Device and method for cleaning heat exchange finned tubes in a heat recovery steam generator

A device (2) and a method for cleaning the outer surface of parallel heat exchange tubes (1) of a heat recovery steam generator, said device comprising at least a frame support (6, 7) and a plurality of heat-resistant cleaning bodies (3) attached to said frame support, the cleaning bodies having a contact surface adapted to remove deposits from the outer surface of said tubes upon contact with the tubes, said frame support being movable in at least a cleaning direction (A) parallel to said tubes.
Prior art

Heat recovery steam generators are of common use in combined power plants. A combined power plant uses more than one thermodynamic cycle to produce power. The heat discharged from one thermodynamic cycle is used as the total or partial heat input for another (bottom) thermodynamic cycle. For example, in a gas-steam combined power plant, the hot exhaust gases of a gas turbine are used to generate steam in a heat recovery steam generator (HRSG) feeding a steam turbine. The HRSG may operate at one or more pressure levels for a better exploitation of the heat made available by the exhaust gases. A heat recovery steam generator is described for example in EP 1 684 011.

A known HRSG has one or more finned tube bundles to exchange heat from a heat source fluid to water or steam. A plurality of tube bundles may operate at different pressure, e.g. forming a water pre-heater, an evaporator and a steam superheater. The water or steam flows inside the tube bundles exposed to the heat source fluid which, as stated above, may be the exhaust combustion gases of a top engine such as a gas turbine or other internal combustion engine.

The content of combustion ash in the heat source fluid will depend on the nature of fuel of the top engine. Some combined power plants are fuelled with natural gas which is known to be a clean fuel and poses minor problems of tubes fouling; however a combined power plant, e.g. a gas-steam plant, can also be fed with many other fuels including fuel oil according to No. 2 ASTM grade or heavier up to No. 6 ASTM grade, or even with crude oil. In some cases the use of a heavy or crude oil could be more attractive than natural gas, e.g. in geographical locations where natural gas is not available while large quantities of crude oil are readily available. Gas turbines specifically designed to operate with liquid fuels or crude oil are now available for such applications.

The combustion of heavy oil or crude oil in the top engine will produce exhaust gases with a high load of ashes and will cause a rapid formation of deposits and caking on the outer surfaces of the finned tubes. The ash load is not only coming from the fuel oil ash content itself but it may be partly generated by fuel additives aimed to increase the ash softening temperature (too low when impurities such as vanadium, lead, zinc, potassium and sodium salts are present in the fuel oil), in order to prevent the top engine components from high temperature corrosion phenomena. Combustion ash adheres to and accumulates at the surfaces of heat transmission finned tubes of HRSG. Hereinafter, adhesion and accumulation will be referred to as "adhesion".

Adhesion of combustion ash to the finned tubes seriously decreases the heat exchange coefficient, raises the tube metal temperature and lowers the capacity of the generator for example in terms of steam production. Also, the greater is the amount of ash that adheres to the tubes, the greater is the temperature of waste combustion gas expelled from the HRSG. A greater tube metal temperature may expose the HRSG to tube mechanical failures impacting the plant reliability and availability.

In summary, the heat transfer coefficient and the integrity of the heat exchanger tubes deteriorates as the deposits grows and builds up during operation so that cleaning of tubes is indispensable.

The prior art of cleaning the outer surface of heat exchange tubes generally relies on soot blowers, especially steam-injection soot blowers. A soot blower installed inside a boiler furnace is operated periodically in order to blow out combustion ash from the surface of the tubes. Removal is effected by blasting the tubes with steam under pressure. The blowers can be retractable to reduce the disturbance to flow outside tubes when the blowers are not in use.

A considerable disadvantage of this method is the consumption of a blowing fluid such as water. In some instances the cost of water could be a relevant cost comparable with or even greater than the cost of fuel. This is especially true when the combined power plant is installed in a location where fresh water is not largely available. The water consumption is high especially when the fuel is a heavy or crude oil forcing to operate the soot blower more frequently than usual. For example it has been estimated that the cleaning of tubes of a HRSG of a commercial size may consume several cubic meters of water per hour. Another drawback is cost and complication especially of retractable blowers.

Manual cleaning of the heat exchanger is also still used in the prior art (example water washing or grid blasting). An essential drawback of manual cleaning is that operation of the heat exchanger needs be interrupt ed, which in a combined power plant means a shut down of the whole plant or at least of the bottom steam turbine. A further drawback of manual cleaning is that manual cleaning can only be performed at given intervals of time, which means that the heat exchanger will suffer a loss of efficiency in the course of operation between two shut downs for cleaning.

Acoustic cleaning, carbon dioxide pellets cleaning are other on-line tube deposit removal techniques tested with unsatisfactory results when finned tubes are being used in heat recovery steam generators.
Summary of the invention

[0011] The aim of the invention is to overcome the above drawback of the prior art. An aim of the invention is to provide a cleaning device and method that enables an efficient and automatic cleaning of outer tube surfaces in a heat recovery steam generator while the generator is operation, improving the reliability and efficiency of the HRSG. Another aim is to provide cleaning of tubes of a HRSG without the need to consume water.

[0012] Said aim is achieved with a cleaning device for cleaning the outer surface of parallel heat exchange finned tubes arranged in line in bundles pertaining to a heat recovery steam generator, the cleaning device comprising at least a frame support and a plurality of heat-resistant cleaning bodies attached to said frame support, the cleaning bodies having a contact surface adapted to remove deposits from the outer surface of said tubes upon contact with the tubes, said frame support being movable in a first direction parallel to said tubes.

[0013] Preferably the tubes are arranged in line and in a plurality of bundles; the travel of the movable cleaning device along said first direction may be delimited by the bundle restraints and/or anti-vibration supports.

[0014] The frame support comprises preferably a plurality of parallel bars carrying a plurality of respective cleaning bodies. Each bar of the frame structure and related cleaning bodies form a linear cleaning element of the device. Linear cleaning elements may be arranged parallel and/or perpendicular to a main axis of the HRSG, i.e. to a main direction of the hot gases when the HRSG is in operation. Preferably the cleaning bodies are distributed along a linear cleaning element at a distance which is about the tube pitch. The tube pitch is the center-to-center distance between adjoining tubes. Preferably the number of cleaning bodies of each cleaning element is equal to number of tubes per row.

[0015] In a preferred embodiment, the cleaning device comprises a first frame support comprising first parallel bars arranged in a first direction and a second frame support comprising second parallel bars arranged in a second direction perpendicular to said first direction. In this embodiment the crossing support beams forms a mesh grid or matrix of cleaning elements which is particularly effective in cleaning the whole surface of tubes. Said first direction is for example parallel to the main direction of the flow of hot gases when the heat recovery steam generator is in use, and said second direction is for example perpendicular to said main direction of the hot gases. A cleaning device as above described is preferably installed for each bundle section (alongside the tube direction) delimited by the bundle restraints and/or anti-vibration supports when forming the bundle cleaning device assembly.

[0016] The cleaning bodies are adapted to remove deposits from tubes, upon direct contact of said cleaning bodies with the finned tubes. Any suitable cleaning body could be used; according to preferred embodiments the cleaning bodies are selected from a group consisting of either metal or composite and synthetic material brush, either metal or composite and synthetic material scraper, either metal or composite and synthetic material lamellae, knitted metal, metal mesh and metal foil.

[0017] The heat-resistant cleaning bodies must be adapted to tolerate the temperature of the hot fluid outside tubes, which may be for example 600 — 850 °C and hence are realized in a suitable material such as a suitable steel. Higher temperatures of the inlet hot gas, close to 800 °C or greater, can be reached for example when the HRSG is installed downstream a gas turbine with post-combustion system.

[0018] A conventional soot blower may also be installed together with a cleaning device according to the invention. Use of both a cleaning device as described and a conventional soot blower in the same HRSG is also contemplated by the invention. Preferably a steam-injection soot blower can be used to clean the first tube bundle(s) (e.g. superheater or high-pressure evaporator) of a HRSG, namely the tubes at highest temperature, so to avoid exposure of the cleaning device and support frames to such temperatures. Whenever applicable, it is however preferred to avoid the use of soot blowers in order to eliminate the related water consumption.

[0019] According to another aspect of the invention, the frame support or any frame support of the cleaning device is/are also movable in at least one of a second direction and a third direction which are perpendicular to said first direction and respectively parallel to and transversal to the exhaust gas stream. More preferably, a short reciprocate movement according to said second and/or third direction is combined with a continuous movement along the first direction parallel to tubes. The reciprocate (alternate) movement in the second and third direction helps to increase the outer tube surface which is contacted by the cleaning bodies during operation. The amplitude of said reciprocate movement is generally about the outer diameter of the finned tubes, and preferably slightly bigger than said diameter.

[0020] In some embodiments of the invention, the alternate movement in said second and/or third direction performs the actual cleaning action passing the cleaning bodies over the tubes, and a movement in the first direction parallel to the tubes has the purpose to position the cleaning device in a given zone of a tube bundle for cleaning. Hence, when the cleaning device is moved in the first direction, the cleaning bodies may not be in contact with the tubes. According to other embodiments, the movement in the first direction parallel to tubes may be carried out with the cleaning bodies contacting the tubes and then may involve a cleaning action.

[0021] The cleaning device is operated by a mechanism which is preferably outside of the HRSG casing to be protected from the hot and aggressive exhaust gas flow.

[0022] A tube bundle of a HRSG may be divided into several sections separated by bundle restraints and/or
anti-vibration supports, especially when tubes have a considerable length, to avoid vibration of tubes. In common embodiments of HRSGs, a tube bundle is divided into three to five sections. In such a case, as such devices obstacle the passage of the cleaning device from one section to another, each section of the tube bundle will have a dedicated cleaning device according to the invention.

Another aspect of the invention is the related method for cleaning the outer surface of parallel heat exchange tubes in a heat recovery steam generator. In accordance with the invention said method comprises at least the step of passing a cleaning device moving in at least a first direction parallel to the tubes, said cleaning device comprising at least a frame support and a plurality of heat-resistant cleaning bodies attached to said frame support, the cleaning bodies having a contact surface adapted to remove deposits from the outer surface of said tubes upon contact with the tubes.

An aspect of the invention is also a heat recovery steam generator (HRSG) comprising the inventive cleaning device, either originally installed within the coil bundles or installed as a retrofit. In a preferred application the HRSG is part of a combined gas-steam power plant with a gas turbine powered by heavy oil or crude oil.

The invention provides cleaning elements such as brushes or scrapers which are moveably mounted inside the HRSG allowing the thorough cleaning of the external surface of the tubes without consumption of a cleaning fluid such as water. Another major advantage is that the cleaning device can work continuously without the need to shut down and access to the HRSG pressure parts; a better and more stable operation of the HRSG is then achieved. A cleaning device according to the invention is also simpler and less expensive than retractable blowers of the prior art. The invention does not need high-pressure steam nozzles or the retraction mechanism. The linear cleaning elements of the cleaning device (comprising a single bar with a plurality of cleaning bodies) are easily removable and replaceable from HRSG cavities between bundles during the periodic shutdown as required by the ordinary maintenance of the top engine components. A further advantage is that the invention allows to implement a combined cycle with a gas turbine powered with less clean fuels like crude oil, which to date has been considered unsuitable for heat recovery steam generation. An aspect of the invention is for example the boosting of a heavy oil or crude oil-powered gas turbine plant by means of addition of a steam turbine and a HRSG with the described cleaning device.

The advantages will be more evident with the following detailed description of preferred embodiments, reported as non-limitative examples.

**Description of the figures**

**[0023]** Fig. 1 is a cross section of a tube bundle of a heat recovery steam generator with a cleaning device according to an embodiment of the invention.

**[0024]** Fig. 2 is a view of the tube bundle and cleaning device of Fig. 1.

**[0025]** Fig. 3 is a view of another embodiment of cleaning device.

**[0026]** Fig. 4 is an enlarged detail of Fig. 3.

**[0027]** Fig. 5 is a simplified section of a heat recovery steam generator.

**Detailed description**

**[0028]** Fig. 1 shows a cross section of a bundle of finned tubes 1 of a heat recovery steam generator. Said bundle could be any tube bundle of said generator, including a water heater, an evaporator or a superheater. In operation the tube bundle is exposed to a hot gas flow G and water or steam flows inside the tubes 1.

**[0029]** A cleaning device 2 is installed to keep the outer surface of tubes 1 clean.

**[0030]** Said cleaning device 2 comprises cleaning bodies 3 attached to a frame support denoted with numeral 6, which in this embodiment comprises several bars 4 parallel to the direction of the gas flow G, and two cross bars 5. Each of the cleaning bodies 3 has at least a contact surface for contact with the outer surface of finned tubes 1; said cleaning bodies 3 may be for example metal brushes, metal scrapers or the like and are adapted to remove deposits from the tubes (Figs. 1-4).

**[0031]** A bar 4 with cleaning bodies 3 forms a linear cleaning element of the device 2. Said linear cleaning element is extended between two rows of the tube bundle; the cleaning bodies 3 project in the interspace between tubes 1 as seen in the figures. Each cleaning body 3 is projected in the interspace between two adjacent tubes in a row when moving the cleaning device along-side the tubes. The cleaning bodies 3 are spaced at suitable intervals over the cleaning element; preferably the distance between two adjoining cleaning bodies 3a, 3b (Fig. 1) is equal to the longitudinal pitch of the finned tubes 1.

**[0032]** In operation, the frame support 6 is moved at least in a first direction A parallel to the tubes 1, as shown in Fig. 2. The frame support 6 can be slowly moved from a top end position to a bottom end position, and back to top, while the HRSG is in operation, thus allowing the cleaning bodies 6 to sweep a given length of the tubes 1 between bundle restraints and/or anti-vibration supports. In a preferred embodiment the frame support 6 while travelling in the direction A is also moved in a reciprocate manner according to a direction B perpendicular to A and/or according to another direction C also perpendicular to A, so to allow an incisive action of the
cleaning bodies 3 on the surface of tubes.

[0033] The portion of tube length cleaned by the frame support 6, due to the stroke along direction A, can be the whole length of tubes or a part thereof. In the latter case, a plurality of respective frame supports 6 can be provided for different sections of the tube bundle.

[0034] Fig. 3 shows a second embodiment of the invention comprising a second frame support 7 above or below the first frame support 6, with bars 8 perpendicular to the bars 4 of said first frame support 6. The bars 8 carry further cleaning bodies 3. In this embodiment the bars 4 and 8 cross each other, so that in a cross section the cleaning device appears to form a mesh grid between the tubes 1. It can be appreciated that first bars 4 are substantially parallel to the main direction of the hot gas G, while the second bars 8 are perpendicular to said direction G. Also in this embodiment the supports 6 and 7 can be reciprocated along any of said directions B and C, or both, in addition to the motion according to said first direction A.

[0035] The presence of the further bars 8 perpendicular to the bars 4 allows arrange the cleaning bodies 3 all around the tubes 1 for a complete cleaning. The cleaning bodies attached to the bars 8 can be oriented in a different manner, e.g. perpendicularly, with respect to the cleaning bodies attached to bars 4.

[0036] In some embodiments, the travel along direction A may serve for positioning the frame 6 or frames 6, 7 while cleaning of tubes is effected by reciprocate motion of said frame or frames 6, 7 in directions B and/or C. In other embodiments, also the displacement along direction A may provide cleaning of tubes.

[0037] The first frame support 6 and - if provided - the second frame support 7 are connected to main cross shafts 9 (for example worm drives) directly or by means of suitable mechanisms such as for example crank and slotted links, or another system for converting a rotary motion into a reciprocating motion. The shafts are rotated by pulleys 10 connected to operating means 11 adapted to provide the reciprocating movement along longitudinal direction B (parallel to gas flow) and, if provided, also along transversal direction C. The operating means 14 are adapted to provide the main movement alongside the tubes and can comprise for example a worm drive with a worm 12 and gear 13 for each operating means 11. Preferably at least part of the operating means 11 and 14 are outside the casing of the HRSG. In any case, the movements to frame supports 6 and 7 can be imparted with transmission means which are per se known to a skilled person.

[0038] Fig. 4 is a detail showing the cleaning bodies 3 around tubes 1. Fig. 4 allows also appreciation of the bare diameter 15 of tubes and diameter 16 of the fins. It can be noted from Fig. 4 how the reciprocation e.g. in direction C (parallel to bars 8) of the metal brushes 3 can sweep and clean the finned tubes 1.

[0039] The invention is applied preferably to heat recovery steam generators with in-line parallel tubes.

[0040] Fig. 5 is an example of a recovery steam generator 110 that can be fitted with a cleaning device realized in accordance with the invention. The cleaning device is not shown.

[0041] The heat recovery steam generator 110 comprises a heat exchange unit 112 in communication with one (or more) steam drums 114. The figure shows three steam drums 114 operating at different pressure levels. In the example the heat exchange unit 112 comprises a high pressure section 116, a medium pressure section 118 and a low pressure section 120. Example pressure values are 130 bar for the high pressure section, 30 bar for the medium pressure section, and 5 bar for low pressure section. Each of said sections comprises one or more bundles of in-line, parallel tubes.

[0042] The heat exchange unit 112 is supported within a HRSG casing comprising main structural frames and roof, left side, right side and floor panels 113 with a gas inlet section 113a in communication with the exhaust of a gas turbine and a gas outlet section 113b in communication with a chimney stack 113c. The steam drums 114 are placed above said HRSG casing 113.

Claims

1. A cleaning device (2) for cleaning the outer surface of parallel heat exchange finned tubes (1) of a heat recovery steam generator, the cleaning device comprising at least a frame support (6) and a plurality of heat-resistant cleaning bodies (3) attached to said frame support, the cleaning bodies having a contact surface adapted to remove deposits from the outer surface of said tubes upon contact with the tubes, said frame support being movable at least in a first direction (A) parallel to said tubes.

2. A cleaning device according to claim 1, said frame support (6) comprising a plurality of parallel bars (4), each of said parallel bars carrying a plurality of respective cleaning bodies (3).

3. A cleaning device according to claim 1, comprising a first frame support (6) with first parallel bars (4) arranged in a first direction, and a second frame support (7) with second parallel bars (8) arranged in a second direction, said first direction being perpendicular to said second direction, each of said first and second parallel bars carrying cleaning bodies (3).

4. A cleaning device according to claim 3, said first bars (4) being parallel to the main direction of hot gases (G) when the heat recovery steam generator is in use and said tube bundle is exposed to hot gases, and said second bars (8) being perpendicular to said main direction of the hot gases.

5. A cleaning device according to any of claims 1 to 4,
said cleaning bodies being distributed on said parallel bars with a distance between consecutive cleaning bodies which is about the tube pitch.

6. A cleaning device according to any of claims 1 to 5, said cleaning bodies (3) being selected from the group consisting of: either metal or composite and synthetic material brush; either metal or composite and synthetic material scraper; either metal or composite and synthetic material lamellae; knitted metal; metal mesh; metal foil.

7. A cleaning device according to any of claims 1 to 6, said frame support (6) or supports (6, 7) being also movable in at least one of a second direction (B) and third direction (C) for cleaning the tubes, said second and third direction being perpendicular to said first direction (A), said second direction being parallel to the exhaust gas stream (G) and said third direction being perpendicular to said exhaust gas stream, when the generator is in operation.

8. A cleaning device according to any of claims 1 to 7, comprising at least one actuator disposed to move said frame support or frame supports (6, 7), said actuator being external to the casing of the heat recovery steam generator.

9. A cleaning device according to any of claims 1 to 8, the travel of the cleaning device in the first direction (A) being delimited by bundle restraints and/or anti-vibration supports of tube bundles.

10. A heat recovery steam generator comprising at least one bundle of parallel heat exchange tubes and comprising a cleaning device according to any of claims 1 to 9.

11. A method for cleaning the outer surface of parallel heat exchange tubes (1) in a heat recovery steam generator while said generator is in operation, the method comprising the step of operating a cleaning device (2) travelling at least in a first direction (A) parallel to said tubes (1), said cleaning device comprising at least a frame support (6, 7) and a plurality of heat-resistant cleaning bodies (3) attached to said frame support, the cleaning bodies having a contact surface adapted to remove deposits from the outer surface of said tubes upon contact with the tubes.

12. A method according to claim 11 where the cleaning device (2) is continuously moved back and forth in said first direction (A).

13. A method according to claim 11 or 12, where the cleaning device (2) is also moved in a reciprocate manner in a second direction (B) and/or is also moved in a third direction (C) while travelling in the first direction (A), said second direction and third direction being perpendicular to said first direction (A), said second direction being parallel to the exhaust gas stream (G) and said third direction being perpendicular to said exhaust gas stream, where:

- the movement in the first direction is combined with said reciprocate movement(s) in the second and/or third direction, and

- said reciprocate movement(s) in the second and/or third direction (B, C) have an amplitude which is about the diameter of tubes (1) and is preferably slightly larger than said diameter.

14. A method for retrofitting a heat recovery generator with bundles of in-line parallel finned tubes, the method comprising the provision of at least one cleaning device (2) according to any of claims 1 to 9.
FIG. 1
## DOCUMENTS CONSIDERED TO BE RELEVANT

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- F22B
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The present search report has been drawn up for all claims.

Place of search: Munich
Date of completion of the search: 2 December 2011
Examiner: Henkes, Roeland

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