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(71) **Applicant: FORTUM OYJ** [FI/FI]; Keilaniementie 1, 02150 Espoo (FI).

(72) **Inventors: DERNJATIN, Pauli**; Tulustie 8a D, 00670 Helsinki (FI). **HUTTUNEN, Marko**; Visamäki 3 A 1, 02130 Espoo (FI).

(74) **Agent: PAPULA OY**; P.O. Box 981, 00101 Helsinki (FI).

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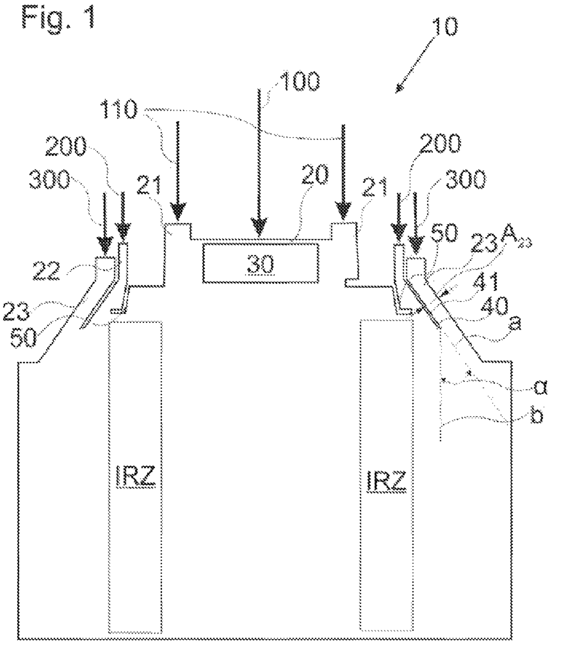
(54) **Title:** METHOD FOR BURNING FUEL, BURNER AND BOILER

Fig. 1




(57) **Abstract:** A method for burning fuel is disclosed. The method comprises supplying cold non- preheated combustion air and dust fuel into a combustion chamber of a boiler through a burner (10) for producing a flame, the combustion air comprising primary air (100), secondary air (200), tertiary air (300). The flame is stabilised by providing a flame stabilising ring (50) at a downstream end of the annular fuel nozzle and primary air is directed through a swirl generator (30) at the primary air nozzle so that primary air has a swirl number (Sp). A stream of tertiary air is guided off with a guide sleeve (40) aligned with a burner throat (41) at an angle (α), so that an inner recirculation zone (IRZ) is formed between a stream of primary air and the stream of tertiary air. The swirl number of primary air is set at 0,4 to 1,0 by the swirl generator; the primary air velocity at the primary air nozzle orifice is set to 30 m/s or less;and the carrier air velocity at the downstream end of the annular fuel nozzle is set to 15 m/s or less. The tertiary air velocity is set so that at the end of

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the guide sleeve (40), the tertiary air velocity is 35 to 50 m/s. Further disclosed are a burner (10) and a boiler comprising a burner.

# METHOD FOR BURNING FUEL, BURNER AND BOILER

## TECHNICAL FIELD

The current disclosure relates to a method for burning fuel, to a burner, and to a boiler comprising a burner.

## BACKGROUND

Combustion of fuel in a boiler furnace requires balancing between different boiler operation variables. The emissions of different harmful substances need to be kept under allowable limits. Further, several issues relating to boiler operation and boiler availability need to be taken into account. Often it is challenging to design boiler operation in order to optimize the combustion process to achieve low emissions of harmful substances and, on the other hand, good flame stability and boiler availability. New emission limits, set to enter into force in the near future, make combustion optimization even more challenging.

The Industrial Emissions Directive (IED) is the main EU instrument regulating pollutant emissions from industrial installations. The IED aims to achieve a high level of protection of human health and the environment taken as a whole by reducing harmful industrial emissions across the EU. IED sets union wide emission limit values for selected pollutants for large combustion plants, waste incineration, and co-incineration plants, i.e. combustion plants with a total rated thermal input equal to or greater than 50 MW, irrespective of the type of fuel used.

For example, the sulfur emission limits for heavy oil, which is often used as a fuel in thermal power plants to offset fuel needs during peak demand periods, necessitate installation of expensive sulfur removal systems. On the other hand, conventional fuel alternatives, natural gas and light oil, are expensive as well. Therefore, there is a pressure to change into bio-based fuels such as bio-based fluid fuels and solid biofuel such as pellets produced from wood, sawdust or lignin. Also other environmental aspects besides legislation may put pressure for changing from non-renewable fuel sources to renewable ones.

Boilers utilising coal as fuel are already fitted with sulfur removal systems, but conventional methods and boilers intended for burning coal cannot necessarily be readily changed into using fuels in dust-form, originating from bio-based pellets or other organic material that are milled into dust. In other word, the combustion technology is not readily interchangeable from coal dust to bio dust, which is coarser and has a wider particle size distribution than the fine, uniform coal dust.

Typically in a cylindrical boiler for burning fuel in dust form, the fuel from a grinding mill together mixed with carrier air (i.e. mill air) and combustion air (core air, secondary air and tertiary air) is fed through annular feed nozzles or channels, via a stabilising ring axially into the combustion chamber of the boiler. The flame is often stabilized by setting the combustion air into a tangential motion, often the second or tertiary air. This can be achieved by directing the air into the furnace trough a swirl generator, which gives tangential motion to the air flowing through it. The swirl generator comprises vanes set at a certain angle to change the direction of the air flow.

The swirl number S of the air is set to give the air a certain tangential velocity. The swirl number S characterizes the ratio of tangential to axial momentum of the air flow. The concept of swirl number is common general knowledge to a person skilled in the art. The calculation of the swirl number can be found e.g. in Beer, J. and Chigier, N., Combustion Aerodynamics, 1972, pages 109-115: $S = 2/3 \times \tan \beta$, wherein the angle β is the angle of the swirl-inducing structure, e.g. swirl vanes of a swirl generator. The swirl number of the air flow can be changed by directing the air flow through a swirler comprising vanes which are set at an angle to the direction of the air flow. The swirler gives tangential motion to the air flowing through it. The swirl number can be adjusted by adjusting the angle of the vanes and by changing the velocity of the air. The vane angle needed to supply the combustion air a certain swirl number S depends on the type of the swirl generator. The swirl generator is commonly located in the secondary or tertiary air flow channel.

When the swirl number is low, a weak swirl is created, and there is little or no flow recirculation. When the swirl number is high, a recirculation zone is formed. A boundary swirl number at which a weak swirl becomes a high swirls can be identified as around 0,6. When the swirl number is increased, a strong recirculation zone is achieved and the flame is stabilized. However, increasing the swirl number of the second and tertiary air causes the fuel to eddy near the heat transfer walls. Heat transfer is impaired by fuel dust in between the hot flow and the heat transfer walls. In addition, increasing the swirl number causes carbon monoxide formed during the combustion moving along with the tangential air flow near the furnace walls, thereby causing severe corrosion problems to the heat transfer surfaces.

Producing a high swirl into the core air (primary air) introduced at the centre of a burner may cause the fuel dust to burn close to the walls of the boiler, which reduces the combustion efficiency. Slag formation on the boiler walls may cause production interruptions for cleaning, and increase the temperature close to the boiler walls. Insufficient combustion reactions may cause CO formation, which in turn may corrode the inside structure of the boiler, and formation of NOx due to incomplete reduction reactions. Further, increased temperature within the combustion chamber may cause damage to the second pass of the boiler due to excess flue exit gas temperatures. In worst cases, burning fuel dust may end up in the second pass and cause slag formation also in that part of the boiler, or even explode in the second pass. Cleaning of second pass causes production breaks and decreases the efficiency of the boiler.

Compared to coal dust, bio-based dust as fuel produces less ash. However, the ash originating from bio-based dust fuels comprises alkalic compounds (Na, K) and chloride compounds. The alkalic compounds makes the ash sticky already at relatively low temperatures, whereas ash from coal dust fuel, the alkalic compounds are sulfonated into stable compounds, such as $Na_2SO_4$. Bio-based fuels do not comprise sulfur, so similar reaction is not possible. In burning bio-based dust fuel by conventional processes disclosed above, there is a risk that the ash ends up in the second pass, in worst case in molten phase due to the high temperature of the combustion chamber.in burning coal dust, this fouling of the second pass is not particularly problematic as the detrimental substances become sulfonated. For this reason, the methods and equipment intended for burning coal dust are not suitable for bio-based fuels.

**OBJECTIVE OF THE INVENTION**

The objective of the invention is to eliminate at least one of the disadvantages mentioned above.

In particular, it is the objective of the invention to provide a method for burning fuel, and a burner, and a boiler with which the above-mentioned problems related to the prior art may be alleviated. According to the invention, the in the method, a burner is utilised, in which the flows of fuel and combustion air may be optimised to enhance ignition of fuel and stabilise the flame by introducing a moderate swirl into the core or primary combustion air and by directing the tertiary air into the combustion chamber of a boiler so that an inner recirculation zone (IRZ) is formed between the main fuel stream, i.e. the primary air stream, and the tertiary air stream. The inner recirculation zone enhances flame stability by stagnating the fuel particles and hot gases in the IRZ, thereby bringing about a constant, complete combustion. When the flame is stabilised, combustion of the dust-form fuel is complete which significantly decreases the migration of dust into the second pass. At the same time, the above-mentioned problems relating to slag formation and increased temperature close to the combustion chamber walls due to high swirl of the primary air may be alleviated, as well as the flue exit gas temperature (FEGT) controlled. The reliability of the boiler may thus be improved, the down-times due to cleaning and/or maintenance decreased, and the overall operating life of the boiler extended.

## SUMMARY OF THE INVENTION

The method according to the current disclosure is characterized by what is presented in claim 1.

The burner according to the current disclosure is characterized by what is presented in claim 14.

The boiler according to the current disclosure is characterized by what is presented in claim 18.

A method for burning fuel comprises supplying cold non-preheated combustion air and dust fuel into a combustion chamber of a boiler through a burner for producing a flame, the combustion air comprising primary air fed through a primary air nozzle at the centre of the burner, secondary air fed through an annular secondary air channel encompassing the primary air nozzle, tertiary air fed through an annular tertiary air channel encompassing the secondary air channel; the dust fuel and carrier gas fed through an annular fuel nozzle arranged coaxially between the primary air nozzle and the secondary air channel; wherein the method, the flame is stabilised by providing a flame stabilising ring at a downstream end of the annular fuel nozzle and primary air is directed through a swirl generator at the primary air nozzle so that primary air has a swirl number. The method is characterized by guiding off a stream of tertiary air with a guide sleeve aligned with a burner throat at an angle formed between a first line extending along the guide sleeve and a second line aligned with the center line of the burner so that an inner recirculation zone is formed between a stream of primary air and the stream of tertiary air; by setting the swirl number of primary air at 0,4 to 1,0 by the swirl generator; by setting the primary air velocity at the primary air nozzle orifice to 30 m/s or less, and the carrier air velocity at the downstream end of the annular fuel nozzle to 15 m/s or less; and by setting the tertiary air velocity so that at the end of the guide sleeve, the tertiary air velocity is 35 to 50 m/s.

According to another aspect of the invention, a burner for producing a flame in a combustion chamber of a boiler comprises a primary air nozzle at the centre of the burner, an annular secondary air channel encompassing the primary air nozzle, an annular tertiary air channel encompassing the secondary air channel, and an annular fuel nozzle arranged coaxially between the primary air nozzle and the secondary air channel, a flame stabilising ring at a downstream end of the annular fuel nozzle and a swirl generator at the primary air nozzle. The burner is characterized in that the tertiary air channel comprises a guide sleeve aligned with the burner throat at an angle formed between a first line extending along the guide sleeve and a second line aligned with the center line of the burner, in that the guide sleeve is arranged to direct a stream of tertiary air off so that an inner recirculation zone is formed between a steam of primary air and a stream of tertiary air; and in that the swirl generator is configured to effect a swirl number of 0,6 to 1,5 to primary air fed into the combustion chamber via the primary air nozzle of the burner.

In another aspect of the invention, a boiler, comprising a burner according to the invention.

The advantage of the invention is that the manner of introducing combustion air flows and fuel into a combustion chamber of a boiler through a burner promotes the efficient combustion of bio-based fuel dust by stabilising the flame and by introducing an inner recirculation zone between the main fuel stream and a tertiary air stream. As the combustion is improved, the temperature inside the combustion chamber is equalized, and no excess temperatures are caused close to the combustion chamber walls. By controlling the temperature within the combustion chamber, also FEGT may be decreased. Migration of incompletely burned fuel and ash into the second pass may be avoided. Emissions of CO, NOx and unburned coke may be decreased.

In an embodiment of the method, the angle formed between a first line extending along the guide sleeve and a second line aligned with the center line of the burner is 30 to 35°.

In an embodiment, the primary air velocity at the primary air nozzle orifice is set to 18 to 25 m/s, preferably to 20 m/s.

In an embodiment, the carrier gas velocity at the downstream end of the annular fuel nozzle is set to 15 m/s to 10 m/s.

In an embodiment, the swirl number of primary air is adjusted by an adjustable swirl generator.

In an embodiment, the swirl number of primary air is adjusted by the swirl generator comprising non-adjustable swirl vanes having a vane angle of 40 to 45°.

In an embodiment, the proportion of tertiary air supplied into the combustion chamber of the boiler is 45 to 55 % of the mass flow rate of the total combustion air supplied into the boiler by the burner, the total combustion air comprising primary air, carrier air, secondary air and tertiary air.

In an embodiment, the ratio of mass flow rate of secondary air to tertiary air being fed into the combustion chamber of the boiler is 1:6 to 1:5.

In an embodiment, the ratio of mass flow rate of primary air to carrier air being fed into the combustion chamber of the boiler is 2:1 to 2,5:1.

In an embodiment, the ratio of mass flow rate of dust fuel to carrier air is substantially 1:1.

In an embodiment, the dust fuel is bio dust obtained by milling dried bio-based raw material chosen from a group comprising: sawdust pellets, wood coke, charcoal, lignin pellets, secondary fractions of bio product plants, agricultural waste, peat, organic municipal waste, non-food energy crops, and the like.

In a further embodiment, the milled bio dust fuel has a particle size range from 0,1 to 2,0 mm.

In an embodiment, the dust fuel is coal dust having a particle size range below 0,2 mm.

In an embodiment of the burner, the angle formed between a first line extending along the guide sleeve and a second line aligned with the center line of the burner is 30 to 35°.

In an embodiment, the swirl generator is adjustable.

In an embodiment, the swirl generator comprises non-adjustable swirl vanes having a vane angle of 40 to 45°.

In an embodiment of the boiler, it comprises at least two burners according to the invention.

The method of burning fuel, the burner, and the boiler described herein may provide significant advantages over the prior art. At least some of the embodiments described herein provide a method and a boiler by which the presence of carbon monoxide close to the furnace walls is greatly reduced. As a result, the corrosion of furnace walls is reduced and boiler availability is improved. At the same time, at least some of the embodiments described herein provide a major reduction of nitrogen oxide emissions, with no significant change in carbon monoxide emissions. In addition, at least some of the embodiments described herein reduce the furnace gas exit temperature (FEGT). The reduced FEGT improves boiler efficiency. A stable flame is achieved by the combination of generating a moderate swirl into primary air and by directing tertiary air off from the primary air so that an inner recirculation zone is formed. Reduced nitrogen oxide emissions result in reduced consumption of ammonia used in reducing nitrogen oxides, and longer lifetime of the catalyst material.

**BRIEF DESCRIPTION OF THE DRAWINGS**

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

Fig. 1 is a simplified cross-sectional view of a burner according to an embodiment of the invention,

Fig. 2 is a three-dimensional projection of the burner in Fig. 1,

Fig. 3 is a schematic presentation of a boiler according to an embodiment of the invention, and

Fig. 4 is a schematic presentation of a boiler according another embodiment of the invention.

**DETAILED DESCRIPTION**

Reference will now be made in detail to the embodiments of the present disclosure, an example of which is illustrated in the accompanying drawings.

The description below discloses some embodiments in such a detail that a person skilled in the art is able to utilize the flotation arrangement and its use, and the method based on the disclosure. Not all steps of the embodiments are discussed in detail, as many of the steps will be obvious for the person skilled in the art based on this disclosure.

For reasons of simplicity, item numbers will be maintained in the following exemplary embodiments in the case of repeating components.

The enclosed figures 1 and 2 illustrate a burner 10. Figures 3 and 4 depict a boiler 1.

The boiler 1 comprises a combustion chamber 2, walls 4, 4a, 4b, a boiler top 5, and a boiler funnel 7 at the bottom of the combustion chamber 2. The boiler 1 further comprises a second pass 3 connected to combustion chamber 2 via a channel 6. Burner 10 or burners 10 are arranged for supplying fuel dust and cold non-preheated combustion air into the combustion chamber 2 of the boiler 1. The boiler 1 may be a top-fired boiler, in which case the burner 10 or burners 10 are arranged at the top 5. The top-fired boiler 1 may comprise one burner 10. The top-fired burner 1 may comprise two burners 10. Alternatively, the boiler 1 may be a wall-fired boiler, in which case a burner 10 or burners 10 are arranged at a wall 4 or at two opposite walls 4a, 4b. The burner 10 or burners 10 may be of any of the embodiments disclosed in the following.

A burner 10 for producing a flame in the combustion chamber 2 of the boiler 1 comprises a primary air nozzle 20 for supplying primary air 100 into the combustion chamber 2 arranged at the center of the burner 10. An annular secondary air channel 22 for supplying secondary air 200 into the combustion chamber 2 is arranged to encompass the primary air nozzle 20, coaxially. An annular tertiary air channel 23 for supplying tertiary air 300 into the combustion chamber 2 is arranged to encompass the secondary air channel 22, coaxially. Further, an annular fuel nozzle 21 is arranged coaxially between the primary air nozzle 20 and the secondary air nozzle 22. Through the annular fuel nozzle 21, carrier air 110 and fuel dust are introduced into the combustion chamber 2 through the burner 10.

The tertiary air channel 23 comprises a guide sleeve 40 aligned with a burner throat 41 at an angle α. The angle α is formed between a first line a extending along the guide sleeve 40, and a second line b aligned with the burner center line. In an embodiment, the angle α is 30 to 35°.

The guide sleeve 40 directs a stream of tertiary air off axially from the stream of primary air 100 exiting the primary air nozzle 20 so that an inner recirculation zone IRZ is formed between the stream of primary air 100 and the stream of tertiary air 300.

The cross-sectional area $A_{23}$ of the tertiary air channel 23 may be configured to produce a desired velocity to the stream of tertiary air exiting the tertiary air channel 23. For example, the diameter of the tertiary air channel 23 may be 39 mm, producing a velocity of 41 m/s of the tertiary air, and a mass flow rate of 5,5 kg/s. The overall dimensions of the burner 10 depend on the desired fuel power of the burner, and the person skilled in the art will be able to calculate the necessary values based on the specifications regarding velocities and mass flow rates of the combustion air fractions, as detailed in the following.

A swirl generator 30 is arranged at the primary air nozzle 20. The swirl generator 30 is configured to provide a moderate swirl into primary air 100 fed through the primary air nozzle 20 so that primary air 100 has a swirl number $S_p$. For example, the swirl number $S_p$ may be 0,45; or 0,5, or 0,7, or 0,85. In an embodiment, the swirl number $S_p$ of primary air 100 is 0,6. The swirl generator 30 is configured to provide a swirl number $S_p$ of 0,4 to 1,0 into primary air 100 by the swirl vanes 31. The swirl generator 30 may comprise non-adjustable swirl vanes 31 for directing primary air 100. The swirl vanes 31 are arranged at a vane angle relative to the flow of primary air 100, the vane angle being 40 to 45°. This is the angle β referred to in the formula presented in Background part of this specification, and allows the calculation of the swirl number $S_p$.

In an embodiment, the swirl generator 30 is adjustable to adjust the swirl number $S_p$ of primary air 100. The swirl generator 30 gives tangential motion to the air flowing through it. The swirl number can be adjusted by adjusting the angle of the swirl vanes 31, as described above, and by changing the velocity of the air. The swirl vane angle needed to supply the combustion air a certain swirl number $S_p$ depends on the type of the swirl generator 30.

The burner 10 further comprises a flame stabilizing ring 50. The flame stabilizing ring 50 is arranged at the annular fuel nozzle 21, which further comprises an outer wall 51 and an outlet. The secondary air nozzle 22 is arranged around the annular fuel nozzle 21 the flame stabilizing ring 50 is attached to the outer wall 51 of the annular fuel nozzle 21 such that it surrounds the outlet of the annular fuel nozzle 21 and protrudes towards the outlet of the secondary air channel 22. The flame stabilizing ring 50 blocks a part of the outlet of the secondary air channel 22.

Carrier air 110 and fuel supplied through the annular fuel nozzle flow on one side of the flame stabilizing ring 50 and secondary air 200 supplied through the secondary air channel 22 flows on the other side of the flame stabilizing ring 50. The flame stabilizing ring 50 blocks a part of the outlet of the secondary air channel 22. A part of the secondary air 200 flow collides with the flame stabilizing ring 50, whereby the flow field of that air is changed. The flame stabilizing ring 50 thus helps in forming the inner recirculation zone IRZ, which is formed downstream of the flame stabilizing ring 50. The inner recirculation zone IRZ is formed by the reverse flow of combustion air back to the burner 10. The inner recirculation zone IRZ is delimited in radial direction, i.e. in the direction perpendicular to the central axis of the annular fuel nozzle 21, by the flame stabilizing ring 50. Behind, i.e. upstream of, the flame stabilizing ring 50 in the secondary air channel 22, a reduced pressure field is provided, which causes stabilization of the flame, or at least enhances the stability of the flame. In addition, the flame ignites better by means of the flame stabilizing ring 50 than without the flame stabilizing ring. The fuel is ignited within the recirculation flow generated inside the flame stabilizing ring 50. The flame stabilizing ring 50 changes the flow field of the flame so as to keep the flame narrow.

The flame stabilizing ring 50 ignites the fuel right in the vicinity of the burner nozzle. To be more precise, the fuel is ignited within the recirculation flow generated inside the flame stabilizing ring 50. As a result of improved ignition, the burning degree of the fuel increases and, consequently, flue gas temperatures in the furnace upper part decrease by about 20 – 50 °C, which increases boiler efficiency. Due to enhanced burning in the burner zone, flue gases are at lower temperature when entering the superheaters and also the temperature distribution within the flue gases is more uniform. Consequently, the material temperatures of the superheater and re-heaters will be kept lower and more uniform. Experience shows that this will result in remarkable reduction of material damages in the heating surfaces. Document WO 2017/212108 A1 discloses one possible suitable flame stabilizing ring 50, but it is self-evident that any other type of flame stabilizing ring can be used as needed.

The method for burning fuel comprises the following steps. Cold, non-preheated combustion air and dust fuel are supplied into the combustion chamber 2 of the boiler 1 through the burner 10, for producing a flame. The combustion air comprises primary air 100 fed through a primary air nozzle 20 at the centre of the burner 10, secondary air 200 fed through an annular secondary air channel 22 encompassing the primary air nozzle 20, and tertiary air 300 fed through an annular tertiary air channel 23 encompassing the secondary air channel 22. Further, carrier air 110 mixed with the dust fuel is supplied into the combustion chamber 2 through an annular fuel nozzle 21 arranged coaxially between the primary air nozzle 20 and the secondary air channel 22. The dust fuel is supplied through the burner by the annular fuel nozzle 21 with carrier air 110. It is to be understood that although the term carrier *air* is used in this specification, the carrier medium may be also some other gas. The carrier air 110 may comprise primary air 100. The carrier air 110 may comprise a mixture of air and flue gas.

In addition over-fire air (OFA) may be supplied into the combustion chamber 2 of the boiler 1 by any suitable conventional means. In case OFA is utilised, it is not calculated into the total combustion air, or into the mass flow rate of the total combustion air, in the embodiments disclosed in this specification.

The flame is stabilized by providing a flame stabilizing ring 50 at the downstream end of the annular fuel nozzle 21 and a swirl generator 30 at the primary air nozzle 20 through which swirl generator, the primary air 100 is directed so that it has a swirl number $S_p$.

Primary air 100 is fed into the combustion chamber 2 of the boiler 1 through the primary air nozzle 20 at the centre of the burner 10. In order to produce a swirl into primary air 100 so that it has a swirl number $S_p$, primary air 100 is directed to flow through the swirl generator 30, at the primary air nozzle 20. The flame stabilizing ring 50 arranged at a downstream end of the annular fuel nozzle 21 enables reducing the swirl number $S_p$ by stabilizing the flame. The swirl number $S_p$ of primary air 100 is set at 0,4 to 1,0. For example the swirl number $S_p$ may be 0,45; or 0,5, or 0,7, or 0,85. In an embodiment, the swirl number $S_p$ of primary air 100 is 0,6.

Swirl is not provided into secondary air 200 and tertiary air 200, i.e. the swirl number for secondary air 200 and tertiary air 300 is 0. Thus, secondary air 200 and tertiary air 300 are in non-swirling motion, or have a very weak swirl.

Tertiary air 300 is guided of with the guide sleeve 40 at angle α. This produces a formation of an inner recirculation zone IRZ between a stream of primary air 100 and tertiary air 300. The inner recirculation zone IRZ enhances flame stability by stagnating the fuel particles and hot gases in the inner recirculation zone IRZ, thereby bringing about a constant, complete combustion, as intensive separation of air and fuel at near burner 10 region is avoided. Flows of air and fuel are more axial to avoid directing of fuel to the furnace walls 4. As spreading of flame is avoided or reduced, carbon monoxide is directed away from the boiler walls 4 by means of improved flow field. The amount of CO near the boiler walls 4 is reduced, which reduces the corrosion of furnace walls caused by CO. Further, axial flow of air and fuel reduces spreading of fuel dust to the boiler walls 4. As the amount of fuel in between the hot flow and heat transfer surfaces at the boiler walls 4 is reduced, heat transfer is improved, which in turn causes reduction in the furnace exit gas temperature (FEGT).

Fuel supplied into the boiler may be dust fuel, i.e. pulverized fuel. In an embodiment, the dust fuel is bio-based dust obtained by milling dried bio-based raw material. The bio-based raw material can be, for example, sawdust pellets, wood coke, charcoal, lignin pellets, secondary fractions of bio product plants, agricultural waste, peat, organic municipal waste, and non-food energy crops. The dust fuel is obtained by milling or grinding the raw material into a dust having a particle size range of 0,1 to 2,0 mm. In another embodiment, the dust fuel is coal dust that has a particle size range of below 0,2 mm. Prior to feeding the dust fuel together with carrier air 110 into the combustion chamber 2 through the burner 10, the dust fuel is mixed with the carrier air in a conventional manner.

Velocity of primary air 100 at the primary air nozzle 20 orifice is set to 30 m/s or less. In an embodiment, the velocity of primary air 100 at the primary air nozzle 20 orifice is set to 18 to 25 m/s. In an embodiment, velocity of primary air 100 at the primary air nozzle 20 orifice is set to 20 m/s.

The velocity of carrier air 110 at the downstream end of the annular fuel nozzle 21 is set to 10 to 15 m/s. In an embodiment, the velocity of carrier air 110 at the downstream end of the annular fuel nozzle 21 is set to 13 m/s. In an embodiment, the velocity of carrier air 110 at the downstream end of the annular fuel nozzle 21 is set to 10 m/s. Velocity of tertiary air 300 is set at 35 to 50 m/s, measured at the end of the guide sleeve 40. The velocity of tertiary air 300 may be 38 m/s; or 40 m/s, or 43 m/s, or 45 m/s, or 47,5 m/s. For example, the cross-sectional area $A_{23}$ of the tertiary air channel 23 is arranged such that the velocity of tertiary air 300 is 35 to 50 m/s.

By providing the tertiary air 300 with a velocity of 35 to 50 m/s, the inner recirculation zone IRZ may be further improved. The recirculation flow upstream of the flame stabilizing ring 50 is enlarged. Also, ignition of the flame is improved. The velocity of the tertiary air 300 may be increased by narrowing the flow path of the air. Relatively high-velocity tertiary air 300 creates strong turbulence, which leads to efficient mixing of combustion air and fuel and quick ignition and hot flame.

The velocity of the secondary air 200 or tertiary air 300 at the outlet of the respective air channels 22, 23 depends on the mass flow rate of the air and on the cross-sectional area of the secondary air channel 21 or tertiary air channel 23 at the outlet of the respective air channel. The mass flow rate Q is defined by the equation $Q = v \cdot A$, wherein v is the velocity of the air and A is the cross-sectional area of an air channel. Having knowledge of the mass flow rate and the desired velocity, the skilled person is able to determine the cross-sectional area of the secondary air channel 22 or the tertiary air channel 23 at the outlet of the channel. The air pressure drop met by the burner is typically 150 mm $H_2O$. This pressure drop will be handled by the force draft fan, which provides secondary air 200 and tertiary air 300 into the boiler 1.

The mass flow rate of the air depends on several factors. The stoichiometric amount of air needed for combustion by each burner depends on the size of the burner. The size of the burner 10 used in the method may be 5 to 50 MW, for example 22,5 MW. Having the knowledge of the desired air coefficient, i.e. the amount of air used for combustion in comparison with the theoretical (stoichiometric) volume of air needed for complete combustion of the fuel, the skilled person is able to determine the mass flow rate of air used for combustion.

The proportion of tertiary air 300 supplied into the combustion chamber 2 of the boiler 1 may be 45 to 55

% of the mass flow rate of the total combustion air supplied into the boiler 1 by the burner 10. The total combustion air comprises the fractions of primary air 100, secondary air 200 and tertiary air 300. In case OFA is used, it is not calculated into the total combustion air. For example, the mass flow rate of total combustion air may be 9,1 kg/s, and the mass flow rate of tertiary air 300 may be 5,5 kg/s.

The ratio of mass flow rate of secondary air 200 to the mass flow rate of tertiary air 300 being fed into the combustion chamber 2 of the boiler 1 may be from 1:6 to 1:5. For example, the mass flow rate of secondary air 200 may be 1,25 kg/s, and the mass flow rate of tertiary air 300 may be 5,5 kg/s (at a velocity of 40 m/s).

The ratio of mass flow rate of primary air 100 to that of carrier air 110 being fed into the combustion chamber 2 of the boiler 1 may be from 2:1 to 2,5:1. For example, the mass flow rate of primary air may be 2,35 kg/s, and the mass flow rate of carrier air 110 may be 1,0 kg/s.

The ratio of mass flow rate of dust fuel to that of carrier air 110 may be substantially 1:1, that is, the ratio of dust fuel to carrier air is close to unity.

The method according to the aforementioned embodiments may be used for top firing a boiler 1, i.e. it may be utilised in a top-fired boiler, in which case the burner 10 or burner 10 are arranged at the top 5 of the boiler 1. Alternatively, the method may be used for wall firing a boiler 1, i.e. it may be utilised in a wall-fired boiler, in which case a burner 10 or burners 10 are arranged at a wall 4. In opposite wall firing, burners 10 are arranged at opposite walls 4a, 4b of the wall-fired boiler 1.

EXAMPLE

The following example details one exemplary embodiment. It is to be understood that the invention is not in any way limited to the following example, but that its features can be varied according to the embodiments disclosed in the above description.

A boiler 1 was fired with bio dust fuel originating from white pellets. For top firing the boiler, two burners 10 arranged at the top 5 of the boiler 1 were used to supply the fuel and cold, non-preheated combustion air into the combustion chamber 2 of the boiler 1, and to produce a flame for burning the fuel.

After milling the white pellets, the particle size range of the dust fuel was 0,1 to 1,1 mm, with 90 % of the dust fuel particles falling into a range of 0,1 to 0,65 mm. Moisture content of the dust fuel was 8,2 % by mass. The lower heating value LHV (i.e. net heating value) of the dust fuel was 18,98 MJ/kg, and the fuel ratio (FR, ratio of fixed carbon to volatile matter) was 0,16. Chemical composition of the dust fuel in dry state was the following: 50,55 % C; 6,25 % H; 48,82 % O; 0,07 % N; and 0,01 % ash. The dust fuel comprised no sulfur.

Dust fuel was fed into the boiler 1 at mass flow rate of 2,613 kg/s, together with carrier air 110 into which it had been mixed prior to supplying it through the burners 10. Carrier air mass flow ratio was 2 x 1,0 kg/s, i.e. 2,0 kg in total for the two burners 10, and the velocity of carrier air at the downstream end of the annular fuel nozzle 21 10 m/s.

Combustion air comprised of

- primary air 100, fed at a mass flow rate of 2 x 2,35 kg/s, i.e. 4,7 kg/s in total for the two burners 10 at an axial velocity of 20 m/s at the primary air nozzle 20 orifice,

- secondary air 200, fed at a mass flow rate of 2 x 1,25 kg/s, i.e. 2,5 kg/s in total for the two burners 10, and

- tertiary air 300, fed at a mass flow rate of 2 x 5,5 kg/s, i.e. 11,0 kg/s in total for the two burners

10 at a velocity of 40 m/s at the downstream end of the tertiary air channel 23.

A swirl generator 30 comprising swirl vanes 31 at a 45° angle was used to produce a swirl number $S_p$ of 0,65 into the primary air 100, as detailed in the above description.

A fuel power of 2 x 22,5 MW, that is 45 MW was obtained with the burners 10. Single stage combustion was used, with no OFA. All walls 4 of the boiler 1 were water-cooled. Combustion air and dust fuel both were split evenly between the two burners 10. The burners 10 comprised means for producing adjustable swirl into primary air 100, and a guide sleeve 40 in the tertiary air channel 23 to produce a 35° angle to the stream of tertiary air 300, in the manner described above. The SR number of both burners 10 was 1,37; the SR number for volatiles 0,84; and flue gas rate 22,8.

As a result, the emissions of CO were 19 mg/m³, and CO ppm 14 at the outlet. Prior to second pass 3, CO was around 120 mg/m³, and around 85 ppm. NOx was 135 mg/m³. Flue exit gas temperature prior to the second pass 3 had a mean value of 1095 to 1100 °C, and a maximum at 1190 to 1210 °C. The proportion of unburned coke was below 5 %. Heat extracted to the water side in the combustion chamber 2 section of the boiler 1, i.e. excluding that of the second pass 3, was 14,8 MW.

The temperature variations within the combustion chamber 2 were significantly evened out by the burners 10 and the method of burning fuel. The temperature at the boiler walls 4 was decreased, as was the temperature at the second pass 3.

The embodiments described hereinbefore may be used in any combination with each other. Several of the embodiments may be combined together to form a further embodiment. A flotation cell to which the disclosure is related, may comprise at least one of the embodiments described hereinbefore. 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 burning fuel, the method comprising supplying cold non-preheated combustion air and dust fuel into a combustion chamber (2) of a boiler (1) through a burner (10) for producing a flame, the combustion air comprising primary air (100) fed through a primary air nozzle (20) at the centre of the burner, secondary air (200) fed through an annular secondary air channel (22) encompassing the primary air nozzle, tertiary air (300) fed through an annular tertiary air channel (23) encompassing the secondary air channel; the dust fuel and carrier gas (110) fed through an annular fuel nozzle (21) arranged coaxially between the primary air nozzle and the secondary air channel; wherein the method, the flame is stabilised by providing a flame stabilising ring (50) at a downstream end of the annular fuel nozzle and primary air is directed through a swirl generator (30) at the primary air nozzle so that primary air has a swirl number ($S_p$), characterized

- by guiding off a stream of tertiary air with a guide sleeve (40) aligned with a burner throat (41) at an angle (α), the angle (α) formed between a first line (a) extending along the guide sleeve and a second line (b) aligned with the center line of the burner so that an inner recirculation zone (IRZ) is formed between a stream of primary air and the stream of tertiary air;

- by setting the swirl number of primary air at 0,4 to 1,0 by the swirl generator;

- by setting the primary air velocity at the primary air nozzle orifice to 30 m/s or less, and the carrier air velocity at the downstream end of the annular fuel nozzle to 15 m/s or less; and

- by setting the tertiary air velocity so that at the end of the guide sleeve (40), the tertiary air velocity is 35 to 50 m/s.

2. The method according to claim 1, c h a r a c t e r i z e d by the angle (α) being 30 to 35°.

3. The method according to claim 1 or 2, c h a r a c t e r i z e d in that the primary air (100) velocity at the primary air nozzle (20) orifice is set to 18 to 25 m/s, preferably to 20 m/s.

4. The method according to any one of claims 1 to 3, c h a r a c t e r i z e d in that the carrier gas (110) velocity at the downstream end of the annular fuel nozzle (21) is set to 10 m/s to 15 m/s.

5. The method according to any one of claims 1 to 4, c h a r a c t e r i z e d in that the swirl number ($S_p$) of primary air (100) is adjusted by an adjustable swirl generator (30).

6. The method according to any one of claims 1 to 4, c h a r a c t e r i z e d in that the swirl number ($S_p$) of primary air (100) is adjusted by the swirl generator (30) comprising non-adjustable swirl vanes having a vane angle of 40 to 45°.

7. The method according to any one of claims 1 to 6, c h a r a c t e r i z e d in that the proportion of tertiary air (300) supplied into the combustion chamber (2) of the boiler (1) is 45 to 55 % of the mass flow rate of the total combustion air supplied into the boiler by the burner (10), the total combustion air comprising primary air (100), carrier air (110), secondary air (200) and tertiary air (300).

8. The method according to any one of claims 1 to 7, c h a r a c t e r i z e d in that the ratio of mass flow rate of secondary air (200) to tertiary air (300) being fed into the combustion chamber (2) of the boiler (1) is 1:6 to 1:5.

9. The method according to any one of claims 1 to 8, characterized in that the ratio of mass flow rate of primary air (100) to carrier air (110) being fed into the combustion chamber (2) of the boiler (1) is 2:1 to 2,5:1.

10. The method according to any one of claims 1 to 9, characterized in that the ratio of mass flow rate of dust fuel to that of carrier air (100) is substantially 1:1.

11. The method according to any one of claims 1 to 10, characterized in that the dust fuel is bio dust obtained by milling dried bio-based raw material chosen from a group comprising: sawdust pellets, wood coke, charcoal, lignin pellets, secondary fractions of bio product plants, agricultural waste, peat, organic municipal waste, non-food energy crops, and the like.

12. The method according to claim 11, characterized in that the milled bio dust fuel has a particle size range from 0,1 to 2,0 mm.

13. The method according to any one of claims 1 to 10, characterized in that the dust fuel is coal dust having a particle size range below 0,2 mm.

14. A burner (10) for producing a flame in a combustion chamber (2) of a boiler (1), the burner comprising a primary air nozzle (20) at the centre of the burner, an annular secondary air channel (22) encompassing the primary air nozzle, an annular tertiary air channel (23) encompassing the secondary air channel, and an annular fuel nozzle (21) arranged coaxially between the primary air nozzle and the secondary air channel, a flame stabilising ring (50) at a downstream end of the annular fuel nozzle and a swirl generator (30) at the primary air nozzle, characterized in

that the tertiary air channel comprises a guide sleeve (40) aligned with the burner throat (41) at an angle (α), formed between a first line (a) extending along the guide sleeve and a second line (b) aligned with the center line of the burner, the guide sleeve arranged to direct a stream of tertiary air off so that an inner recirculation zone (IRZ) is formed between a steam of primary air and a stream of tertiary air; and that the swirl generator is configured to effect a swirl number ($S_p$) of 0,6 to 1,5 to primary air (100) fed into the combustion chamber via the primary air nozzle of the burner.

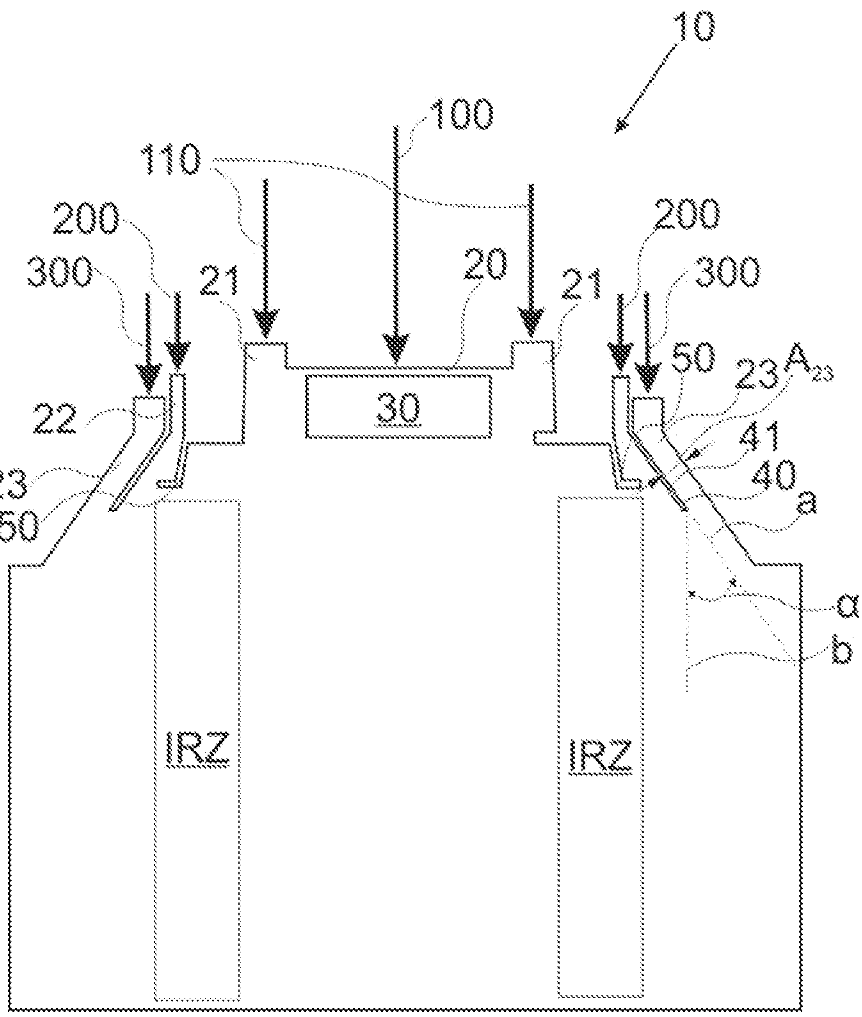
15. The burner according to claim 14, c h a r a c t e r i z e d in that the angle (α) is 30 to 35°.

16. The burner according to claim 14 or 15, c h a r a c t e r i z e d in that the swirl generator (30) is adjustable.

17. The burner according to claim 14 or 15, c h a r a c t e r i z e d in that the swirl generator (30) comprises non-adjustable swirl vanes having a vane angle of 40 to 45°.

18. A boiler (1) comprising a burner (10) according to any one of claims 16 to 19.

19. The boiler according to claim 18, c h a r a c t e r i z e d in that it comprises at least two burners (10) according to any one of claims 14 to 17.


10
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21
20
21
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Fig. 1

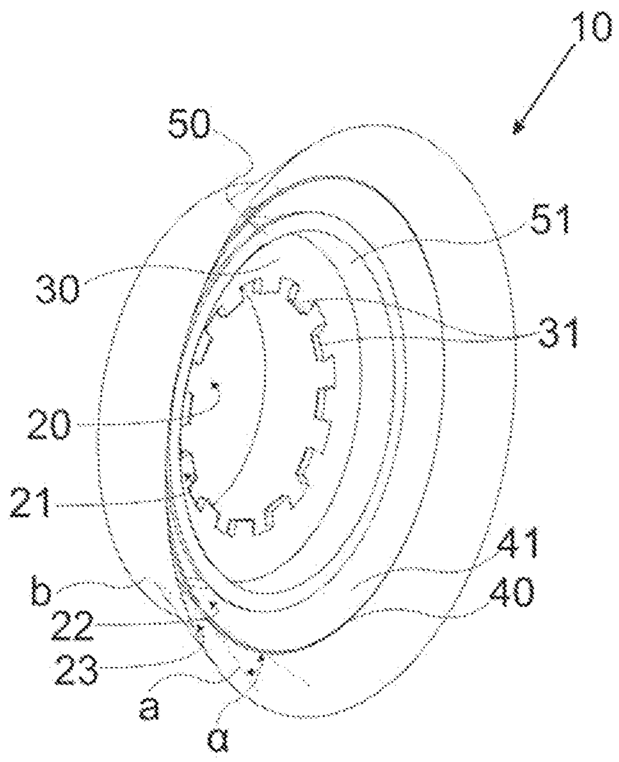


Fig. 2

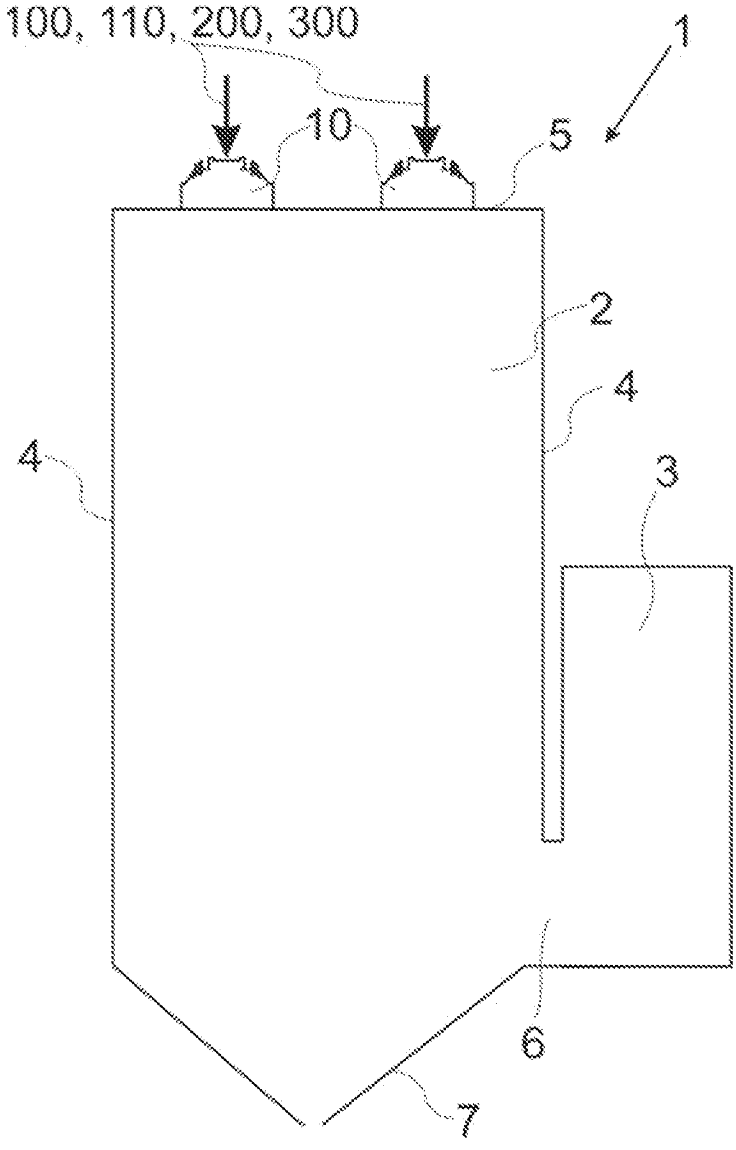


Fig. 3

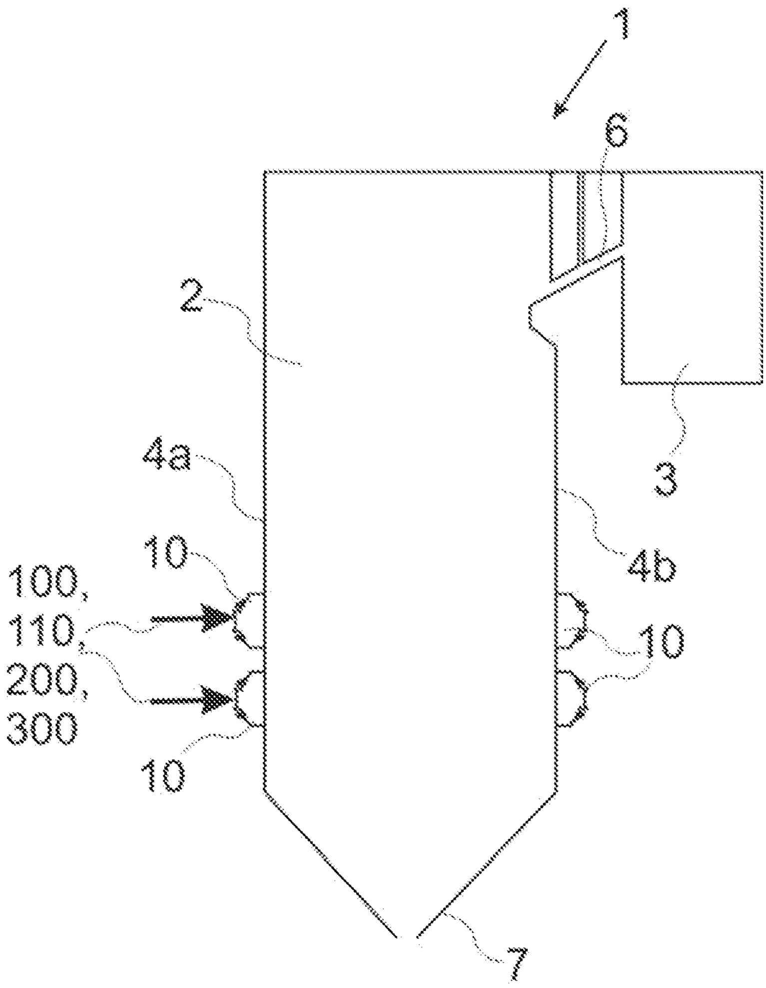


Fig. 4

**INTERNATIONAL SEARCH REPORT**

International application No.
PCT/FI2018/050928

A. **CLASSIFICATION OF SUBJECT MATTER**

See extra sheet

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: F23D, F23C, F23R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

FI, SE, NO, DK

Electronic data base consulted during the international search (name of data base, and, where practicable, search terms used)

EPODOC, EPO-Internal full-text databases, WPIAP

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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| A | GB 671937 A (POWER JETS RES & DEV LTD)<br>14 May 1952 (14.05.1952)<br>the whole document, especially figures 1-6 | 1-19 |
| A | US 2013305971 A1 (HAMEL STEFAN [DE] et al.)<br>21 November 2013 (21.11.2013)<br>the whole document, especially figures 1-4B | 1-19 |

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 01 April 2019 (01.04.2019) | 03 April 2019 (03.04.2019) |

Name and mailing address of the ISA/FI
Finnish Patent and Registration Office
FI-00091 PRH, FINLAND
Facsimile No. +358 29 509 5328

Authorized officer
Janne Pirhonen
Telephone No. +358 29 509 5000

| Patent document cited in search report | Publication date | Patent family members(s) | Publication date |
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CLASSIFICATION OF SUBJECT MATTER

IPC
***F23D 23/00*** (2006.01)
***F23C 7/00*** (2006.01)
***F23C 6/04*** (2006.01)
***F23R 3/14*** (2006.01)
*F23D 1/02* (2006.01)