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(71) Applicant: **Fortum OYJ**
02150 Espoo (FI)

(72) Inventors:
- **Dernjatin, Pauli**
  00670 Helsinki (FI)
- **Heikkilä, Jouko**
  00350 Helsinki (FI)
- **Huttunen, Marko**
  Espoo (FI)

(74) Representative: **Papula Oy**
P.O. Box 981
00101 Helsinki (FI)

(54) **METHOD FOR FEEDING AIR TO A FLUIDIZED BED BOILER, A FLUIDIZED BED BOILER AND FUEL FEEDING MEANS FOR A FLUIDIZED BED BOILER**

(57) The invention relates to a method for feeding air to a fluidized bed boiler. The method comprises supplying primary air into the first combustion zone (I) from under the fluidized bed and supplying combustion air for volatile matter into the first combustion zone (I) along with the fuel supply. Part of the combustion air for volatile matter is supplied as a first combustion air supply mixed with the fuel supply and part of the combustion air for volatile matter is supplied as a second combustion air supply surrounding at least part of the fuel supply. The velocity at which the combustion air for volatile matter is supplied in both the first and the second combustion air supplies is 10 to 25 m/s. The invention further relates to a fluidized bed boiler and fuel feeding means.

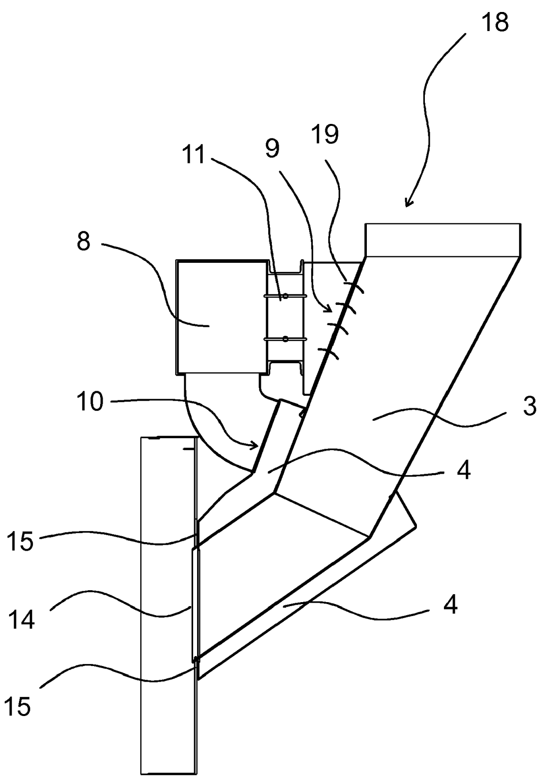

Fig.4

EP 3 054 214 A1

Description

FIELD OF THE INVENTION

[0001] The present invention relates to a method for feeding air to a fluidized bed boiler. The present invention further relates to a fluidized bed boiler and to fuel feeding means for a fluidized bed boiler.

BACKGROUND OF THE INVENTION

[0002] Fluidized bed boilers are in general use for producing energy from biofuels of various kinds and from oil-based waste. Fuels of this type are characterized in that the share of volatile matter is high in the dry matter of the fuel. The fuel used in fluidized bed boilers often contains fine and light particles, which are easily carried away with the fluidizing gas and secondary air into the upper parts of the furnace. Controlling combustion and reduction of nitrogen oxide emissions with this type of fuels is challenging.

[0003] In the near future, new, significantly stricter nitrogen oxide (NO_x) emission limits depending on the fuel power of the boiler are about to enter into force in the member states of the European Union (Industrial Emissions Directive, IED). There is thus the need for developing better ways to reduce nitrogen oxide emissions.

[0004] There are two main types of fluidized bed boilers: bubbling fluidized bed boilers (BFB) and circulating fluidized bed boilers (CFB). In fluidized bed boilers, combustion is stabilized by a fluidized bed having a large thermal capacity. The fluidized bed consists of a fine incombustible material, such as sand, which is fluidized by supplying fluidizing gas into the bed from below. The main difference between BFB boilers and CFB boilers is in fluidization velocity. Low gas velocity is used in BFB boilers and the position of the solids layer is relatively stationary, forming a fluidized bed in the lower part of the furnace. 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.

[0005] Nitrogen oxide emissions are conventionally reduced using staged air supply. The fuel is supplied on top of the fluidized bed or into 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.

[0006] 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):

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

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

[0007] Additionally, 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:

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

[0008] 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.

[0009] 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.

[0010] 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, i.e. combustion air for volatile matter, is supplied into the furnace in connection with the fuel supply in the same direction as the fuel itself. The combustion air for volatile matter can be supplied either with the fuel or within the immediate vicinity of the fuel supply point in the same direction as the fuel itself. The quantity of combustion air for volatile matter is adjusted to be such that the combustion of volatile matter released from the fuel will take place in substoichiometric conditions in relation to the volatile matter. The air coefficient in relation to volatile matter, that is, SR_{VOL}, in the primary air zone is as high as possible, however, less than 1.

[0011] In the method described in WO 2006084954 A1, the combustion air for volatile matter may supplied within the immediate vicinity of the fuel supply point in the same direction as the fuel itself. In order to increase the air coefficient for volatile matter SR_{VOL} close to 1, the amount of combustion air for volatile matter supplied in connection with the fuel is such that the velocity of the air supplied parallelly with the fuel is high as compared to the velocity of the fuel supply. Depending on the pipe construction, the velocity of the combustion air for volatile matter may be, for instance, 30 - 40 m/s. The great velocity difference between the stream of combustion air for volatile matter and the fuel stream causes underpressure at the outlet of the fuel feed pipe. Equalization of pressures at the outlet of the fuel feed pipe causes mixing of the streams and spreading of the fuel feed particles to the walls of the furnace forming slags. Slagging prevents full utilization of the system and reduces boiler availability by increasing the need for maintenance. In addition, the desired flux flow of the fuel into the fluidized bed is not achieved. With such a high velocity, the combustion air for volatile matter crashes aggressively into the fluidized bed and results in escape of sand from the fluidized bed. As a consequence, the fluidized bed does not work in the way planned. An alternative way of supplying combustion air for volatile matter described in WO 2006084954 A1 is such that the combustion air for volatile matter is supplied together with the fuel. In this case, the fuel is not efficiently directed into the fluidized bed. Due to these drawbacks, reduction in nitrogen oxide emissions is not sufficient.

[0012] GB 2286345 describes a solution for fluidized bed combustion for directing fuel into the fluidized bed in which a high velocity collar or curtain of air, recycled flue gas or a proportion of each surrounds the fuel or fuel and air/gas mixture. The gas curtain is usually of higher velocity than the fuel or fuel and air/gas mixture. The high velocities and the velocity difference of the gas curtain and the fuel or fuel and air/gas mixture cause the fuel and air to crash into the fluidized bed in too high a velocity, thereby causing slagging of the boiler walls and escape of sand from the fluidized bed.

PURPOSE OF THE INVENTION

[0013] The purpose of the invention is to provide a new type of method for feeding air to a fluidized bed boiler with improved fluid dynamics inside the furnace, thus enabling more efficient reduction of nitrogen oxide emissions of the boiler and improvement of the efficiency of the boiler. Further, the purpose of the invention is to provide a fluidized bed boiler and fuel feeding means for a fluidized bed boiler.

SUMMARY

[0014] The present invention relates to a method for feeding air to a fluidized bed boiler burning fuel. The fluidized bed boiler comprises a fluidized bed and a boiler furnace comprising a first combustion zone (I). Air needed for burning the fuel in the fluidized bed is supplied in stages into the boiler furnace for causing substoichiometric combustion in the first combustion zone (I). The method comprises:

- supplying primary air into the first combustion zone (I) from under the fluidized bed for fluidizing the bed material;
- supplying combustion air for volatile matter into the first combustion zone (I) along with the fuel supply.

[0015] Part of the combustion air for volatile matter is supplied as a first combustion air supply mixed with the fuel supply and part of the combustion air for volatile matter is supplied as a second combustion air supply surrounding at least part of the fuel supply. The velocity at which the combustion air for volatile matter is supplied in both the first and the second combustion air supplies is 10 to 25 m/s.

[0016] The present invention further relates to a fluidized bed boiler comprising a fluidized bed, a boiler furnace comprising furnace walls and a first combustion zone (I),
primary air nozzles under the fluidized bed for supplying primary air into the first combustion zone (I) for fluidizing the bed material,

at least one fuel feed pipe on at least one furnace wall in the first combustion zone (I) for supplying fuel into the fluidized bed, the at least one fuel feed pipe comprising a first outlet, and

an inlet for supplying combustion air for volatile matter into the first combustion zone (I) along with the fuel supply.

[0017] The boiler comprises at least one air feed channel around at least part of the length of the fuel feed pipe and surrounding at least part of the fuel feed pipe, the at least one air feed channel comprising a second outlet. Part of the combustion air for volatile matter is arranged to be supplied into the boiler furnace through the fuel feed pipe as a first combustion air supply mixed with the fuel supply and part of the combustion air for volatile matter is arranged to be supplied into the furnace through the at least one air feed channel as a second combustion air supply surrounding at least part of the fuel supply. The cross-sectional area of the fuel feed pipe at the first outlet and of the at least one air feed channel at the second outlet is arranged to be such that the velocity at which the combustion air for volatile matter is supplied in the first combustion air supply and in the second combustion air supply is 10 to 25 m/s.

[0018] The present invention further relates to a fluidized bed boiler comprising a fluidized bed, a boiler furnace comprising furnace walls and a first combustion zone (I),

primary air nozzles under the fluidized bed for supplying primary air into the first combustion zone (I) for fluidizing the bed material,

at least one fuel feed pipe on at least one furnace wall in the first combustion zone (I) for supplying fuel into the fluidized bed, and

an inlet for supplying combustion air for volatile matter into the first combustion zone (I) along with the fuel supply.

[0019] The boiler comprises at least one air feed channel around at least part of the length of the fuel feed pipe and surrounding at least part of the fuel feed pipe. Part of the combustion air for volatile matter is arranged to be supplied into the boiler furnace through the fuel feed pipe as a first combustion air supply mixed with the fuel supply and part of the combustion air for volatile matter is arranged to be supplied into the furnace through the at least one air feed channel as a second combustion air supply surrounding at least part of the fuel supply.

[0020] The present invention further relates to fuel feeding means for a fluidized bed boiler comprising at least one fuel feed pipe for supplying fuel into the fluidized bed, the fuel feed pipe comprising a first outlet, and an inlet for supplying combustion air for volatile matter along with the fuel supply. The fuel feeding means comprise at least one air feed channel around at least part of the length of the fuel feed pipe and surrounding at least part of the fuel feed pipe, the at least one air feed channel comprising a second outlet. Part of the combustion air for volatile matter is arranged to be supplied through the fuel feed pipe as a first combustion air supply mixed with the fuel supply and part of the combustion air for volatile matter is arranged to be supplied through the at least one air feed channel as a second combustion air supply surrounding at least part of the fuel supply. The cross-sectional area of the fuel feed pipe at the first outlet and of the at least one air feed channel at the second outlet is arranged to be such that the velocity at which the combustion air for volatile matter is supplied in the first combustion air supply and in the second combustion air supply is 10 to 25 m/s.

[0021] The present invention further relates to fuel feeding means for a fluidized bed boiler comprising at least one fuel feed pipe for supplying fuel into the fluidized bed, and an inlet for supplying combustion air for volatile matter along with the fuel supply. The fuel feeding means comprise at least one air feed channel around at least part of the length of the fuel feed pipe and surrounding at least part of the fuel feed pipe. Part of the combustion air for volatile matter is arranged to be supplied through the fuel feed pipe as a first combustion air supply mixed with the fuel supply and part of the combustion air for volatile matter is arranged to be supplied through the at least one air feed channel as a second combustion air supply surrounding at least part of the fuel supply.

[0022] The inventors surprisingly found out that when part of the combustion air for volatile matter is supplied as mixed with the fuel supply and part of the combustion air for volatile matter is supplied as surrounding at least part of the fuel supply in a manner where the velocities of the two air supplies are controlled, fluid dynamics at the outlet of the fuel feed pipe are improved. Flux flow of the fuel and the combustion air for volatile matter into the fluidized bed is achieved. Feeding of the fuel and combustion air for volatile matter into the fluidised bed is more easily controlled, thereby reducing slagging of the boiler walls and escape of sand from the fluidized bed. Improvements in fluid dynamics thus facilitate full utilization of the boiler. Maintenance intervals are extended, which improves boiler availability. Further, operating costs are reduced.

[0023] According to the invention, combustion air for volatile matter is supplied as divided into first and second combustion air supplies. The first combustion air supply is mixed with the fuel supply. The second combustion air supply surrounds at least part of the fuel supply. The fuel is more efficiently migrated into the fluidized bed when it is mixed with combustion air for volatile matter, causing efficient combustion of the fuel. In addition, combustion air for volatile matter forms a curtain of combustion air around the fuel stream or part of the fuel stream, thereby directing the fuel stream, including fine fuel particles, into the fluidized bed and preventing escape of fuel particles to the upper parts of the furnace. The air curtain also prevents fuel particles from ending up on the boiler walls. If the fuel stream is not directed into the fluidized bed, fine fuel particles are easily captured and carried to the upper parts of the furnace by fluidizing air fed from the bottom of the furnace to fluidize the bed material. Because essentially all the fuel is forced into the fluidized bed, the amount of unburned fuel is minimized and combustion of the fuel is more complete. Also, the dwell time of the fuel in the furnace is increased and the combustion is easier to control.

[0024] The velocity at which the combustion air for volatile matter is supplied in both the first and the second combustion air supplies is 10 to 25 m/s. The velocity at which the combustion air for volatile matter is supplied means the velocity of the combustion air for volatile matter at the outlet of the air feed pipe or the air feed channel. By controlling the velocities of air supplies the crash of air into the fluidized bed and escape of sand can be reduced. The velocity of the air supply depends on the cross-section of the pipe or channel in which the supply flows, i.e. the smaller the cross-section, the faster the flow. Good fluid dynamics at the outlet of the fuel feed pipe are achieved when the velocity at which the combustion air for volatile matter is supplied in both supplies is 10 to 25 m/s. According to CFD (Computational Fluid Dynamics) calculations, the overall fluid dynamics in fluidized bed boiler furnace relative to nitrogen oxide emissions are improved when output velocities of both combustion air supplies are in this velocity range. Because the combustion air for volatile matter is directed to the furnace both mixed with the fuel supply and surrounding at least part of the fuel supply, the total additional air flow needed to increase SR_{VOL} near value 1 is divided into larger cross-section of the pipe, and the velocity of the air is decreased. As a consequence, nitrogen oxide emissions are decreased and combustion is enhanced. Too high velocities end up in increasing nitrogen oxide emissions.

[0025] The method and the fluidized bed boiler according to the present invention lead to improved reduction in nitrogen oxide emissions. Better nitrogen oxide reduction is achieved when combustion air for volatile matter is supplied both mixed with the fuel supply and surrounding at least part of the fuel supply together, as compared to supplying combustion air for volatile matter either mixed with the fuel supply or surrounding the fuel supply solely or together but with a large velocity difference between the two air supplies. Similar results have been achieved for boilers of both high and low furnace load. In bubbling fluidized bed boilers of furnace loads of 144 MW/m^3 and 120 MW/m^3, nitrogen oxide emissions have been reduced by 100 - 150 mg/Nm^3, thereby reducing overall nitrogen oxide emissions by 20 - 30 % as compared to conventional staged combustion. The above results are achieved when SR_{VOL} in the first combustion zone is approximately 0.95 and the refractory lining in the lower part of the furnace extends to a height of 1.8 meters from the surface of the fluidized bed.

[0026] The current invention also reduces the temperature of the flue gas at the furnace exit (Furnace Exit Gas Temperature, FEGT). Volatile matter released from the fuel is burnt as low in the furnace as possible. As a result, most of the volatile matter can be burnt before the second combustion zone. Also, the fuel particles are forced to the fluidized bed and therefore do not escape to the upper parts of the furnace. Thus the temperature in the upper part of the furnace and of flue gases at the nose of the furnace is not excessively risen. Low FEGT improves the efficiency of the boiler. Similar results have been achieved for boilers of both high and low furnace load. In bubbling fluidized bed boilers of furnace loads of 144 MW/m^3 and 120 MW/m^3, temperature of the flue gas at the furnace exit (FEGT) has been reduced by 50 to 100 °C as compared to conventional staged combustion. The above results are achieved when SR_{VOL} in the first combustion zone is approximately 0.95 and the refractory lining in the lower part of the furnace extends to a height of 1.8 meters from the surface of the fluidized bed.

[0027] Low FEGT also decreases fouling of the heat transfer surfaces. 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.

[0028] The first combustion zone (I) begins from the height level of the primary air nozzles and extends up to below the height level of secondary air nozzles. For a bubbling fluidized bed boiler, the length of the first combustion zone (I) may be optimized by optimizing the height of secondary air nozzles by the method described in EP 2574841 A2, the contents of which is incorporated herein by reference. In one embodiment, the method comprises supplying secondary air above the first combustion zone (I). In one embodiment, the fluidized bed boiler comprises a boiler furnace comprising secondary air nozzles on at least one furnace wall above the first combustion zone (I) for supplying secondary air above the first combustion zone (I). In one embodiment, the fluidized bed boiler comprises a boiler furnace comprising secondary air nozzles on at least one furnace wall above the first combustion zone (I) for supplying secondary air into the second combustion zone (II).

[0029] In one embodiment, the fluidized bed boiler is a bubbling fluidized bed boiler, and the method comprises supplying secondary air into the second combustion zone (II) located above the first combustion zone (I). The second combustion zone (II) begins from the height level of the secondary air nozzles and extends up to below the height level of tertiary air nozzles. The second combustion zone (II) is substoichiometric. In one embodiment, the fluidized bed boiler is a bubbling fluidized bed boiler, and the method comprises supplying tertiary air into a third combustion zone (III) located above the second combustion zone (II). In one embodiment, the fluidized bed boiler is a bubbling fluidized bed boiler which comprises tertiary air nozzles on at least one furnace wall above the second combustion zone (II) for supplying tertiary air into the third combustion zone (III). In one embodiment, the tertiary air nozzles are located 2 - 4 meters below the furnace nose.

[0030] In one embodiment, the fluidized bed boiler is a circulating fluidized bed boiler, and the method comprises supplying secondary air into the third combustion zone (III) located above the first combustion zone (I). In a circulating fluidized bed boiler, the third combustion zone (III) begins from the height level of the secondary air nozzles and extends up to the height level of furnace nose. In the third combustion zone (III), the total air coefficient SR_{TOT} is about 1.2.

[0031] The first and second combustion zones (I,II) are substoichiometric. By substoichiometric combustion it is meant that the total air coefficient SR_{TOT} is kept substoichiometric. The total air coefficient SR_{TOT} is kept superstoichiometric in the third combustion zone (III), in which the combustion is completed.

[0032] Part of the combustion air for volatile matter is supplied as a first combustion air supply mixed with the fuel supply. A small amount of carrier air may also be supplied with the fuel supply.

[0033] Part of the combustion air for volatile matter is supplied as a second combustion air supply surrounding at least part of the fuel supply. In one embodiment, the second combustion air supply fully surrounds the fuel supply. In one embodiment, the second combustion air supply surrounds the fuel supply on three sides but not on side below the fuel supply. In one embodiment, the at least one air feed channel surrounds the fuel feed pipe on all sides.

[0034] In one embodiment, the at least one air feed channel surrounds the fuel feed pipe on three sides but not on side below the fuel feed pipe. In one embodiment, the at least one air feed channel surrounds the fuel feed pipe on all sides. The at least one air feed channel may be one air feed channel or several separate air feed channels surrounding at least part of the fuel feed pipe.

[0035] In one embodiment, at least part of the length of the fuel feed pipe is surrounded by at least one air feed channel. In one embodiment, at least part of the circumference or perimeter of the cross section of the fuel feed pipe is surrounded by at least one air feed channel. The inlet for supplying combustion air for volatile matter or the at least one air feed channel may contain means for directing the air flow, such as guide vanes.

[0036] In one embodiment, the fuel is biofuel, peat or oil-based waste. In one embodiment, biofuel comprises wood and industrial sewage sludge. In one embodiment, oil-based waste comprises plastics waste. In one embodiment, the fluidized bed boiler is a circulating fluidized bed boiler and the fuel comprises coal.

[0037] In one embodiment, several fuel feed pipes are located on two opposite furnace walls. The fuel feed pipe comprises a first outlet for directing fuel into the furnace. The outlets of the fuel feed pipes are usually located side by side at the same height. The cross-section of the fuel feed pipe may be of any shape. In one embodiment, the cross-section of the fuel feed pipe is rectangular. In one embodiment, the cross-section of the fuel fee pipe is round.

[0038] The bed material is fluidized by supplying fluidizing gas from under the fluidized bed. In one embodiment, fluidizing gas is supplied trough primary air nozzles. 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 are in continuous motion and the bed efficiently mixes together the bed material and the fuel supplied into it. In a BFB boiler the fluidizing gas velocity is set such that the particles will not escape along with the gas flow into the upper part of the boiler but will form a fluidized bed in the lower part of the boiler. In a CFB boiler, the fluidizing gas velocity is set such that the fluidized bed extends to the upper part of the boiler.

[0039] EP 2574841 A2 discloses ways to adjust certain boiler parameters, which may be used together with the current invention for improving nitrogen oxide reduction. The content of EP 2574841 A2 is disclosed herein by reference. For BFB boilers the distance of the fuel supply openings from the surface of the bubbling fluidized bed described in EP 2574841 A2 may be used to improve nitrogen oxide reduction. For both BFB and CFB boilers, the vertical supply angle and horizontal supply angle of the fuel chutes, the arrangement of secondary and tertiary air nozzles in rows including nozzles blowing a small, medium and large air jet, and the side air nozzles placed between the outermost fuel supply chutes and the side wall described in EP 2574841 A2 may be used to improve nitrogen oxide reduction.

[0040] In addition to primary air, the first combustion zone (I) is supplied with combustion air for volatile matter in order to enhance nitrogen oxide reduction. The amount of primary air supplied into the first combustion zone (I) as a fluidizing gas or as a part of it does not change as compared to conventional fluidized bed combustion. The total amount of combustion air in the first combustion zone (I) is thus increased by adding combustion air for volatile matter. In one embodiment, the air coefficient in relation to volatile matter SR_{VOL} in the first combustion zone (I) is in the substoichiometric area. That is, SR_{VOL} is below 1.

[0041] 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.

[0042] Since SR_{VOL} is in substoichiometric area, combustion of volatile matter released from the fuel in pyrolysis takes place in substoichiometric conditions in relation to volatile matter. In one embodiment, the air coefficient in relation to volatile matter is below 1, but as high as possible in order to enhance combustion of volatile matter in the first combustion zone (I). The higher the air coefficient SR_{VOL} in relation to 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. Most of the volatile matter can be burnt in the first combustion zone (I) before the supply of secondary air. In one embodiment, the total air coefficient SR_{TOT} in the first combustion zone is substoichiometric.

[0043] In one embodiment the air coefficient in relation to volatile matter SR_{VOL} in the first combustion zone (I) is 0.9 - 1.0. When the air coefficient in relation to volatile matter SR_{VOL} in the first combustion zone (I) is 0.9 - 1.0, nitrogen oxides are efficiently reduced, whereby a major part of the fuel's volatile matter will burn already in the first combustion zone (I). In one embodiment the air coefficient in relation to volatile matter SR_{VOL} in the first combustion zone (I) is 0.95 - 1.0. The optimum air coefficient in relation to volatile matter SR_{VOL} in the first combustion zone (I) depends on the fuel, because different fuels have different contents of volatile matter.

[0044] In one embodiment the boiler is a bubbling fluidized bed boiler and the boiler furnace comprises a second combustion zone (II) located above the first combustion zone (I), and the total air coefficient SR_{TOT} in the second combustion zone (II) is 0.75 - 0.85. In one embodiment the total air coefficient SR_{TOT} in the second combustion zone (II) is 0.8. In one embodiment the total air coefficient SR_{TOT} in the second combustion zone (II) is 0.75 - 0.85. In one embodiment the total air coefficient SR_{TOT} in the second combustion zone (II) is 0.8. Substoichiometric conditions are maintained above the first combustion zone (I).

[0045] In one embodiment, the combustion air for volatile matter comprises secondary air. In one embodiment the combustion air for volatile matter consists of secondary air. The amount of secondary air provided above the first combustion zone (I) is decreased correspondingly. In one embodiment, part of the secondary air is supplied as combustion air for volatile matter into the first combustion zone (I). In one embodiment, the temperature of the combustion air for volatile matter is 150 to 250 °C. Secondary air is typically preheated in order to enhance combustion in the furnace, the temperature of secondary air in a fluidized bed boiler typically being in a range of 150 - 250 °C. As a result of mixing hot combustion air for volatile matter with the fuel supply, drying of the fuel particles and subsequent pyrolysis already begin inside the fuel feed pipe. Consequently, combustion of the fuel begins earlier and is enhanced in the lower part of the furnace, thereby increasing the temperature in the lower part of the furnace. The time available for combustion is increased. When hot combustion air for volatile matter is used, the result of combustion is better. Most of the volatile matter released from the fuel in pyrolysis is burnt in the first combustion zone before supply of secondary air. In addition, mixing of the combustion air for volatile matter with the fuel is improved by the high temperature. The high temperature of the combustion air for volatile matter also keeps the fuel supply chutes dry and clean, and no separate "fluidizing air" is needed in the supply chute for cleaning the chute.

[0046] In one embodiment, the fluidized bed boiler comprises secondary air nozzles on at least one furnace wall above the first combustion zone (I) for supplying secondary air above the first combustion zone (I), and the inlet is connected to the secondary air for supplying secondary air at least as part of the combustion air for volatile matter. In one embodiment, the inlet is connected to the secondary air for supplying secondary air as the combustion air for volatile matter. In one embodiment, the temperature of the combustion air for volatile matter is arranged to be 150 to 250°C.

[0047] In one embodiment the velocity at which the combustion air for volatile matter is supplied in both the first and the second combustion air supplies is 12 to 20 m/s. Good fluid dynamics are achieved when the velocity is in this range. In one embodiment the velocity at which the combustion air for volatile matter is supplied in both the first and the second combustion air supplies is 15 to 20 m/s. In one embodiment, the velocity at which the combustion air for volatile matter is supplied in the first combustion air supply is the same as the velocity at which the combustion air for volatile matter is supplied in the second combustion air supply. This way, flux flow is achieved directing the fuel into the fluidized bed.

[0048] In one embodiment, the velocity at which the combustion air for volatile matter is supplied in the first combustion air supply is 12 to 20 m/s. In one embodiment, the velocity at which the combustion air for volatile matter is supplied in the first combustion air supply is 15 to 20 m/s. In one embodiment, the velocity at which the combustion air for volatile matter is supplied in the first combustion air supply is 15 m/s.

[0049] In one embodiment the velocity at which the combustion air for volatile matter is supplied in the second combustion air supply is 12 to 20 m/s. In one embodiment the velocity at which the combustion air for volatile matter is supplied in the second combustion air supply is 15 to 20 m/s. In one embodiment the velocity at which the combustion air for volatile matter is supplied in the second combustion air supply is 15 m/s.

[0050] In one embodiment the first combustion air supply comprises 60 to 70 % of the combustion air for volatile matter and the second combustion air supply comprises 30 to 40 % of the combustion air for volatile matter. According to CFD calculations and confirmed by experiments in fluidized bed boilers, fluid dynamics in the furnace in relation to reduction of nitrogen oxide emissions are improved when 60 to 70 % of combustion air for volatile matter is supplied as mixed with the fuel supply and from 30 to 40 % of combustion air for volatile matter is supplied as surrounding the fuel supply. The fuel particles end up into the fluidized bed, thereby preventing fouling of the heat transfer surfaces of the boiler. This solution reduces nitrogen oxide emission levels to about 250 mg/Nm^3.

[0051] In one embodiment the fuel is supplied into the first combustion zone (I) through a fuel feed pipe, and the first combustion air supply is mixed with the fuel supply and supplied into the furnace simultaneously with the fuel supply through said fuel feed pipe. In one embodiment, the fuel supply and first combustion air supply are mixed in the fuel feed pipe.

[0052] In one embodiment the second combustion air supply is supplied into the first combustion zone (I) through at least one air feed channel arranged around at least part of the length of the fuel feed pipe and surrounding at least part of the fuel feed pipe.

[0053] In one embodiment the first combustion air supply and the second combustion air supply are simultaneously supplied into the first combustion zone (I).

[0054] In one embodiment the method is carried out in a bubbling fluidized bed boiler, in which the fluidized bed has a top surface and the boiler furnace has a lower part which is equipped with a refractory lining extending to a height of 1.8 - 2.4 meters from the top surface of the fluidized bed. In one embodiment, the boiler is a bubbling fluidized bed boiler, in which the fluidized bed (1) has a top surface and the boiler furnace has a lower part which is equipped with a refractory lining extending to a height of 1.8 - 2.4 meters from the top surface of the fluidized bed.

[0055] In one embodiment, the refractory lining extends to a height of 1.8 - 2.0 meters from the top surface of the fluidized bed. 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. One way of lowering the fluidized bed temperature in a bubbling fluidized bed boiler is by reducing the boiler's refractory lining surface in the region between the primary air level and the secondary air level. In typical bubbling fluidized bed boilers of today, the refractory lining surface in 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 refractory lining 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 refractory lining prevents radiation heat transfer to the water pipes lining the furnace. When the refractory lining is lowered, the generated heat is more efficiently transferred into the water pipes. Consequently, the temperature of the flue gas in the upper part of the furnace is decreased.

[0056] In one embodiment, the fuel feed pipe comprises a first opening for directing part of the combustion air for volatile matter as a first combustion air supply from the inlet into the fuel feed pipe, and the at least one air feed channel comprises a second opening for directing part of the combustion air for volatile matter as a second combustion air supply from the inlet into the at least one air feed channel. The openings may be on any side of the fuel feed pipe or the air feed channel.

[0057] In one embodiment, at least one of the first and second openings comprises at least one control damper for directing 60 to 70 % of the combustion air for volatile matter from the inlet into the fuel feed pipe and 30 to 40 % of the combustion air for volatile matter from the inlet into the at least one air feed channel. In one embodiment, a first control damper directs 60% of the combustion air for volatile matter from the inlet into the fuel feed pipe. In one embodiment, a second control damper directs 40% of the combustion air for volatile matter from the inlet into the at least one air feed channel.

[0058] In one embodiment, the fuel feed pipe comprises a first outlet and the at least one air feed channel comprises a second outlet and the cross-sectional area of the fuel feed pipe at the first outlet and of the at least one air feed channel at the second outlet is arranged to be such that the velocity at which the combustion air for volatile matter is supplied in the first combustion air supply and in the second combustion air supply is 10 to 25 m/s. In one embodiment, the velocity at which the combustion air for volatile matter is supplied in the first combustion air supply and in the second combustion air supply is arranged to be 12 to 25 m/s. In one embodiment, the velocity at which the combustion air for volatile matter is supplied in the first combustion air supply and in the second combustion air supply is arranged to be 15 to 25 m/s. In one embodiment, the velocity at which the combustion air for volatile matter is supplied in the first combustion air supply and in the second combustion air supply is arranged to be 15 m/s. In one embodiment, the velocity at which the combustion air for volatile matter is supplied in the first combustion air supply is arranged to be the same as in the second combustion air supply.

[0059] The amount of combustion air for volatile matter is determined by the amount of primary air supplied into the first combustion zone (I) so that the value of SR_{VOL} in the first combustion zone (I) is in the correct area. The velocity of the combustion air for volatile matter in the fuel feed pipe is affected by the mass flow of the air and the cross-section of the fuel feed pipe. Similarly, the velocity of the combustion air for volatile matter in the at least one air feed channel is affected by the mass flow of air and the cross-section of the at least one air feed channel. The velocity of the combustion air for volatile matter in the fuel feed pipe is also affected by the mass flow of fuel.

[0060] Several advantages are achieved by using the current invention. Fluid dynamics in the furnace are improved by supplying part of the combustion air for volatile matter as mixed with the fuel supply and part of the combustion air for volatile matter as surrounding at least part of the fuel supply. Controlled feed of fuel and air into the fluidised bed reduce slagging of the boiler walls and escape of sand from the fluidized bed. Improvements in fluid dynamics thus facilitate full utilization of the boiler. Boiler availability and efficiency is improved since maintenance intervals are extended. Further, operating costs are reduced.

[0061] Improvements in fluid dynamics also facilitate more efficient reduction in nitrogen oxide emissions. The nitrogen oxide emissions may be reduced to 250 - 300 mg/Nm^3. The combustion air for volatile matter supplied as described forces the fuel into the fluidized bed, thereby minimizing the amount of unburned fuel and resulting in more complete combustion of the fuel. Also, dwell time of the fuel in the furnace is increased and the combustion is easier to control. In addition, the high temperature of the secondary air used as combustion air for volatile matter enhances combustion and increases the temperature in the lower part of the furnace as well as keeps the fuel supply chutes clean and dry. The temperature of flue gas at the furnace exit (FEGT) is also reduced, since combustion takes place lower in the furnace. Also, low FEGT reduces corrosion in the super heater area and fouling of heat transfer surfaces is reduced. The temperature of flue gas may be further reduced by lowering the refractory lining in the lower part of the furnace, thereby enhancing heat transfer in the lower part of the furnace.

[0062] The embodiments of the invention described hereinbefore may be used in any combination with each other. Several of the embodiments may be combined together to form a further embodiment of the invention. The method, the fluidized bed boiler and the fuel feeding means, to which the invention is related, may comprise at least one of the embodiments of the invention described hereinbefore.

BRIEF DESCRIPTION OF THE DRAWINGS

[0063] The accompanying drawings, which are included to provide a further understanding of the invention and constitute a part of this specification, illustrate embodiments of the invention and together with the description help to explain the principles of the invention. In the drawings:

- **Fig. 1** is schematic sectional front view of the furnace of a bubbling fluidized bed boiler (BFB),
- **Fig. 2** is schematic sectional front view of the furnace of a circulating fluidized bed boiler (CFB),
- **Figs. 3a-3e** show the fuel feed pipe and the air feed channel from the inside the furnace according to a first, second, third, fourth and fifth embodiment of the present invention,
- **Fig. 4** is a schematic sectional view of the fuel feed pipe and the air feed channel according to one embodiment of the invention.
- **Fig. 5** is a schematic perspective view of a bubbling fluidized bed boiler showing peat particles on boiler walls when combustion air for volatile matter is supplied using a method according to one embodiment of the invention.
- **Fig. 6** is a schematic perspective view of a bubbling fluidized bed boiler showing peat particles on boiler walls when combustion air for volatile matter is supplied using a method according to prior art.

DETAILED DESCRIPTION OF THE INVENTION

[0064] Figures 1 and 2 show schematic sectional front views of the furnace of a bubbling fluidized bed boiler and a circulating fluidized bed boiler, respectively. The figures are basic views of the boilers and they are not intended to present the fluidized bed boiler on its correct scale.

[0065] In the BFB boiler of figure 1, the fluidized bed 1 is in the lower part 12 of the furnace 2. The fluidized bed 1 consists of fluidized bed material, into which fluidizing gas is supplied through primary air nozzles 6 arranged in the bottom of the furnace 2, which primary air 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.

[0066] In figure 1, fuel is supplied above the fluidized bed 1 surface through one or several fuel feed pipes 3 located on two opposite furnace walls 5. Combustion air for volatile matter is supplied into the first combustion zone (I) along with the fuel supply. Part of the combustion air for volatile matter is supplied as a first combustion air supply mixed with the fuel supply and part of the combustion air for volatile matter is supplied as a second combustion air supply surrounding at least part of the fuel supply. The first and second combustion air supplies together direct the fuel into the fluidized bed 1. As a result, fuel particles and sand will not escape from the fluidized bed 1 when the mixture of air and fuel hits the top surface of the bubbling fluidized bed 1. The fuel feeding means 18 are presented in more detail in figure 4. A small amount of carrier air may be brought along with the fuel into the boiler, its main function being to prevent clogging of the supply chute.

[0067] In figure 1, secondary air is supplied into the furnace 2 from secondary air nozzles 7 located above the fuel supply level on two opposite furnace walls 5, the reference number of which walls are not presented in figure 1.

[0068] The space confined between the height level of primary air nozzles 6 and the secondary air nozzles 7, which space contains the fluidized bed 1 and the volume above it all the way up to a level under the secondary air nozzles 7, forms a first combustion zone (I). Into the first combustion zone (I), fuel is supplied through fuel feed pipes 3, fluidizing gas is supplied through primary air nozzles 6, and combustion air for volatile matter is supplied along with the fuel. Air conducted into the first combustion zone (I) along with the fuel supply is 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 high temperatures in the first combustion zone (I). When air is supplied into the furnace 2 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).

[0069] Tertiary air is supplied above the secondary air nozzles 7 through tertiary air nozzles 16 arranged in the upper part of the furnace 2. The tertiary air nozzles 16 are usually placed 2 - 4 meters below the furnace nose.

[0070] The space confined between the secondary air nozzles 7 and the tertiary air nozzles 16, which space begins from the height level of the secondary air nozzles 7 and ends under the tertiary air nozzles 16, forms a second combustion zone (II). Into the second combustion zone (II), secondary air is supplied through the secondary air nozzles 7, 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).

[0071] The burning of fuel continues further in a third combustion zone (III) beginning from the height level the tertiary air nozzles 16. 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.

[0072] In figure 1, the lower part 12 of the furnace comprises refractory lining 13 which protects the walls of the furnace 2 from erosion caused by fluidizing bed material and extends from the top surface of a fluidized bed to a height of 1.8 - 2.4 meters. The height of the refractory lining 13 may be different from the fuel supply height.

[0073] The air coefficient SR_{VOL} for volatile matter in the first combustion zone (I) is in a range of 0.9 - 1.00. In the second combustion zone (II), the total air coefficient SR_{TOT} is in a range of 0.75 - 0.85. In the third combustion zone (III), the total air coefficient SR_{TOT} is about 1.15.

[0074] 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} in relation to the volatile matter of the fuel, whereby a lot of hydrocarbon radicals will result. In the second combustion zone (II), combustion air is supplied into the furnace from the secondary air nozzles 7 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.

[0075] 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. 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 in relation to 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.

[0076] Figure 2 shows a schematic sectional front view of the furnace of a circulating fluidized bed boiler. In the CFB boiler of figure 2, the fluidized bed 1 extends to the upper part of the furnace 2. The fluidized bed 1 consists of fluidized bed material, into which fluidizing gas is supplied through primary air nozzles 6 arranged in the bottom of the furnace 2, which primary air makes the fluidized bed material fluidize. The fluidizing gas may be just air or it may be a mixture of air and a circulating gas.

[0077] In figure 2, fuel is supplied into the fluidized bed 1 through one or several fuel feed pipes 3 located on two opposite furnace walls 5. Combustion air for volatile matter is supplied into the first combustion zone (I) along with the fuel supply. Part of the combustion air for volatile matter is supplied as a first combustion air supply mixed with the fuel supply and part of the combustion air for volatile matter is supplied as a second combustion air supply surrounding at least part of the fuel supply. The first and second combustion air supplies together direct the fuel into the fluidized bed 1. As a result, fuel particles and sand will not escape from the fluidized bed 1 when the mixture of air and fuel hits the top surface of the bubbling fluidized bed 1. The fuel feeding means 18 are presented in more detail in figure 4. A small amount of carrier air may be brought along with the fuel into the boiler, its main function being to prevent clogging of the supply chute.

[0078] In figure 2, secondary air is supplied into the furnace 2 from secondary air nozzles 7 located above the fuel supply level on two opposite furnace walls 5, the reference number of which walls are not presented in figure 2.

[0079] The space confined between the height level of primary air nozzles 6 and the secondary air nozzles 7, which space contains part of the fluidized bed 1 all the way up to a level under the secondary air nozzles 7, forms a first, substoichiometric combustion zone (I). Into the first combustion zone (I), fuel is supplied through fuel feed pipes 3, fluidizing gas is supplied through primary air nozzles 6, and combustion air for volatile matter is supplied along with the fuel. Air conducted into the first combustion zone (I) along with the fuel supply is taken from the secondary air register, whereby it reduces the quantity of air to be supplied into the third combustion zone (III). A larger supply of air into the first combustion zone (I) will result in high temperatures in the first combustion zone (I).

[0080] The space above the secondary air nozzles 7, which space begins from the height level of the secondary air nozzles 7 and extends to the upper part of the furnace 2, forms a third, superstoichiometric combustion zone (III). Into the third combustion zone (III), secondary air is supplied through the secondary air nozzles 7, to be mixed together with a flue gas flow rising upwards from the first combustion zone (I). The upper part of the CFB boiler of figure 2 further comprises an exit chute and a separation system for separating solids from the flue gas (not presented).

[0081] The air coefficient SR_{VOL} for volatile matter in the first combustion zone (I) is in a range of 0.9 - 1.00. In the third combustion zone (III), the total air coefficient SR_{TOT} is about 1.2.

[0082] Figures 3a-3e show the fuel feed pipe 3 and the at least one air feed channel 4 from the inside the furnace according to the first, second, third, fourth and fifth embodiment of the present invention. The fuel feed pipe 3 comprises a first outlet 14 for supplying fuel and combustion air for volatile matter into the furnace. The at least one air feed channel 4 comprises a second outlet 15 for supplying combustion air for volatile matter into the furnace. The cross-section of the fuel feed pipe 3 may be of any shape, e.g. rectangular or round. The air feed channel 4 may be one continuous air feed channel 4 or separate air feed channels 4 on different sides of the fuel feed pipe 3.

[0083] In figures 3a and 3d, one continuous air feed channel 4 surrounds the fuel feed pipe 3 on all sides, thereby forming a second combustion air supply around the whole fuel supply. In figure 3b, one continuous air feed channel 4 surrounds the fuel feed pipe 3 on all sides except from below, thereby forming a second combustion air supply around three sides of the fuel supply, but not below it. In figure 3c, three separate air feed channels 4 surround the fuel feed pipe 3 on all sides except from below, thereby forming a second combustion air supply around three sides of the fuel supply, but not below it. In figure 3e, four separate air feed channels 4 surround the fuel feed pipe 3 on all sides, thereby forming a second combustion air supply around the whole fuel supply.

[0084] Figure 4 shows a schematic sectional view of the fuel feed pipe 3 and the air feed channel 4 according to one embodiment of the invention. The fuel feeding means 18 comprise a fuel feed pipe 3 and an air feed channel 4 around part of the length of the fuel feed pipe 3 and surrounding the fuel feed pipe 3 on all sides. The fuel feeding means 18 further comprise an inlet 8 for supplying combustion air for volatile matter along with the fuel. The fuel feed pipe 3 and the air feed channel 4 end in the first outlet 14 and the second outlet 15, respectively. Through these outlets fuel and combustion air for volatile matter are directed into the furnace. The inlet 8 is connected to secondary air for supplying secondary air as combustion air for volatile matter. The upper side of the fuel feed pipe 3 comprises a first opening for directing combustion air for volatile matter from the inlet 8 into the fuel feed pipe 3. The upper side of the air feed channel 4 comprises a second opening for directing combustion air for volatile matter from the inlet 8 into the air feed channel 4. The control dampers 11 direct 60 % of the combustion air for volatile matter from the inlet into the fuel feed pipe and 40 % of the combustion air for volatile matter into the air feed channel 4. The guide vanes 19 direct the air flow smoothly into the fuel feed pipe 3. The cross-sectional area of the fuel feed pipe 3 at the first outlet 14 and of the air feed channel 4 at the second outlet 15 is such that the velocity at which the combustion air for volatile matter is supplied in both the fuel feed pipe 3 and the air feed channel 4 is 15 to 20 m/s.

[0085] Figure 5 shows a schematic perspective view of a bubbling fluidized bed boiler showing peat particles on boiler walls when combustion air for volatile matter is supplied using a method according to one embodiment of the invention. Figure 6 shows a schematic perspective view of a bubbling fluidized bed boiler showing peat particles on boiler walls when combustion air for volatile matter is supplied using a method according to prior art, i.e. when combustion air for volatile matter is supplied around the fuel supply but not trough the fuel feed pipe 3 mixed with the fuel. The peat particles of the fuel form slag 14 on boiler walls. When combustion air for volatile matter is supplied using the method according to the invention (figure 5), slagging of boiler walls is reduced as compared to the method according to prior art (figure 6).

[0086] 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} and air coefficient in relation to volatile matter SR_{VOL} in a bubbling fluidized bed boiler in which no combustion air for volatile matter is supplied (Table 1) and in a boiler in which combustion air for volatile matter is supplied along with the fuel as described above (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.

[0087] In table 1, furnace air is supplied into the first combustion zone (I) 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} and air coefficients in relation to volatile matter SR_{VOL} in a bubbling fluidized bed boiler in which no combustion air for volatile matter is supplied.

	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

(continued)

	Wood SR_{TOT}	Wood SR_{VOL}	Peat SR_{TOT}	Peat SR_{VOL}
Tertiary air	1.15	1.59	1.15	1.95

[0088] In this air distribution, the air coefficient in relation to 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. 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}.

[0089] Table 2 shows the air distribution in a bubbling fluidized bed boiler, 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 along with the fuel supply. Part of the combustion air for volatile matter is supplied as mixed with the fuel supply and part of the combustion air for volatile matter is supplied as surrounding at least part of the fuel supply. The air coefficient SR_{VOL} in relation to volatile matter in the first combustion zone (I) is 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} and air coefficients in relation to volatile matter SR_{VOL} in a bubbling fluidized bed boiler in which combustion air for volatile matter is supplied along with the fuel.

	Wood SR_{TOT}	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
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

[0090] In this case, the combustion air for volatile matter supplied into the first combustion zone (I) along 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.

[0091] It is obvious to a person skilled in the art that with the advancement of technology, the basic idea of the invention may be implemented in various ways. The invention and its embodiments are thus not limited to the examples described above; instead they may vary within the scope of the claims.

Claims

1. A method for feeding air to a fluidized bed boiler burning fuel, the fluidized bed boiler comprising a fluidized bed (1) and a boiler furnace (2) comprising a first combustion zone (I), in which method air needed for burning the fuel in the fluidized bed (1) is supplied in stages into the boiler furnace (2) for causing substoichiometric combustion in the first combustion zone (I), and which method comprises:

- supplying primary air into the first combustion zone (I) from under the fluidized bed (1) for fluidizing the bed material;
- supplying combustion air for volatile matter into the first combustion zone (I) along with the fuel supply,

characterized in that

- part of the combustion air for volatile matter is supplied as a first combustion air supply mixed with the fuel

supply and part of the combustion air for volatile matter is supplied as a second combustion air supply surrounding at least part of the fuel supply, and
- the velocity at which the combustion air for volatile matter is supplied in both the first and the second combustion air supplies is 10 to 25 m/s.

2. The method according to claim 1, **characterized in that** the air coefficient in relation to volatile matter SR_{VOL} in the first combustion zone (I) is 0.9 - 1.0.

3. The method according to claim 1 or 2, **characterized in that** the boiler is a bubbling fluidized bed boiler and the boiler furnace (2) comprises a second combustion zone (II) located above the first combustion zone (I), and the total air coefficient SR_{TOT} in the second combustion zone (II) is 0.75 - 0.85.

4. The method according to any of the preceding claims, **characterized in that** the combustion air for volatile matter comprises secondary air.

5. The method according to any of the preceding claims, **characterized in that** the first combustion air supply comprises 60 to 70 % of the combustion air for volatile matter and the second combustion air supply comprises 30 to 40 % of the combustion air for volatile matter.

6. The method according to any of the preceding claims, **characterized in that**, the fuel is supplied into the first combustion zone (I) through a fuel feed pipe (3), and the first combustion air supply is mixed with the fuel supply and supplied into the boiler furnace (2) simultaneously with the fuel supply through said fuel feed pipe (3).

7. The method according to any of the preceding claims, **characterized in that** the second combustion air supply is supplied into the first combustion zone (I) through at least one air feed channel (4) arranged around at least part of the length of the fuel feed pipe (3) and surrounding at least part of the fuel feed pipe (3).

8. The method according to any of the preceding claims, **characterized in that** the first combustion air supply and the second combustion air supply are simultaneously supplied into the first combustion zone (I).

9. A fluidized bed boiler comprising a fluidized bed (1), a boiler furnace (2) comprising furnace walls (5) and a first combustion zone (I),
primary air nozzles (6) under the fluidized bed (1) for supplying primary air into the first combustion zone (I) for fluidizing the bed material,
at least one fuel feed pipe (3) on at least one furnace wall (5) in the first combustion zone (I) for supplying fuel into the fluidized bed (1), the at least one fuel feed pipe (3) comprising a first outlet (14), and
an inlet (8) for supplying combustion air for volatile matter into the first combustion zone (I) along with the fuel supply,
characterized in that
the boiler comprises at least one air feed channel (4) around at least part of the length of the fuel feed pipe (3) and surrounding at least part of the fuel feed pipe (3), the at least one air feed channel (4) comprising a second outlet (15);
part of the combustion air for volatile matter is arranged to be supplied into the boiler furnace (2) through the fuel feed pipe (3) as a first combustion air supply mixed with the fuel supply and part of the combustion air for volatile matter is arranged to be supplied into the furnace (2) through the at least one air feed channel (4) as a second combustion air supply surrounding at least part of the fuel supply; and
the cross-sectional area of the fuel feed pipe (3) at the first outlet (14) and of the at least one air feed channel at the second outlet (15) is arranged to be such that the velocity at which the combustion air for volatile matter is supplied in the first combustion air supply and in the second combustion air supply is 10 to 25 m/s.

10. The fluidized bed boiler according to claim 9, **characterized in that** the fluidized bed boiler comprises secondary air nozzles (7) on at least one furnace wall (5) above the first combustion zone (I) for supplying secondary air above the first combustion zone (I), and the inlet (8) is connected to the secondary air for supplying secondary air at least as part of the combustion air for volatile matter.

11. The fluidized bed boiler according to claim 9 or 10, **characterized in that** the fuel feed pipe (3) comprises a first opening (9) for directing part of the combustion air for volatile matter as a first combustion air supply from the inlet (8) into the fuel feed pipe (3), and the at least one air feed channel (4) comprises a second opening (10) for directing part of the combustion air for volatile matter as a second combustion air supply from the inlet (8) into the at least one air feed channel (4).

12. The fluidized bed boiler according to any of claims 9 to 11, **characterized in that** at least one of the first and second openings (9,10) comprises at least one control damper (11) for directing 60 to 70 % of the combustion air for volatile matter from the inlet (8) into the fuel feed pipe (3) and 30 to 40 % of the combustion air for volatile matter from the inlet (8) into the at least one air feed channel (4).

13. The fluidized bed boiler according to any of claims 9 to 12, **characterized in that** the boiler is a bubbling fluidized bed boiler, in which the fluidized bed (1) has a top surface and the boiler furnace (2) has a lower part which is equipped with a refractory lining (13) extending to a height of 1.8 - 2.4 meters from the top surface of the fluidized bed (1).

14. Fuel feeding means for a fluidized bed boiler comprising at least one fuel feed pipe (3) for supplying fuel into the fluidized bed (1), the fuel feed pipe (3) comprising a first outlet (14), and an inlet (8) for supplying combustion air for volatile matter along with the fuel supply, **characterized in that** the fuel feeding means comprise at least one air feed channel (4) around at least part of the length of the fuel feed pipe (3) and surrounding at least part of the fuel feed pipe (3), the at least one air feed channel (4) comprising a second outlet (15); and part of the combustion air for volatile matter is arranged to be supplied through the fuel feed pipe (3) as a first combustion air supply mixed with the fuel supply and part of the combustion air for volatile matter is arranged to be supplied through the at least one air feed channel (4) as a second combustion air supply surrounding at least part of the fuel supply; and the cross-sectional area of the fuel feed pipe (3) at the first outlet (14) and of the at least one air feed channel (4) at the second outlet (15) is arranged to be such that the velocity at which the combustion air for volatile matter is supplied in the first combustion air supply and in the second combustion air supply is 10 to 25 m/s.

15. The fuel feeding means for a fluidized bed boiler according to claim 14, **characterized in that** the fuel feed pipe (3) comprises a first opening (9) for directing part of the combustion air for volatile matter as a first combustion air supply from the inlet (8) into the fuel feed pipe (3), and the at least one air feed channel (4) comprises a second opening (10) for directing part of the combustion air for volatile matter as a second combustion air supply from the inlet (8) into the at least one air feed channel (4).

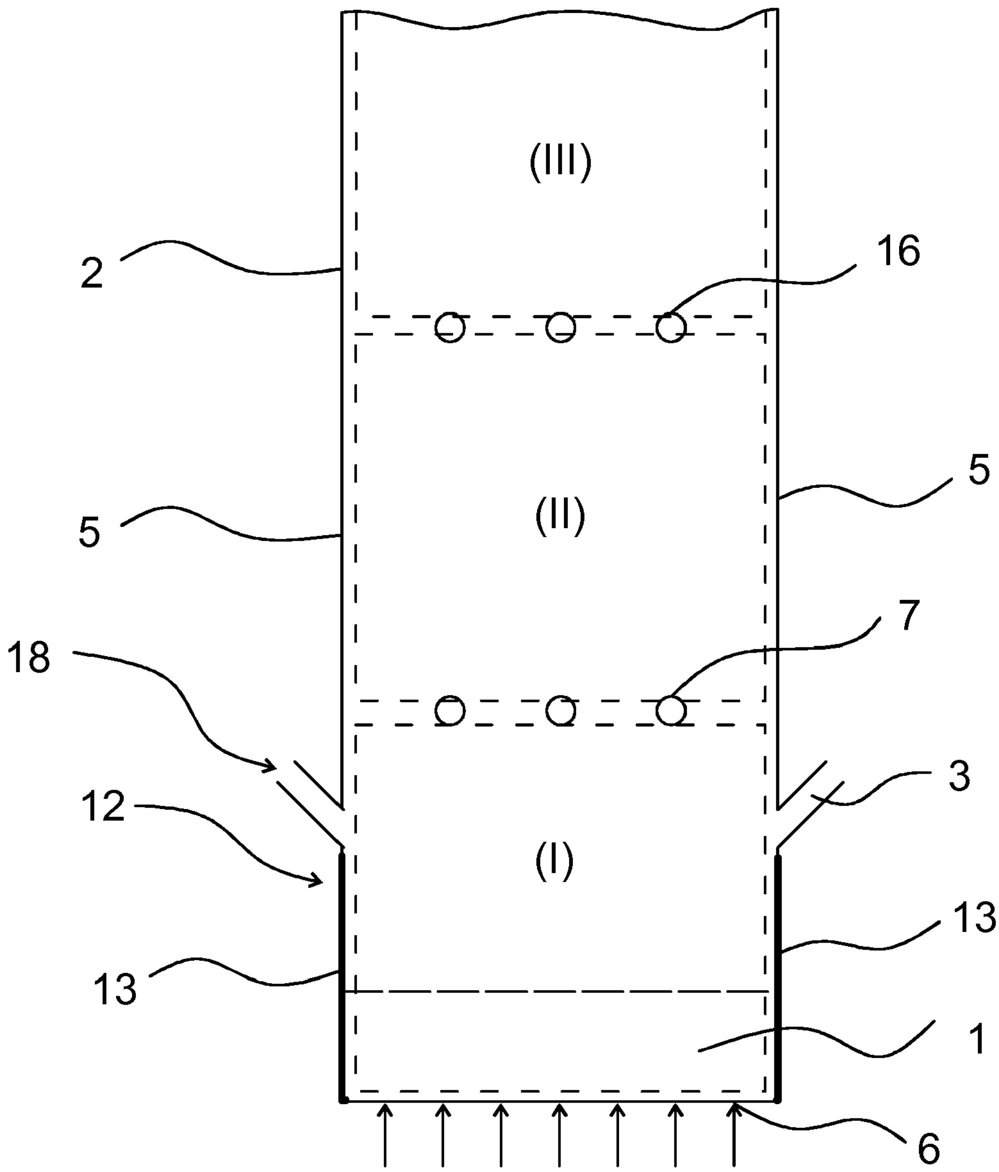

Fig. 1

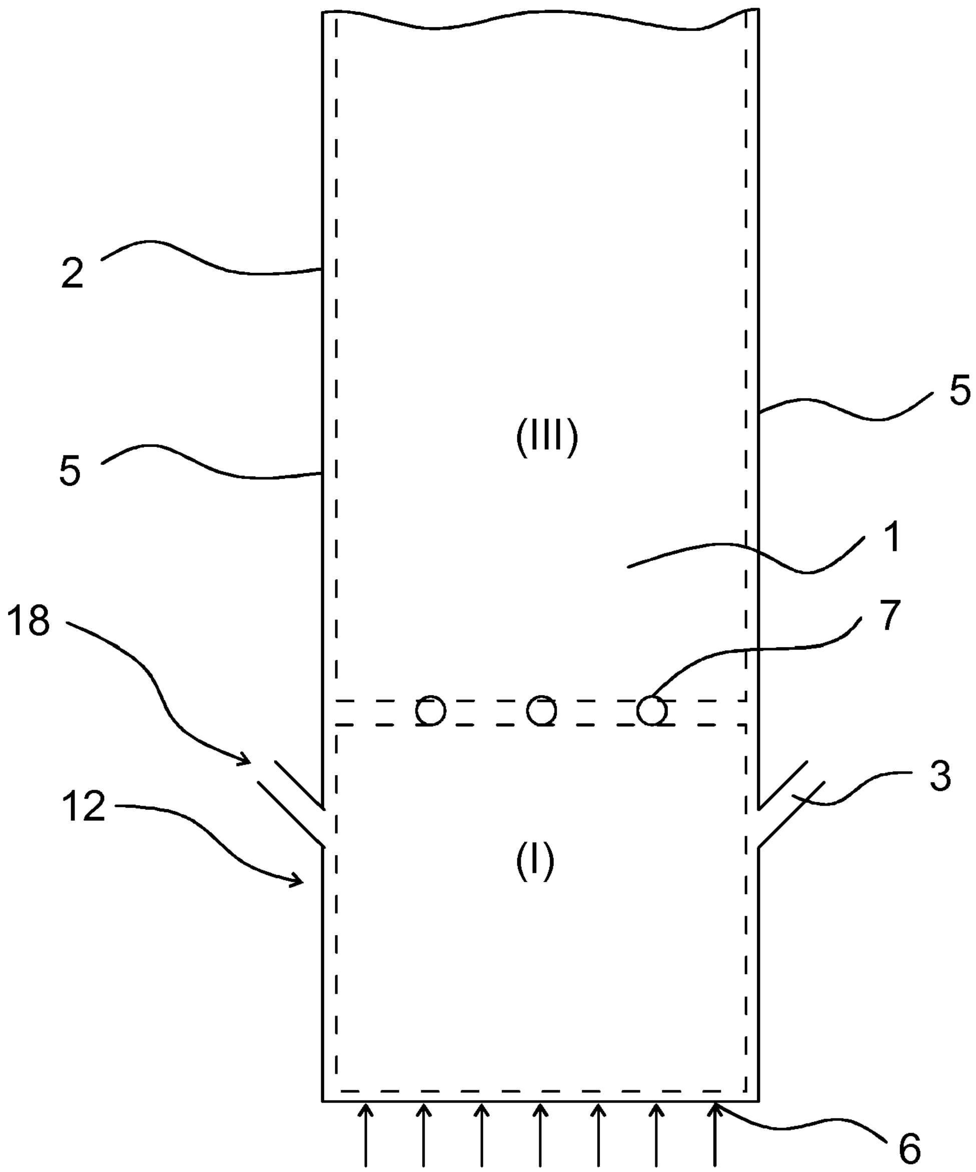

Fig. 2

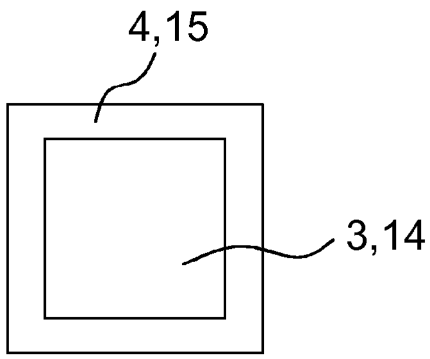

Fig.3a

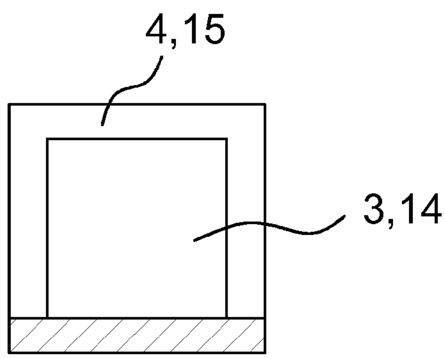

Fig.3b

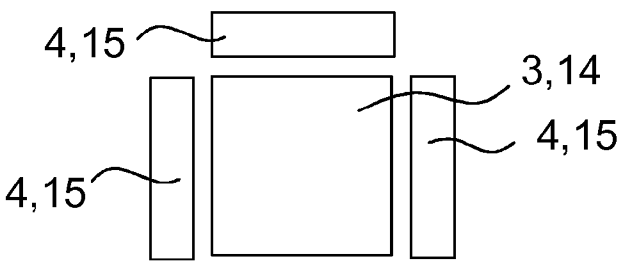

Fig.3c

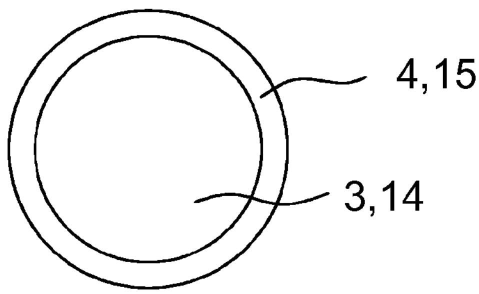

Fig.3d

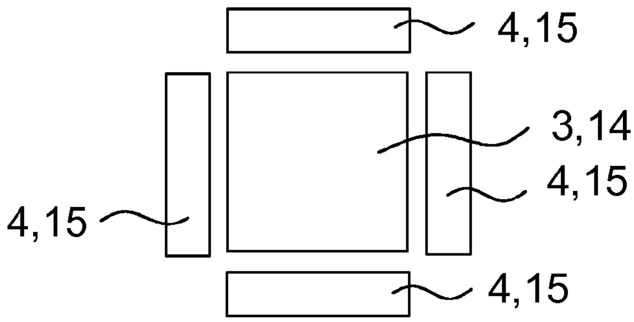

Fig.3e

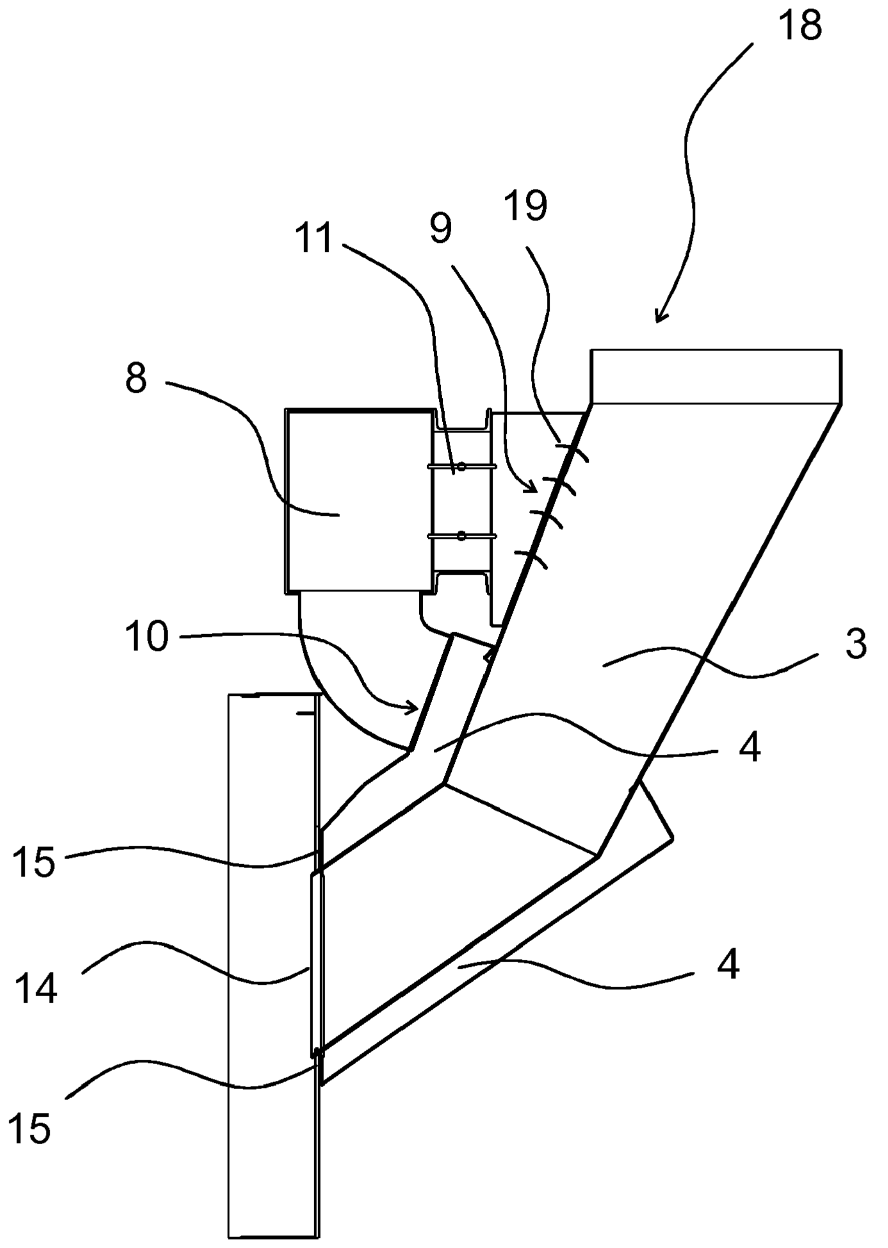

Fig.4

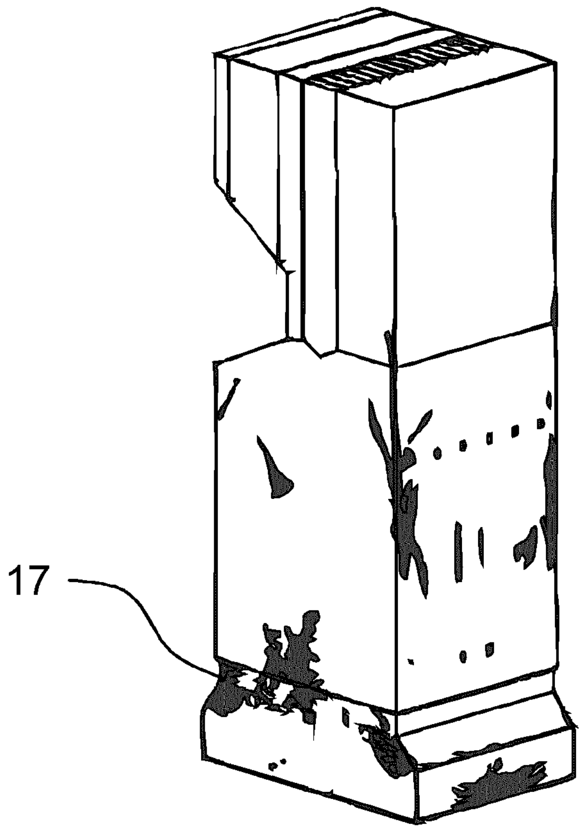

Fig.5

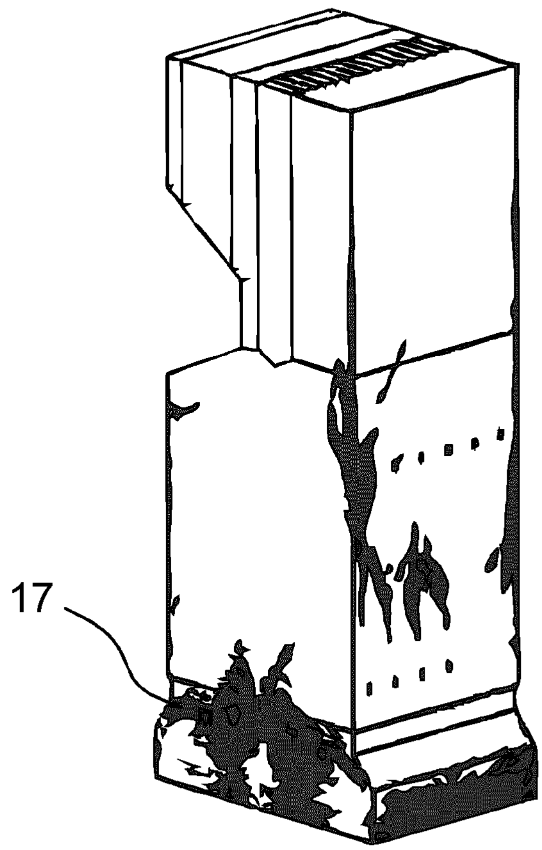

Fig.6

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EUROPEAN SEARCH REPORT

Application Number
EP 16 15 4668

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X,D	WO 2006/084954 A1 (KVAERNER POWER OY [FI]; DERNJATIN PAULI [FI]; FABRITIUS MARKO [FI]; RO) 17 August 2006 (2006-08-17) * page 12, line 15 - page 14, line 2; claims 10, 11; figures 1-3c *	1-15	INV. F23L9/02 F23C6/04 F23C10/00 F23C10/22 F23L9/06
A	EP 1 397 613 A1 (KVAERNER POWER OY [FI]) 17 March 2004 (2004-03-17) * paragraphs [0015] - [0016], [0022]; figure 2 *	1-15	
A,D	GB 2 286 345 A (WICKHAM MARK FREDERICK [GB]) 16 August 1995 (1995-08-16) * page 6, lines 25-35; figure 1 *	1-15	
A,D	EP 2 574 841 A2 (FORTUM OYJ [FI]) 3 April 2013 (2013-04-03) * the whole document *	1-15	

TECHNICAL FIELDS SEARCHED (IPC)

F23L
F23C

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	30 June 2016	Coli, Enrico

2

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30-06-2016

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2006084954 A1	17-08-2006	CA 2597159 A1	17-08-2006
		EP 1846694 A1	24-10-2007
		FI 20055063 A	12-08-2006
		US 2008149012 A1	26-06-2008
		WO 2006084954 A1	17-08-2006
EP 1397613 A1	17-03-2004	CA 2446950 A1	21-11-2002
		DE 60120787 T2	24-05-2007
		EP 1397613 A1	17-03-2004
		US 2004261675 A1	30-12-2004
		WO 02093074 A1	21-11-2002
GB 2286345 A	16-08-1995	NONE	
EP 2574841 A2	03-04-2013	EP 2574841 A2	03-04-2013
		FI 20115962 A	31-03-2013

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

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Patent documents cited in the description

- WO 2006084954 A1 **[0010] [0011]**
- GB 2286345 A **[0012]**
- EP 2574841 A2 **[0028] [0039]**