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(54) Method for reducing nitrogen oxide emissions and corrosion in a bubbling fluidized bed boiler and a bubbling fluidized bed boiler

(57) To reduce nitrogen oxide emissions and corrosion in a bubbling fluidized bed boiler that burns biofuel or waste, air is supplied into the boiler furnace (1) in stages so that two sub-stoichiometric combustion zones (I), (II) and a superstoichiometric zone (III) are brought about. The first combustion zone (I) begins from the height level of primary air supply nozzles (3) and it extends above the fluidized bed (2), ending under the height level (hS) of secondary air nozzles (6). The second combustion zone (II) begins from the height level (hS) of the secondary air nozzles (6) and ends under the height level (hT) of tertiary air nozzles (7). The third combustion zone (III) begins from the height level (hT) of the tertiary air nozzles. The length of the first combustion zone (I) is optimized by placing the secondary air nozzles (6) at a height (hS) from the top surface of the fluidized bed (2), which height (hS) is chosen according to a given calculation formula and calculated according to furnace-specific variables, reference values and design point-specific variables. The design point-specific variables are different in a boiler with a high furnace load and in a boiler with a low furnace load.

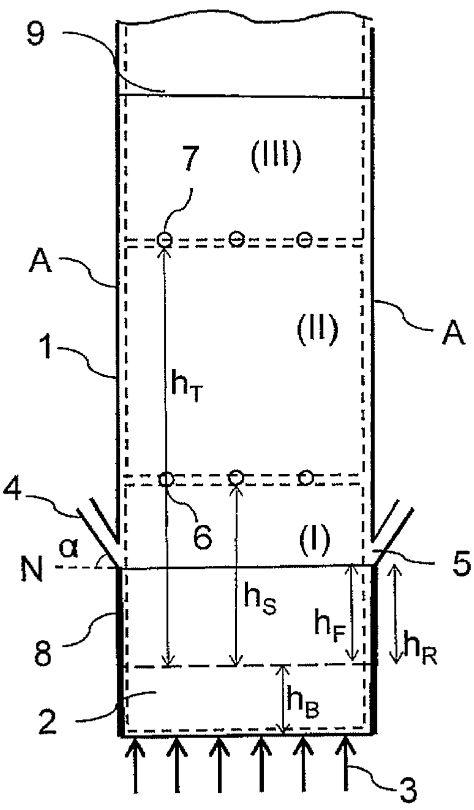

FIG. 3

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Description

FIELD OF THE INVENTION

[0001] The invention concerns a method in accordance with the preamble to claim 1 for reducing nitrogen oxide emissions and corrosion in a bubbling fluidized bed boiler burning biofuel or waste. The invention also concerns a bubbling fluidized bed boiler in accordance with claim 5.

BACKGROUND OF THE INVENTION

[0002] There are two main types of fluidized bed boilers: bubbling fluidized bed boilers (BFB) and circulating fluidized bed boilers (CFB). The main difference between these two boiler types is in fluidization velocity. Low gas velocity is used in BFB boilers and the position of the solids layer is relatively stationary. In CFB boilers higher gases velocities are used sufficient to suspend the particle bed and entrain particles, which are recirculated via an external loop back into the fluidized bed.

[0003] Bubbling fluidized bed boilers are in general use for producing energy from biofuels of various kinds (peat, wood, industrial sewage sludge and other such) and from oil-based waste (for example, plastics waste). Fuels of this type are characterized in that the share of volatile matter is high in the dry matter of the fuel.

[0004] In fluidized bed combustion, nitrogen oxides (NO_x) are mainly the result of the oxidation of organic nitrogen in the fuel. Emission standards for nitrogen oxides concerning bubbling fluidized bed boilers will become significantly stricter in the next few years. The quantity of nitrogen oxides can be reduced e.g. by methods to do with combustion technology, by injecting ammonia into the furnace and by catalytic purification of the flue gases. Methods of combustion technology are used to prevent formation of nitrogen oxides or to convert into other compounds those nitrogen oxides, which are produced in earlier stages of combustion. The present invention concerns a method of combustion technology and a related device construction.

[0005] In a bubbling fluidized bed boiler, a bubbling fluidized bed, that is, a fluidized bed is located in the lower part of the furnace and it consists of a fine incombustible material, such as sand, which is fluidized by supplying fluidizing gas into the bed from below. The fluidizing gas may consist solely of primary air or it may be a mixture of primary air and an inert gas, such as flue gas. The fluidizing gas is set to flow with such a velocity that the particles in the fluidized bed will not escape along with the gas flow into the upper part of the boiler but they will remain in the lower part of the boiler forming a fluidized bed, which is in continuous motion and which efficiently mixes together the bed material and the fuel supplied into it.

[0006] The combustion air needed for burning the fuel is generally supplied in stages and in several separate parts into the boiler furnace in such a way that a part of the combustion air is formed by primary air, that is, fluidizing air, which is blown along with the fluidizing gas, and a part is formed by secondary air supplied above the fluidized bed, while the rest of the combustion air is supplied into the upper part of the furnace as tertiary air.

[0007] The furnace of a bubbling fluidized bed boiler can be divided vertically into three successive combustion zones based on the combustion air supply into the different zones. The fluidized bed and the space above it, all the way to the level below the secondary air nozzles, form the first combustion zone (I), into which primary air is brought mainly along with the fluidizing gas supplied from below the fluidized bed, besides which a minor quantity of primary air arrives in connection with the fuel supply as carrier air and as cooling air for the start-up burners. The second combustion zone (II) is located in the space between the secondary air supply level and the tertiary air supply level. Secondary air is supplied into the second combustion zone (II) mainly through secondary air nozzles located in the lower part of the zone. If there are load carrying burners in the furnace, a small part of the secondary air is supplied as cooling air for the load carrying burners. The third combustion zone (III) begins from the tertiary air supply level and combustion air is brought into it through tertiary air nozzles.

[0008] The fuel is supplied on top of the fluidized bed with the aid of carrier air, which is used for, among other things, preventing clogging of the fuel supply chutes. In the fluidized bed and above it fuel particles are dried, volatile matter is released, that is, pyrolysis occurs, and the carbonized residue is incinerated. Drying and pyrolysis are very fast events. The volatile matter released in pyrolysis comprises mainly methane CH_4 and carbon monoxide CO as well as ammonia NH_3 and hydrogen cyanide HCN. The volatile matter rises upwards in the furnace and it will burn when reaching an oxygen-containing region. In a fluidized bed boiler operating with staged air supply, the combustion of volatile matter takes place mainly under the effect of secondary air and partly also under the effect of tertiary air. The combustion of carbonized residue of fuel particles takes place under the effect of primary, secondary and tertiary air.

[0009] It is possible with the aid of staged air supply to reduce the formation of nitrogen oxides in a bubbling fluidized bed boiler. In the presence of oxygen, NH_3 and HCN react into nitrogen monoxide NO. By staging the air supply, reducing substoichiometric areas are formed in the furnace of the bubbling fluidized bed boiler. In these areas, NH_3 and HCN formed from the fuel are reduced into molecular nitrogen in accordance with reaction equations (1) and (2):

$$NH_3 \xrightarrow{+OH} NH_2 \xrightarrow{+H} NH \xrightarrow{+H} N \xrightarrow{+NO} N_2 \quad (1)$$

$$HCN \xrightarrow{+O} NCO \xrightarrow{+H} NH \xrightarrow{+H} N \xrightarrow{+NO} N_2 \quad (2)$$

[0010] In addition, nitrogen oxides are reduced with the aid of an internal re-burning reaction, in which hydrocarbon radicals formed in the pyrolysis will take part in reducing the nitrogen oxides. An example of such a reaction is described in reaction equation (3), in which $-CH_i$ acts as the hydrocarbon radical:

$$NO \xrightarrow{+CHi} HCN \xrightarrow{+O,+OH} H_iNCO \xrightarrow{+H} NH_i \xrightarrow{+NO} N_2 \quad (3)$$

[0011] Reducing areas are usually formed by adjusting the volume of primary and secondary air. The furnace is kept substoichiometric as regards oxygen until the supply of tertiary air, whereby the available dwell time for reactions (1) and (2) is maximized and the quantity of NH_3 and HCN before the tertiary air level is minimized. The optimum total air coefficient SR_{tot} for NO_x emissions before the tertiary air supply is just under 1, depending on the combustion temperature. The air needed for complete combustion of volatile matter and of the carbonized residue is brought into the furnace as tertiary air. NH_3 and HCN remaining in the flue gases will oxidize into nitrogen oxides after the tertiary air supply.

[0012] With these conventional measures in accordance with staged air supply it is possible to reduce nitrogen oxide emissions by approximately 30 % in comparison with non-staged air supply. Fine and light fuels are problematic, because some fuel particles will not end up in the fluidized bed, but they are carried away with the fluidizing gas and the secondary air into the upper parts of the furnace. Thus, it is close to impossible to bring about for such fuels any controlled combustion conditions in the furnace which are favorable for the reduction of nitrogen oxides.

[0013] WO 2006084954 A1 describes a solution, which aims at reducing nitrogen oxide emissions of a bubbling fluidized bed boiler by using staged air supply in such a way that a part of the primary air is supplied into the furnace in connection with the fuel supply in the same direction as the fuel itself. In the publication, this part of primary air is called combustion air for volatile matter. Essentially all fuel supplied into the furnace is thus forced on to the surface of the fluidized bed, whereby the fuel is made to mix into the fluidized bed and to dry quickly. The pyrolysis following after the drying and the combustion of volatile matter released in the pyrolysis also occurs almost immediately after the fuel has mixed into the fluidized bed. Owing to the quick mixing together of fuel and oxygen, a major part of the volatile matter released from the fuel can be burnt above the fluidized bed before the secondary air supply level. The combustion of volatile matter causes a high temperature, which maximizes the occurrence of hydrocarbon radicals formed from the fuel and promotes reduction of released nitrogen oxides.

[0014] According to WO 2006084954 A1, the quantity of combustion air for volatile matter, supplied in connection with the fuel supply, is adjusted to be such that the combustion of volatile matter released from the fuel burnt at each time will take place in substoichiometric conditions in relation to the volatile matter. The air coefficient for volatile matter, that is, SR_{vol}, in the primary air zone is hereby as high as possible, however, less than 1, preferably in a range of 0.75 - 0.97 and most preferably in a range of 0.90 - 0.95. The total air coefficient, that is, SR_{tot}, on the same furnace level varies in a range of 0.50 - 0.80, being preferably 0.65. The solution does not change the air volume supplied into the furnace and not either the total air coefficient, but it changes the air distribution in the boiler, so that the air coefficient for volatile matter is as high as possible at as low a level as possible in the furnace and for as long a time as possible before the secondary air level.

[0015] The air coefficient or the stoichiometric ratio SR tells how much air must be used for the combustion in comparison with the theoretical (stoichiometric) volume of air needed for complete combustion of the fuel. In substoichiometric combustion, the air coefficient SR is under 1, and in superstoichiometric combustion the air coefficient SR is over 1.

[0016] When the aim is to reduce nitrogen oxide emissions with means of combustion technology in existing boilers, the temperature of flue gases should not usually rise from the present-time values at the nose of the furnace. If in connection with changes in the combustion technology the flue gas temperature becomes too high or if the temperature distribution of flue gas is very uneven, this will lead to contamination of the heat transfer surfaces of the boiler's second draft, especially when burning fuels that contain lots of alkali metals. On the other hand, with chlorine-bearing fuels high flue gas temperatures may cause strong corrosion in the super-heater area.

[0017] The size of a furnace can be characterized by furnace load, which can be obtained by dividing the fuel power supplied into the boiler by the volume of the furnace. The values of furnace load used in this application are calculated using furnace volume up to the level of the nose of the boiler. Furnace load illustrates the residence time of fuel gases in the furnace.

[0018] Bubbling fluidized bed boilers are typically manufactured for various furnace loads. According to one classification, a low furnace load is about 90 - 110 kW/m^3, an average furnace load is about 110 - 130 kW/m^3 and a high furnace load is about 130 - 150 kW/m^3. In boilers with high furnace load, the combustion temperature is high, whereby fluidized bed temperatures can easily exceed those temperatures, which are permissible from the viewpoint of softening of the ash. Typically, the temperature of the fluidized bed should be kept within a range of 800 - 900 °C. If the bed temperature rises much above 900 °C and the fuel contains much alkali metals, this could lead to agglomeration of ash particles in the fluidized bed.

PURPOSE OF THE INVENTION

[0019] The objective of the invention is to bring about a method of combustion technology and a fluidized bed boiler, with which it is possible to reduce nitrogen oxide emissions in the combustion of biofuel or waste and at the same time to prevent corrosion of the furnace and the super-heater area.

SUMMARY

[0020] The method according to the invention is characterized by the features presented in the characterizing part of claim 1.

[0021] Correspondingly, the bubbling fluidized bed boiler according to the invention is characterized by the features presented in the characterizing part of claim 5.

[0022] The invention concerns a method for reducing nitrogen oxide emissions and corrosion in a bubbling fluidized bed boiler burning biofuel and/or waste. In this method, air required for fuel combustion is supplied in stages into the boiler furnace in such a way that at least two substoichiometric zones (I) and (II) are brought about, which have as one of their objectives to reduce the formation of nitrogen oxides, as well as at least one superstoichiometric zone (III), in which the combustion is completed. The combustion zones comprise a first combustion zone (I), which begins from the height level of the primary air supply nozzles and extends above the fluidized bed up to below the height level of secondary air nozzles; a second combustion zone (II), which begins from the height level of the secondary air nozzles and extends up to below the height level of tertiary air nozzles; and a third combustion zone (III), which begins from the height level of the tertiary air nozzles.

[0023] In the method according to the invention, the length of the first combustion zone (I) is optimized by placing the secondary air nozzles at a height h_s from the top surface of the bubbling fluidized bed, which height h_s is calculated from the formula:

$$h_S = \frac{Q_f}{LHV_{ref}\,\rho_{ref} A} t_{ref} \quad \frac{q_f}{q_{f,ref}} \qquad (1 + f_{a,ref} SR_{vol,ref})$$

wherein:

hS = the height of the secondary air level from the top surface of the bubbling fluidized bed [m]
Qf = the boiler's full fuel power [MW]
A = the boiler's cross-sectional area [m2]
qf = the boiler's full furnace load under the nose [kW/m3]
LHVref = lower heat value of the fuel [MJ/kg]
pref = fuel density [kg/m3]
qf,ref = furnace load [kW/m3]
fa,ref = air requirement of volatile matter in the fuel [kg air/kg fuel]
tref = dwell time (in a normal state NTP; T = 0 oC, p = 1 atm) [s]
SRvol,ref = air coefficient for fuel volatile matter in the first combustion zone (I),
in which formula some variables are furnace-specific, some variables are reference values and thus constants, and some variables are design point-specific reference values, which are chosen based on the furnace load of the bubbling fluidized bed boiler.

[0024] Some variables used in the calculation, such as the boiler's full fuel power Q_f, the boiler's cross-sectional area A and the boiler's full furnace load q_f under the nose, are variables specific to the furnace.

[0025] The reference values, which are the fuel's lower heat value LHV_{ref}, the fuel density pref, the furnace load $q_{f,ref}$ and the air requirement of volatile matter in the fuel $f_{a,ref}$, are empirically chosen constants.

[0026] The dwell time t_{ref} and the air coefficient $SR_{vol, ref}$ for fuel volatile matter in the first combustion zone (I) are design point-specific reference values. The design point used at each time is chosen based on a furnace-specific consideration. Typically, in a boiler with a high furnace load the dwell time t_{ref} is shorter and the air coefficient $SR_{vol, ref}$

for volatile matter is lower than in a boiler with a low furnace load.

[0027] The design point-specific reference values t_{ref} and $SR_{vol, ref}$ are preferably chosen based on the boiler's furnace load, so that in a boiler with a high furnace load the values t_{ref} = 6 s and $SR_{vol, ref}$ = 0.7 are used, and in a boiler with a low furnace load the values t_{ref} = 7 s and $SR_{vol, ref}$ = 0.9 are used. A boiler with q_f higher than 130 kW/m^3 is regarded as a boiler of a high furnace load, and a boiler with q_f lower than 130 kW/m^3 is regarded as a boiler of a low furnace load. When required, it is possible to deviate from the shown limit value of 130 kW/m^3, for example, when the fuel mainly used in the boiler is especially dry or especially wet.

[0028] The invention also concerns a bubbling fluidized bed boiler suitable for burning biofuel and waste, comprising a furnace, in the lower part of which there is a fluidized bed into which primary air is supplied through primary air nozzles located under the fluidized bed and fuel is supplied through fuel supply openings in the walls of the furnace, which fuel supply openings are located at a first height above the fluidized bed surface. The furnace also has a set of secondary air nozzles, which are located at a second height above the fluidized bed surface, and a set of tertiary air nozzles, which are located at a third height above the fluidized bed surface. Hereby a first combustion zone (I) is formed in the furnace of the bubbling fluidized bed boiler, which zone comprises a fluidized bed and above this a space up to under the height level of the secondary air nozzles, a second combustion zone (II), which extends from the height level of the secondary air nozzles up to under the height level of the tertiary air nozzles, and a third combustion zone (III), which begins from the height level of the tertiary air nozzles. Said first combustion zone (I) and second combustion zone (II) are arranged to operate in a substoichiometric fashion so that the total air coefficient SR_{tot} is less than 1 in each zone.

[0029] In a bubbling fluidized bed boiler according to the invention, the secondary air nozzles are located at a certain height from the top surface of the bubbling fluidized bed, which height is calculated with the aid of the following formula:

$$h_S = \frac{Q_f}{LHV_{ref}\,\rho_{ref} A} t_{ref} \; \frac{q_f}{q_{f,ref}} \quad (1 + f_{a,ref} SR_{vol,ref})$$

wherein:

h_s = height of the secondary air level from the top surface of the bubbling fluidized bed [m]
Q_f = the boiler's full fuel power [MW]
A = the boiler's cross-sectional area [m^2]
q_f = the boiler's full furnace load under the nose [kW/m^3]
LHV_{ref} = the fuel's lower heat value [MJ/kg]
ρ_{ref} = fuel density [kg/m^3]
$q_{f, ref}$ = furnace load [kW/m^3]
$f_{a, ref}$ = air requirement of volatile matter in the fuel [kg air/kg fuel]
t_{ref} = dwell time (in a normal state NTP; T = 0 °C, p = 1 atm) [s]
$SR_{vol, ref}$ = air coefficient for fuel volatile matter in the first combustion zone (I),
in which formula some variables are furnace-specific, some variables are reference values and thus constants, and some variables are design point-specific variables, which are chosen based on the boiler's furnace load.

[0030] If it is desired in terms of combustion technology to minimize nitrogen oxide emissions and at the same time to minimize the flue gas temperature at the furnace nose, the bubbling fluidized bed boiler should always be operated in such a way that in the first combustion zone (I) the air coefficient for volatile matter, that is, SR_{vol}, is in a range of 0.9 - 1.0. If SR_{vol} is raised close to a value of 1.0 by supplying into the first combustion zone (I) a theoretical quantity of oxygen needed for the combustion of volatile matter, this will result in a raised combustion temperature in the upper part of the fluidized bed. An increased heat radiation will thus also raise the fluidized bed temperatures, typically by about 20 - 50 °C. If the fluidized bed boiler is made with a high furnace load and if the fuel is especially dry (water content less than 45 weight-%), this may result in the rise of fluidized bed temperature above the permissible temperature limits.

[0031] One way of lowering the fluidized bed temperature in a bubbling fluidized bed boiler is by reducing the boiler's masonry surface in the region between the primary air level and the secondary air level. In typical bubbling fluidized bed boilers of today, the lower part of the furnace is made by laying bricks to a height of about 2.5 - 5 meters from the surface of the bubbling fluidized bed. The purpose of the masonry is to protect the boiler's water pipes against corrosion and contamination, but at the same time it also increases the temperatures in the part above the fluidized bed, because the masonry prevents radiation heat transfer to the water pipes lining the furnace.

[0032] In a solution according to the invention, it is recommended, especially in boilers with a high furnace load, to change over to a masonry height of 1.8 - 2.4 meters from the fluidized bed surface, preferably 1.8 - 2.0 meters from the fluidized bed surface.

[0033] If the fluidized bed temperatures would even after this be too high, nitrogen oxides can be reduced by maintaining a low air coefficient SR_{vol} for volatile matter in the first combustion zone (I), for example, close to a value of 0.7, and a short dwell time in the first combustion zone (I). A short dwell time is achieved by locating the secondary air supply level relatively close to the fluidized bed surface above it, which optimum distance can be calculated with the aid of the mathematical formula presented in the claims. The second combustion zone (II) following after the first combustion zone (I) can thus have a longer dwell time, whereby the combustion of volatile matter and the reactions minimizing the quantity of nitrogen oxides can be brought to an end in the second combustion zone (II).

[0034] The invention comprises two alternative embodiments for reducing nitrogen oxides in the flue gases of a bubbling fluidized bed boiler. The embodiment to use at each time is chosen primarily on the basis of the boiler's furnace load. When the bubbling fluidized bed boiler has a high furnace load (for example, over 130 kW/m^3), and especially when burning a dry fuel (for example, moisture less than 45 weight-%), then according to the invention an optimum air coefficient SR_{vol} = 0.9 - 1.0 for volatile matter in the fuel is not utilized in the first combustion zone (I), but the operation is in a lower SR_{vol} range of 0.65 - 0.75. Instead, when the boiler has a low furnace load (for example, less than 130 kW/m^3), a SR_{vol} range of 0.9 - 1.0, which is the optimum range for the nitrogen oxide reduction, is used in the first combustion zone (I). The air coefficient SR_{vol} for volatile matter can be increased in the first combustion zone (I), for example, in a manner presented in WO 2006084954 A1 by supplying into the first combustion zone (I) along with the fuel supply a desired volume of combustion air, which is preferably taken from the secondary air register, where the air temperature is in a range of 165 - 330 °C.

[0035] WO 2006084954 A1 defines air coefficients for the various combustion zones, but it does not concern itself with the grounds for design of the entire air distribution system or with the optimum location of devices. Nor does the publication concern itself with limitations of the method of combustion technology, such as high furnace load. The air coefficients defined in WO 2006084954 A1 for two different methods do not thus contain basic design information in sufficient detail.

[0036] In a bubbling fluidized bed boiler according to the invention, the fuel used can be e.g. peat, wood, industrial sludge, chlorine-bearing plastics waste, as well as mixtures of these. The optimum air coefficient for fuel volatile matter, that is, SRvol, in the first combustion zone (I) depends on the fuel used. For example, with peat the optimum air coefficient is SR_{vol} = 1.0 and with wood SR_{vol} = 0.9.

[0037] The distance of the fuel supply openings from the surface of the bubbling fluidized bed is also of significance. When the first combustion zone (I) functions in a range of SR_{vol} = 0.9 - 1.0 and the combustion air for volatile matter is supplied together with the fuel, the fuel supply openings must not be too close to the surface of the bubbling fluidized bed and the vertical fuel supply angle must not be too steep to avoid the risk that the combustion air for volatile matter supplied together with the fuel would carry with it from the fluidized bed particles, which drift along with the flue gas all the way to the boiler outlet.

[0038] In a boiler with a low furnace load, the fuel supply openings are preferably arranged at a height of 2.0 - 2.6 meters from the fluidized bed surface, and in a boiler with a high furnace load they are at a height of 1.8 - 2.0 meters from the fluidized bed surface. In a boiler with a low furnace load, the vertical fuel supply angle, which in this context means the angle between the fuel chute and the normal of the furnace wall, may be about 25° - 35°, and in a boiler with a high furnace load it may be about 35° - 40°.

[0039] There are usually two or three fuel supply chutes and supply openings side by side at the same height on one or both side walls of the fluidized bed boiler. Seen from above, the supply chutes are usually arranged perpendicular to the wall in question, whereby the fuel flow will leave the fuel supply opening in the direction of the wall's normal. Then there is a risk that from the fuel supply openings which are outermost, that is, closest to the adjacent front or back wall of the furnace, the fuel may spread on to the front or back wall of the furnace. This risk can be avoided by inclining the outermost fuel supply chutes in the horizontal direction in such a way that the direction of motion of the fuel discharging from the supply openings will be 5 - 15° away from that boiler side wall which is closest to the supply opening. This angle is called the fuel chute's horizontal supply angle. It is especially important to guide the fuel flow away from the adjacent wall when chlorine- or sulfur-bearing fuel is being burnt.

[0040] In an advantageous embodiment of the invention, a side air nozzle is mounted in between a fuel chute located on a first wall of the furnace and an adjacent second wall, through which nozzle airflow can be blown into the furnace to prevent the fuel released from the fuel chute from attaching itself to the second wall.

[0041] In an advantageous embodiment of the invention, secondary air nozzles and/or tertiary air nozzles are arranged in two opposite rows on two opposite walls of the furnace, and in each row there are nozzles blowing a small air jet, nozzles blowing an air jet of medium size and nozzles blowing a large air jet. The nozzles are arranged to alternate so that every second nozzle is a nozzle blowing a small air jet and every second nozzle is a nozzle blowing a medium-sized or a large air jet. In addition, the nozzles are arranged in a staggered fashion so that opposite to each nozzle blowing a small air jet there is on the opposite wall a nozzle blowing a medium-sized or large air jet. Of the outermost nozzles in each row at least one is a nozzle blowing a large air jet, and of the nozzles located in the central part of each row at least one is a nozzle blowing a medium-sized air jet. With the aid of the outermost air jets the adjacent walls are "swept" and an area with a high oxygen content is brought about near the walls which are perpendicular to these nozzle walls. The small air jets have a weak penetration, but their purpose is in fact to sweep the nozzle wall and to bring about an area with high oxygen content close to the nozzle wall.

[0042] When the intention is to burn a fuel with a high content of chlorine and/or sulfur in the bubbling fluidized bed boiler, the supply of fuel and combustion air is preferably arranged in a way to efficiently prevent the furnace walls adjacent to the fuel supply from being contaminated and from corroding. Hereby it is preferable to use in the boiler all three solutions presented above: the outermost supply chutes are inclined 5-15° away from the side wall which is adjacent to the fuel supply spot, there are side air nozzles between the outermost supply chutes and the side wall, and secondary and/or tertiary air nozzles are arranged to blow air blasts in the manner described above in such a way that such conditions are brought about near the furnace walls that will prevent the walls from corroding and from being contaminated.

[0043] Reduction of nitrogen oxides by a two-staged substoichiometric combustion, which is followed by the use of tertiary air in a third combustion zone, produces substoichiometric conditions near the furnace walls. If the fuel contains much chlorine and/or sulfur, strong corrosion of the evaporator walls will result. With the method according to the invention it is possible to reduce the amount of nitrogen oxides in the flue gas, however, at the same time keeping the corrosion of both the furnace and the super-heater surfaces in the second draft within the permitted limits.

[0044] The tertiary air nozzles are preferably located 2 - 4 meters below the furnace nose.

[0045] At the present time, primary air supplied into the fluidized bed from under the bed is distributed evenly over the entire fluidized bed area. Coarse wood fuel in particular will fly from the fuel supply chute in point-form into the fluidized bed, and this will result on the one hand in areas with much fuel and little air and on the other hand in areas with much air and little fuel. This will lead to uneven combustion and to high nitrogen oxide emissions. Primary air could advantageously be distributed into the fluidized bed in such a way that more primary air than the average volume is supplied to fuel-rich areas and, correspondingly, less primary air than the average volume is supplied to fuel-poor areas. However, an uneven supply of primary air must not cause uneven floating of the fluidized material.

BRIEF DESCRIPTION OF THE DRAWINGS

[0046] The invention is described in the following by referring to the examples shown in the appended figures, but there is no intention to restrict the invention narrowly to the embodiments presented in the figures.

Figure 1 is a schematic perspective view of a bubbling fluidized bed boiler.
Figure 2 is a schematic perspective view of the lower part of a bubbling fluidized bed boiler.
Figure 3 is a schematic sectional front view of the furnace of a bubbling fluidized boiler designed for a high furnace load.
Figure 4 is a schematic sectional front view of the furnace of a bubbling fluidized boiler designed for a low furnace load.
Figure 5 is a simplified sectional view of the cross-section of a furnace at the level of fuel supply chutes.
Figure 6 is a side view of air jets supplied into a furnace.
Figure 7 is a schematic sectional view of a furnace at the air jet level.

DETAILED DESCRIPTION OF THE INVENTION

[0047] Figure 1 shows schematically a bubbling fluidized bed boiler and its furnace 1. The lower part of the furnace 1 is provided with masonry 8, which protects the pipes (not shown) of a water-steam circuit located on the walls A, B of furnace 1 from overheating. Fuel is supplied into the furnace 1 through fuel supply openings 5 located in two opposite walls A of the furnace. Air needed for fuel combustion is supplied through primary air nozzles (not shown) located in the bottom of the furnace and through secondary air nozzles 6 and tertiary air nozzles (not shown) located in the walls B of the furnace 1. In the upper part of the furnace 1 there is a nose 9 that reduces the boiler's flow cross-sectional area, whereupon the flow of flue gases turns through super-heaters (not shown) in the upper part of the boiler into a flue gas duct 13. Figure 1 also shows start-up burners 10 near the fuel supply height as well as load bearing burners 11 at an upper position on the wall B of the furnace 1.

[0048] Figure 2 shows enlarged a part of the lower part of the furnace 1 of a bubbling fluidized bed boiler. Fuel supply openings 5 are arranged on the furnace wall A. In between each fuel supply opening 5 and the nearest wall B a side air nozzle 12 is fitted on the wall A, from which nozzle air can be blown in between the fuel flow and the side wall B parallel with the side wall B. The side air nozzles 12 are used to prevent the side walls B from corroding and from being contaminated, especially when the fuel contains much sulfur or chlorine.

[0049] Figures 3 and 4 show in principle the furnace 1 of a bubbling fluidized bed boiler seen from the front. In Figure 3 the boiler is a bubbling fluidized bed boiler designed for a high furnace load and in Figure 4 it is a fluidized bed boiler designed for a low furnace load. Please note that the figures are just basic views and they are not intended to present a bubbling fluidized boiler on its correct scale.

[0050] In the lower part of the furnace 1 there is a fluidized bed 2 consisting of fluidized bed material, into which bed fluidizing gas is supplied through nozzles 3 arranged in the bottom of the furnace 1, which gas makes the fluidized bed material float and bubble. The fluidizing gas may be just air or it may be a mixture of air and a circulating gas. The height h_B of the fluidized bed is usually about 800 mm, that is, the distance of the top surface of the bubbling fluidized bed 2 from the height level of primary air nozzles 3 is about 800 mm.

[0051] Fuel is supplied above the fluidized bed 2 surface by fuel supply devices 4, 5, which comprise a fuel supply chute 4, which is directed obliquely downwards and ends in a supply opening 5 located in the furnace wall A. A small amount of carrier air is also usually brought along with the fuel into the boiler, its main function being to prevent clogging of the supply chute 4. The fuel supply openings 5 are located at an optimum height h_F from the top surface of fluidized bed 2, which optimum height h_F can be determined on the basis of the bubbling fluidized bed boiler's furnace load and some other variables.

[0052] In boilers with a high furnace load, the distance h_F between the fuel supply openings 5 and the top surface of fluidized bed 2 is usually in a range of 1.8 - 2.0 meters. An acute angle α is formed between the fuel supply chute 4 and the normal N of the furnace wall A, which angle in a boiler with a high furnace load is about 35° - 40°. This angle is called vertical supply angle α. Masonry 8 extends from the fluidized bed surface to a height h_R, which height is in a range of 1.8 - 2.0 meters in a boiler with a high furnace load.

[0053] Secondary air is supplied into the furnace 1 from secondary air nozzles 6 located above the fuel supply level at height level h_s. The distance h_s of the secondary air nozzles 6 from the top surface of fluidized bed 2 can be optimized on the basis of the bubbling fluidized bed boiler's furnace load and some other variables.

[0054] The space confined between the height level of primary air nozzles 3 and the secondary air nozzles 6, which space contains the fluidized bed 2 and the volume above it all the way up to a level under the secondary air nozzles 6, forms a first combustion zone (I). Into the first combustion zone (I), fuel is supplied through supply openings 5 along with a small quantity of carrier air, and through primary air nozzles 3 is supplied fluidizing gas, which can be, for example, air or a mixture of air and flue gas.

[0055] Tertiary air is supplied above the secondary air nozzles 6 through tertiary air nozzles 7 arranged in the upper part of the furnace 1. The distance h_T of the tertiary air nozzles 7 from the top surface of the fluidized bed 2 can also be optimized according to the furnace load and some other variables. The tertiary air nozzles 7 are usually placed 2 - 4 meters below the furnace nose 9.

[0056] The space confined between the secondary air nozzles 6 and the tertiary air nozzles 7, which space begins from the height level h_s of the secondary air nozzles 6 and ends under the tertiary air nozzles 7, forms a second combustion zone (II). Into the second combustion zone (II), secondary air is supplied through the secondary air nozzles 6, to be mixed together with a flue gas flow rising upwards from the first combustion zone (I) and containing non-combusted gases and particles deriving from the fuel, which gases and particles will be further combusted in the second combustion zone (II).

[0057] The burning of fuel continues further in a third combustion zone (III) beginning from the height level h_T of the tertiary air nozzles 7. The first combustion zone (I) and the second combustion zone (II) are substoichiometric zones, whereas the third combustion zone is a superstoichiometric zone, that is, the total air coefficient SR_{tot} in the third combustion zone (III) is over 1.

[0058] The fine fuel supplied into the fluidized bed 2 dries immediately on coming into contact with the hot fluidized bed material, and it undergoes pyrolysis essentially in its entirety. The volatile matter released from the fuel in connection with the pyrolysis will burn in and above the surface of the fluidized bed 2 with the aid of primary air. The combustion of volatile matter takes place in the first combustion zone (I) in conditions that are substoichiometric as regards the air coefficient SR_{vol} for volatile matter. The higher the air coefficient SR_{vol} for volatile matter, the more quickly the volatile matter will burn, at the same time causing a high local temperature and forming a maximum quantity of hydrocarbon radicals, which are needed for the reduction of nitrogen oxides formed from the fuel.

[0059] The reduction to molecular nitrogen of nitrogen oxides formed from the fuel is carried out mainly in two stages. In the first substoichiometric combustion zone (I) a major part of the volatile matter of the fuel and a part of the carbonization residue are burnt. This takes place in conditions which are substoichiometric as regards the air coefficient SR_{vol} for the volatile matter of the fuel, whereby a lot of hydrocarbon radicals will result. In the embodiment according to Figure 3 (a boiler with high furnace load), the primary air needed for this stage is brought into the furnace mainly through the primary air nozzles 3 as fluidizing gas. A small quantity of air comes into the first combustion zone (I) in connection with the fuel supply through the supply chutes 4 and as cooling air for the start-up burners.

[0060] In the second combustion zone (II), combustion air is supplied into the furnace from the secondary air nozzles 6 so much that substoichiometric combustion conditions are maintained, whereby the total air coefficient SR_{tot} in the second combustion zone (II) is in a range of 0.75 - 0.85, preferably about 0.8.

[0061] Figure 4 shows a fluidized bed boiler with a low furnace load. In this embodiment, primary air is supplied into the first combustion zone (I) mainly in two phases: on the one hand, as fluidizing air through the primary air nozzles 3 and, on the other hand, in connection with the fuel supply as combustion air for the volatile matter. Air conducted into the first combustion zone (I) in connection with the fuel supply is preferably taken from the secondary air register, whereby it reduces the quantity of air to be supplied into the second combustion zone (II). A larger supply of air into the first combustion zone (I) will result in such temperatures in the first combustion zone (I), which are higher than in the boiler with a high furnace load shown in Figure 3. When air is supplied into the furnace 1 along with the fuel supply, the fuel is made to ignite quickly and a major part of the fuel's volatile matter can be burnt before the second combustion zone (II).

[0062] In a fluidized bed boiler with a low furnace load, the distance h_F of the fuel supply openings 5 from the top surface of the fluidized bed 2 is preferably 2.0 - 2.6 meters, and the height h_R of masonry 8 is preferably 2.5 - 4.0 meters. Although the refractory masonry 8 is shown in Figures 3 and 4 as extending up to the height of the fuel supply openings 5 by and large, this need not necessarily be so, but the height h_R of masonry 8 may be different from the fuel supply height h_F. The vertical supply angle α formed between the supply chute 4 and the normal N of the wall A in the furnace 1 is in an approximate range of 25° - 35° in a boiler with low furnace load. When air intended for the combustion of volatile matter is supplied along with the fuel into the fluidized bed, the higher fuel supply height h_F and the more obtuse supply angle α make sure that particles will not escape from the fluidized bed 2 when the mixture of air and fuel hits the top surface of the bubbling fluidized bed 2.

[0063] The optimum height level h_s for the secondary air nozzles 6 is calculated according to the boiler's furnace load and some other parameters with the aid of the formula presented earlier.

[0064] In a boiler with a low furnace load, the air coefficient SR_{vol} for volatile matter in the fuel is in a range of 0.9 - 1.00, preferably about 0.95, in the first combustion zone (I). In the second combustion zone (II), the total air coefficient SR_{tot} is about 0.8, that is, of essentially the same magnitude as in a boiler with a high furnace load. In the third combustion zone (III), the total air coefficient SR_{tot} is about 1.15 irrespective of whether the boiler is with a low furnace load or with a high furnace load.

[0065] The solution according to the invention aims at optimizing the combustion of the fuel's volatile matter in the two first substoichiometric combustion zones (I) and (II) of the furnace. In a boiler with a low furnace load, the first combustion zone (I) is longer and it operates with a higher air coefficient SR_{vol} for volatile matter than the corresponding zone (I) in a boiler with a high furnace load. In a boiler with a low furnace load, the second combustion zone (II) is shorter than in a boiler with a high furnace load, but the total air coefficient SR_{tot} in the second combustion zone (II) is essentially the same, about 0.8, in each boiler. This means in practice that in a boiler with a low furnace load, the first combustion zone (I) operates in a range of SR_{vol} = 0.95 - 1.00, which is an optimum range for the reduction of nitrogen oxides, whereby a major part of the fuel's volatile matter will burn already in the first combustion zone (I). In a boiler with a high furnace load, the temperature of the first combustion zone (I) must be limited, for which reason the air coefficient for volatile matter is preferably kept within a range of SR_{vol} = 0.65 - 0.75. In order to complete the reactions that aim at reduction of nitrogen oxides before the third combustion zone (III), which operates substoichiometric, the length (h_T - h_S) of the second combustion zone (II) is increased in comparison with the corresponding length in a boiler with a low furnace load.

[0066] Figure 5 shows a cross-sectional view of the furnace 1 of a bubbling fluidized bed boiler near the fuel supply height. On the two first walls A of the furnace there are three supply chutes 4, 4a, 4b on each. Each fuel supply chute 4, 4a, 4b ends in a fuel supply opening 5, from which a fuel flow F discharges into the furnace. The central fuel supply chutes 4 are fitted perpendicular to the wall A as seen from above, whereby the fuel flow F leaves from the supply openings 5 in the direction of the normal N of the wall A. The fuel supply chutes 4a and 4b located nearest to a side wall B are mounted at an angle β to the normal N of the first wall A. The size of this so-called horizontal supply angle β is 5-15°, preferably about 10°. The purpose of the angle β is to turn the fuel flows F discharging from the fuel supply chutes 4a, 4b, which are nearest to the furnace's side wall B, away from the adjacent wall B, which is intended to reduce the contamination and/or corrosion of the side walls B. This is especially important when fuel containing much chlorine and/or sulfur is being burnt.

[0067] In addition to the fuel supply chutes 4a, 4b mounted in an oblique position, the furnace in Figure 5 is equipped with side air nozzles 12 in the manner known from Figure 2, each nozzle being fitted in between the outermost fuel supply chute 4a, 4b and the side wall B. The side air nozzles 12 are fitted to blow air in the direction of the side wall B near the fuel supply height, whereby they prevent the fuel flow discharging from the fuel supply chute 4a, 4b from ending up on the side wall B. It is also possible to direct the side air nozzles 12 to blow air obliquely downwards towards the fluidized bed at a suitable vertical angle (not shown). The solution is advantageous especially when fuel containing much chlorine and/or sulfur is being burnt in the bubbling fluidized bed boiler.

[0068] A third way of reducing contamination of furnace walls is by adjusting the momentum of air jets blown from the secondary and/or tertiary air nozzles 6, 7 in such a way that airflows are blown from the nozzles located nearest to the fuel supply wall A with a higher momentum, on an average, than from the nozzles located nearest to the central part of the wall B provided with air nozzles 6, 7. Figures 6 and 7 illustrate this principle.

[0069] Figure 6 shows a side view of air jets S, L, which are blown from secondary or tertiary air nozzles located on two opposite walls B_1 and B_2 of the furnace 1, that is, seen from the direction of the wall A. Figure 7 shows the corresponding air jets S, M, L seen from above.

[0070] On each one of the two opposite walls B_1 and B_2 of the furnace 1 there are mounted eight air nozzles R_1, R_2 in one row, of which some nozzles are nozzles 6_S blowing a small air jet S, some are nozzles 6_M blowing an air jet M of medium size and some are nozzles 6_L blowing a large air jet L. Different momenta of the air jets S, M and L blown from the different nozzles 6_S, 6_M, 6_L can be brought about with technology known as such, for example, with the aid of valves (not shown). The air jets leaving the nozzles situated at different positions have momenta differing from each other in such a way that air jets S with a small momentum alternate with air jets M, L having a larger momentum. Opposite to each air jet S having a small momentum there is on the opposite furnace wall either one of the air jets M or L with a higher momentum. Air jets L with a high momentum are used in the outermost position, that is, in the position nearest to the adjacent wall A, and air jets M with a medium-sized momentum are used in a position near the central part of the wall B. Thus, air jets discharging from the air nozzles located on the nozzle walls B_1, B_2 will efficiently sweep the surfaces both of the nozzle walls B_1, B_2 and of the adjacent walls A. With the aid of the outermost large air jets L an oxygen-rich area is provided near the walls A which are perpendicular to the nozzle walls B_1 and B_2. With the aid of the weak penetration of the small air jets S an oxygen-rich area is provided near the nozzle walls B_1, B_2. The velocity of the small air jets S is preferably less than 15 m/s.

[0071] When burning fuels that are difficult in view of corrosion and contamination, it is possible in the same furnace to use, as is shown in Figure 5, a horizontal inclination by angle β for the outermost fuel chutes and side air blowers 12 as well as the staggered positions of air jets shown in Figures 6 and 7, which provides an oxygen-rich zone near to the furnace walls A, B.

[0072] In the following, the invention is described by referring to examples presented in Tables 1 and 2. The tables show stage by stage the total air coefficients SR_{tot} in a boiler with a high furnace load (Table 1) and in a boiler with a low furnace load (Table 2) when using peat or wood as fuel. The total air coefficient SR_{tot} increases in the vertical direction of the furnace as more air is supplied into the furnace.

[0073] Into the first combustion zone (I) of the furnace air is supplied mainly together with the fluidizing gas as fluidizing air and in connection with the fuel supply as carrier air. The small air volume used for cooling start-up burners has only a minor effect on the total air coefficient SR_{tot} of the first combustion zone (I).

Table 1. Total air coefficients SR_{tot} in a fluidized bed boiler with a high furnace load.

	Wood SR_{tot}	Wood SR_{Vol}	Peat SR_{tot}	Peat SR_{Vol}
Fluidizing air	0.40	0.56	0.35	0.60
Carrier air	0.45	0.62	0.40	0.68
Cooling air for start-up burners	0.47	0.66	0.43	0.73
Secondary air	0.80	1.11	0.80	1.36
Cooling air for load bearing burners	0.83	1.15	0.83	1.41
Tertiary air	1.15	1.59	1.15	1.95

[0074] Addition of secondary air at the beginning of the second combustion zone (II) and addition of tertiary air at the beginning of the third combustion zone (III) clearly raise the total air coefficient SR_{tot}.

[0075] In a boiler with a high furnace load, the fuel supply openings are preferably situated at a height of about 1.8 - 2.0 meters from the surface of the bubbling fluidized bed, and the vertical supply angle for the fuel supply chutes is in a range of 35° - 40°.

[0076] The air distribution according to Table 1 is suitable for use in boilers with a high furnace load and when the fuel is especially dry (under 45 weight-% water in the fuel). In this air distribution, the air coefficient for volatile matter of the fuel in the first combustion zone (I), that is, SR_{vol}, is in a range of 0.65 - 0.75, whereby the combustion temperatures are low in the lower part of the furnace.

[0077] Table 2 shows the air distribution in a bubbling fluidized bed boiler with a low furnace load, where additional air taken from the secondary air register and intended for the combustion of fuel's volatile matter in the first combustion zone (I) is supplied into the boiler furnace in connection with the fuel supply. The air coefficient SR_{vol} for volatile matter should be kept within an optimum range for the reduction of nitrogen oxides, which range is 0.9 - 1.0.

Table 2. Total air coefficients SR_{tot} in a fluidized bed boiler with a low furnace load.

	Wood $SR_{to}t$	Wood SR_{vol}	Peat SR_{tot}	Peat SR_{vol}
Fluidizing air	0.40	0.56	0.44	0.74
Carrier air	0.45	0.62	0.48	0.82
Combustion air for volatile matter	0.62	0.86	0.56	0.95
Cooling air for start-up burners	0.65	0.90	0.59	1.00

(continued)

	Wood $SR_{to}t$	Wood SR_{vol}	Peat SR_{tot}	Peat SR_{vol}
Secondary air	0.80	1.11	0.80	1.36
Cooling air for load bearing burners	0.83	1.15	0.83	1.41
Tertiary air	1.15	1.59	1.15	1.95

[0078] In this case, the combustion air for volatile matter supplied into the first combustion zone (I) in connection with the fuel supply clearly raises the total air coefficient. However, after the supply of secondary air, the total air coefficient is at the same level as in Table 1. Thus, the total air volume to be supplied into the bubbling fluidized bed boiler is the same as in the case shown in Table 1, but the air distribution is different, when in the solution according to Table 2 a part of the secondary air of Table 1 is supplied into the first combustion zone (I) along with the fuel supply.

[0079] In a boiler with a low furnace load, the fuel supply openings are preferably situated at a height of about 2.0 - 2.6 meters from the surface of the bubbling fluidized bed and the vertical supply angle of the fuel supply chutes is 25° - 35°. With a sufficient distance of the supply openings from the fluidized bed and with a sufficiently obtuse supply angle the combustion air for volatile matter is prevented from carrying along particles from the fluidized bed.

[0080] The combustion air for volatile matter supplied into the furnace in connection with the fuel supply is preferably taken from the secondary air, whereby the temperature of the supplied air is in a range of 165 - 330 °C. A sufficiently high temperature of the combustion air for volatile matter will keep the fuel supply chute dry and clean, and no separate "fluidizing air" is needed in the supply chute for cleaning the chute. The flow rate of the combustion air for volatile matter is at an optimum level of 10 - 15 m/s in the fuel supply chutes. This sufficiently low velocity will also for its own part prevent the combustion air for volatile matter from crashing aggressively into the fluidized bed and thus prevents the resulting escape of sand.

[0081] The tertiary air nozzles are preferably located about 2 - 4 meters below the nose of the furnace.

[0082] It is recommendable always when possible to use the method intended for boilers with a low furnace load for reducing nitrogen oxides.

[0083] Many different modifications of the invention are possible within the scope defined by the claims presented in the following.

Claims

1. A method for reducing nitrogen oxide emissions and corrosion in a bubbling fluidized bed boiler burning biofuel and/or waste, in which method air needed for burning the fuel is supplied in stages into the boiler furnace (1), so that at least two substoichiometric zones (I), (II) are brought about, which have as one objective to reduce the formation of nitrogen oxides, and at least one superstoichiometric zone (III), in which the combustion is completed, which combustion zones comprise:

- a first combustion zone (I), which begins from the height level of primary air nozzles (3) and extends above the fluidized bed (2), ending under the height level (h_S) of secondary air nozzles (6);
- a second combustion zone (II), which begins from the height level (h_S) of the secondary air nozzles (6) and ends under the height level (h_T) of tertiary air nozzles (7); and
- a third combustion zone (III), which begins from the height level (h_T) of the tertiary air nozzles,

characterized in that the length of the first combustion zone (I) is optimized by locating the secondary air nozzles (6) at a certain height (h_S) from the top surface of the bubbling fluidized bed (2), which height (h_S) is calculated from the formula:

$$h_S = \frac{Q_f}{LHV_{ref}\,\rho_{ref}A} t_{ref} \quad \frac{q_f}{q_{f,ref}} \qquad (1 + f_{a,ref} SR_{vol,ref})$$

wherein:

h_S = height of the secondary air level from the top surface of the bubbling fluidized bed [m]
Q_f = full fuel power of the boiler [MW]
A = cross-sectional area of the boiler [m^2]

q_f = boiler's full furnace load below the nose [kW/m^3]
LHV_{ref} = lower heat value of the fuel [MJ/kg]
ρ_{ref} = fuel density [kg/m^3]
$q_{f, ref}$ = furnace load [kW/m^3]
$f_{a, ref}$ = air requirement of volatile matter in the fuel [kg air/kg fuel]
t_{ref} = dwell time (in a normal state NTP) [s]
$SR_{vol, ref}$ = air coefficient for fuel volatile matter in the first combustion zone (I),
in which formula some variables are furnace-specific variables, some variables are reference values and thus constants, and some variables are design point-specific reference values, which are chosen according to the boiler's furnace load.

2. Method according to claim 1, **characterized in that** the design point-specific reference values t_{ref} and $SR_{vol, ref}$ are chosen according to the boiler's furnace load so that in a boiler with a high furnace load, having a furnace load higher than 130 kW/m^3, the values t_{ref} = 6 s and $SR_{vol, ref}$ = 0.7 are used, and in a boiler with a low furnace load, having a furnace load lower than 130 kW/m^3, the values t_{ref} = 7 s and $SR_{vol, ref}$ = 0.9 are used.

3. Method according to claim 1 or 2, **characterized in that** in a boiler with a high furnace load the air coefficient SR_{vol} for volatile matter in the first combustion zone (I) is kept within a range of 0.65 - 0.75, preferably at a value of about 0.7, by adjusting the supply of primary air.

4. Method according to claim 1 or 2, **characterized in that** in a boiler with a low furnace load the air coefficient SR_{vol} for volatile matter in the first combustion zone (I) is kept within a range of 0.9 - 1.0, preferably within a range of 0.95 - 1.0, by supplying into the first combustion zone (I) besides the primary air also additional air intended for the combustion of the fuel's volatile matter, which additional air is supplied to the furnace along with the fuel supply and preferably taken from a secondary air register.

5. Bubbling fluidized bed boiler suitable for burning biofuel and/or waste, which comprises a furnace (1), in which there are

- a fluidized bed (2) into which primary air is supplied through primary air nozzles (3) located under the fluidized bed and fuel is supplied through fuel supply openings (5) located in the walls of the furnace (1), which fuel supply openings (5) are located at a first height (h_F) above the surface of the fluidized bed (2),
- a set of secondary air nozzles (6), which are located at a second height (h_S) above the surface of the fluidized bed (2),
- a set of tertiary air nozzles (7), which are located at a third height (h_T) above the surface of the fluidized bed (2),

whereby the following zones are formed in the furnace (1) of the bubbling fluidized bed boiler:

- a first combustion zone (I), which comprises a fluidized bed (2) and a space above it all the way up to a level under the height level (h_S) of the secondary air nozzles (6),
- a second combustion zone (II), which extends from the height level (h_S) of the secondary air nozzles (6) all the way up to a level under the height level (h_T) of the tertiary air nozzles (7),
- a third combustion zone (III), which begins from the height level (h_T) of the tertiary air nozzles (7),

which first combustion zone (I) and second combustion zone (II) are arranged to operate substoichiometric in such a way that the total air coefficient SR_{tot} is under 1 in each zone,
characterized in that the secondary air nozzles (6) are located at a certain height (h_S) from the top surface of the bubbling fluidized bed (2), which height is calculated with the aid of the following formula:

$$h_S = \frac{Q_f}{LHV_{ref}\,\rho_{ref} A} t_{ref} \quad \frac{q_f}{q_{f,ref}} \qquad (1 + f_{a,ref} SR_{vol,ref})$$

wherein:

h_S = height of the secondary air level from the top surface of the bubbling fluidized bed [m]
Q_f = full fuel power of the boiler [MW]
A = cross-sectional area of the boiler [m^2]

q_f = full furnace load of boiler under the nose [kW/m^3] LHV_{ref} = lower heat value of fuel [MJ/kg]
ρ_{ref} = fuel density [kg/m^3]
$q_{f, ref}$ = furnace load [kW/m^3]
$f_{a, ref}$ = air requirement of volatile matter in the fuel [kg air/kg fuel]
t_{ref} = dwell time (in a normal state NTP) [s]
$SR_{vol, ref}$ = air coefficient for fuel volatile matter in the first combustion zone (I),
in which formula some variables are furnace-specific variables, some variables are reference values and thus constants, and some variables are design point-specific reference values, which are chosen according to the boiler's furnace load.

6. Bubbling fluidized bed boiler according to claim 5, **characterized in that** the height h_S of the secondary air level is calculated by using the values t_{ref} = 6 s and $SR_{vol, ref}$ = 0.7 for a boiler with a high furnace load having a furnace load higher than 130 kW/m^3.

7. Bubbling fluidized bed boiler according to claim 5, **characterized in that** the height h_S of the secondary air level is calculated by using the values t_{ref} = 7 s and $SR_{vol, ref}$ = 0.9 for a boiler with a low furnace load having a furnace load lower than 130 kW/m^3 .

8. Bubbling fluidized bed boiler according to any one of claims 5-7, **characterized in that** the lower part of the furnace (1) is equipped with masonry (8), which extends to a height of 1.8 - 2.4 meters from the surface of the fluidized bed (2), preferably to a height of 1.8 - 2.0 meters from the surface of the fluidized bed (2).

9. Bubbling fluidized bed boiler of low furnace load according to claim 7, **characterized in that** the fuel supply openings (5) are fitted at a height (h_F) of 2.0 - 2.6 meters from the surface of the fluidized bed (2) and the vertical supply angle (α) of the fuel chutes (4) is 25° - 35°.

10. Bubbling fluidized bed boiler of high furnace load according to claim 6, **characterized in that** the fuel supply openings (5) are fitted at a height (h_F) of 1.8 - 2.0 meters from the surface of the fluidized bed (2) and the vertical supply angle (α) of the fuel chutes (4) is 35° - 40°.

11. Bubbling fluidized bed boiler according to any one of claims 5-10, **characterized in that** the fuel supply chutes (4, 4a, 4b) are placed in connection with a first furnace wall (A) and that the fuel supply chutes (4a, 4b) located nearest to a second furnace wall (B), which is perpendicular to the first wall (A), are turned in the horizontal direction away from said second wall (B) by a horizontal supply angle (β), which horizontal supply angle (β) is in a range of 5-15°, preferably about 10°.

12. Bubbling fluidized bed boiler according to any one of claims 5-11, **characterized in that** between the fuel supply chute (4a, 4b) on the first furnace wall (A) and the nearest second wall (B) a side air nozzle (12) is mounted, through which an airflow can be blown into the furnace (1) to prevent the fuel released from the fuel supply chute (4a, 4b) from attaching to the nearest second wall (B).

13. Bubbling fluidized bed boiler according to any one of claims 5-12, **characterized in that**

- the secondary air nozzles (6) and/or the tertiary air nozzles (7) are arranged in two opposite rows (R_1, R_2) on two opposite walls (B_1, B_2) of the furnace (1),
- in each row (R_1, R_2) there are nozzles (6_S) blowing a small air jet (S), nozzles (6_M) blowing a medium-sized air jet (M) and nozzles (6_L) blowing a large air jet (L), which nozzles are arranged to alternate in such a way that every second nozzle is a nozzle (6_S) blowing a small air jet (S) and every second nozzle is a nozzle (6_M, 6_L) blowing a medium-sized (M) or a large air jet (L),
- the nozzles are arranged in a staggered fashion, so that opposite to each nozzle (6_S) blowing a small air jet (S) there is on the opposite wall (B_1, B_2) a nozzle (6_M, 6_L) blowing a medium-sized (M) or a large air jet (L),
- of the outermost nozzles in each row (R_1, R_2) at least one is a nozzle (6_L) blowing a large air jet (L) and of the nozzles located in the central area of each row (R_1, R_2) at least one is a nozzle (6_M) blowing a medium-sized air jet (M).

14. Bubbling fluidized bed boiler according to claim 5, **characterized in that** it comprises outermost fuel supply chutes (4a, 4b) inclined inwards in the manner described in claim 11, side air nozzles (12) arranged in the manner described in claim 12 and secondary and/or tertiary air supply nozzles (6, 7) arranged in the manner described in claim 13, whereby the boiler is especially suitable for burning fuel containing chlorine and/or sulfur.

15. Bubbling fluidized bed boiler according to any one of claims 5-14, **characterized in that** the tertiary air nozzles (7) are located 2 - 4 meters below the nose (9) of the furnace (1).

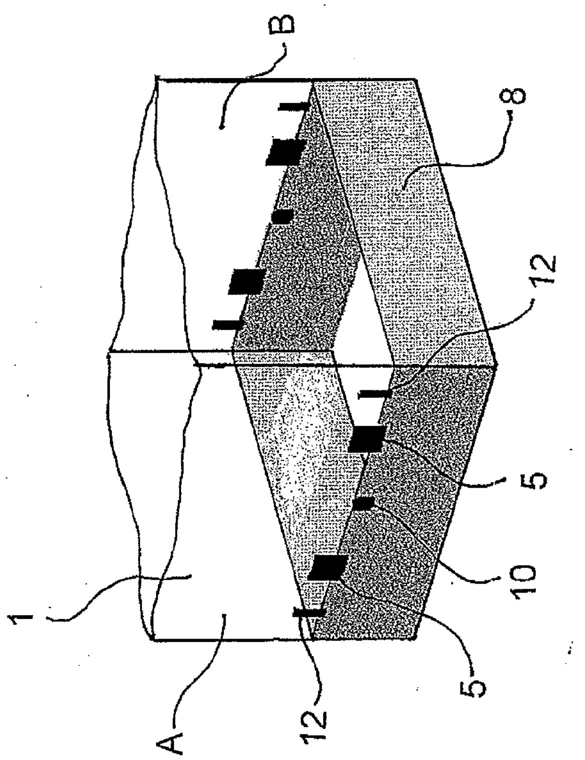

FIG. 2

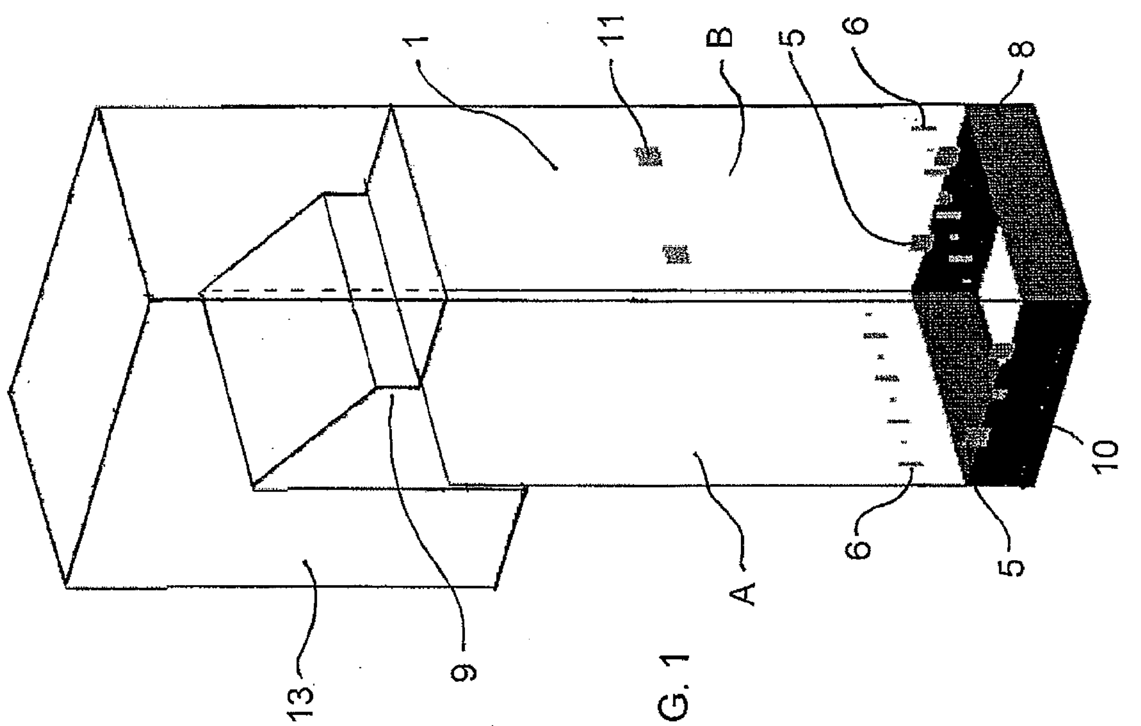

FIG. 1

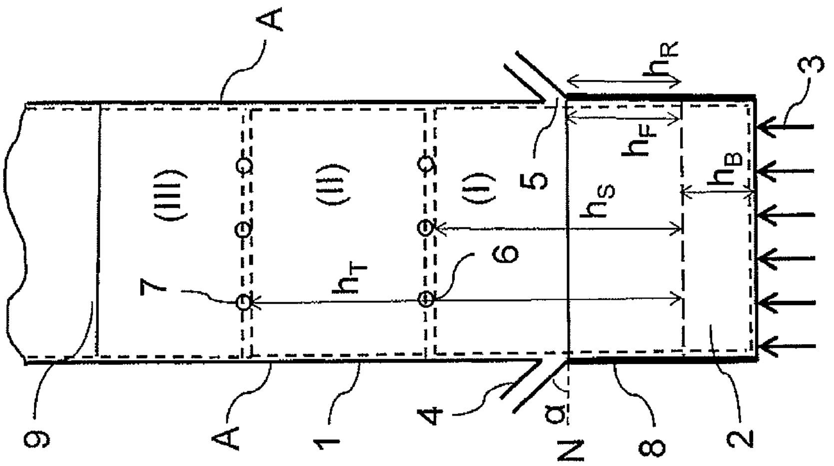
A
A
h_R
3
5
h_F
h_B
(III)
(II)
(I)
h_S
7
h_T
6
9
1
4
α
N
8
2

FIG. 4

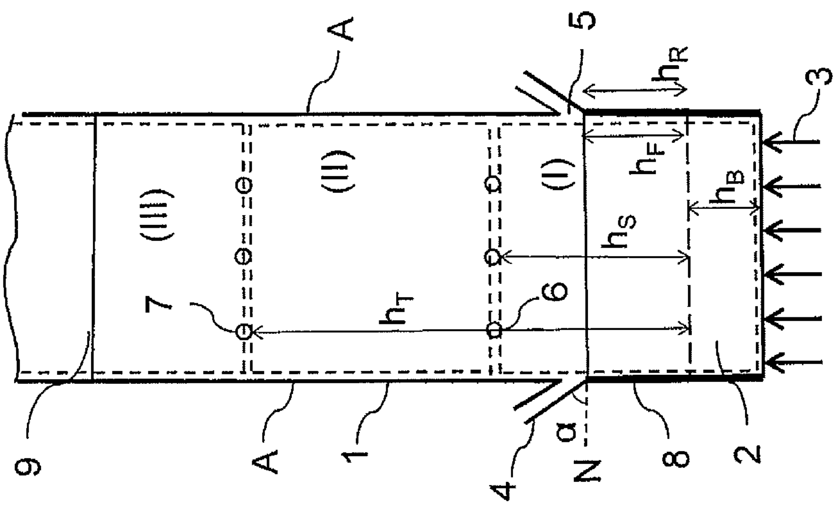
A
5
h_R
3
h_F
h_B
(III)
(II)
(I)
h_S
7
h_T
6
9
A
1
4
α
N
8
2

FIG. 3

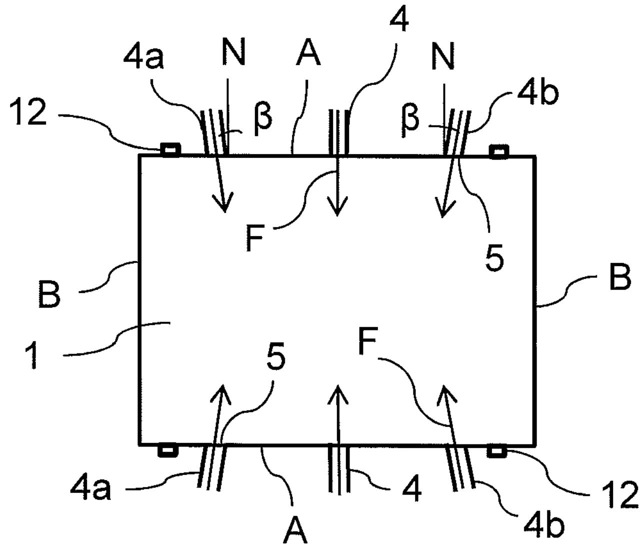

FIG. 5

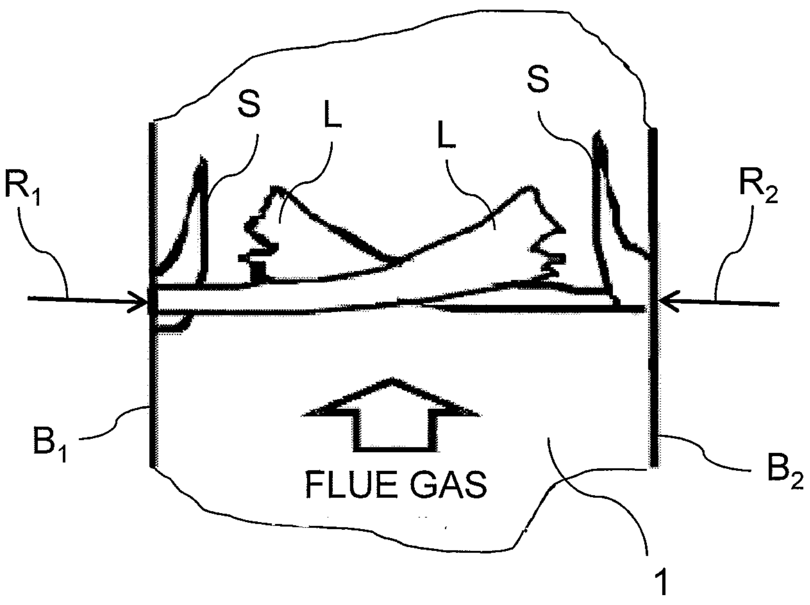

FIG. 6

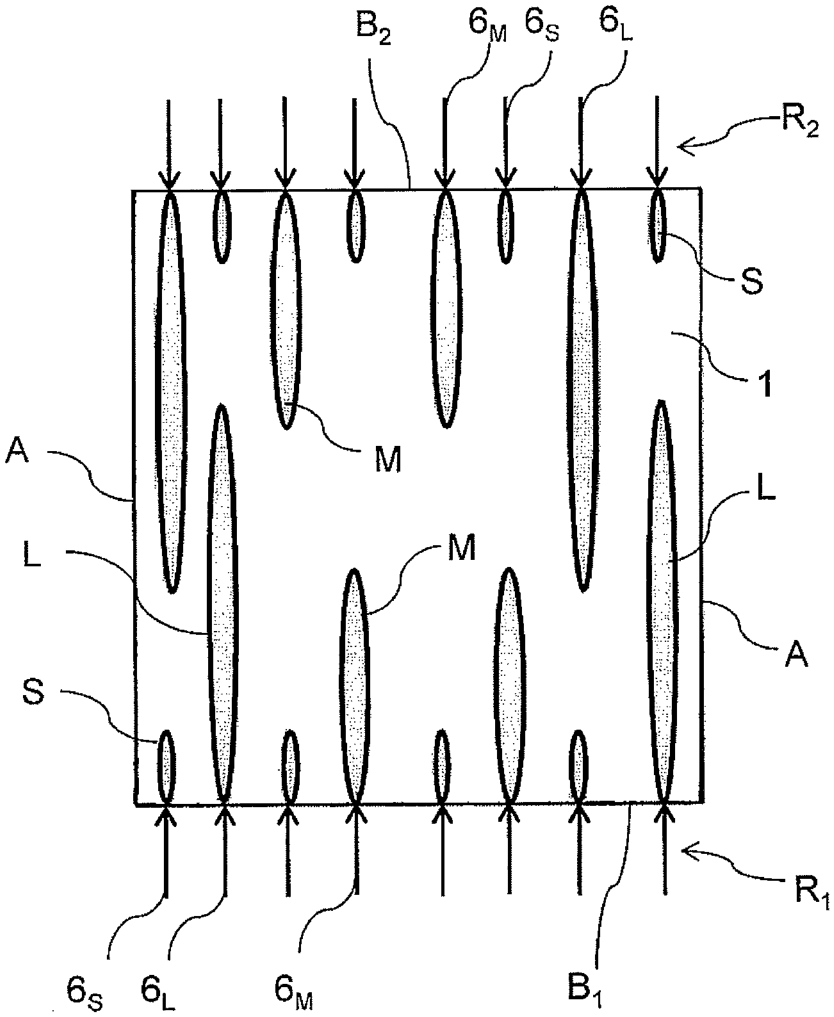

FIG. 7

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- WO 2006084954 A1 **[0013] [0014] [0034] [0035]**