanisms by which carbon monoxide may be formed in furnaces include incomplete combustion of fuel; incomplete combustion of combustible material when the material to be heated in the furnace is also intended to be combusted; and/or conversion of carbonaceous material that is present in or on the material to be heated. Examples of such conversion include pyrolysis and/or incomplete combustion of the carbonaceous material.

[0006] Various technologies exist for removing carbon monoxide from the gaseous off-gas that leaves the furnace, such as absorption of the carbon monoxide onto absorbents, or adding reactants to the off-gas which react with the carbon monoxide to neutralize it. Such technologies exhibit drawbacks such as expense and difficulty of implementation and control.

[0007] Thus, the lack of control on the real temperature that reaches the material that is being heated inside the furnaces does not allow to efficiently control the combustion of the fuels and oxidants that are being burned inside the furnace to heat the material to be heated, melted or combusted.

[0008] The present invention provides a simple and efficient system that is able to accurately measure the real and current temperature of the refractory material inside the heating chamber during operation of the furnace allowing working at the maximum working temperature of the refractory material which optimizes the heating process. It further provides a method for controlling the combustion inside the furnaces that optimizes consume of fuel and gaseous oxidants used to heat the material and that also avoids, or at least minimize, emission of carbon monoxide from the furnaces. It further allows improving efficiency and production rates and provides a better control on the properties and quality of the manufactured products.

DESCRIPTION OF THE INVENTION

[0009] A first object of the invention is a system for measuring a temperature inside a furnace. The furnace

comprises a vessel that defines a heating chamber in which a material is to be heated. The furnace further comprises an openable door, at least one burner configured to burn a fuel and a gaseous oxidant and a flue through which an exhaust flame extends out of the heating chamber. Each one of the burners of the furnace generates a corresponding flame inside the heating chamber that heats the material. Although the fuel may reach the furnace in the form of a gas, a liquid or a liquified gas, the fuel is in its gaseous state when burned by the burner. Additional oxidant, in case of extra necessity due to the presence of carbonaceous material in the material to be heated, can be provided through one extra oxidant lance placed close by to the burner itself.

[0010] The system further comprises at least one multi-wavelength pyrometer coupled to the furnace. The at least one multi-wavelength pyrometer is oriented towards a portion of a refractory lining of the vessel that is not in direct contact with the heated material, such that the beams emitted by the multi-wavelength pyrometer are projected directly onto said portion of the refractory lining in the heating chamber. This kind of pyrometers are able to provide with a more precise temperature measurement capacity that the classical mono-wavelength pyrometers when working in atmospheres with dense fumes and metal particles in suspension as the typical atmosphere developed at these furnaces when ferrous or non-ferrous materials are heated. The at least one multi-wavelength pyrometer is configured to measure the temperature of the corresponding portion of the refractory lining during operation of the furnace, in other words, during the heating of the material inside the heating chamber carried out by the at least one burner of the furnace. The multi-wavelength pyrometer is able to determine the temperature of the portion of the refractory lining by capturing the radiation of the spectrum emitted by the refractory lining in a broad wavelength at the same time and spot in said portion. The temperature is then defined by the ratio of these signals which gives the current temperature of the portion of the refractory lining. This temperature of the portion of the refractory lining provides certain information about the temperature reached by the material that is being heated.

[0011] It is key aspect of this kind of furnaces to have an accurate control of the refractory lining temperature because during the heating operation of the material, the refractory lining transmits huge amounts of heat to the material being heated. Thus, the higher the temperature reached by the refractory material, without damaging said refractory lining, the greater the heat transfer to the material being heated. Therefore, by controlling the temperature of the refractory lining a better control of the heating process in the furnace can be obtained.

[0012] As used herein, the term "vessel" refers to containers of various sizes and shapes which are designed to hold materials at elevated temperatures, e.g., at temperatures above the melting point of the material. These vessels are widely used in many industrial applications,

e.g., in the metal manufacturing sector. As known in the art, these vessels are normally made of metals and are lined with refractory material (that can be installed in brick form lining the inner surface of the vessel or can be directly casted on the inner surface of the vessel) in order to protect the metallic part of the vessel from the high-temperature materials placed therein. For example, the refractory material that is used to be installed as the inner protective layer of the vessels may be magnesia (MgO) based refractory materials that incorporate different magnesia aggregates and eventually some binding agents. Other refractory materials may be andalusite (Al₂SiO₅) based refractory materials, magnesia combined with carbon based refractory materials, etc. The working temperature of the refractory materials may reach up to 2000°C or even higher. In particular, the working temperature of the refractory materials in the steel manufacturing industry may range between 1500-1800°C.

[0013] As used herein, the term "material" may refer to any material or substance that can be heated in a furnace. Examples of such materials include metals, e.g., ferrous metals such as iron and steel, metallic ores (e.g., ferrous ores) and other metallic compounds, combination of metallic compounds or combination of metallic and non-metallic compounds. These metallic materials include finished products as well as scrap. Additional examples of materials include non-ferrous metals, such as aluminium and copper, including finished products as well as scrap, and ores and other compounds thereof. Heating of any such materials prepare them for subsequent chemical and/or physical processing steps.

[0014] As used herein, the term "heating chamber" refers to the enclosed space defined by the walls of the vessel in which the material is to be heated. The temperature reached inside the heating chamber may be high enough to heat the material, to melt the material or to combust the material.

[0015] In some embodiments, the furnace may further comprise resistances to heat the material inside the heating chamber. In this way the combined effect of the burners and the resistances may accelerate the heating process.

[0016] In some embodiments, the fuel used to be burned by the burners of the furnace may be selected from a group comprising natural gas, propane, butane, heavy oil, light oil, Coke Oven Gas (COG), Blast Furnace Gas (BFG), biogas, other syngas with different compositions, and any combination thereof. The fuel may be also any other substance or combination of substances with the ability to produce heat or power by burning.

[0017] In some embodiments, the gaseous oxidant may be selected from a group comprising pure oxygen, low purity oxygen, air enriched with oxygen, or any combination thereof. The gaseous oxidant may be also any other gaseous reactant comprising oxygen and having the ability of removing electrons from other reactants, preferably from fuel, during a redox reaction.

[0018] In some embodiments, the furnace is a horizon-

tally oriented furnace and the at least one multi-wavelength pyrometer is oriented towards a portion of the refractory lining located at the end of the heating chamber and at a distance from the level reached by the liquid form of the material being heated. As used herein, the term "horizontally oriented furnace" refers to furnaces whose longitudinal axis is substantially parallel to the floor of the industrial facility, or under small inclination angle as tilting rotary furnaces, on which it is installed. Preferably, the at least one multi-wavelength pyrometer projects the infrared beams for measuring the temperature on a portion of the refractory lining that is located at the end of the heating chamber, in proximity to the surface of the material, e.g., 20-30 cm over the material surface, and within the area defined by an angle of -60° to 60° relative to an axis perpendicular to the surface of the material. The area of the refractory lining located at the end of the vessel is the area of the refractory material that normally reaches the higher temperatures and thus, it might be recommendable to measure the temperature is said area to do not reach a temperature that may exceed the working temperature of the refractory material. Besides, by measuring the temperature in areas of the refractory lining which are in close proximity to the material being heated may be recommendable since these areas present the highest heat transfer rates with the material that is being heated.

[0019] In some more preferred embodiments, the furnace is selected from a group comprising rotary furnaces, tilting rotary furnaces and reverberatory furnaces, among others. All these furnaces are substantially horizontally oriented relative to the floor of the facility on which they are located. In particular, rotary furnaces refer to substantially horizontal furnaces that rotate relative to its longitudinal axis. Tilting rotary furnaces are rotary furnaces that have the ability to tilt relative to its longitudinal axis and in a vertical direction. Reverberatory furnaces are horizontally oriented furnaces that isolate the material being heated or processed from contact with the fuel, but not from contact with combustion gases. In some cases, reverberatory furnaces can also tilt vertically during the transfer process of the already melted material and once the material has been transferred, the furnace recovers its horizontally oriented position.

[0020] In some embodiments, the at least one multi-wavelength pyrometer is a two-colour infrared thermometer. The two-colour infrared thermometer simultaneously measures the energy emitted by the portion of the refractory lining on which it is projected in two adjacent infrared spectral bands. They typically employ a layered "sandwich" detector with a dual photodiode to obtain the two distinct signals. The two-colour infrared thermometers are able to obtain a correct temperature reading even if the radiation picked up by the detector is weakened by up to 90% due to visual obstructions generated by particles in suspension, dust, smoke, etc. This makes these thermometers especially useful for environments such as the heating chambers of this type of furnaces.

[0021] In some embodiments, the at least one multi-wavelength pyrometer is coupled to the openable door or to a wall of the vessel. In some other embodiments, there may be at least one multi-wavelength pyrometer coupled to the openable door of the furnace and at least another multi-wavelength pyrometer coupled to the walls of the furnace. The multi-wavelength pyrometers may be inserted into holes located in the openable door and/or the walls of the vessel which are connected with the heating chamber by interposition of corresponding portholes through which the beams generated by the pyrometers can be sent and received.

[0022] In some embodiments, the system comprises more than one multi-wavelength pyrometer to carry out redundant temperature measurements in order to improve the reliability of the measure obtained. In such embodiments, the multi-wavelength pyrometers may be oriented towards the same portion of the refractory lining, towards adjacent portions of the refractory lining or to separated portions of the refractory lining provided that said separated portions are within the area located at the end of the heating chamber that is in close proximity to the surface of the material and delimited by an angle of -60° to 60° relative to an axis perpendicular to the surface of the material. The system may calculate the arithmetic average of the temperatures measured by all or part of the multi-wavelength pyrometers to obtain a more accurate and reliable measure.

[0023] In some embodiments, the system further comprises a heating control module communicatively coupled to the at least one multi-wavelength pyrometer and to the at least one burner. The heating control module is configured to receive the temperature measured from the at least one multi-wavelength pyrometer, and to modify at least one of the amount of fuel and the amount of gaseous oxidant being burned by the at least one burner in the heating chamber based on the received temperature measure. To do so, the heating control module may compare the received measure with a predefined temperature and adjust the amount of fuel and/or gaseous oxidant to be burned based on the result of said comparison.

[0024] Preferably, the predefined temperature is the maximum working temperature of the refractory lining. This maximum working temperature is the maximum temperature that the refractory material can reach without its properties being degraded by heat. By working maximum working temperature of the refractory lining, processing times of the material and fuel and oxidant consumptions are significantly reduced which imply a n increase in heating process optimization.

[0025] For example, the heating control system may adjust the amount of gaseous oxidant, e.g., oxygen, that is delivered to the furnace to be burned by the burners by increasing or decreasing the amount of gaseous oxidant relative to the amount of fuel that is fed into said burners. Alternatively, the heating control system may adjust the amount of fuel, e.g., natural gas, that is avail-

able in the furnace to be burned by the burners by increasing or decreasing the amount of fuel relative to the amount of gaseous oxidant that is fed into said burners. Therefore, the heating control module adjusts the amounts of fuel and/or gaseous oxidant which are injected to be burned by the burners based on the temperature measured. Preferably, the heating control module adjusts the amounts of fuel and/or gaseous oxidant burned in the furnace based on the temperature measured and maintaining the corresponding stoichiometric relationship between the fuel and the oxidant. In this way, the amount of at least one of the fuel and the gaseous oxidant can be increased or decreased to modify the heating power of the flames inside the combustion chamber so as to increase or decrease the temperature inside the combustion furnace. Thus, the heating process can be optimized subjecting the refractory material to the preestablished temperature at any time during the heating process. In addition, by adjusting the amounts of fuel and/or gaseous oxidant during the heating process, the energy consumption of the combustion furnace can be optimized. Besides, by optimizing the heating process, the refractory lining and the material are subjected to a substantially constant temperature during most of the heating process (except for the period until the refractory material reaches the predefined temperature for the first time) avoiding the existence of temperature peaks or drops that may affect the quality or properties of the final product.

[0026] In some embodiments, the system comprises at least one digital camera that is located outside the furnace or that is attached to the openable door or to the walls of the vessel. These cameras are configured to take images of the flames inside the heating chamber and/or the exhaust flame. Preferably, the cameras located outside the furnace are configured to take images of the exhaust flame while the cameras attached to the furnace are configured to take images of at least one of the flames generated by the burners inside the heating chamber. The openable door and/or the walls may have drilled holes with corresponding portholes in which the respective cameras are inserted.

[0027] In some embodiments, the heating control module is configured to receive the images of the flames from the cameras and to determine a carbon monoxide concentration in the flames based on at least one parameter of the flame in the images. For example, the at least one parameter may be selected from a group comprising the flame intensity, flame area, flame length, colour coordinates (U,V) of the flame and any combination thereof.

[0028] In some embodiments, the heating control module is configured to modify the at least one of the amount of the fuel and the amount of the gaseous oxidant being burned by the at least one burner in the heating chamber based on a combination of the measured temperature and the carbon monoxide concentration in at least one of the flames inside the heating chamber and the exhaust flame.

[0029] Therefore, the heating control module may adjust the amounts of fuel and/or gaseous oxidant which are injected to be burned by the burners based on only the temperature measured or based on a combination of the temperature measured together with the amount of carbon monoxide determined from the images of the flames. In such embodiments, the heating control module is configured to find a compromise between the amount of fuel and the amount of gaseous oxidant being combusted within the heating chamber in such a way that the temperature of the refractory material is as close as possible to the predefined temperature and at the same time the emission of carbon monoxide is minimized. Preferably, the emission of carbon monoxide should tend to zero provided that the current temperature of the refractory material is as close to the predefined temperature as possible.

[0030] The carbon monoxide that is formed in the heating chamber and that exists said chamber via the flue may be produced by any one or more of several possible mechanisms, such as incomplete combustion of fuel in the burners; incomplete combustion of combustible material when the material to be heated in the furnace is also intended to be combusted; and/or conversion of carbonaceous material that is in or on the material to be heated, examples of such conversion including pyrolysis or incomplete combustion of the carbonaceous material. In those cases in which the material to be heated comprises carbonaceous material, such carbonaceous matter may be organic compounds. For example, scrap that comprises aluminium, copper, iron and/or steel may carry thereon carbonaceous matter such as paint or other organic coatings, organic food and/or human waste, and the like. Cullet that is present in glassmaking materials may carry thereon organic material that is a residue of food products or other organic matter that had been present on the cullet before it is recycled as cullet.

[0031] In some embodiments, the material to be heated in the combustion chamber of the combustion furnace comprises metal.

[0032] In some embodiments, at least a portion of the material that is heated in the furnace is combusted or melted. In those cases, in which at least a portion of the material is melted, the furnace can be considered as a melting furnace. For example, the materials to be melted may include any metal such as iron, steel, metal oxides and other metal compounds. Other examples include products that are melted together in a glassmaking furnace to form molten glass; such materials include recycled glass pieces known as cullet, and raw materials known as batch which are molten together to make glass, such materials including typically sodium oxide, potassium oxide, and silicates of sodium and potassium. Another example of such an operation is a cement kiln, in which raw materials typically including lime or limestone, and silica and/or aluminosilicates (clays) and other desired additives, are heated together so that they melt and react with each other to form the compounds which constitute

cement. In those cases in which a portion or all of the material is to be combusted, the furnace can be considered as an incinerator. Materials that may be heated to be combusted include all combustible products such as carbonaceous fuels, and solid waste.

[0033] A second object of the present invention is a method for controlling combustion in a furnace. The method comprises providing a system as previously described and measuring a temperature of a portion of the refractory lining of the heating chamber with the at least one multi-wavelength pyrometer during operation of the furnace. Then, the heating control module receives the temperature measured and compares it to a preestablished temperature for the refractory lining. Based on the result of the comparison, the heating control module adjusts at least one of an amount of the fuel and an amount of the gaseous oxidant being burned by the burners in the heating chamber. Preferably, the predefined temperature is the maximum working temperature of the refractory lining.

[0034] In some embodiments, the heating control system may adjust the amount of gaseous oxidant, e.g., oxygen, that is available in the furnace to be burned by the burners by increasing or decreasing the amount of gaseous oxidant relative to the amount of fuel that is fed into said burners. In some other embodiments, the heating control system may adjust the amount of fuel to be burned by the burners by increasing or decreasing the amount of fuel relative to the amount of gaseous oxidant that is fed into said burners. Therefore, the heating control module adjusts the amounts of fuel and/or gaseous oxidant which are injected to be burned by the burners based on the temperature measured, and thus, based on the difference between the temperature measured and the preestablished temperature. Preferably, the heating control module will adjust the amounts of fuel and/or gaseous oxidant which are injected to be burned by the burners based on the temperature measured maintaining a corresponding stoichiometric relationship between the fuel and the oxidant.

[0035] In some embodiments, when the temperature measured exceeds the preestablished temperature, the method comprises modifying at least one of the amount of fuel and the amount of gaseous oxidant to amounts thereof that are effective to lower the temperature of the refractory lining to be equal than the preestablished temperature for a predetermined period of time.

[0036] In some embodiments, when the temperature measured is lower than the preestablished temperature, the method comprises modifying at least one of the amount of fuel and the amount of gaseous oxidant to amounts thereof that are effective to increase the temperature of the refractory material to be equal than the preestablished temperature for a predetermined period of time.

[0037] In some embodiments, the heating control module receives images of at least one of the flames inside the heating chamber and the exhaust flame from the at

least one digital camera. Each burner of the furnace generates a flame that heats the material inside the heating chamber. For example, the heating control module may receive only images of an external camera that take images of the exhaust flame, or may only receive images from one or more cameras coupled to the furnace that take pictures of the one or more flames inside the heating chamber, or may receive images of both, the exhaust flame and of the flames inside the heating chamber.

[0038] Then, the heating control module determines the carbon monoxide concentration in the flames based on at least one parameter of the flames in the images and compares the determined carbon monoxide concentration to a preestablished carbon monoxide concentration. Said at least one parameter of the flames may be the flame intensity, flame area, flame length, colour coordinates (U,V) of the flame and any combination thereof, among other parameters. After that, the heating control module causes the at least one burner to modify at least one of an amount of the fuel and an amount of the gaseous oxidant being burned in the heating chamber based on a combination of the result of the comparison of temperatures and the result of the comparison of carbon monoxide concentration.

[0039] More particularly, the heating control module is configured to find a compromise between the amount of fuel and the amount of gaseous oxidant being combusted within the heating chamber in such a way that the temperature of the refractory lining is as close as possible to the predefined temperature and at the same time the emission of carbon monoxide is minimized. In this way, the heating process is optimized at the same time that carbon monoxide concentration is minimized.

[0040] In some embodiments, when the temperature measured exceeds the preestablished temperature and/or the carbon monoxide concentration exceeds the preestablished carbon monoxide concentration, the method comprises modifying at least one of the amount of fuel and the amount of gaseous oxidant being burned in the heating chamber to amounts thereof that are effective to lower the carbon monoxide concentration in the heating chamber as long as the temperature of the refractory lining is as close as possible to the preestablished temperature for a predetermined period of time.

[0041] In some embodiments, when the temperature measured is lower than the preestablished temperature and/or the carbon monoxide concentration exceeds the preestablished carbon monoxide concentration, the method comprises modifying at least one of the amount of fuel and the amount of gaseous oxidant being burned in the heating chamber to amounts thereof that are effective to lower the carbon monoxide concentration in the heating chamber as long as the temperature of the refractory lining is as close as possible to the preestablished temperature for a predetermined period of time.

[0042] The system for measuring the temperature inside the furnaces and the methods for controlling the combustion inside the heating chamber of the furnace

herein described present several advantages and/or differences compared with previous devices and techniques. In particular, it is provided that this solution is able to accurately measure the current temperature of the refractory lining inside the heating chamber during operation of the furnace. The method for controlling the combustion inside the furnaces is able, by maintaining the refractory material at a predefined working temperature during the whole heating process, to optimize consume of fuel and gaseous oxidants used to heat the material and it is also able to avoid, or at least minimize, emission of carbon monoxide from the furnaces. It further allows improving efficiency and production rates of the heating process and provides a better control on the properties and quality of the manufactured products

BRIEF DESCRIPTION OF THE DRAWINGS

[0043] To complete the description and in order to provide for a better understanding of the invention, a set of drawings is provided. Said drawings form an integral part of the description and illustrate different embodiments of the invention, which should not be interpreted as restricting the scope of the invention, but just as examples of how the invention can be carried out.

[0044] The drawings comprise the following figures:

Figure 1 shows a system for measuring the temperature inside a rotary furnace, according to a particular embodiment of the invention.

Figure 2, shows a system for measuring the temperature inside a rotary furnace that also measures the carbon monoxide concentration inside the rotary furnace, according to a particular embodiment of the invention.

Figure 3 shows a system for measuring the temperature inside a reverberatory furnace, according to a particular embodiment of the invention.

Figure 4 shows a flow diagram of a method for controlling combustion in a furnace, according to a particular embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0045] Figure 1 shows a system 100 for measuring the temperature inside a rotary furnace 101. It should be understood that the system 100 of Figure 1 may include additional components and that some of the components described herein may be removed and/or modified without departing from a scope of the described system 100. Additionally, implementation of the system 100 is not limited to such embodiment.

[0046] While the furnace 100 depicted in this embodiment is a rotary furnace with the shape that is typical of furnaces that can be rotated about its longitudinal axis, the present invention may be practiced with any other type of furnace, including horizontally oriented furnaces, and with a different shape as well.

[0047] The rotary furnace 101 comprises a vessel 102 that defines a heating chamber 103 in which a material 104, for example iron, is to be heated above its melting temperature (1540°C approx.). The furnace 101 further comprises an openable door 105 through which raw material is introduced, one burner 106 that burns a fuel, e.g., natural gas, and a gaseous oxidant, e.g., oxygen, in a stoichiometric relationship (e.g., 2.1 mols of O₂ per mol of natural gas to optimize burning operation) generating a heating flame 108 that heats the material 104, and a flue or chimney 107 coupled to the openable door 105 through which an exhaust flame 109 extends out of the heating chamber 103. Through the flue 107 off-gases generated inside the heating chamber 103 also exit together with the exhaust flame 109. While the rotary furnace 101 of Figure 1 depicts only one burner 106 located in the openable door 105, the furnace 101 may comprise a different number of burners, generating a corresponding number of heating flames in the heating chamber, which may be located in the openable door and/or in the walls of the furnace. The burner 106 receives the fuel and the gaseous oxidant from respective sources not shown in this figure.

[0048] The vessel 102 and the openable door 105 are made of a metal or a metal alloy that is able to withstand very high temperatures and their inner surface is lined with a layer of refractory material 110 that can be installed in brick form lining the inner surface of the vessel 102 or can be directly casted on the inner surface of the vessel 102. This layer of refractory material 110, for example MgO based refractory material, protects the vessel 102 and the openable door 105 from the heat, pressure and chemical attacks coming from the heated and molten materials placed therein. The layer of refractory material 110 substantially covers the inner surface of the vessel 102 and of the openable door 105. The MgO based refractory material has a maximum operation temperature of 2000 °C.

[0049] The system 100 further comprises a two-colour infrared thermometer 111 which is coupled to the openable door 105. More particularly, the two-colour infrared thermometer 111 is inserted in a sigh port (not shown in this figure) in the openable door 105. The two-colour infrared thermometer 111 is oriented relative to the vessel 102 such that the infrared beam emitted by the thermometer 111 is projected onto a portion 112 of the refractory lining 110 that is not in direct contact with the heated material 104. The two-colour infrared thermometer 111 captures the infrared radiation emitted by the portion 112 of the refractory lining 110 with a dual photodiode at two wavelengths at the same time and spot in the portion 112. Then, the temperature of the portion 112 of the refractory lining 110 is defined by the ratio of these two signals (each of the two signals captured by the dual photodiode at the two different wavelengths). Preferably, the portion 112 will be located at the end of the vessel 102, in other words, the portion 112 will be located in front of the openable door 105 and at a distance "d" from

the surface 113 of the material 104 being heated since this area of the refractory lining 110 reaches the highest temperatures. This portion will be also determined by the surface delimited by an angle " α " relative to a perpendicular axis 114 to the surface 113 of the material 104. More preferably, the distance "d" will be in the range between 20 and 30 cm, and the angle " α " will be in the range between 30° and 60°.

[0050] The system 100 further comprises a heating control module 115 communicatively coupled to the two-colour infrared thermometer 111 and to the burner 106. The heating control module 115 receives the temperature measured by the two-colour infrared thermometer 111 and modifies the amount of natural gas and/or the amount of oxygen being burned by the burner 106 in the heating chamber 103 based on the received measure. To do so, the heating control module 115 compares the received measure with a predefined temperature and adjust the amount of natural gas and/or oxygen to be burned based on the result of said comparison. By way of example, the predefined temperature may be the maximum operation temperature, i.e., 2000°C, of the MgO based refractory material or any other temperature lower than this maximum operation temperature but close to it, such as 1900°C or 1950 °C. Since the melting temperature of the iron is 1540°C approximately, these working temperatures of the refractory lining (the temperature inside the heating chamber will be similar to the temperature of the refractory material) will be high enough to melt the iron.

[0051] For example, the heating control module 115 may increase or reduce the amount of natural gas being burned to adjust the current temperature of the refractory lining 110 to the preestablished temperature. Simultaneously or alternatively, the heating control module 115 may increase or reduce the amount of the oxygen being burned to adjust the current temperature of the refractory lining 110 to the preestablished temperature. Preferably, the heating control module 115 may increase or reduce the amount of oxygen or natural gas being burned to adjust the current temperature of the refractory lining 110 to the preestablished temperature, maintaining the stoichiometric relationship between the oxygen and the natural gas.

[0052] The system 100 may comprise an injection control module (not shown in the figure) configured to control the flow rate of the oxidant and the fuel to burner 106 (or to multiple burners if the system 100 comprises more than one burner 106). The injection control module may act on respective valves of the fuel and oxidant injectors (not shown) of the burner 106 to adjust the amount of fuel and/or gaseous oxidant being burned inside the heating chamber 103.

[0053] During the heating process of the material 104, the temperature of the portion 112 of the refractory lining 110 is measured by the two-colour infrared thermometer 111 and the power of the burner 106 is adjusted based on said measure so that it continues to provide energy to the furnace 101 and promote the melting of the material

104 in the heating chamber 103. When the preestablished temperature (preferably, the maximum operation temperature of the refractory lining 110) is reached in the refractory lining 110, the power of the burner 106 is adjusted so that it does not exceed or fall below the preestablished temperature or a certain margin over or below said preestablished temperature. In particular, if the temperature exceeds said preestablished temperature or margin, the burner 106 will reduce its power (by for example reducing the amount of fuel and oxidant being burned) to a minimum or it may even stop and if the temperature falls below said preestablished temperature or margin, the burner 106 will increase its power (by for example increasing the amount of fuel and oxidant being burned).

[0054] Figure 2 shows a system 200 for measuring the temperature inside a rotary furnace 201 that also measures the carbon monoxide (CO) concentration inside the heating chamber 203 of the furnace 201. It should be understood that the system 200 of Figure 2 may include additional components and that some of the components described herein may be removed and/or modified without departing from a scope of the described system 200. Additionally, implementation of the system 200 is not limited to such embodiment.

[0055] The system 200 comprises all the elements of the system 100 of Figure 1 and a digital camera 217 located outside the furnace 201 and positioned relative to the furnace 201 so that the aperture of the camera 217 is pointed towards the exhaust flame 209 to take images of said exhaust flame 209. The system 200 also comprises a sight port in a wall of the vessel 202 through which the heating flame 208 inside the heating chamber 203 is observed by another digital camera 218 to take images of said heating flame 208. Both cameras 217 and 218 are communicatively coupled to the heating control module 215 so that the taken images can be sent to the heating control module 215.

[0056] The aperture and exposure of the cameras 217 and 218 can be manually or automatically adjusted to prevent blooming of the image due to the high light intensity emitted by the flames 208 and 209. The cameras 217 and 218 create a digital electronic image of flames 208 and 209, based on at least one parameter of the flame, such as the intensity of the flames 208 and 209. The electronic images are transmitted electronically by the cameras 217 and 218 to the heating control module 215.

[0057] The heating control module 215 converts the digital signal corresponding to the images of the flames 208 and 209 to one or more values that represent the intensity or variety of intensities of the flame, and may comprise a range of values over the area of the flame that is within the field of view of the cameras 217 and 218. The intensities are detected and expressed digitally to create an array of values that correspond to the detected intensity. There is a direct relationship between the detected intensity parameter and the concentration

of carbon monoxide that is present in the flame. Similarly, there are direct relationships between other parameters of the flame such as flame area, flame size, colour coordinates (U,V), and the concentration of carbon monoxide in the flame that could be used. Besides, there are other direct relationships between some combinations of the mentioned flame parameters and the CO concentration of the same. Therefore, these other parameters or combination of parameters could be used to obtain the CO concentration.

[0058] In such embodiment, the heating control module 215 compares the detected intensity parameter to preestablished correlations of the intensity parameter to actual concentrations of CO in the flames 208 and 209. These preestablished correlations intensity-CO concentration can be previously established by simultaneously measuring the concentration of CO in the flames via an established technique such as gas sampling using a gas sampling probe followed by analysis of the sampled gas, or continuous emission monitoring, and observing the value of the expressed parameter that is derived from the value based on intensity as detected by the camera, and recording the measured concentration and the parameter value together where they can be read together, such as in a computer or in a written catalogue. In this way, each intensity parameter that is expressed by the system corresponds to an actual concentration value of CO in the flame. The determination of the pre-existing correlations between the expressed parameter and the measured CO concentration, can have already been carried out, during the initial setup of the system at a furnace, and usually does not need to be repeated at a given furnace every time that the furnace is being operated. However, the operator may find it preferable to establish a fresh set of correlations for different furnaces, as well as at a given furnace in situations in which the conditions under which the given furnace is to be operated will differ significantly.

[0059] The system 200 further comprises a lance 216 to inject supplemental oxidant into the heating chamber 203 when additional oxidant needs to be passed into the heating chamber 203. This additional oxidant is used to react with the existing CO in the heating chamber 203 so its concentration is reduced. The flow of oxidant through lance 216 may be controlled by the same injection control module that manages the injection of the burners 206 or by an independent injection control module. The injection control modules are all managed by the heating control module 215. The oxidant that passes through lance 216 can be oxygen, air, oxygen-enriched air, or higher purity oxidant having an oxygen content of at least 50 vol. % and even at least 90 vol. %. The oxygen content of oxidant that is fed through lance 216 into furnace 201 can be the same or different relative to the oxygen content of the oxidant that is fed to the burners 206.

[0060] During the heating process of the material 204, the temperature of the portion 212 of the refractory lining

210 is measured and the power of the burner 206 is adjusted so that it continues to provide energy to the furnace 201 and promote the melting of the material 204 in the heating chamber 203. When the preestablished temperature is reached in the refractory lining 210, the power of the burner 206 is adjusted (being increased or lowered) so that it does not exceed or fall below the preestablished temperature or a certain margin over or below said preestablished temperature. Thus, the amount of fuel and/or gaseous oxidant injected to be burned by the burner will be adjusted as described for the embodiment of figure 1 during the melting process.

[0061] At the same time that the temperature of the refractory lining 210 is controlled as described in the previous paragraph, the CO concentration is also measured by the heating control module 215. A value for the concentration of CO in the flames is previously set up, such that CO concentration values above that preestablished value are considered to do not be acceptable and should be lowered. For example, a CO concentration of a 3 vol. % or higher may be considered unacceptable for several reasons, such as being dangerous, being environmental harmful, violating environmental regulations or indicating an undesired imbalance of economic and thermodynamic conditions in the furnace.

[0062] When the detected and processed intensity parameter of the flames 208,209 corresponds to an actual CO concentration that exceeds the preestablished threshold value, then the system performs an action that results in injecting additional oxidant, via the lance 216 within the furnace 201 so the additional oxygen is to react with CO present in the heating chamber 203 so that at least part of the excess of CO detected is burned inside the furnace 201 and less CO leaves the furnace 201 via the flue 207. This extra oxidant is independent of that needed to burn the fuel and can be varied at any time to suit the level of CO detected. Normally, the CO is generated during the first phase of the heating process. In particular the CO is normally generated during the first 15-20 minutes that corresponds to the loading of the raw material and the beginning of the heating when the carbonaceous material is burned. The rest of the time no CO is usually generated as all the carbonaceous metal has already been burned.

[0063] Although, preferably, the system will have a lance 216 to provide the additional oxidant into furnace 201 to react with the detected excess of CO so that the operator does not have to adjust the stoichiometric ratio of the oxidant and fuel being fed through the burners 206, other ways to inject additional oxidant could be used. For example, the heating control module 215 may increase the amount of oxidant being fed into furnace 201 using the burners 206 and/or the lance 216 without increasing the flow rate of fuel. Alternatively, the heating control module 215 may decrease the amount of fuel burnt into furnace, without decreasing the amount of oxidant fed into furnace 201.

[0064] The injection of additional oxidant will continue

until the detected and processed value representing the CO concentration in the flame decreases to a value equal to or less than the aforementioned preestablished threshold value. More preferably, the additional oxidant should be provided until the detected and processed value is less than the preestablished threshold value, such as 0.5% to 2% below the preestablished threshold value, to minimize the number of times that the injection of the additional oxygen has to be carried out.

[0065] By way of example, when natural gas is used as fuel and oxygen as gaseous oxidant a stoichiometric relationship of 2.1 moles of oxygen per mole of natural gas can be used. With this stoichiometric relationship all natural gas is burned inside the furnace 201 and there is no CO emission (theoretically). However, due to the presence of carbonaceous materials in the material 204 being heated or other causes, an excess of CO could be detected. Then, the amount of oxygen in the heating chamber 203 should be increased so the additional oxygen reacts with the CO excess and it is burned. Thus, the heating control module 215 may increase the stoichiometric relationship to 2.2 (or higher) moles of oxygen per mole of natural gas for a period of time, injecting said additional oxygen through lance 216. This allows the CO to be burned without increasing or decreasing the fuel that is being burned by the burners 206 so the temperature of the refractory lining 210 can be maintained at the predefined temperature. Since the injection the additional oxidant is independent of the burner, the stoichiometric relationship of the burner to manage the temperature of the refractory lining 210 and the injection of additional oxidant to lower the CO concentration could be managed separately by the heating control module 215.

[0066] Figure 3 shows a system 300 for measuring the temperature inside a reverberatory furnace 301, according to a particular embodiment of the invention. It should be understood that the system 300 of Figure 3 may include additional components and that some of the components described herein may be removed and/or modified without departing from a scope of the described system 300. Additionally, implementation of the system 300 is not limited to such embodiment.

[0067] The system 300 may be similar to the systems 100, 200 of Figures 1 and 2 but installed in the reverberatory furnace 301 of Figure 3. The reverberatory furnace 301 isolates the material being heated or processed from contact with the fuel, but not from contact with combustion gases. The furnace 301 comprises six burners, four air-fuel burners 306a and two oxygen-fuel burners 306b. In such embodiment, there is a camera 317 located outside the vessel 302 to take images of the exhaust flame 309 and a camera coupled to or located in proximity to the vessel 302 to take images through a sight port of the heating flames 308. In particular, said camera 318 takes images of the heating flame, resulting of the merge of the flames 308 generated by the six burners 306a-b, before it exits through the flue 307. The flue is fluidly coupled to the vessel 302 instead of being coupled to the open-

able door 305. Both cameras 317 and 318 are communicatively coupled to the heating control module 315 so that the taken images can be sent to it and from that images, the heating control module 315 is able to derive the CO concentration inside the heating chamber 303. The two-colour infrared thermometer 311 is also configured to measure the temperature of the portion 312 of the refractory lining 310 in the heating chamber 303 during operation of the furnace 301.

[0068] Based on the measured temperature of the portion 312 and the CO concentration in the flames 308, 309 and the corresponding deviations from the respective preestablished temperature and maximum CO concentration, the heating control module 315 may modify at least one of the amount of the fuel and the amount of the gaseous oxidant being burned by the burners 306a-b in the heating chamber 303 as it has been explained for the embodiment of Figure 2.

[0069] Figure 4 shows a flow diagram of a method 400 for controlling combustion in a furnace, according to a particular embodiment of the invention. Although Figure 4 will be explained making reference to the system of Figure 1, the method 400 for controlling combustion in a furnace may be implemented in the system of figures 2 and 3.

[0070] At step 401 of the method 400, a system 100 for measuring the temperature inside a furnace 101 is provided. The method 400 may be further practiced with any other type of horizontally oriented furnace and with a different shape as well.

[0071] At step 402 of the method 400, the multi-wavelength pyrometer 111 measures the temperature of the portion 112 of the refractory lining 110 in the heating chamber 103 during operation of the furnace 101. There may be more than one multi-wavelength pyrometer 111 measuring different portions of the refractory lining 110 and the resulting temperature may be an average all the measured temperatures.

[0072] At step 403 of the method 400, the heating control module 115 receives the temperature measured and compares it to a preestablished temperature. This preestablished temperature may be equal or less than the maximum operation temperature of the refractory material of the refractory lining

[0073] At step 404 of the method 400, the heating control module adjusts at least one of the amount of fuel and the amount of gaseous oxidant being burned by the burners 106 in the heating chamber 103 based on the result of the comparison.

[0074] In some embodiments, the heating control system 115 may adjust the amount of gaseous oxidant, e.g., oxygen, that is available in the furnace 101 to be burned by the burners 106 by increasing or decreasing the amount of gaseous oxidant relative to the amount of fuel that is fed into said burners 106. In some other embodiments, the heating control system 115 may adjust the amount of fuel in the furnace that is available in the furnace 101 to be burned by the burners 106 by increasing

or decreasing the amount of fuel relative to the amount of gaseous oxidant that is fed into said burners 106. Therefore, the heating control module 115 adjusts the amounts of fuel and/or gaseous oxidant which are injected to be burned by the burners 106 based on the temperature measured, and thus, based on the difference between the temperature measured and the preestablished temperature.

[0075] In some embodiments, when the temperature measured exceeds the preestablished temperature, the method comprises modifying at least one of the amount of fuel and the amount of gaseous oxidant to amounts thereof that are effective to lower the temperature of the refractory lining 110 and thus, the temperature in the heating chamber 103, to be equal than the preestablished temperature for a predetermined period of time.

[0076] In some embodiments, when the temperature measured is lower than the preestablished temperature, the method comprises modifying at least one of the amount of fuel and the amount of gaseous oxidant to amounts thereof that are effective to increase the temperature of the refractory lining 110 and thus, the temperature in the heating chamber 103, to be equal than the preestablished temperature for a predetermined period of time.

[0077] In some embodiments, the heating control module receives images of at least one of the flames inside the heating chamber and the exhaust flame from the at least one digital camera. Each burner of the furnace generates a flame that heats the material inside the heating chamber. For example, the heating control module may receive only images of an external camera that take images of the exhaust flame, or may only receive images from one or more cameras coupled to the furnace that take pictures of the one or more flames inside the heating chamber, or may receive images of both, the exhaust flame and of the flames inside the heating chamber.

[0078] In some embodiments, the method comprises receiving, at the heating control module, images of at least one of the flames inside the heating chamber and the exhaust flame from the at least one camera and determining, by the heating control module, a CO concentration in the flames based on at least one parameter of the flames in the images. The CO concentration in the flames corresponds to the CO concentration in the heating chamber. Then, the heating control module compares the determined CO concentration to a preestablished CO concentration and causes the at least one burner to modify at least one of an amount of the fuel and an amount of the gaseous oxidant being burned in the heating chamber based on a combination of the result of the comparison of temperatures and the result of the comparison of carbon monoxide concentrations. Preferably, the heating control module will be configured to find a compromise between the amount of fuel and the amount of gaseous oxidant being combusted within the heating chamber in such a way that the temperature of the refractory material is as close as possible to the predefined temperature and

at the same time the emission of carbon monoxide is minimized. Preferably, the emission of carbon monoxide should tend to zero provided that the current temperature of the refractory material is as close to the predefined temperature as possible.

[0079] The heating control module 115, 215 includes hardware and software logic to perform the functionalities described above. More particularly, the heating control module 115, 215 may integrate a processing unit that may be at least one of a central processing unit (CPU), a semiconductor-based microprocessor, a graphics processing unit (GPU), a field-programmable gate array (FPGA) configured to retrieve and execute instructions, other electronic circuitry suitable for the retrieval and execution instructions stored on a machine-readable storage medium, or a combination thereof. The processing unit may fetch, decode, and execute instructions stored on machine-readable storage medium to perform the functionalities described above. The machine-readable storage medium may be located either in the heating control module 115, 215 or remote from but accessible to the heating control module 115, 215 (e.g., via a computer network) for execution. As used herein, a "machine-readable storage medium" may be any electronic, magnetic, optical, or other physical storage apparatus to contain or store information such as executable instructions, data, and the like.

[0080] In this text, the term "comprises" and its derivations (such as "comprising", etc.) should not be understood in an excluding sense, that is, these terms should not be interpreted as excluding the possibility that what is described and defined may include further elements, steps, etc. The term "another," as used herein, is defined as at least a second or more. The term "coupled," as used herein, is defined as connected, whether directly without any intervening elements or indirectly with at least one intervening elements, unless otherwise indicated. Two elements can be coupled mechanically, electrically, or communicatively linked through a communication channel, pathway, network, or system.

[0081] The invention is obviously not limited to the specific embodiments described herein, but also encompasses any variations that may be considered by any person skilled in the art (for example, as regards the choice of materials, dimensions, components, configuration, etc.), within the general scope of the invention as defined in the claims.

Claims

1. A system (100) for measuring a temperature inside a furnace (101), wherein the furnace (101) comprises:
 - a vessel (102) defining a heating chamber (103) in which a material (104) is to be heated;
 - an openable door (105);

- at least one burner (106) configured to burn a fuel and a gaseous oxidant, each burner (106) generating a flame (108) inside the heating chamber (103) that heats the material (104); and a flue (107) through which an exhaust flame (109) extends out of the heating chamber (103); **characterized in that** the system (100) comprises at least one multi-wavelength pyrometer (111) coupled to the furnace (101), the at least one multi-wavelength pyrometer (111) being oriented towards a portion (112) of a refractory lining (110) of the heating chamber (103) not in direct contact with the material (104), such that the at least one multi-wavelength pyrometer (111) is configured to measure the temperature of the corresponding portion (112) of the refractory lining (110) during operation of the furnace (101).
2. The system (100) according to claim 1, wherein the furnace (101) is a horizontally oriented furnace and the at least one multi-wavelength pyrometer (111) is oriented towards a portion (112) of the refractory lining (110) located at the end of the heating chamber (103) and at a distance (d) over a surface (113) of the material (104) when it becomes liquid.
 3. The system (100) according to claim 1 or 2, wherein the furnace (101) is selected from a group comprising rotary furnaces, tilting rotary furnaces and reverberatory furnaces.
 4. The system (100) according to any one of the preceding claims, wherein the at least one multi-wavelength pyrometer (111) is a two-colour infrared thermometer.
 5. The system (100) according to any one of the preceding claims, wherein the at least one multi-wavelength pyrometer (111) is coupled to the openable door (105) or to a wall of the vessel (102).
 6. The system (100) according to any one of the preceding claims, comprising a heating control module (115) communicatively coupled to the at least one multi-wavelength pyrometer (111) and to the at least one burner (106), the heating control module (115) being configured to:
 - receive the measured temperature of the portion (112) of the refractory lining (110) from the at least one multi-wavelength pyrometer (111); and
 - modify at least one of an amount of the fuel and an amount of the gaseous oxidant being burned by the at least one burner (106) in the heating chamber (103) based on the measured temperature.
 7. The system (200) according to any one of the preceding claims, comprising at least one camera (217,218) located outside the furnace (201) or attached to the openable door (205) or to the walls of the vessel (202), the at least one camera (217,218) being configured to take images of at least one of the flames (208) inside the heating chamber (203) and the exhaust flame (209).
 8. The system (200) according to claim 7, wherein the heating control module (215) is configured to:
 - receive the images of the flames (208,209) from the at least one camera (217,218); and
 - determine a carbon monoxide concentration in the flames (208,209) based on at least one parameter of the flame (208,209) in the images.
 9. The system (200) according to claim 8, wherein the at least one parameter is selected from a group comprising flame's intensity, flame area, flame length, colour coordinates (U,V), of the flame and any combination thereof.
 10. The system (200) according to any one of claims 8 or 9, wherein the heating control module (215) is configured to modify the at least one of the amount of the fuel and the amount of the gaseous oxidant being burned by the at least one burner (206) in the heating chamber (203) based on a combination of the measured temperature and a carbon monoxide concentration in at least one of the flames (208) inside the heating chamber (203) and the exhaust flame (208).
 11. A method (400) for controlling combustion in a furnace, comprising:
 - providing (401) a system (100,200) as described in any one of claims 1 to 10;
 - measuring (402) a temperature of a portion of the refractory lining of the heating chamber with the at least one multi-wavelength pyrometer during operation of the furnace;
 - comparing (403), by a heating control module, the measured temperature to a preestablished temperature for the refractory lining;
 - modifying (404) at least one of an amount of the fuel and an amount of the gaseous oxidant being burned in the heating chamber based on the result of the comparison.
 12. The method according to claim 11, wherein the preestablished temperature is the maximum working temperature of the refractory material of the refractory lining.
 13. The method (400) according to claims 11 or 12,

wherein when the temperature measured exceeds the preestablished temperature, the method (400) comprises modifying, by the heating control module, at least one of the amount of fuel and the amount of gaseous oxidant to amounts thereof that are effective to lower the temperature of the refractory lining to be equal than the preestablished temperature for a predetermined period of time. 5

14. The method (400) according to any one of claims 11 to 13, wherein when the temperature measured is lower than the preestablished temperature, the method (400) comprises modifying, by the heating control module, at least one of the amount of fuel and the amount of gaseous oxidant to amounts thereof that are effective to increase the temperature of the refractory lining to be equal than the preestablished temperature for a predetermined period of time. 10 15

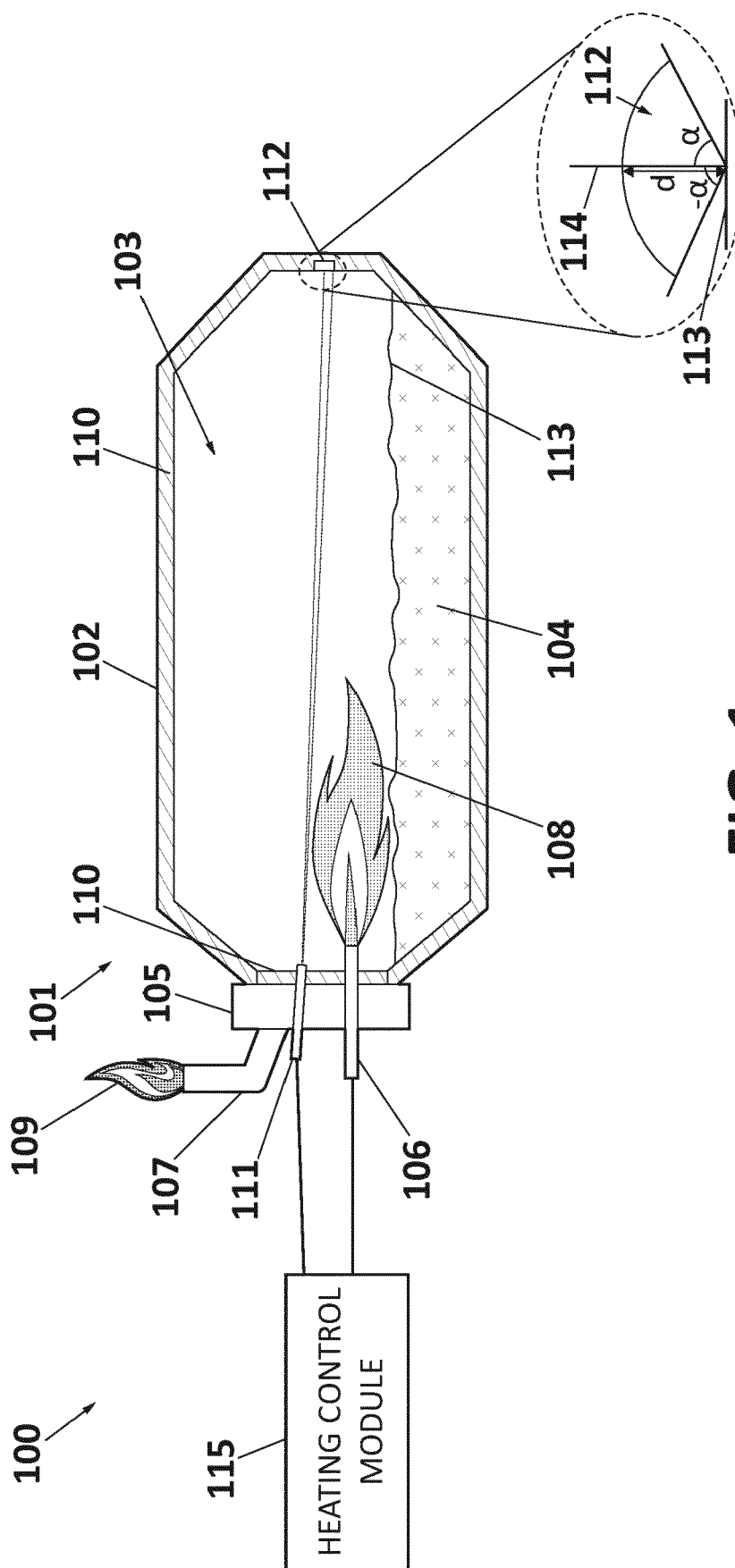
15. The method (400) according to any one of claims 11 to 14, comprising: 20

receiving, at the heating control module, images of at least one of the flames inside the heating chamber and the exhaust flame from the at least one camera; 25
determining, by the heating control module, a carbon monoxide concentration in the flames based on at least one parameter of the flames in the images; 30
comparing, by the heating control module, the determined carbon monoxide concentration to a preestablished carbon monoxide concentration; and 35
causing, by the heating control module, the at least one burner to modify at least one of an amount of the fuel and an amount of the gaseous oxidant being burned in the heating chamber based on a combination of the result of the comparison of temperatures and the result of the comparison of carbon monoxide concentrations. 40

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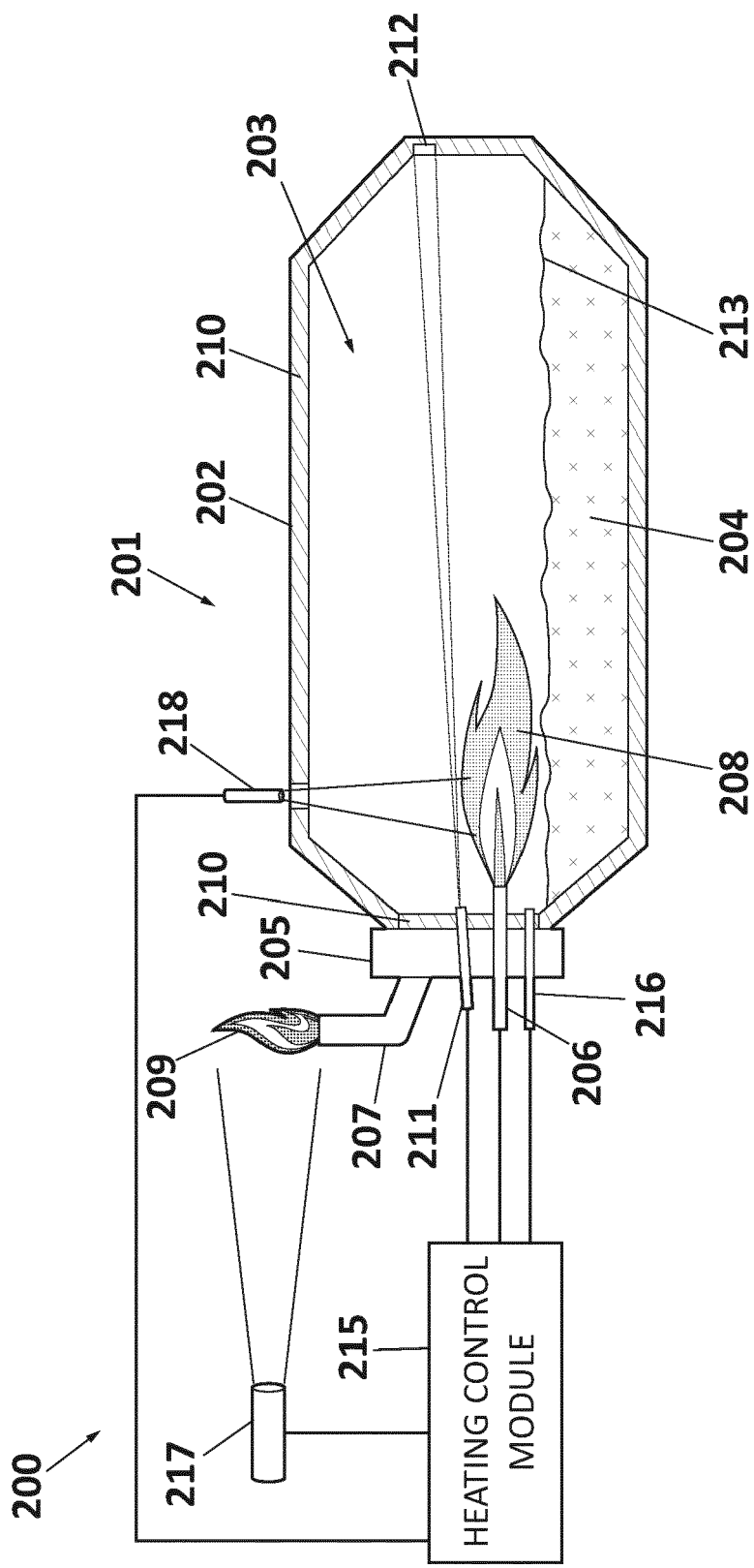


FIG. 2

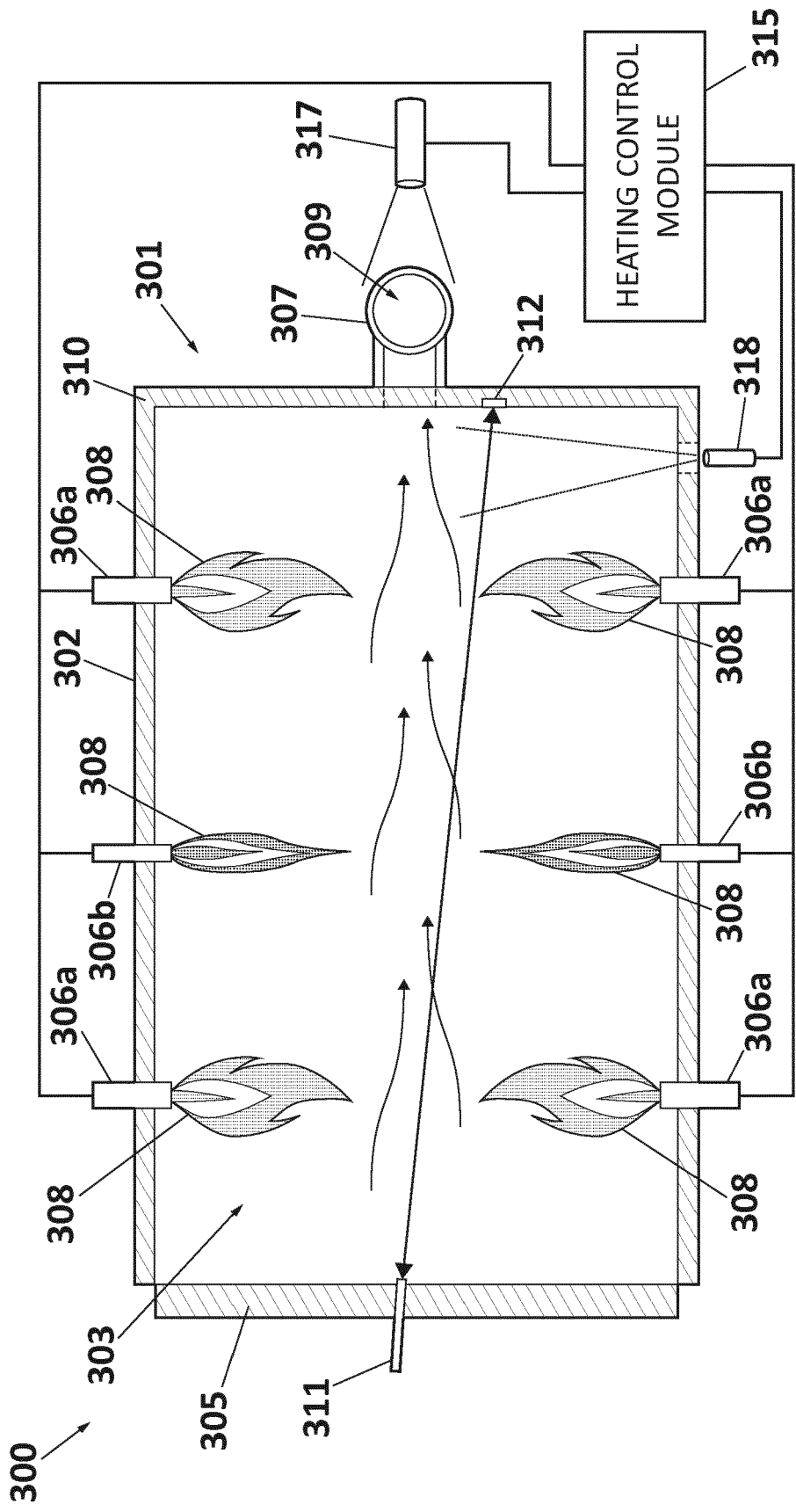
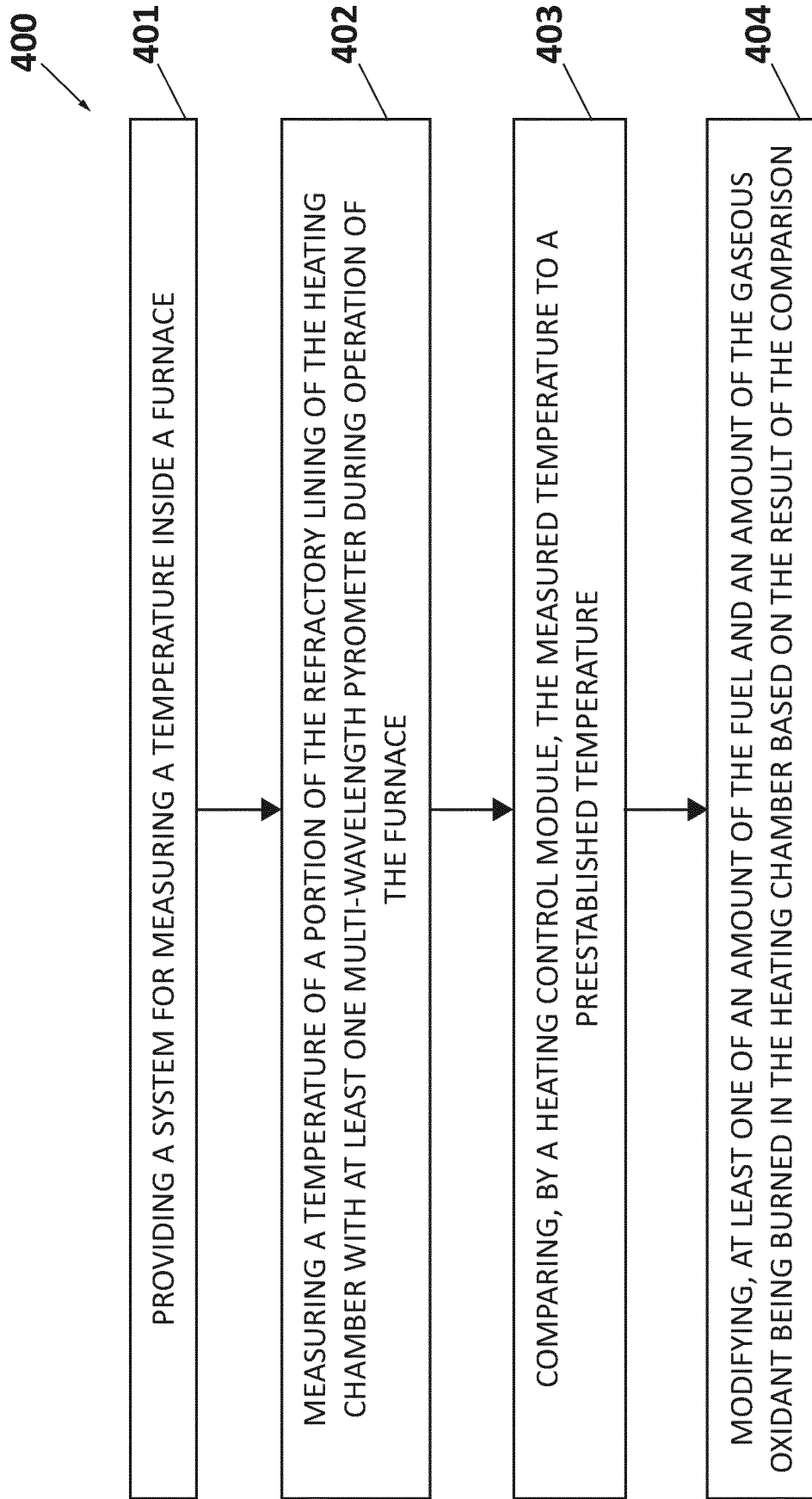


FIG. 3

**FIG. 4**



EUROPEAN SEARCH REPORT

 Application Number
 EP 20 38 2841

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Place of search Munich		Date of completion of the search 21 December 2020	Examiner Gavriliu, Alexandru
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