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SIEMENS CORPORATION
INTELLECTUAL PROPERTY DEPARTMENT
170 WOOD AVENUE SOUTH
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F22B 37/00 (2006.01)(52) **U.S. Cl.** **122/7 R**(57) **ABSTRACT**(21) Appl. No.: **12/223,992**(22) PCT Filed: **Jan. 3, 2007**(86) PCT No.: **PCT/EP2007/050030**§ 371 (c)(1),
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A steam generator of a technical plant, in particular a power plant, comprising a heating gas passage enclosed by a gas-tight enclosing wall, wherein the heating gas passage has a number of heating surfaces through which a flow medium can flow, is to ensure especially reliable cleaning of the heating gas flowing off from the heating gas passage at an especially low design and production cost. To this end, provision is made according to the invention for at least one of the heating surfaces to be at least partly provided with a catalytic coating on its side facing the heating gas.

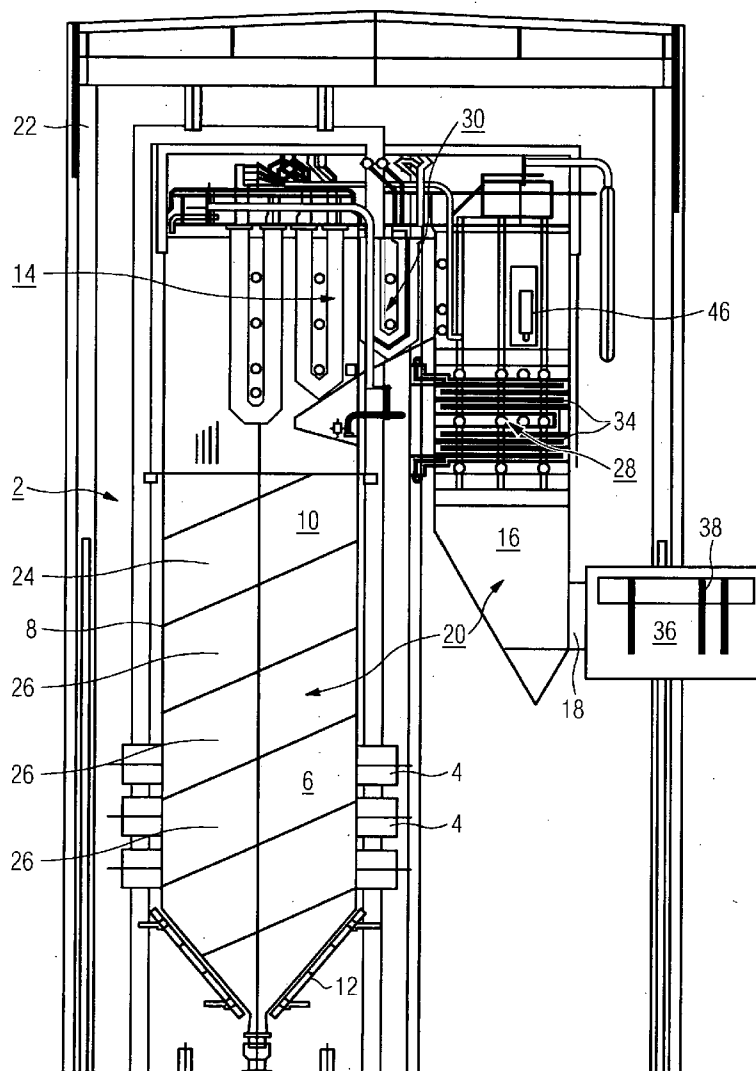


FIG 1

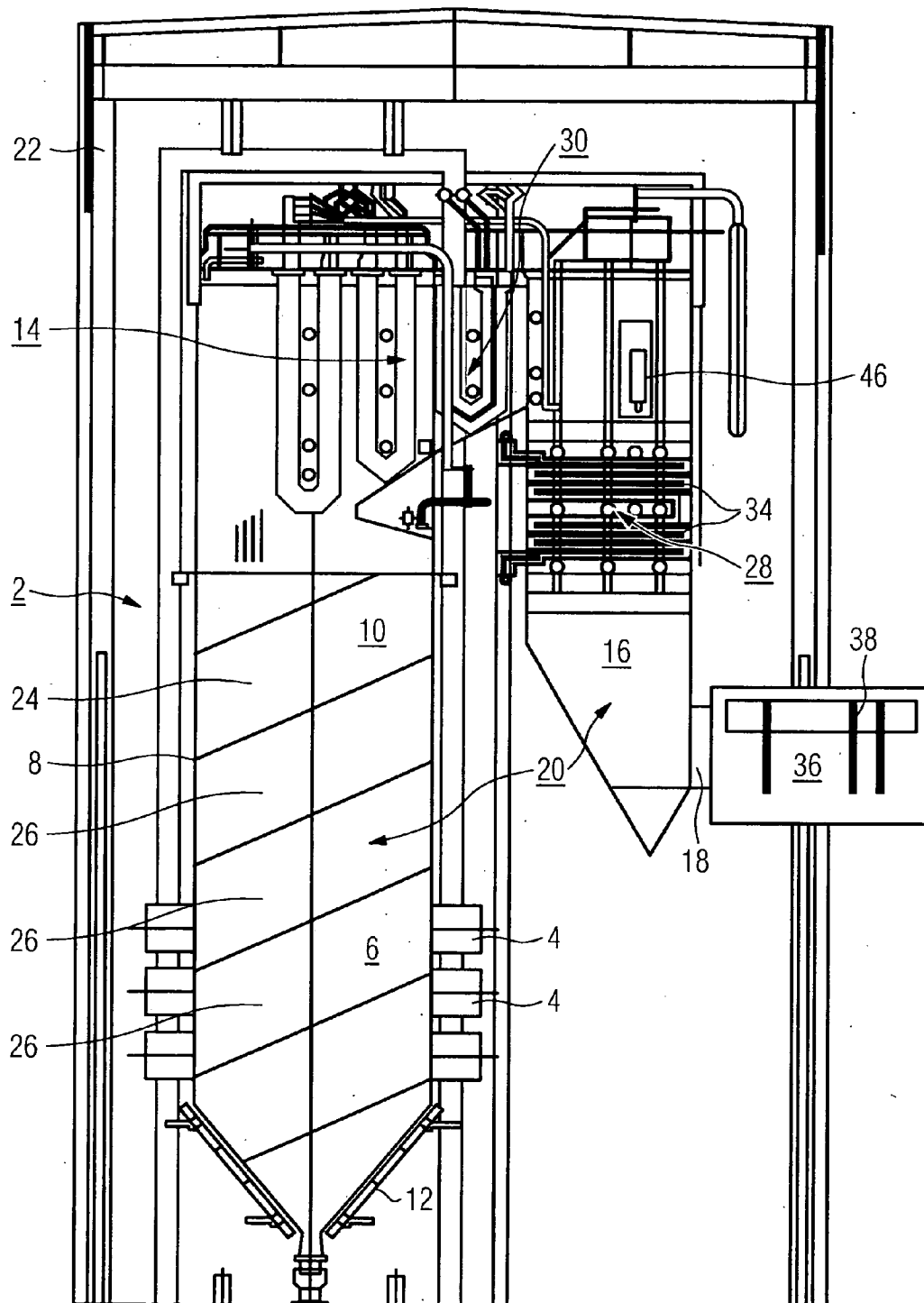


FIG 2

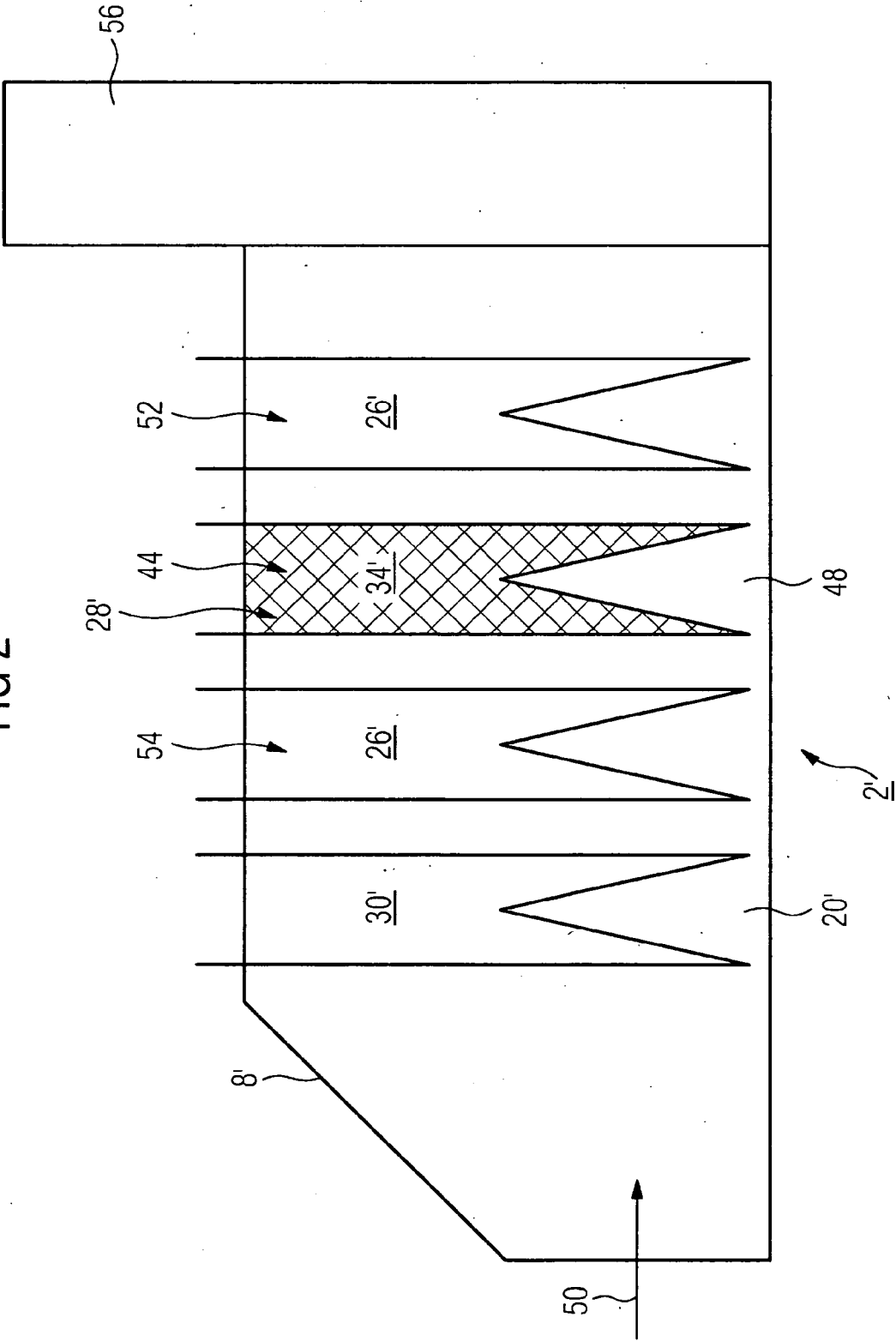
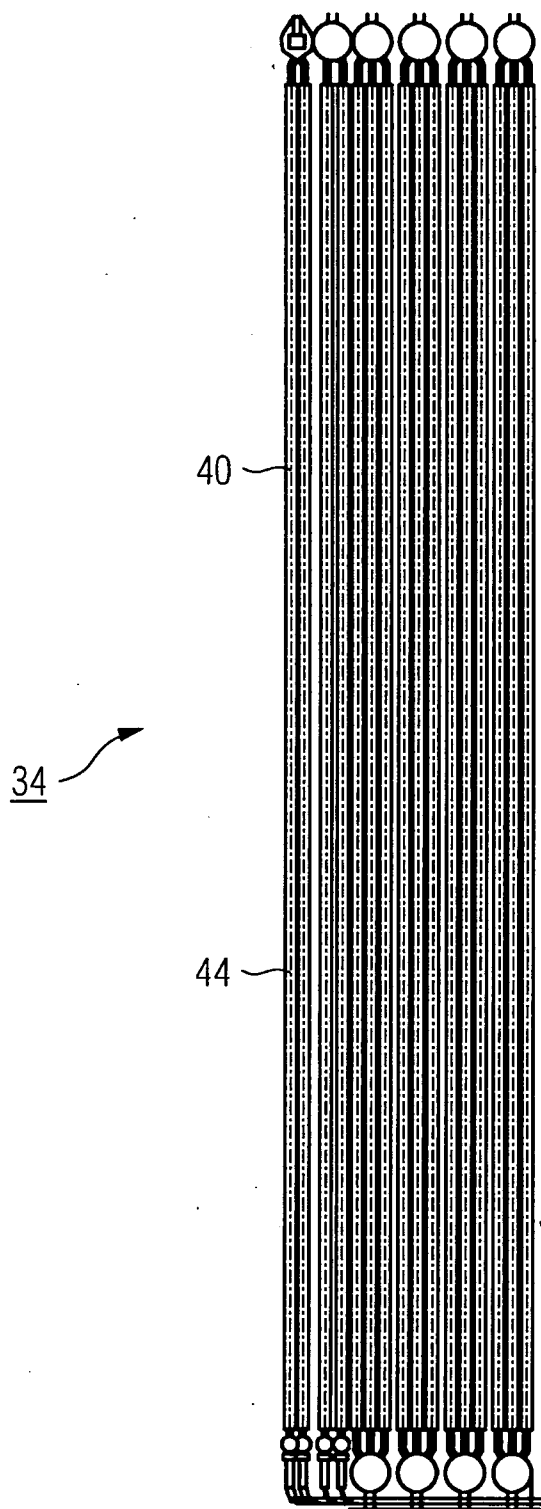


FIG 3



STEAM GENERATOR

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application is the US National Stage of International Application No. PCT/EP2007/050030, filed Jan. 3, 2007 and claims the benefit thereof. The International Application claims the benefits of European application No. 06003189.5 filed Feb. 16, 2006, both of the applications are incorporated by reference herein in their entirety.

FIELD OF INVENTION

[0002] The invention relates to a steam generator of a technical plant, in particular a power plant, comprising a heating gas passage enclosed by a gas-tight encasing wall, wherein the heating gas passage has a number of heating surfaces through which a medium can flow.

BACKGROUND OF THE INVENTION

[0003] In a power plant with a steam generator, the heating gas generated in the burner during the combustion of a fossil fuel or the hot exhaust gas flowing from a gas turbine is used in the steam generator to vaporize a flow medium. The steam generator normally has steam generator pipes bundled or assembled to form heating surfaces for the vaporization of the flow medium, whose heating leads to a vaporization of the flow medium within the heating surfaces by the radiated heat of the burner flames or the convective interaction with the heating gas. In this case, a part of the heating surfaces generally directly forms the gas-tight enclosing wall of the heating gas passage, also referred to as the gas flue, with another part of the heating surfaces being connected to the heating gas passage and projecting into said passage to increase the effective useable surface. The steam produced by the steam generator can in turn, for example, be provided for a connected external process or to drive a steam turbine. If the steam drives a steam turbine, a generator or a working machine is normally driven by the turbine shaft of the steam turbine. If it is a generator, the power generated by the generator can be used to supply an interconnected and/or isolated system.

[0004] Depending on the type of fuel used and on the design characteristics of the steam generator, the exhaust gas leaving the steam generator or the downstream technical system contains pollutants in the form of nitrogen oxides, carbon oxides and/or sulfur oxides, as well as solid particles such as flue ash and/or soot, which can damage the environment. In modern power plants, efforts are increasingly made to minimize the pollutant emissions by primary measures, as they are called, which mainly concern the burners of the steam boiler or the gas turbine upstream of the boiler, and are designed to result in optimized, low-emission combustion processes. In cases in which such measures are not possible or are associated with expensive conversion measures, or are not adequate in order to comply with the legally specified limit values, the so-called secondary measures are necessary in order to filter and separate or otherwise render the pollutants in the flue gas or exhaust gas harmless, e.g. by chemical conversion into less harmful reaction products or products which are easier to handle.

[0005] DeNO_x catalytic converter devices, which are fitted at a suitable point in the heating gas passage of the steam generator by means of associated supporting structures, are normally used, particularly to reduce the nitrogen oxides

present in the heating gas, see example in EP 0 753 701 A1. In DeNO_x catalytic converter devices of this kind, nitrogen oxides contained in the heating gas flowing through are reduced by spraying in, or injecting in, an ammonia solution which reacts with the catalytic material, with water (H₂O) and elementary nitrogen (N₂) being produced as reduction products. The process is also known as selective catalytic reduction (SCR). The disadvantage with this concept is that the DeNO_x catalytic converter device requires additional installation space within the heating gas passage and comparatively expensive mounting and attaching structures, which increases the total cost for the erection and installation of the steam boiler. Because of the absence of installation space, existing old systems can frequently only be retrofitted and brought up to date at a comparatively high cost.

SUMMARY OF INVENTION

[0006] The object of the invention is therefore to provide a steam generator of the type mentioned in the introduction, which has a particularly low design and production cost and guarantees especially reliable cleaning of the heating gas before said gas leaves the steam generator at the outlet end.

[0007] The object is achieved according to the invention in that at least one of the heating surfaces is at least partially provided with a catalytic coating on its side facing the heating gas.

[0008] The invention is based on the concept that a steam generator designed for a particularly low design and production cost should have an especially low overall height, or particularly short overall length if the boiler is of the horizontal type, so that the material requirement and the time expenditure for the production of the enclosing walls, and where necessary, the static requirements for the associated supporting structure are minimized. A particularly compact and simple construction can be achieved in that the exhaust gas cleaning devices, which were previously provided as separate components requiring a comparatively high installation space, can be integrated into the heat transfer elements, already present in any case and required to operate the steam generator, especially into the heating elements and heating surfaces formed from the steam generator pipes. These are especially evaporator heating surfaces or economizer heating surfaces in an area of the steam generator in which the heating gas flowing past usually is at temperatures of approximately 300° C. to 400° C. A particularly effective and space-saving integration of the cleaning function for the heating gas can be achieved with an increased cleaning effect at the same time, in that the heating surfaces are used not only for heat transfer but also additionally as carriers for a catalytically active surface coating. In this case, the coating is advantageously chosen so that by contact and interaction with the through-flowing heating gas it causes, or at least promotes, a decomposition or conversion of pollutants carried in the heating gas, without it being itself "consumed" or wearing out (catalytic converter principle). With the concept envisaged here, the supporting structures for the previously normal separate catalytic converter devices in particular are thus omitted.

[0009] With an application of this concept which is particularly important in practice, the surface coating applied to the heating surfaces of the steam generator is advantageously such that in conjunction with the already known and proven principle of selective catalytic reduction (SCR), which is also normally used in the previous DeNO_x catalytic converter devices and denitrogenation systems, it brings about a con-

version or decomposition of the nitrogen oxides and/or carbon oxides present in the heating gas. Furthermore, for this purpose, an injection device for a reduction means, especially a liquid containing ammonia, is advantageously arranged in the heating gas passage of the steam generator so that when the steam generator is operating the heating gas decomposed by the injection of the reduction means flows over the respective catalytic coating surface.

[0010] In other words, the catalytically active coating on the heating surface(s) or on the surface of the steam generator pipes forming the particular heating surface serves to activate and/or maintain a reaction between the reducing agent introduced into the heating gas and the nitrogen oxides of the heating gas. With the SCR process, the nitrogen oxides are reduced to nitrogen and water by the presence and interaction of the catalytic converter material, with the aid of the reducing agent injected into the gas flue or heating gas passage, usually with air as the carrier current.

[0011] The amount of nitrogen oxide occurring in the steam generator normally depends on the type of fossil fuel burned and the way in which the steam generator operates. To be able to comply with the legal limits at all operating states, the amount of reducing agent injected is therefore varied depending upon the fossil fuel used and the operating parameters at that moment.

[0012] Particularly effective catalytic coatings can be achieved on the basis of recent knowledge from nanostructure research. A design aim achievable with the aid of nanotechnology is, in particular, coating material that can be easily and durably applied to almost any surface contours of the steam generator heating surfaces. Materials particularly used as the catalytic materials for the catalysis of the nitrogen oxide decomposition are titanium oxide, vanadium pentoxide or tungsten oxide. Catalytic converters based on zeolite can be used as an alternative. Materials particularly preferred for this are ammonium mordenite and H-beta-zeolite. Finally, it is also conceivable that catalytic converter materials will in future be discovered or developed which also activate or promote a decomposition of pollutants (e.g. nitrogen oxides) carried in hot gas, without the injection of a reducing agent or other chemical reagent. In this case, the injection device described above can also be omitted.

[0013] The catalytic coated heating surface(s) can be part areas of the enclosing wall of the wall heating surfaces forming the heating gas passage. Additionally or alternatively, heating surfaces projecting into the heating gas passage or other built-in parts with a catalytic surface coating of the aforementioned type can be provided. Platen heating surfaces, as they are called, are particularly suitable for this purpose. A platen heating surface in this case is a number of steam generator pipes connected in parallel for the flow of the flowing medium, terminating in a common inlet and a common outlet collector, with the steam generator pipes lying close together in a plane and thus forming a number of plate-type heating surfaces mounted within the gas flue. Alternatively, the coated heating surface can also be a pipe nest heating surface with which the individual pipes are not, in contrast to a platen heating surface, joined to each other by webs. Especially with the inclusion of such internal heating surfaces, the overall surface available for catalytic coating is comparatively large. Previously unattainable reduction rates for the pollutants carried in the heating gas can be achieved in this way and therefore also particularly low pollutant limits can be reliably and permanently complied with out the need

for design compromises, such as unsatisfactory temperature profiles, allowing for flow instability, expensive firing concepts and burner configurations etc, which would increase the production cost or impair the energy efficiency of the steam generator.

[0014] For a particularly effective exhaust gas cleaning, the catalytic coated heating surfaces should be arranged in an area of the heating gas passage which, with regard to the usual operating temperatures prevailing in said heating gas passage, guarantees a high effectiveness of the generally temperature-sensitive catalytic cleaning process. In the case of denitrogenation of the heating gas according to the SCR principle, the respective catalytic coated heating surface is therefore advantageously arranged in a region in which the heating gas flowing past has a temperature of between approximately 300° C. and 400° C. at rated load operation of the steam generator.

[0015] The concept explained here can be applied to steam generators of different construction and operating principle, e.g. with horizontal or upright boilers as well as with natural circulation, forced circulation or forced throughput, and with different firing concepts, e.g. fluidized bed firing or dry dust firing. Also, the arrangement of the heating surfaces at the flow medium end, for example evaporator heating surfaces, superheater heating surfaces and also heating surfaces forming part of an economizer or air preheater can be specified in advance virtually as required.

[0016] In a particularly preferred first variant, which, for example, is also particularly suitable for a waste-heat steam generator arranged downstream of a gas turbine, the steam generator includes a heating gas passage, also known as a horizontal gas passage, through which heating gas or exhaust gas from the gas turbine flows in an essentially horizontal direction, provided with a number of heating surfaces each provided with a catalytic coating. This can especially be evaporator heating surfaces or economizer heating surfaces in an area of the steam generator in which the heating gas flowing past normally has temperatures of approximately 300° C. to 400° C.

[0017] In a second, also particularly advantageous, variant which is particularly useful for fossil firing by means of burners fitted in the steam generator, the steam generator is constructed with an upright boiler as a two-passage type and during operation has a first vertical gas flue through which heating gas flows from bottom to top but which at the heating gas end is connected via a horizontal gas flue to a second vertical gas flue through which the heating gas flows from top to bottom. In this case, the particular catalytic coated heating surface is preferably arranged in the area of the horizontal gas flue or of the second vertical gas flue or also in a section of the heating gas passage downstream of this heating gas end, whereby it can preferably be a superheater heating surface, an economizing heating surface or also an air preheating surface depending on the design operating temperature of the catalytic converter material.

[0018] The particular advantages achieved by the invention are that by the application of a catalytically active coating, designed for flue gas cleaning and denitrogenation, to the heating surfaces present in a steam generator, the DeNO_x catalytic converter device, which has been usual up to now and required a separate installation space, can be omitted, which enables a particularly compact and cost-effective construction of the steam generator. Because the heating surfaces available for coating are comparatively large, very good pol-

lution reduction rates can be achieved even where the requirements regarding the burner(s) are kept low. Furthermore, existing power plants or steam generators, in which up to now no secondary emission reduction measures have been taken, can be relatively easily retrofitted and adapted to the increasing environmental requirements and more stringent legal limits, e.g. by the retrospective application of a catalytically active coating to the existing heating elements or by replacing uncoated heating surfaces by coated heated surfaces.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] Various exemplary embodiments of the invention are further explained with the aid of drawings. The drawings are as follows:

[0020] FIG. 1 A schematic showing a side elevation of a two-flue type generator fired by fossil fuel,

[0021] FIG. 2 A schematic showing a side elevation of a waste-heat steam generator with a horizontal steam boiler,

[0022] FIG. 3 A plan view of a heating surface of a steam generator formed by steam generator pipes.

[0023] Parts that are the same in all illustrations are given the same reference characters.

DETAILED DESCRIPTION OF INVENTION

[0024] The steam generator 2 according to FIG. 1 designed as a once-through steam generator includes a number of burners 4 for a fossil fuel. The burners 4 are arranged in a combustion chamber 6 which is formed by a bottom part of the enclosing wall 8 of a first vertical gas flue 10. This enclosing wall 8 merges at the bottom end of the vertical gas flue 10, formed by said enclosing wall 8, into a funnel-shaped base 12. The steam generator 2 is of the two-flue type. For this purpose a second vertical gas flue 16 is arranged, via a horizontal gas flue 14, downstream of the first vertical gas flue 10 for the heating gas generated by burning the fossil fuel. A further horizontal gas flue 18, which finally terminates in an exhaust stack or chimney (not illustrated) is connected to the second vertical gas flue 16. The gas flues 10, 14, 16, 18, together form a heating gas passage 20. The complete arrangement, apart from the exhaust stack, is arranged inside a supporting structure 22 and supported by said supporting structure 22 by means of struts.

[0025] The enclosing wall 8 of the first vertical gas flue 10 is constructed of steam generator pipes (not illustrated in more detail) which are welded to each other on their long sides by means of webs or "fins" to form a gas-tight joint, and which wind, essentially in the form of a helix, around the cylindrical inner space 24. A number of adjacent steam generator pipes are thus assembled together to form an evaporator heating surface 26, forming a segment of the enclosing wall 8, for a parallel admission of water as the flow medium. Water preheated by an economizer 28 is applied via a common inlet manifold (not illustrated) to the inlet ends of the steam generator pipes forming an evaporator heating surface 26. The water vapor, generated in the steam generator pipes of an evaporator heating surface 26 due to the heating by the burners, flows from the output end via a common outlet manifold (not illustrated) and is then fed to a superheater unit.

[0026] For this purpose, a number of superheating surfaces 30 in the form of platen heating surfaces are arranged downstream of the evaporator heating surfaces 26 of the first vertical gas flue 10, with the platen heating surfaces being arranged mainly in the area of the horizontal gas flue 14. Each

of the, mainly convectively-heated, superheater heating surfaces 30 has a number of parallel steam generator pipes for the throughflow of the flow medium. The steam generator pipes of a superheater heating surface 30 are connected together to form a diaphragm wall. To achieve this, each steam generator pipe of the respective superheater heating surface 30 is welded by a web in each case with each adjacent steam generator pipe of the same superheater heating surface 30. The steam generator pipes assigned in each case to a superheater heating surface 30 are arranged close to each other horizontally in a plane and each thus, as a platen heating surface, forms a plate-type heating surface. The plate-type superheater heating surfaces 30 formed in this way are mounted inside the horizontal gas flue 14. The superheated steam, above the evaporation temperature, flowing from the steam generator pipes of the superheater heating surfaces 30 can, for example, be used to drive a steam turbine, not illustrated here.

[0027] A part of the superheater heating surfaces 30 can also be used for the intermediate superheating of the partially expanded flow medium flowing from the first turbine stage of the steam turbine, so that the flow medium, which is then reheated, can be fed to the next stage of the steam turbine.

[0028] Due to the heat transfer to the flow medium flowing through the evaporator heating surfaces 26 and the superheater heating surfaces 30, the temperature of the heating gas flowing in the heating gas passage 20 increases as it progresses along the flow path. When entering the second vertical gas flue 16, the temperature of the heating gas is still approximately 300° C. to 400° C. With this amount of residual heat, the flow medium, which is still cold and liquid, flowing through the pipes of the economizer 28, also called a feed-water preheater, is preheated before entering the steam generator pipes of the evaporator heating surfaces 26 downstream of the economizer at the flow medium end. This type of utilization of the heating gas waste heat enables the overall efficiency of the steam generator to be increased by a few percentage points. The economizer 28 has several pipe-bundle heating surfaces each made up of pipes 32 arranged in parallel at the flow medium end, the economizer heating surfaces 34, which project into the heating gas passage 20. The base surfaces of the plate-type economizer heating surfaces 34 are in this case aligned parallel to the direction of flow of the heating gas, so that both sides of the pipe arrangement can be exposed to the flow. The individual pipes 32 themselves are arranged vertically relative to the direction of flow of the heating of gas in the embodiment shown in FIG. 1.

[0029] After passing the economizer heating surfaces 34, the temperature of the heating gas is typically still only about 250° C. to 400° C., which is, however, sufficient for a convective heating of the air preheater 36 arranged in the end area of the heating gas passage 20. Similar to the economizer 28, the air preheater 36 has heating surfaces 38 formed from pipe bundles, but it is not the flow medium to be vaporized which flows through these heating surfaces 38 but instead the combustion air to be fed to the burners 4 of the steam generator 2, which means that they are preheated before entering the combustion zone.

[0030] With its compact and simple construction, the steam generator 2 is designed for an effective cleaning and denitrogenation of the heating gas flowing from the heating gas passage 20 as exhaust gas. For this purpose, as shown in the side elevation in FIG. 3, the heating surfaces 34 of the economizer 28, i.e. those pipes 40 carrying the flow medium, are

provided on the outside facing toward the heating gas with a coating **44**, as a catalytic converter, which effects the activation and maintenance of an SCR denitrogenation reaction. In this case, e.g. titanium oxide or zeolite material is used as the coating material, which is applied to the base material of the pipes **40** and/or of any webs connecting them by means of a coating process familiar to the person skilled in the art, before assembling the steam generator **2**. By means of the catalytic converter material, the activation energy required for the SCR reaction, during which the nitrogen oxide carried in the heating gas is reduced to elementary nitrogen and water by an ammonia solution injected into the heating gas flow, is reduced.

[0031] The ammonia injection takes place, as shown in FIG. 1, with the aid of an injection device **46** arranged in the heating gas passage **20** upstream of the economizer heating surface **34**, with the injection device **46** being fed by means of a compressed air device (not illustrated) from a storage tank for ammonia water. The nozzles of the injection device **46** are adjusted and aligned so that the best possible mixture of the ammonia-laden liquid spray with the heating gas is obtained combined with the best possible uniform wetting of the catalytic coated economizer heating surfaces **34** over which the created mixture flows.

[0032] With a further embodiment not shown here, instead of the economizer heating surfaces **34**, the heating surfaces **38** of the air preheater **36**, are provided with the catalytic coating. In this case the injection device **46** is arranged in the section of the heating gas passage **20** between the economizer **38** and the air preheater **36**. Depending on the operating range of the catalytic converter material and the temperature profile, determined by the heating, along the flow path for the heating gas, it can be useful, instead of the economizer **28** or the air preheater **36**, to apply the catalytic coating to the superheater heating surfaces **30** arranged in the horizontal gas flue **14**.

[0033] FIG. 2 shows a further embodiment of a steam generator **2'** designed as a waste-heat steam generator, with a horizontal water-pipe boiler, which is arranged downstream of a gas turbine (not illustrated here) and is heated by the exhaust gas from the gas turbine. The exhaust gas of the gas turbine in this case flows through the horizontal gas flue **48**, enclosed by the gastight enclosing wall **8'**, in the direction shown by the direction arrow **50**. In doing so, the heating gas loses a large part of the heat it contains by convective heat transfer to the wall heating surfaces forming the enclosure wall **8'** or to the pipe bundle heating surfaces arranged inside the heating gas passage **20'**, as a result of which the flow medium carried in the heating surfaces is preheated, vaporized and then superheated. For this purpose economizer heating surfaces **34'**, evaporator heating surfaces **26'** and superheater heating surfaces **30'**, arranged appropriately in series at the flow medium end, are provided, with in the exemplary embodiment shown in FIG. 2 the evaporator heating surfaces **26'** being further subdivided into the heating surfaces of a medium pressure evaporator **52** and of a high pressure evaporator **54**. The heating gas whose temperature has reduced the most after its heat output to the flow medium leaves the steam generator **2'** via an exhaust stack **56** designed as a vertical gas flue. Needless to say, many variations with respect to the configuration and flow medium arrangement of the heating surfaces are familiar to the person skilled in the art, but are not dealt with individually here.

[0034] Furthermore, what is decisive is that a number of heating surfaces are provided at least partially with a catalytic

surface coating **44** on their side facing the heating gas, which brings about or promotes a reduction in the pollutant carried in the heating gas. When choosing which heating surfaces are to be coated, the temperature limits of the local pattern of the heating gas temperature (in steady-state, rated-load operation) are again an important design criterion depending on the temperature limits to be maintained for the catalytic reaction. The heating surface configuration shown in FIG. 2 especially considers the heating surfaces **26'** of the medium pressure evaporator **52** and of the high pressure evaporator **54**, and also the economizer heating surfaces **34'**, and in FIG. 2 the economizer heating surfaces **34'** were chosen, by way of example, for the coating in each case. The catalytic coating **44** is schematically shown in FIG. 2 by the hatching. Similar to the exemplary embodiment shown in FIG. 1, with the steam generator **2'** in FIG. 2 an injection device for the chemical reagent to be injected into the heating gas can be arranged upstream of the coated heating surfaces in the heating gas passage **20'**. For clarity however, it is not shown in FIG. 2.

1.-10. (canceled)

11. A steam generator of a power plant, having a heating gas passage enclosed by a gas-tight enclosing wall, comprising:

- a plurality of heating surfaces through which a flow medium flows, wherein the heating surfaces are evaporator heating surfaces or economizer heating surfaces assigned to an economizer; and
- a catalytic coating arranged on a face of at least one of the heating surfaces facing the heating gas.

12. The steam generator as claimed in claim **11**, wherein the coating applied to the respective heating surface catalyzes or brings about a conversion or decomposition of pollutants present in the heating gas.

13. The steam generator as claimed in claim **12**, wherein the coating applied to the respective heating surface catalyzes or brings about a conversion or decomposition of nitrogen oxides and/or carbon oxides.

14. The steam generator as claimed in claim **13**, further comprising an injection device for a reduction agent arranged such that during the operation of the steam generator the heating gas, decomposed following the injection with the reduction agent, flows over the respective catalytic coated heating surface.

15. The steam generator as claimed in claim **14**, wherein the reduction agent is a liquid containing ammonia.

16. The steam generator as claimed in claim **15**, wherein the catalytic surface coating is formed by nanoparticles applied to the base material of the respective heating surface, the catalytic surface coating material is selected from the group consisting of: titanium oxide, vanadium pentoxide, tungsten oxide, a zeolite material and combinations thereof.

17. The steam generator as claimed in claim **16**, wherein the respective catalytic coated heating surface is a wall heating surface integrated into the enclosing wall.

18. The steam generator as claimed in claim **17**, wherein the respective catalytic coated heating surface is a platen heating surface, arranged within or projecting into the heating gas passage.

19. The steam generator as claimed in claim **18**, wherein the respective catalytic coated heating surface is arranged in an area in which the heating gas flowing past has a temperature of between approximately 3000 C and 4000 C at rated load operation of the steam generator.

20. The steam generator as claimed in claim **19**, wherein the steam generator is a horizontal type steam generator.

21. The steam generator as claimed in claim **20**, wherein the horizontal type steam generator is a waste-heat steam generator with a horizontal gas passage through which the heating gas flows in an essentially horizontal direction.

22. The steam generator as claimed in claim **19**, wherein the steam generator is of the two-passage type with fossil fuel firing, with a first vertical gas passage through which the heating gas flows from bottom to top during operation, the heating gas end connected via a horizontal

gas passage to a second vertical gas passage through which the heating gas flows from top to bottom, the respective catalytic coated heating surface is a superheater heating surface, or an economizer heating surface, arranged in the area of the second vertical gas passage.

23. The steam generator as claimed in claim **22**, wherein the respective catalytic coated heating surface is part of an air preheater arranged at an outlet end in the heating gas passage.

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