Title: A BOILER AND A PROCESS FOR THE EXTRACTION OF ENERGY FROM A FUEL

Abstract: The present invention relates to a process and a boiler for the extraction of energy from a fuel. Typically, the boiler comprises a gasification zone and a burnout zone being separated by at least one partitioning construction and being connected to at least one furnace room. The boiler typically further comprise one or more grates supporting the fuel, wherein and/or by means of which fuel is transported from the gasification zone to the burnout zone. The process typically comprises the steps of: (i) feeding the fuel to the gasification zone and at least partial gasification of the fuel therein by means of heating; (ii) successively, feeding of the at least partially gasified fuel from the gasification zone to the burnout zone, and at least partially burnout of the fuel, which burnout is preferably effected by addition of an oxidising agent.
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A BOILER AND A PROCESS FOR THE EXTRACTION OF ENERGY FROM A FUEL

The invention disclosed herein has been developed with a view to meeting the demands made to rational, efficient and environmentally sound exploitation of biomass for energy production, including combined energy and heat production.

In Denmark energy production based on solid fuel, including biomass, has been realised primarily by combustion in steam generation boilers. In the most recent systems, combustion is realised on a water-cooled vibration grate. This technique has some advantages which will be maintained to the extent possible in the present invention. These advantages may be summarised as follows:

- Wear of a water-cooled vibration grate is limited in comparison to other grates.
- The vibrations of the grate have a stabilising effect on the combustion due to the compression of the burned ashes and the counteraction of inhomogenities caused by channel formations in the fuel layer.
- The water-cooling of the grate allows the quantity of air administered through the fuel layer to be varied freely.

However, combustion on a water-cooled vibration grate has a number of disadvantages which will be eliminated or minimised by the present invention. These disadvantages may be summarised as follows:

- Combustion of wood chips and straw, respectively, is realised in different ways. Consequently, a system for the combustion of wood chips cannot burn straw, and a system for the combustion of straw can only burn a certain quota of straw.
- The burnout of the slag is incomplete.
- KCl in the fuel is to a great extent liberated to the furnace room and makes heavy demands on the construction of the boiler in order to prevent corrosion and clogging, and reduces the heat transfer on the heat transferring faces of the boiler dramatically.
- Large quantities of material are carried from the grate, especially when the load is high. This also contributes to clogging and results in losses.
- Excess air control and steam production control are not optimal.
- The state on the grate varies with the physical properties of the fuel and requires frequent inspections of the boiler, especially if fuel of a varying quality is used.
- The varying state on the grate and the unstable level of excess air result in relatively high emissions of CO and NOx. In particular CO can be very unstable from time to time.
- The relative absorption of heat in overheaters varies dramatically with the water content of the fuel and the degree of fouling.
An object of preferred embodiments of the present invention is that the fuel is preferably assumed to be straw and wood chips in an arbitrary ratio, and other types of biomass must be combustible as well. The aim of preferred embodiments of the present invention is that apart from requirements with respect to the handling and a certain minimum calorific value, there are no particular requirements to the fuel.

Preferred embodiments of the present invention attempts to fulfil the above objects by means of a process for the extraction of energy from a fuel in a boiler, preferably comprising at least one gasification zone and at least one burnout zone. These zones are separated by at least one partitioning construction, and the zones are preferably connected to at least one furnace room. Further, the boiler preferably comprises one or more grates supporting the fuel, on which and/or by means of which fuel is transported from the at least one gasification zone to the at least one burnout zone.

Preferably, the process comprises the following steps:
- feeding of the fuel to the gasification zone and at least partial gasification of the fuel therein by means of heating, the heat for the heating being at least partially generated by an oxidation process resulting at least partially from a reaction between a fraction of the fuel, e.g. combustible gasses from the fuel, and an oxidising agent supplied to the gasification zone, causing a quantity of non-oxidised, combustible gasses fed to the furnace room to be provided;
- successively, feeding of the at least partially gasified fuel from the gasification zone to the burnout zone and at least partially burnout of the fuel, which burnout is preferably effected by addition of an oxidising agent.

Even though it is preferred in some embodiments of the invention to fully gasificate the fuel in the gasification chamber, the invention is not limited to such embodiments. As indicated above the fuel is in particular preferred embodiment at least partial gasified and the fuel is after gasification fed to the burnout zone. Similarly, the burnout of the fuel in the burnout zone is in some preferred embodiments of the invention performed fully, but the invention is not limited to such embodiments.

As discussed above, the present invention utilises gasification of the fuel. Typically, the term gasification refers to a process in which heat is added to a material while no oxidation agent is added resulting in that the volatile combustible constituents are released. In connection with the present invention, it is preferred that more than 70%, such as more than 80%, preferably more than 90% of the materials volatile combustible constituents are released in the gasification zone.
In relation to the present invention, gasification is preferably self-driven in the sense that the heat needed for keeping the gasification running is preferably provided by introducing an oxidizing agent into the gasification zone to react with a fraction of the released volatile substances to produce heat. The fraction, referenced to stoichiometric ratio, is typically and preferably between 10-40%, such as between 15-25%, preferably between 15-20%, of the total amount of the released substances. In particular, when the fuel is wood chips, the fraction is around 30% resulting in a temperature around 800°C to 900°C. The heat generated in this manner heats the material to be gasified (the fuel). The oxidation agent introduced is typically and preferably atmospheric air, and is typically and preferably fed into the gasification zone to oxidize a fraction of the released volatile substances. Typically and preferably, the temperature of the fuel during gasification is between 700°C and 900°C, such as between 750°C and 850°C and even more preferably between 775°C and 825°C.

Typically and preferably, the term gasification zone refers to a continuous region on one or more grates, on which there is a substantially covering layer of fuel. The volume filled by the covering fuel layer and the gas volume immediately above are usually included in the gasification zone. Further, the gasification zone is preferably surrounded by a construction which, in combination with the flow of combustion air and the generated gasification and combustion products in the zone, substantially prevent leakage of gasses from the burnout zone and the furnace room. The surrounding construction of the gasification zone also prevents the feeding of other fuel than that fed to the boiler system, and fuel is prevented from leaving the gasification zone, except from that passing through a limited opening in the burnout zone.

As also discussed above, the present invention utilises burnout of the fuel. Typically and preferably, the term burnout refers to a process in which the combustible substances, i.e. those substances which contribute to production of energy by oxidising, of the fuel remaining after the fuel has been subjected to a gasification process are oxidised. In connection with the present invention, it is preferred that more than 85%, such as 90%, even more preferably more than 95%, such as more than 98% of these remaining combustible substances are oxidised during burnout.

The burnout is similar to the gasification typically and preferably self-driven in the sense that the energy needed to heat the fuel to the temperature of the burnout is developed by oxidising the fuel.
Typically and preferably, the term burnout zone refers to a continuous region on one or more grates, on which there is a partially covering layer of fuel. The volume filled by the partially covering fuel layer and the gas volume immediately above are usually included in the burnout zone. Preferably, the burnout zone is surrounded by a construction which, in combination with the flow of combustion air and the generated gasification and combustion products in the zone, substantially prevent the intrusion of gasses from the gasification zone and the furnace room. The surrounding construction of the burnout zone also prevents the feeding of other fuel than that from the gasification zone. Further, at the end of the grate there is an opening to a ash extraction system, where the burned ashes may be carried away.

By letting the energy extraction take place in a gasification zone and a burnout zone that are both well defined by interaction between the grate, the fuel and the partitioning construction a process and a boiler is provided, wherein the partitioning construction may keep gasses generated in the two zones separate and may retain excess fuel in the gasification zone, so that the layer thickness of the fuel at the beginning of the burnout zone may become well defined. This has *inter alia* the advantage that control of the process and thus the operation of the boiler is relatively simple, as the two energy conversion processes can be controlled separately, and as the layer thickness in the burnout zone may be well defined.

The gasification zone and the burnout zone are preferably connected to at least one furnace room. This connection/these connections is/are typically and preferably of such kind that gases produced in the gasification zone are led to the furnace room without passing through the burnout zone. The connection between the burnout zone and the furnace room is typically and preferably of such kind that heat and gases, if any, produced in the burnout zone are led to the furnace room without passing through the gasification zone. In particular preferred embodiments the burnout zone and the furnace room are two regions in a channel and in such embodiments the furnace room may preferably be defined as that region of the channel where the gas produced in the gasification zone are introduced, ignited and burned and where the heat and gases produced, if any, in the burnout zone are introduced and the gases ignited, if any.

In particular preferred embodiments, the partitioning construction between the gasification zone and the burnout zone is substantially preventing gasses from the gasification zone and the burnout zone from mixing. Furthermore, the partitioning construction determines preferably the height of the fuel fed to the burnout zone and determines preferably the height in embodiments where transport of the fuel from the gasification zone to the burnout zone is effected by said one or more grates.
The walls of the gasification zone are preferably panel walls filled with a fluid, e.g. water, or steam under pressure above atmospheric pressure, e.g. 2 bar, e.g. 10 bar, e.g. 20 bar.

In some preferred embodiment the grates used are water-cooled vibrations grates and in other preferred embodiments, at least one of said one or more grates is a water-cooled vibration grate.

Preferably, the quantity of degassed fuel transported from the gasification zone to the burnout zone is determined by the frequency and/or the amplitude of grate activations.

The quantity of wholly or partially degassed fuel transported from the gasification zone to the burnout zone corresponds, preferably to a calorific value of between 1 per cent and 50 per cent of the total energy supply, e.g. between 5 per cent and 20 per cent, or preferably between 10 per cent and 20 per cent of the total firing.

It is in general preferred that at least part of the oxidising agent is fed to the gasification zone through the grate and in some preferred embodiments the total amount of oxidising agent needed for the gasification is introduced through the grate. As an alternative or in combination thereto, a part of the oxidising agent or the total amount thereof may preferably be introduced into the gasification zone without passing through the grate, for instance introduce through wall parts enclosing, such as restricting the gasification zone. The oxidising agent fed to the gasification zone through the grate is preferably used to control the quantity of the energy extracted from the fuel in the gasification zone. Such a control may typically and preferably include introducing a larger amount of the oxidising agent in cases where more energy is needed and a smaller amount in cases where less energy is needed to heat the fuel during the gasification process.

Typically and preferably, the oxidising agent is fed to the burnout zone through the grate. Furthermore, the oxidising agent fed to the burnout zone through the grate is preferably used to control the quantity of energy extracted from the fuel in the burnout zone. Such a control may typically and preferably include introducing a larger amount of the oxidising agent in cases where more energy is needed and a smaller amount in cases where less energy is needed to heat the fuel during the burnout process.
Preferably, the quantity of oxidising agent supplied through the grate in the gasification zone constitutes between 20 per cent and 95 per cent of the total quantity of oxidising agent supplied through the entire grate, e.g. between 50 per cent and 95 per cent, or preferably between 60 per cent and 95 per cent.

In particular preferred embodiments, the fuel is supplied supplied to the gasification zone is supplied in least one place in the gasification zone. Typically and preferably the fuel is fed transversely to the direction in which the gasified fuel is transported from the gasification zone to the burnout zone.

Preferably, the fuel supplied in the gasification zone is supplied in such a way that the height of the fuel layer in at least part of the gasification zone is substantially constant, e.g. essentially close to the partition wall.

Furthermore, the fuel supplied in the gasification zone is preferably supplied in such a way that the temperature in at least part of the gasification zone, e.g. essentially close to partition wall, is essentially constant, e.g. between 100° Celsius and 200° Celsius.

Additionally, the fuel supplied in the gasification zone is preferably supplied in such a way that the said fuel is affecting at least part of the partition wall with an essentially constant force.

Furthermore, the fuel is preferably fed to the fuel layer in the gasification zone in such a way that the generated gasses are cooled to between 70° Celsius and 500° Celsius, e.g. between 80° Celsius and 300° Celsius, e.g. 90° Celsius and 200° Celsius, or preferably between 110° Celsius and 150° Celsius.

In many preferred embodiments of the present invention, it is preferred that a fraction of the heat generated by oxidation in a first layer of the fuel in the gasification zone heats and dries fuel in a second layer in the gasification zone, said second layer being located above the first layer. Furthermore, the share of heat used to heat the second layer in the gasification zone constitutes preferably at least 50 per cent of the generated heat, e.g. 65 per cent, e.g. 80 per cent.

The vertical distance from the upper part of the grate to the lower part of the underside of the partitioning construction is in many preferred embodiments of the present invention preferably between 100 mm and 900 mm, e.g. between 150 mm and 700 mm, or preferably between 200 mm and 500 mm.
The gasses generated above the burnout zone are in many preferred embodiments preferably fed to the furnace room, wherein they are mixed, in at least one step, e.g. at least two steps, with gas from the gasification zone and an oxidising agent, e.g. combustion air, e.g. air, e.g. air mixed with gasses from the furnace room.

Preferably, at least a fraction and preferably the total amount of the gas generated in the gasification zone is fed from the gasification zone and to the furnace room via at least one nozzle, preferably being formed as ejectors ejecting an oxidising agent into the furnace room and at the same time pulling the gas with.

In many preferred embodiments, the area of the holes in the part of the grate placed in the gasification zone constitutes preferably between 50 per cent and 1000 per cent relative to the holes in the part of the grate placed in the burnout zone, e.g. between 75 per cent and 400 per cent, e.g. between 80 per cent and 200 per cent, or preferably between 90 per cent and 150 per cent. Additionally, the grate is preferably divided into at least two zones, in which the feeding of the oxidising agent is regulated separately.

In many preferred embodiments, the quantity of oxidising agent supplied in the front part of the grate constitutes preferably between 50 per cent and 500 per cent relative to the quantity supplied in the back part of the grate, e.g. between 75 per cent and 200 per cent, or preferably between 100 per cent and 150 per cent.

The lower part of the partitioning construction separating the gasification zone and the burnout zone has preferably a slope of between 25 degrees and 65 degrees with respect to the upper part of the partitioning construction, thereby typically causing fuel pushing against this part of the partitioning construction to be pushed downwards, which results in compression of the fuel, e.g. between 35 degrees and 55 degrees, or preferably 45 degrees.

In many preferred embodiment, the speed with which the grate transports the fuel is higher in some parts of the grates, e.g. higher in the part of the grate essentially placed below the partition wall than in the part of the grate essentially placed in the final part of the burnout zone. Alternatively or in combination thereto, the speed with which the grate transports the fuel may preferably decrease from a distance before the part of the grate essentially placed below the part of the partitioning construction until the ash extraction system in the burnout zone. Furthermore, the decreasing speed on the grate is preferably achieved by varying the angle on leaf springs supporting the grate.
An aqueous steam may preferably be supplied below the grate for the part of the grate essentially placed below the part of the partitioning construction and at least part of the burnout zone, e.g. through at least one tube with evenly spaced holes. Furthermore, the aqueous steam supplied below the grate may preferably be supplied with a view to control the oxidation temperature of the fuel essentially placed on the part of the grate situated above the at least one tube, and wherein the oxidisation temperature is controlled to being between 400° Celsius and 1200° Celsius, e.g. between 500° Celsius and 1100° Celsius, e.g. between 600° Celsius and 1000° Celsius, e.g. between 700° Celsius and 900° Celsius, e.g. between 700° Celsius and 800° Celsius, or preferably between 750° Celsius and 800° Celsius.

Preferably, the end wall of the burnout zone has a slope causing at least part of the wall to incline towards the final part of the grate.

Typically and preferably, the fuel consists of biofuel, solid fuel, or a combination thereof. Typically examples of preferred fuels are biofuel, e.g. grasses, plant residue, such as rice cuts, bedding, sawdust, wood waste, straw, wood, wood chips, sea weed, peat, coal, coke, household waste, or a combination thereof or a combination thereof.

Similarly, the present invention provides an apparatus for the extraction of energy from a fuel in a boiler, said apparatus comprising at least one gasification zone, at least one burnout zone, at least one furnace room and one or more grates for transporting the fuel through and/or supporting the fuel in the boiler during the energy extraction.

Preferably, the apparatus according to the present invention comprises
- a gasification zone for the gasification of the fuel;
- at least one device for the feeding of an oxidising agent in at least one place in the boiler;
- a device for transporting non-oxidised, combustible gasses generated in the gasification zone from the gasification zone to the furnace room.

Preferably, the furnace room is situated relative to the burnout zone and/or in connection with the furnace room in such a way that heat generated in the burnout zone is led to the furnace room, and this conduction of heat is preferably effected by natural conduction, forced conduction, radiation, or a combination thereof.

In preferred embodiment of the apparatus according to the present invention the walls of the gasification zone are preferably panel walls filled with a fluid, e.g. water, or a steam under pressure above atmospheric pressure, e.g. 2 bar, e.g. 10 bar, e.g. 20 bar.
Furthermore, at least one of said one or more grates may preferably be a water-cooled vibration grate.

In apparatus according to the present invention, the vertical distance from the upper part of the grate to the lower part of the underside of the partitioning construction may preferably be between 100 mm and 900 mm, e.g. between 150 mm and 700 mm, or preferably between 200 mm and 500 mm.

Furthermore, apparatus according to the present invention may preferably comprise at least one nozzle for feeding at least a fraction and preferably the total amount of the gas generated in the gasification zone from the gasification zone and to the furnace room, said nozzles being preferably formed as ejectors ejecting an oxidising agent into the furnace room and at the same time pulling the gas with.

Additionally, in apparatus according to the present invention the grate(s) may preferably comprise holes through which an oxidising agent may be introduced into gasification zone and/or the burnout zone, and wherein the area of the holes arranged in the part of the grate placed in the gasification zone constitutes between 50 per cent and 1000 per cent relative to the holes in the part of the grate placed in the burnout zone, e.g. between 75 per cent and 400 per cent, e.g. between 80 per cent and 200 per cent, or preferably between 90 per cent and 150 per cent.

Additionally, the grate may preferably be divided into at least two zones, in which the feeding of the oxidising agent is regulated separately.

In preferred embodiments of apparatus according to the present invention, the lower part of the partitioning construction separating the gasification zone and the burnout zone has preferably a slope of between 25 degrees and 65 degrees with respect to the upper part of the partitioning construction, thereby typically causing fuel pushing against this part of the partitioning construction to be pushed downwards, which results in compression of the fuel, e.g. between 35 degrees and 55 degrees, or preferably 45 degrees.

Additionally, in preferred embodiment of the apparatus the end wall of the burnout zone has preferably a slope causing at least part of the wall to incline towards the final part of the grate.
The invention and specific embodiments thereof are described in the following with reference to the accompanying figure, wherein:

Fig. 1 shows a boiler in accordance with the present invention.

In Fig. 1 the following reference numbers are used with the following significance:

1. Panel walls - also including wall 1a
2. Overheating tubes
3. Water-cooled vibration grate
4. Leaf springs for guiding the vibration grate
5. Pinion for vibration grate
6. Air boxes being divided into zone for feeding air through the vibration grate
7. Air box having air nozzles for injecting combustion air
8. Venturi for injection of gasses from gasification zone to furnace room
9. Fuel supply
10. Fuel
11. Supporting structure for the grate
12. Water containing ash extraction system
13. The boiler's flue gas duct
14. Gasification zone
15. Burnout zone
16. Furnace room

As mentioned above, specific embodiments of the invention are described in the following, and it is envisaged that alterations of these embodiments of the invention are within the scope of the present invention.

The combustion process is realised on a water-cooled vibration grate 3 which is divided into a gasification zone section and a burnout zone section. The division into the gasification zone 14 and the burnout zone 15 is provided by a wall 1a through the furnace room 16. The wall 1a keeps the gasses of the two zones 14, 15 separate, and the underside of the wall 1a is 3-500 mm above the grates and retains excess fuel 10 in the gasification zone 14, so that the layer thickness at the beginning of the burnout zone 15 is well defined.

In the gasification zone 14 a layer thickness of fuel 10 is established, which ensures efficient cooling of the generated gasses, typically to 150-300°C. The fuel 10 is fed in a number of places across the grate 3 at a speed which is adjusted to the height of the fuel layer, so that the height is relatively constant across the entire boiler width. The air feeding be-
low the vibration grate 3 is used to control the conversion in the gasification zone 14 and consequently also the boiler load.

Fuel 10 corresponding to a calorific value of 10-20 per cent of the total firing is transported with the generated ashes on to the burnout zone 15. The quantity is controlled by the activation frequency of the vibration grate 3.

Due to the special division into a gasification zone 14 and a burnout zone 15, an aim of preferred embodiments of the present invention is that no K compounds escape to the gas phase in the gasification zone 14. Consequently, a highly increased concentration of KCl in the burnout zone 15 is to be expected. Preferably, the combustion in the burnout zone 15 should be effected with minimum liberation of KCl and particles.

The gasses generated above the burnout zone 15 are led upwards in the boiler and into the furnace room 16, and combustion air and gas from the gasification zone 14 are fed to the furnace room 16 in several steps by means of a venturi arrangement 8 as shown in Fig. 1. That is the gas from the gasification zone 14 is fed by a selection of the nozzles supplying the combustion air being formed as ejectors ejecting the combustion air into the furnace room 16 and pulling the gas with. This ensures safe ignition of the gasses in the furnace room 16 as well as good mixing.

In general and as it appears from fig. 1, the gasification zone 14 and the burnout zone 15 are connected to the furnace room 16. This connection/these connections is/are of such kind that gases produced in the gasification zone 14 are led to the furnace room 16 without passing through the burnout zone 15. The connection between the burnout zone and the furnace room is of such kind that heat and gases, if any, produced in the burnout zone 15 are led to the furnace room 16 without passing through the gasification zone 14.

In the embodiment of fig.1 the burnout zone and the furnace room are two regions in a channel and in this case the furnace room 16 may preferably be defined as that region of the channel where the gas produced in the gasification zone 14 are introduced, ignited and burned and where the heat and gases produced, if any, in the burnout zone 15 are introduced and the gases ignited, if any.

The following technical details are normally and preferably included in the invention.
1. Ensuring a high specific load
Preferably, the gasification zone should be delimited physically, as the thermal output per area in this zone is increased dramatically thereby, as the limitation therefor is normally constituted by large specific quantities of air fed below the grate 3 resulting in a strong entrainment of particles to the furnace room outside high fuel layer areas.

Preferably, 80-90 per cent of the energy conversion takes place in the gasification zone 14.

It is preferred to reduce the specific quantity of air dramatically in the transition between the gasification zone 14 and the burnout zone 15 by reducing the specific hole area in the grate 3. Further, it is preferred to divide the grate 3 into zones, so that the distribution of air can be adjusted in the various zones.

2. Ensuring the possibility of a compact boiler construction
Most important in this connection is the reduction of the load of KCl and entrained particles in the flue gas.

3. Ensuring ignition very close to the front wall
It is preferred as well as critical that the fuel layer in a gasifier is ignited across the entire surface. Otherwise air leakage may occur in the generated gas with the risk of deflagration. The problem is particularly relevant for wet wood chips. Since the material is transported downwards along the grate 3, problems may arise in connection with ensuring the ignition very close to the front wall. Such problems are sometimes seen in traditional vibration grates.

In order to further the ignition propagation, the grate air flow is gradually increased in the front part of the grate 3 concurrently with an attempt to create a material flow some way up the fuel layer, said material flow moving backwards on the grates with respect to the rising warm gasses.

4. Geometry at the material outflow from the gasification box
In order to ensure transport of entangled fuels, e.g. straw, by the vibration grate 3, and ensure that the fuel is cut at a well defined height, the lower part of the partition wall has a slope of approximately 45°. The vibration grate will press the fuel to the wall, and due to the slope this will result in a vertical pressure compressing burned structures of ashes. The straw will be transported forwards as the combustion progresses.

At the opposite wall it may be necessary to establish a mechanical system drawing the straw downwards, thus avoiding dead zones.
5. Decreasing transportation speed in the burnout zone
In order that especially straw can be compressed during the outflow from the gasification zone, it is preferred that the transportation speed of the grate 3 with regard to free fuel is set higher than the actual migration velocity of the straw. In the case of a normal grate, this would lead to the break-up of the fuel layer and the formation of spaces between the fuel segments in the gasification zone.

In order to avoid this phenomenon, the vibration grate 3 is constructed with a decreasing transportation speed from some point before the outflow and until the ash extraction system. Thus the fuel will be compressed in the longitudinal direction, and at the ash extraction system the transport of substances will be effected partially by the fuel pushing from behind. Consequently, the intention is to ensure good contact between the grate air and the fuel in the entire burnout zone 15.

The variable transportation speed is typically realised by providing a varying angle to the leaf springs controlling the movement of the grate 3. The horizontal movement must necessarily be identical along the entire length of the grate 3, but the flexibility of the grate 3 allows the vertical movement to vary.

6. Steam conversion zone
In the case of combustion on vibration grate 3 with a large layer thickness, temperatures of 1100-1200°C occur at the bottom of the fuel layer. At these temperatures, KCl will be liberated to the gas phase, provided that no other components of ashes binding it exist.

In the gasification zone, this KCl in the gas phase will condense on to the cold fuel further up the fuel layer, and a heavy concentration of KCl occurs in the mixture of ashes, coke and fuel drawn to the burnout zone 15. As the covering cold fuel layer disappears in the burnout zone 15, the collected KCl quantum will be liberated to the gas phase without further measures being taken.

In order to reduce the liberation of KCl, the temperature in the burnout zone 15 is reduced dramatically. To this end steam is supplied in an area below the transition zone (the zone between the gasification zone and the burnout zone) and the beginning of the burnout zone 15. Aqueous steam will thus be reduced to hydrogen, and the liberated oxygen atom will oxidise the coke. Thus, large quantities of energy are consumed, and the temperature is reduced. As the reaction is also highly temperature-dependent, the positioning in the beginning of the zone will contribute to the stabilisation of the temperature level.
A further advantage of using steam conversion for the burnout of coke is a considerable reduction of the gas volume generated in the gasification zone 14, and thus a reduction of both the KCl quantity carried with the gas and the quantity of particles carried therewith. In steam conversion one CO molecule and one H2 molecule are generated per converted carbon atom. In the oxidation with air to CO and CO₂ in equal quantities, a gas is formed with 3,54 molecules per converted carbon atom.

The injection of steam is carried out directly below the grate 3 in a number of transverse steam tubes having evenly spaced, small holes. Thus the share of steam along the grate 3 is trimmed by trimming the access to the individual tubes, so that the fuel layer temperature is as homogenous as possible.

The aim is preferably to keep the combustion temperature in the area of 750-800°C.

In the case of high concentrations of KCl in the fuel, it may be necessary to lower the temperature in large parts of the burnout zone 15 by adding small quantities of aqueous steam.

7. No disturbing gas movement in the burnout zone

When the slag cannot be completely burned out on an ordinary vibration grate, this is normally due to the following two conditions:

- The state on the grate is unstable, and there are periods in which an insufficient quantity of air is fed to the fuel layer before it reaches the ash extraction system.
- Turbulence and gas flows in the area in front of the ash extraction system cause particles to be stirred up and flung down into the ash extraction system.

The controlled state at the beginning of the burnout zone 15 reduces the first condition considerably.

Since the mixing of gas from the burnout zone 15 and the gasification zone 14 is effected in a controlled manner further up, there is no need, contrary to what is normally the case, for air nozzles to ensure this mixing right above the grate 3. Thus it is possible to establish a homogenous flow field which is directed upwards with a low turbulence above the burnout zone 15. The geometrical shape of the room is designed in such a way that a slight deflection of the gas flow is ensured, resulting in any blown-up particles falling down further back on the grate 3.

8. Control of the level of excess air prior to the final air feeding
Normally, the share of the absorption of heat in the furnace room will increase dramatically when the moisture content in the fuel is reduced. In order not to have to build in a superfluous overheating area to ensure full overheating in this situation, the operation is adjusted to the humidity of the fuel.

In the case of dry fuel, a large air deficit below the top step of the air delivery is used. Thus the temperature and thereby the heat supply are reduced. In order for this to have any significant impact on the ability to overheat, the final step of the air feeding should be effected immediately before the first overheater. This presupposes that the combustion at this point is a pure gaseous combustion, and that the mixing is efficient.

The presence of dry fuel renders such an air deficit possible, which on wet fuel will result in an unstable ignition.

As the intention is to control the ability to overheat, no extra instrumentation is required, since the control is based on a wish for a certain (minimum) injection into the injection coolers of the overheater.

9. Ensuring a stable, low level of excess air

Air diversion at the vibration of the grate 3 is introduced in the present invention, so that the combustion rate is not changed from prior to after a vibration.

As the temperature in the outlet from the gasification zone 14 is kept low, variations of the fuel feeding will not affect the combustion rate. This is consequently controlled solely by air flows which can be controlled much more accurately.

The pauses of the grate 3 between the vibrations are kept within the operation interval, in which the flash gasification does not occur. If the pauses are prolonged beyond a load-dependent, critical value, channels will be formed in the fuel layer, and the collapse of the fuel layer leads to flash gasification, which can be seen in operation as a brief increase of the CO value, without the O₂ percentage measurably dropping.

The aim is that the O₂ percentage in the flue gas is kept below 2.0 per cent on average with fluctuations below +/-0.2 per cent.
10. Ensuring high efficiency
The primary preconditions of high efficiency are high pressures and overheating temperatures and a limited auxiliary power consumption. Further, a low level of excess air contributes to obtaining a high efficiency, especially by heat production by condensation of steam in the flue gas.

The inherent consumption in the present invention is kept low by design of the main part of the air supply for low pressures - no higher than 3 kPa. An independent fan with a pressure of 6-8 kPa and a share of the total air of 10-15 per cent is established for the exit mixing in the furnace room and any other critical purposes. It is assumed that the pressure is in the area of vessel boilers.

The achievement of overheating temperatures without use of large areas presupposes a high input temperature to the overheaters. In order to obtain this, the distance between the final air feeding and the first overheater is minimised.

The first overheater is constructed with bevel shoulders or spaces, so that CO caught in the borderline layer around the front tubes is carried into the main stream prior to the cooling thereof under 800-1000°C.

11. Ensuring a low CO
The reason for the frequent, very poor CO performance on grate-fired boilers is an uncontrolled mixing of air and gasification products from the parts of the grate, on which the temperature is insufficient for ensuring ignition. The present invention eliminates this problem by ensuring a controlled feeding of the cold gasses from the gasification zone.

In order to prevent any significant problems from arising in connection with the burning of the gasses at temperatures as low as 800°C, a good mixing and a stable level of excess air are provided. In broad boilers the O₂ level may advantageously be regulated at several points across the boiler.

In order to ensure a good mixing close to the overheaters, a geometry for the final air feeding based on 'crossover jets in several layers' is used, which is adjusted to the divisions in the first overheater. The pressure to these air nozzles is regulated independently of other air systems.

The aim is preferably a CO value below 50 mg/Nm³ at 6 per cent for all fuels.
12. Ensuring a low NOx

The establishment of a large volume with almost stoichiometrical condition will cause a large part of the nitrogen content of the fuel to be converted into free nitrogen. If at the same time a low level of excess air is maintained following the final air feeding, the formation of NOx may be limited.

In the case of wet fuels, a considerable heat loss will take place prior to the final air feeding, causing the transition to oxidising conditions to take place at the lowest possible temperature, ensuring a low NOx emission.

In the case of dry fuels, this heat loss must be limited with a view to ensuring the desired heat distribution in the boiler. In order to reduce NOx, particularly in connection with these types of operation, the process is realised in steps, so that the air is supplied immediately prior to the gas in a number of steps. The air feeding is effected so that a local level of excess air occurs in a number of very limited areas. In this way, nitrogen compounds are oxidised, which is the precondition of the formation of free nitrogen.

The aim is preferably a NOx value of below 200 mg/Nm³ at 6 per cent O₂, if <1 per cent nitrogen in the fuel free of ashes and water.

13. Water-cooled walls

In order to avoid tar deposits on the walls of the gasification section, the walls are implemented as liquid filled panel walls which in operation reach a temperature of 300-350°C. Advantageously, the water-cooled walls are used in the start-up of the system.

14. Start-up, stop and safety

In the start-up of a system that is normally closed down, a start-up burner above the burnout zone 15 is launched. A small quantity of fuel is fed to the grate 3 and is distributed by means of vibration in an even, thin layer across the entire surface, whereupon the vibration cycle of the grate 3 stops. The fuel is ignited in the gasification zone 14 by influx of heat, and the burner ensures combustion of the gasses generated in the gasification zone 14. The ignition will propagate upwards along the grate 3 and reach the back wall. When this has been accomplished, the fuel feeding and the vibration cycle of the grate 3 restart. The fuel dosage is slowly increased, resulting in a smooth transition from overstoichiometry to understoichiometry in the gasification zone, and the risk of deflagration is avoided.
In the case of a normal shutdown, the fuel feeding is interrupted and the fuel layer is burned out. The vibration grate 3 is kept running, so that there is a constant, largely normal combustion in the burnout zone 15, until overstoichiometry occurs in the gasification zone 14.

In the case of an emergency shutdown, the air supply to the grate 3 is cut off, and the air nozzles are opened in order to ventilate and cool the furnace room. During start-up the air feeding is reduced, and the grate air is let in gradually. If the combustion is started thereby, the normal operation is resumed.

If the combustion is not started by the feeding of air to the grate 3, the air quantities are increased and a normal boiler ventilation is carried out before start-up. Excess fuel on the grate 3 is discharged into the ash extraction system prior to restart. For reasons of safety, it is necessary to empty out the fuel, if the restart is not effected within a short period (approximately 1 hour).

Gas passage from the gasification zone to the furnace room is, on account of start-up and shutdown, dimensioned for briefly high temperatures.

**SUMMARY**

The above embodiments provide a number of advantages, e.g. one or more of the following advantages:

- Many mechanical constructions are avoided.
- The gas from the gasification zone is cooled and is not cleaned.
- The air for the gasification is preheated in the boiler, allowing a better cooling of flue gas to be achieved at high feed water temperatures.
- The use of steam for steam conversion will be lower.
- The ability of the vibration grate to loosen mildly vitrified particles is exploited.
- Not performing a 100 per cent conversion in the gasification zone reduces the problems connected to the vitrification of ashes.

When comparing the invention to straw-firing on a vibration grate, at least the following significant differences may be identified:

- The fuel in the front part of the grate is shielded from influx, so that the supply of new fuel does not lead to increased gasification. This fact provides a completely different possibility of achieving a stable combustion speed.
- The ignition is effected by flame propagation at the bottom of the layer, rather than by means of so-called 'ignition nozzles' blowing warm gas into the layer. The ignition nozzles can be dispensed with because of the shielding from influx from above.
The partition wall between the gasification zone and the burnout zone adjusts the material transport on the grate, so that the height is the same in all operation scenarios. At the same time it contributes to breaking down the frequently occurring large, open structures of ashes.

It is expected that it is unnecessary to cut up the bales of straw in the same way as in existing systems. A fall shaft, into which whole 'bale layers' fall, will probably be sufficient.

The reduction of the KCl liberation will influence the design (and the price) of the boiler system significantly.

When comparing the invention to wood chip firing on a vibration grate, at least the following significant differences may be identified:

- The cold gasses from the gasification areas are not mixed uncontrollably.
- As the fuel is not thrown in, entrainment of fine particles in the flue gas is avoided.
- The state around the ignition zone becomes much better defined, as the spreader does not determine the distribution of fuel along the grate. Thus, a counterflow of material at the top of the fuel layer may be created, without the risk of the forward transport coming to a halt at the bottom of the layer.
CLAIMS

1. A process for the extraction of energy from a fuel in a boiler comprising at least one gasification zone and at least one burnout zone, said zones being separated by at least one partitioning construction and being connected to at least one furnace room, said boiler further comprising one or more grates supporting the fuel, wherein and/or by means of which fuel is transported from said at least one gasification zone to said at least one burnout zone, said process comprising:
   - feeding the fuel to the gasification zone and at least partial gasification of the fuel therein by means of heating, the heat for the heating being at least partially generated by an oxidation process resulting at least partially from a reaction between a fraction of the fuel, e.g. combustible gasses from the fuel, and an oxidising agent supplied to the gasification zone, causing a quantity of non-oxidised, combustible gasses fed to the furnace room to be provided.
   - successively, feeding of the at least partially gasified fuel from the gasification zone to the burnout zone, and at least partially burnout of the fuel, which burnout is preferably effected by addition of an oxidising agent.

2. A process according to claim 1, wherein the partitioning construction between the gasification zone and the burnout zone is substantially preventing gasses from the gasification zone and the burnout zone from mixing, and further preferably determining the height of the fuel fed to the burnout zone when transport of the fuel from the gasification zone to the burnout zone is effected by said one or more grates.

3. A process according to claims 1-2, wherein the walls of the gasification zone are panel walls filled with a fluid, e.g. water, or a steam under pressure above atmospheric pressure, e.g. 2 bar, e.g. 10 bar, e.g. 20 bar.

4. A process according to claims 1-3, wherein at least one of said one or more grates is a water-cooled vibration grate.

5. A process according to claims 1-4, wherein the quantity of degassed fuel transported from the gasification zone to the burnout zone is determined by the frequency and/or the amplitude of grate activations.

6. A process according to claims 1-5, wherein the quantity of wholly or partially degassed fuel transported from the gasification zone to the burnout zone corresponds to a calorific value of between 1 per cent and 50 per cent of the total firing, e.g. between 2 per cent
and 40 per cent, e.g. between 5 per cent and 20 per cent, or preferably between 10 per cent and 20 per cent of the total firing.

7. A process according to claims 1-6, wherein at least part of the oxidising agent is fed to the gasification zone through the grate.

8. A process according to claim 7, wherein the oxidising agent fed to the gasification zone through the grate is used to control the quantity of the energy extracted from the fuel in the gasification zone.

9. A process according to claims 1-6, wherein the oxidising agent is fed to the burnout zone through the grate.

10. A process according to claim 9, wherein the oxidising agent fed to the burnout zone through the grate is used to control the quantity of energy extracted from the fuel in the burnout zone.

11. A process according to claims 1-10, wherein the quantity of oxidising agent supplied through the grate in the gasification zone constitutes between 20 per cent and 95 per cent of the total quantity of oxidising agent supplied through the entire grate, e.g. between 50 per cent and 95 per cent, or preferably between 60 per cent and 95 per cent.

12. A process according to claims 1-11, wherein the fuel is supplied in at least one place in the gasification zone.

13. A process according to claim 12, wherein the fuel is fed transversely to the direction in which the gasified fuel is transported from the gasification zone to the burnout zone.

14. A process according to claims 12-13, wherein the fuel supplied in the gasification zone is supplied in such a way that the height of the fuel layer in at least part of the gasification zone is substantially constant, e.g. essentially close to the partition wall.

15. A process according to claims 12-13, wherein the fuel supplied in the gasification zone is supplied in such a way that the temperature in at least part of the gasification zone, e.g. essentially close to partition wall, is essentially constant, e.g. between 100° Celsius and 200° Celsius.
16. A process according to claims 12-13, wherein the fuel supplied in the gasification zone is supplied in such a way that the said fuel is affecting at least part of the partition wall with an essentially constant force.

17. A process according to claims 12-16, wherein fuel is fed to the fuel layer in the gasification zone in such a way that the generated gasses are cooled to between 70° Celsius and 500° Celsius, e.g. between 80° Celsius and 300° Celsius, e.g. 90° Celsius and 200° Celsius, or preferably between 110° Celsius and 150° Celsius.

18. A process according to any of the preceding claims, wherein a fraction of the heat generated by oxidation in a first layer of the fuel in the gasification zone heats and dries fuel in a second layer in the gasification zone, said second layer being located above the first layer.

19. A process according to claim 18, wherein the share of heat used to heat the second layer in the gasification zone constitutes at least 50 per cent of the generated heat, e.g. 65 per cent, e.g. 80 per cent.

20. A process according to any of the preceding claims, wherein the vertical distance from the upper part of the grate to the lower part of the underside of the partitioning construction is between 100 mm and 900 mm, e.g. between 150 mm and 700 mm, or preferably between 200 mm and 500 mm.

21. A process according to any of the preceding claims, wherein the gasses generated above the burnout zone are fed to the furnace room, wherein they are mixed, in at least one step, e.g. at least two steps, with gas from the gasification zone and an oxidising agent, e.g. combustion air, e.g. air, e.g. air mixed with gasses from the furnace room.

22. A process according to any of the preceding claims, wherein at least a fraction and preferably the total amount of the gas generated in the gasification zone is fed from the gasification zone and to the furnace room via at least one nozzle, preferably being formed as ejectors ejecting an oxidising agent into the furnace room and at the same time pulling the gas with.

23. A process according to any of the preceding claims, wherein the area of the holes in the part of the grate placed in the gasification zone constitutes between 50 per cent and 1000 per cent relative to the holes in the part of the grate placed in the burnout zone, e.g. between 75 per cent and 400 per cent, e.g. between 80 per cent and 200 per cent, or preferably between 90 per cent and 150 per cent.
24. A process according to claim 23, wherein the grate is divided into at least two zones, in which the feeding of the oxidising agent is regulated separately.

25. A process according to claims 1-24, wherein the quantity of oxidising agent supplied in the front part of the grate constitutes between 50 per cent and 500 per cent relative to the quantity supplied in the back part of the grate, e.g. between 75 per cent and 200 per cent, or preferably between 100 per cent and 150 per cent.

26. A process according to claims 1-25, wherein the lower part of the partitioning construction separating the gasification zone and the burnout zone has a slope of between 25 degrees and 65 degrees with respect to the upper part of the partitioning construction, causing fuel pushing against this part of the partitioning construction to be pushed downwards, which results in compression of the fuel, e.g. between 35 degrees and 55 degrees, or preferably 45 degrees.

27. A process according to claims 2-26, wherein the speed with which the grate transports the fuel is higher in some parts of the grates, e.g. higher in the part of the grate essentially placed below the partition wall than in the part of the grate essentially placed in the final part of the burnout zone.

28. A process according to claims 2-27, wherein the speed with which the grate transports the fuel decreases from a distance before the part of the grate essentially placed below the part of the partitioning construction until the ash extraction system in the burnout zone.

29. A process according to claims 28, wherein the decreasing speed on the grate is achieved by varying the angle on leaf springs supporting the grate.

30. A process according to claims 2-29, wherein aqueous steam is supplied below the grate for the part of the grate essentially placed below the part of the partitioning construction and at least part of the burnout zone, e.g. through at least one tube with evenly spaced holes.

31. A process according to claim 30, wherein the aqueous steam supplied below the grate is supplied with a view to control the oxidation temperature of the fuel essentially placed on the part of the grate situated above the at least one tube, and wherein the oxidisation temperature is controlled to being between 400° Celsius and 1200° Celsius, e.g. between 500° Celsius and 1100° Celsius, e.g. between 600° Celsius and 1000° Celsius, e.g. between
700° Celsius and 900° Celsius, e.g. between 700° Celsius and 800° Celsius, or preferably between 750° Celsius and 800° Celsius.

32. A process according to any of the preceding claims, wherein the end wall of the burnout zone has a slope causing at least part of the wall to incline towards the final part of the grate.

33. A process according to any of the preceding claims, wherein the fuel consists of biofuel, solid fuel, or a combination thereof.

34. A process according to any of the preceding claims, the fuel being biofuel, e.g. seed grass, plant residue, bedding, sawdust, wood waste, straw, wood, wood chips, sea weed, or a combination thereof.

35. A process according to any of the preceding claims, the fuel being solid fuel, e.g. peat, coal, coke, household waste, or a combination thereof.

36. An apparatus for the extraction of energy from a fuel in a boiler comprising at least one gasification zone, at least one burnout zone, at least one furnace room and one or more grates for transporting the fuel through and/or supporting the fuel in the boiler during the extraction of energy, said apparatus comprising

- a gasification zone for gasifying the fuel;
- at least one device for feeding an oxidising agent at least one place in the boiler;
- a device for transporting non-oxidised, combustible gasses generated in the gasification zone from the gasification zone to the furnace room.

the furnace room being arranged relative in the burnout zone and/or being connected to the furnace room in such a way that heat generated in the burnout zone is conducted to the furnace room, said conduction of heat being effected by means of natural conduction, forced conduction, or a combination thereof.

37. An apparatus according to 36, wherein the walls of the gasification zone are panel walls filled with a fluid, e.g. water, or a steam under pressure above atmospheric pressure, e.g. 2 bar, e.g. 10 bar, e.g. 20 bar.

38. An apparatus according to claims 36 or 37, wherein at least one of said one or more grates is a water-cooled vibration grate.
39. An apparatus according to any of claims 36-38, wherein the vertical distance from the upper part of the grate to the lower part of the underside of the partitioning construction is between 100 mm and 900 mm, e.g. between 150 mm and 700 mm, or preferably between 200 mm and 500 mm.

40. An apparatus according to any of claims 36-39, comprising at least one nozzle for feeding at least a fraction and preferably the total amount of the gas generated in the gasification zone from the gasification zone and to the furnace room, said nozzles being preferably formed as ejectors ejecting an oxidising agent into the furnace room and at the same time pulling the gas with.

41. An apparatus according to any of the claims 36-40, wherein the grate(s) comprises holes through which an oxidising agent may be introduced into gasification zone and/or the burnout zone, and wherein the area of the holes arranged in the part of the grate placed in the gasification zone constitutes between 50 per cent and 1000 per cent relative to the holes in the part of the grate placed in the burnout zone, e.g. between 75 per cent and 400 per cent, e.g. between 80 per cent and 200 per cent, or preferably between 90 per cent and 150 per cent.

42. An apparatus according to claim 41, wherein the grate is divided into at least two zones, in which the feeding of the oxidising agent is regulated separately.

43. An apparatus according to any of claims 36-42, wherein the lower part of the partitioning construction separating the gasification zone and the burnout zone has a slope of between 25 degrees and 65 degrees with respect to the upper part of the partitioning construction, causing fuel pushing against this part of the partitioning construction to be pushed downwards, which results in compression of the fuel, e.g. between 35 degrees and 55 degrees, or preferably 45 degrees.

44. An apparatus according to any of claim 36-43, wherein the end wall of the burnout zone has a slope causing at least part of the wall to incline towards the final part of the grate.
### INTERNATIONAL SEARCH REPORT

**International Application No:** PCT/DK 02/00600

### A. CLASSIFICATION OF SUBJECT MATTER

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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):**

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

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

**EPO-Internal**

### C. DOCUMENTS CONSIDERED TO BE RELEVANT

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<td>DE 33 45 867 A (WAERMETECHNIK DR PAULI GMBH) 27 June 1985 (1985-06-27) figure 1</td>
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<td>US 4 495 872 A (SHIGAKI MASANOBU) 29 January 1985 (1985-01-29) figures 1,2</td>
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[X] Further documents are listed in the continuation of box C. [X] Patent family members are listed in annex.

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**Date of the actual completion of the international search:**

5 December 2002

**Date of mailing of the international search report:**

15.01.2003

Name and mailing address of the ISA:

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TOMAS LUND /ELY
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