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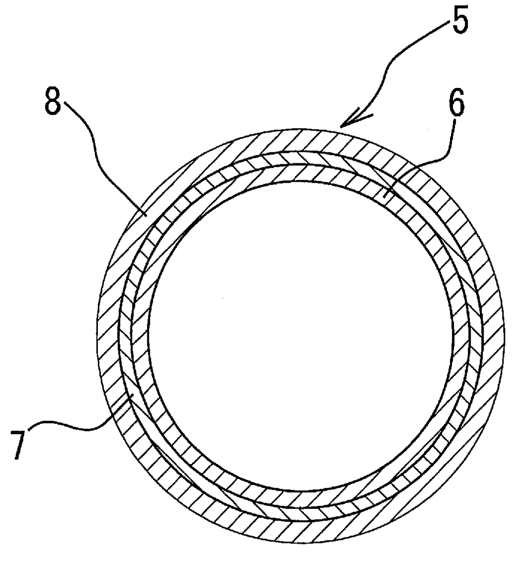
(54) IN-BED HEAT TRANSFER TUBE FOR FLUIDIZED BED BOILER

(57) The present invention relates to an immersed heat transfer tube installed in a fluidized bed of a fluidized-bed boiler for recovering combustion heat generated when a fuel such as RDF (refuse derived fuel) with high calorific value containing biomass and plastics, or wastes is combusted. An immersed heat transfer tube (5) which is installed in a fluidized bed (3) of a fluidized-bed boiler (1) includes a water tube (6) through which a fluid flows, a cylindrical protector (8) provided at an outer circumferential side of the water tube (6) and configured to protect the water tube (6), and a packed bed (7) provided between the water tube (6) and the protector (8).

FIG. 3



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Description

Technical Field

[0001] The present invention relates to immersed heat transfer tubes installed in a fluidized bed in a fluidized-bed boiler for recovering combustion heat generated when a fuel such as RDF (refuse derived fuel) with high calorific value containing biomass and plastics, or wastes, etc. is combusted.

Background Art

[0002] In recent years, use of energy resources has been required from the viewpoint corresponding to the problems of steep rise in the prices of fossil fuels, global warming, and the like. Thus, the importance of power generation systems combusting RDF or wastes as one of thermal recycle is increasing. Among such power generation systems, there is a power generation system which recovers thermal energy, generated when a fuel such as RDF or wastes, etc. is combusted in a fluidized-bed boiler, by using immersed heat transfer tubes. In this power generation system combusting the fuel such as RDF or wastes, etc. in the fluidized-bed boiler, since RDF or wastes contains chlorine, part of the chlorine moves to fluidizing particles (fluidizing sand) and then is deposited on the immersed heat transfer tubes, thus causing corrosive attack by molten salt on the immersed heat transfer tubes. Since the immersed heat transfer tubes are worn by intense fluidization of fluidizing particles (fluidizing sand), the immersed heat transfer tubes are subjected to the corrosive attack by molten salt in addition to the wear, and thus the immersed heat transfer tubes tend to suffer a great deal of tube thickness reduction.

[0003] Heretofore, measures against tube thickness reduction have been taken by applying thermal spray of self fluxing alloy (Ni-based) or weld overlay of stainless steel on heat transfer tubes installed in a fluidized bed. However, sufficient effect has not been obtained.

[0004] Japanese laid-open patent publication No. 5-187789 (Patent document 1) discloses a wear-resistant structure of heat transfer tubes in which heat transfer tubes are covered with studs and a refractory material to control tube thickness reduction. However, the structure disclosed in Patent document 1 results in a reduced heat transfer rate and requires an increased heat transfer area because the heat transfer tubes are covered with the refractory material. Another drawback is that the heat transfer tubes covered with the refractory material increase the diameter of heat transfer tubes, making it difficult to lay out the heat transfer tubes.

[0005] On the other hand, Japanese laid-open patent publication No. 7-217801 (Patent document 2) proposes a method for attaching protectors or a method for weld overlay or thermal spray, as a method for preventing heat transfer tubes from causing tube thickness reduction due to wear, and points out the problems of the conventional measures against tube thickness reduction by stating that attachment of the protectors greatly reduces heat transfer and the cost of weld overlay and thermal spray are high (see paragraph [0004]). Thus, Patent document 2 proposes that heat transfer tubes be made of wear-resistant high-chromium steel or stainless steel. However, though the method disclosed in Patent document 2 is effective to prevent the tube thickness reduction due to wear, the heat transfer tubes have poor durability in an environment where they are directly subject to wear and corrosive attack by molten salt at the same time.

Citation List

Patent Literature

[0006]

Patent document 1: Japanese laid-open patent publication No. 5-187789
Patent document 2: Japanese laid-open patent publication No. 7-217801

Summary of Invention

Technical Problem

[0007] As described above, in the conventional fluidized-bed boiler, although various measures such as weld overlay and attachment of protectors against wear and tube thickness reduction caused by corrosive attack by molten salt to the immersed heat transfer tubes have been taken, such conventional attempts have been focused on increasing the heat-transfer performance of heat transfer tubes to transfer the heat of the fluidizing particles quickly to boiler water that flows through the heat transfer tubes.

[0008] The present inventors have gotten the following knowledge from the continuous operation of the fluidized-bed boiler over a long period of time by using various immersed heat transfer tubes. Specifically, in the case where chloride is contained in a fuel such as biomass-based RDF or wastes, part of the chloride moves to the fluidizing particles (fluidizing sand) after combustion, and then the chloride in the fluidizing particles forms an eutectic salt with alkali metals (Na, K, etc.) contained in the fuel while the fluidized bed is operated at a temperature ranging from 700 to 850°C. The eutectic salt in its molten state is condensed at a temperature of 650 to 700°C, for example. Therefore, if the surface temperature of the immersed heat transfer tubes is higher than the condensing temperature of the eutectic salt, the eutectic salt is prevented from being condensed on the surface of the immersed heat transfer tubes, so that tube thickness reduction due to corrosive attack by molten salt can be reduced. The present inventors have found that the tube thickness reduction due to corrosive attack by molten salt can be reduced when the surface temperature of the immersed heat transfer tubes whose durability is increased by providing protectors made of stainless steel such as SUS310S and disposed around the outer circumferential surfaces of water tubes is lower than the above-described condensing temperature and exceeds a predetermined temperature (e.g., 450°C).

[0009] Based on the above knowledge, the present inventors have conceived that (1) increasing the heat transfer rate between the fluidized bed and the protectors and (2) lowering the heat transfer rate between the protectors and the water tubes are effective in order to adjust the surface temperature of the protectors to a temperature range for suppressing the corrosive attack by molten salt and controlling the tube thickness reduction.

[0010] Therefore, it is an object of the present invention to provide an immersed heat transfer tubes for a fluidized-bed boiler which suppresses corrosive attack by molten salt, controls tube thickness reduction, and has a good durability by lowering heat transfer rate between protectors and water tubes while ensuring an economically sufficient heat transfer amount by all the immersed heat transfer tubes.

Solution to Problem

[0011] In order to achieve the above object, according to the present invention, there is provided an immersed heat transfer tube for a fluidized-bed boiler which is installed in a fluidized bed, the immersed heat transfer tube comprising: a water tube through which a fluid flows; a protector provided at an outer circumferential side of the water tube and configured to protect the water tube; and a packed bed provided between the water tube and the protector.

[0012] According to the present invention, the heat of the fluidizing particles is transferred to the water tube through the protector and the packed bed, thus heating the fluid in the water tube. Since the packed bed interposed between the water tube and the protector has a low heat conductivity, the heat transfer rate between the protector and the water tube can be lowered. Therefore, the temperature difference between the surface of the protector and the surface of the water tube can be increased. Thus, the corrosive attack by molten salt can be suppressed to decrease the tube thickness reduction, and durability of the immersed heat transfer tube can be increased.

[0013] According to a preferred aspect of the present invention, a surface temperature of the protector is kept in the range of 450 to 650°C.

[0014] According to a preferred aspect of the present invention, the packed bed is formed by filling solid particles.

[0015] According to the present invention, since a void of the packed bed comprises air having a low heat conductivity, the heat transfer rate between the protector and the water tube can be lowered. In this case, if the heat transfer rate is too low, heat transfer becomes inefficient. Consequently, the material, shape of solid particles, and thickness of the packed bed are suitably selected to keep the surface temperature of the protector in the range of 450 to 650°C, preferably in the range of 480 to 620°C.

[0016] According to a preferred aspect of the present invention, the packed bed has a packing ratio of solid particles which is in the range of 0.5 to 0.9. Here, the packing ratio is defined as a value obtained by dividing the volume [m^3] occupied by the packing material by the volume [m^3] of the gap between the outer surface of the water tube and the inner surface of the protector.

[0017] According to the present invention, by employing the packing ratio of the packing material within the above range, when the protector is thermally expanded, the space formed between the surface (upper surface) of the packed bed and the inner surface of the protector by the gravitational sedimentation of the packing material, i.e., a thickness of air layer is reduced, thereby ensuring heat transfer to the water tube.

[0018] According to a preferred aspect of the present invention, the packed bed has a heat conductivity ranging from 0.4 to 1.4 W/mK.

[0019] According to the present invention, since the heat conductivity of the packed bed is in the range of 0.4 to 1.4 W/mK, the heat transfer rate between the protector and the water tube can be lowered. Therefore, the temperature difference between the surface of the protector and the surface of the water tube can be increased, and thus the surface temperature of the protector can be kept in the range of 450 to 650°C.

[0020] According to a preferred aspect of the present invention, a thickness of the packed bed is in the range of 2 to 4 mm.

[0021] According to a preferred aspect of the present invention, the protector is made of stainless steel.

[0022] According to a preferred aspect of the present invention, the stainless steel comprises SUS304 or SUS316 or

SUS310S.

[0023] According to the present invention, since the protector is made of stainless steel comprising SUS304, SUS316, SUS310S, or the like, the tube thickness reduction due to corrosive attack by molten salt can be suppressed.

[0024] According to a preferred aspect of the present invention, the protector has a fin on an outer surface thereof.

[0025] According to the present invention, since the protector has a fin having excellent heat exchange performance on an outer surface thereof, the heat transfer rate from the fluidizing particles to the protector can be increased. Therefore, a sufficient heat transfer amount can be obtained.

[0026] According to a preferred aspect of the present invention, the fin comprises a helical fin.

[0027] According to a preferred aspect of the present invention, the fin comprises a pin fin.

[0028] According to the present invention, there is provided a fluidized-bed boiler configured to combust a fuel in a fluidized bed and to recover combustion heat by an immersed heat transfer tube, the fluidized-bed boiler comprising: an immersed heat transfer tube according to any one of claims 1 to 11; wherein a fluidized-bed temperature is controlled in the range of 700 to 900°C.

[0029] According to the present invention, the amount of the fluidizing air supplied to the fluidized bed is adjusted depending on the calorific value of the fuel or the like, and thus the temperature of the fluidized bed is controlled in the range of 700 to 900°C. The amount of the heat held by the fluidized bed which is kept in the range of 700 to 900°C is transferred to the water tube through the protector and the packed bed, thus heating saturated water in the water tube. The packed bed that is interposed between the water tube and the protector can reduce the heat transfer rate between the protector and the water tube. Therefore, the temperature difference between the surface of the protector and the surface of the water tube can be increased, and the surface temperature of the protector can be kept in the range of 450 to 650°C.

[0030] According to a preferred aspect of the present invention, an amount of a fluidizing air in an area of the fluidized bed where the immersed heat transfer tube is provided is set so that u_o/u_{mf} is in the range of 2.0 to 4.0.

[0031] According to the present invention, since the fluidizing condition for the fluidized bed (moving bed) in which the immersed heat transfer tube is installed is set so that u_o/u_{mf} is in the range of 2.0 to 4.0, the fluidization of the fluidized bed (moving bed) becomes vigorous to increase the heat transfer rate from the fluidizing particles to the protector. Thus, even in the immersed heat transfer tube with the packed bed interposed between the protector and the water tube, an overall heat transfer rate and a heat transfer amount can be kept at the same level as those of the immersed heat transfer tube having a weld overlay. Consequently, a sufficient heat transfer amount can be obtained.

[0032] According to a preferred aspect of the present invention, the fluidized-bed boiler comprises an internally circulating fluidized-bed boiler which comprises a combustion chamber configured to combust the fuel therein, and a heat recovery chamber having the immersed heat transfer tube therein and configured to recover the combustion heat; and an amount of a fluidizing air in the heat recovery chamber is set so that u_o/u_{mf} is in the range of 2.0 to 4.0 to circulate fluidizing particles between the combustion chamber and the heat recovery chamber.

[0033] According to the present invention, since the combustion chamber for combusting the fuel and the heat recovery chamber for recovering the heat are separated from each other, a trouble caused by incombustibles in the fuel which twine around the immersed heat transfer tube does not occur. Further, by regulating the amount of the fluidizing air in the heat recovery chamber, the amount of heat recovered by the immersed heat transfer tube can be controlled.

Advantageous Effects of Invention

[0034] The present invention offers the following advantages:

(1) The immersed heat transfer tube comprises a water tube, a packing material, and a protector, and a packed bed is provided between the water tube and the protector, and thus the heat transfer rate between the protector and the water tube can be lowered. Therefore, the temperature difference between the surface of the protector and the surface of the water tube can be increased to keep the surface temperature of the protector in the range of 450 to 650°C. Thus, the corrosive attack by molten salt of the heat transfer tube can be suppressed to decrease the tube thickness reduction, and durability of the immersed heat transfer tube can be highly improved.

(2) Since the protector is made of stainless steel comprising SUS304, SUS316, SUS310S, or the like, the tube thickness reduction due to corrosive attack by molten salt can be suppressed.

(3) Since the fluidizing condition for the fluidized bed (moving bed) in which the immersed heat transfer tube is installed is set so that u_o/u_{mf} is in the range of 2.0 to 4.0, the fluidization of the fluidized bed (moving bed) becomes vigorous to increase the heat transfer rate from the fluidizing particles to the protector. Thus, even in the immersed heat transfer tube with the packed bed interposed between the protector and the water tube, an overall heat transfer rate and a heat transfer amount can be kept at the same level as those of the immersed heat transfer tube having a weld overlay. Consequently, an economically sufficient heat transfer amount can be ensured.

(4) Since the protector has a fin having excellent heat exchange efficiency on an outer surface thereof, the heat

transfer rate from the fluidizing particles to the protector can be increased. Therefore, an economically sufficient heat transfer amount can be ensured.

Brief Description of Drawings

[0035]

FIG. 1 is a schematic cross-sectional view showing a fluidized-bed boiler having immersed heat transfer tubes according to an embodiment of the present invention;
FIG. 2 is a schematic cross-sectional view showing a fluidized-bed boiler having immersed heat transfer tubes according to another embodiment of the present invention;
FIG. 3 is a schematic cross-sectional view of an immersed heat transfer tube;
FIG. 4A is a view showing experimental results of a conventional immersed heat transfer tube with a weld overlay of stainless steel on a water tube;
FIG. 4B is a view showing experimental results of the immersed heat transfer tube according to the present invention;
FIG. 5 is a front elevational view of the immersed heat transfer tubes;
FIG. 6 is a vertical cross-sectional view of the immersed heat transfer tube;
FIG. 7A is a view showing an immersed heat transfer tube according to another embodiment and a front elevational view of the immersed heat transfer tube;
FIG. 7B is a view showing the immersed heat transfer tube according to another embodiment and a vertical cross-sectional view of the immersed heat transfer tube;
FIG. 8A is a view showing an immersed heat transfer tube according to still another embodiment and a front elevational view of the immersed heat transfer tube; and
FIG. 8B is a view showing the immersed heat transfer tube according to still another embodiment and a vertical cross-sectional view of the immersed heat transfer tube.

Description of Embodiments

[0036] Immersed heat transfer tubes for a fluidized-bed boiler according to embodiments of the present invention will be described below with reference to FIGS. 1 through 8B. In FIGS. 1 through 8B, identical or corresponding parts are denoted by identical reference numerals, and will not be described in duplication.

[0037] FIG. 1 is a schematic cross-sectional view showing a fluidized-bed boiler having immersed heat transfer tubes according to an embodiment of the present invention. As shown in FIG. 1, the fluidized-bed boiler 1 comprises a furnace 2 having a substantially cylindrical shape or substantially square tubular shape, a fluidized bed 3 for combusting a fuel such as wastes or RDF, etc., and a hearth plate (furnace bottom plate) 4 for supporting the fluidized bed 3 thereon. Immersed heat transfer tubes 5 are disposed in the fluidized bed 3. The fluidized bed 3 is filled with fluidizing particles such as silica sand, so that the immersed heat transfer tubes 5 are embedded in the fluidizing particles. The hearth plate 4 has a number of gas diffusion nozzles for ejecting air as a fluidizing gas into the furnace 2.

[0038] In the fluidized-bed boiler 1 configured as shown in FIG. 1, the fuel is supplied from a supply port (not shown) to the fluidized bed 3. At this time, the fluidizing air is ejected at a uniform flow rate into the entire fluidized bed 3, and thus the fluidized bed 3 becomes a so-called bubbling-type fluidized bed wherein the fluidizing particles are fluidized vigorously up and down. The fuel supplied into the furnace is pyrolyzed and combusted in the fluidized bed 3, and the fluidizing particles are heated to a high temperature by combustion heat, thus keeping the fluidized bed 3 at a temperature ranging from 700 to 900°C. The temperature of the fluidized bed 3 is controlled by regulating an amount of the fluidizing air. The fluidizing particles that have been heated to the high temperature are brought into contact with the immersed heat transfer tubes 5, and a fluid (boiler water) in the immersed heat transfer tubes 5 recovers heat from the fluidizing particles by heat exchange with the fluidizing particles.

[0039] FIG. 2 is a schematic cross-sectional view showing a fluidized-bed boiler having immersed heat transfer tubes according to another embodiment of the present invention. As shown in FIG. 2, the fluidized-bed boiler 11 comprises a furnace 12 having a substantially square tubular shape, and the interior of the furnace 12 is divided by a pair of right and left partition walls 13, 13 into one central combustion chamber 14 and two heat recovery chambers 15, 15 on both sides of the combustion chamber 14. A fluidized bed 20 for reacting thermally a fuel such as wastes or RDF, etc. is formed in the combustion chamber 14. The fluidized bed 20 is supported by a hearth plate 30. The hearth plate 30 installed in the furnace 12 has a chevron shape which is the highest at its center and is gradually lowered toward the opposite side edges. The hearth plate 30 has a number of gas diffusion nozzles for ejecting air as a fluidizing gas into the furnace. Fluidized beds 23 are formed in the respective heat recovery chambers 15 and supported by hearth plates 31. Each of the hearth plates 31 has a number of gas diffusion nozzles for ejecting air as a fluidizing gas into the furnace.

[0040] As shown in FIG. 2, four air chambers 32, 32, 33, 33 are formed below the chevron-shaped hearth plate 30.

These air chambers 32, 32, 33, 33 are supplied with fluidizing air from outside of the furnace 2. By adjusting the opening degrees of regulating valves (not shown) to control the flow rates of air supplied to the air chambers 32, 32, 33, 33, the fluidizing air is ejected from the air diffusion nozzles above the two central air chambers 32, 32 so as to give a substantially small fluidizing velocity and from the air diffusion nozzles above the two air chambers 33, 33 on both sides so as to give a substantially large fluidizing velocity. As a result, a moving bed 21 in which the fluidizing particles move downwardly at a relatively low speed is formed above the central region of the hearth plate 30, and fluidized beds 22 in which the fluidizing particles move upwardly are formed above both side regions of the hearth plate 30. Therefore, the fluidizing particles move from the moving bed 21 to the fluidized beds 22 in a lower portion of the fluidized bed 20, and move from the fluidized beds 22 to the moving bed 21 in an upper portion of the fluidized bed 20, thus forming right and left circulating flows of the fluidizing particles circulating between the moving bed 21 and the fluidized beds 22. The partition walls 13 have respective slanted portions which function as reflector walls for allowing the ascending fluidizing particles to turn into the inner side of the furnace 12.

[0041] In the internally circulating fluidized-bed boiler 11 configured as shown in FIG. 2, the fuel is supplied from a supply port (not shown) to the moving bed 21. At this time, the opening degrees of the regulating valves are adjusted to control an amount of the fluidizing air such that an amount of the fluidizing air supplied to the moving bed 21 is smaller than an amount of the fluidizing air supplied to the fluidized beds 22. According to the present embodiment, the amount of the fluidizing air supplied to the moving bed 21 is set so that u_o/u_{mf} is in the range of 2 to 3 and the amount of the fluidizing air supplied to the fluidized beds 22 is set so that u_o/u_{mf} is in the range of 4 to 6. Here, u_o represents a superficial velocity and u_{mf} represents a minimum fluidizing superficial velocity.

[0042] The fuel supplied to the moving bed 21 sinks into the fluidizing particles and moves downwardly together with the fluidizing particles. At this time, the fuel is decomposed by the heat of the fluidizing particles to generate a combustible gas from a combustible component in the fuel, thus producing a brittle pyrolysis residue. The pyrolysis residue typically includes incombustibles and unburned combustibles (char) which become brittle by pyrolysis. The pyrolysis residue produced in the moving bed 21 moves downwardly and reaches the hearth plate 30 together with the fluidizing particles, and then moves along the inclined hearth plate 30 toward the fluidized beds 22. The pyrolysis residue which has reached the fluidized beds 22 is brought into contact with the fluidizing particles that are vigorously fluidized, and thus the unburned combustibles are separated from the incombustibles. The incombustibles from which the unburned combustibles have been separated are discharged together with part of the fluidizing particles from incombustible discharge ports 17.

[0043] On the other hand, the unburned combustibles which have been separated from the incombustibles move upwardly together with the fluidizing particles that are fluidized by supply of the fluidizing air. At this time, the unburned combustibles are combusted by the supplied fluidizing air to produce a combustion gas while heating the fluidizing particles, and are turned into particles of unburned combustibles and ash that are fine enough to be carried by the gas. The high-temperature fluidizing particles that have reached the upper portions of the fluidized beds 22 partly flow into the moving bed 21. In the fluidized beds 22, the fluidizing particles are heated to a temperature which is high enough to completely pyrolyze the fuel when the fluidizing particles flow into the moving bed 21. The fluidizing particles that have flowed into the moving bed 21 receive the supplied fuel again, and repeat the above thermal reactions in the moving bed 21 and the fluidized beds 22. The moving bed 21 is kept at a temperature ranging from 700 to 900°C, and the fluidized beds 22 are kept at a temperature ranging from 700 to 900°C.

[0044] Further, the high-temperature fluidizing particles in the upper portions of the fluidized beds 22 partly flow over the upper ends of the partition walls 13 into the heat recovery chambers 15. The fluidizing particles that have entered the heat recovery chambers 15 form fluidized beds 23 in which the fluidizing particles move downwardly. The hearth plates 31 in the heat recovery chambers 15 are slanted downwardly from the inner wall side of the furnace 12 toward the combustion chamber side. Openings 18 are provided at lower portions of the heat recovery chambers 15. The fluidizing particles that have entered the heat recovery chambers 15 descend while forming the fluidized beds 23, and circulate from the openings 18 into the combustion chamber 14. The temperature of the fluidizing particles that flow into the heat recovery chambers 15 is in the range of 700 to 900°C. The immersed heat transfer tubes 5 are disposed in the fluidized beds 23 in the heat recovery chambers 15. The high-temperature fluidizing particles are brought into contact with the immersed heat transfer tubes 5 while moving downwardly, and thus a fluid (boiler water) in the immersed heat transfer tubes 5 recovers heat from the fluidizing particles by heat exchange with the fluidizing particles. The amount of heat recovered by the immersed heat transfer tubes 5 can be controlled by adjusting an amount of the fluidizing air to be ejected from the gas diffusion nozzles on the hearth plates 31 of the fluidized beds 23 so that u_o/u_{mf} is the range of 2 to 4. The fluidizing particles that have circulated into the combustion chamber 14 are supplied to the fluidized beds 22, and ascend together with the fluidizing particles of the fluidized beds 22. The fluidizing particles partly enter the heat recovery chambers 15 again, and repeat heat exchange with the fluid in the immersed heat transfer tubes 5.

[0045] The immersed heat transfer tubes 5 that are used in the bubbling-type fluidized-bed boiler shown in FIG. 1 and the internally circulating fluidized-bed boiler shown in FIG. 2 will be described below.

[0046] FIG. 3 is a schematic cross-sectional view of the immersed heat transfer tube 5. As shown in FIG. 3, the immersed heat transfer tube 5 comprises a water tube 6 through which a fluid (boiler water) flows, a cylindrical protector

8 provided at an outer circumferential side of the water tube 6 and configured to protect the water tube 6, and a packed bed 7 provided between the water tube 6 and the protector 8. The water tube 6 is made of a steel tube for boilers and heat exchangers such as STB410S which has a wall thickness of 4 to 8 mm. The fluid (boiler water) that flows through the water tube 6 is saturated water having a pressure of 2 MPa to 12 MPa. The packed bed 7 is formed by filing solid particles such as sand, stainless steel powder, magnesium oxide, iron, or alumina, and is formed in a hollow cylindrical shape having a wall thickness of 2 to 4 mm. The packed bed 7 has a heat conductivity ranging from 0.4 to 1.4 W/mK calculated according to the calculation formula described in "Powder Reaction", NIKKAN KOGYO SHIMBUN, LTD., p. 54 - 57. The packed bed 7 may be made of any other packing materials than those enumerated above insofar as the heat conductivity falls within the above range.

[0047] The packing material should preferably be a powder and granular material. Further, the packing ratio of the packing material should preferably be in the range of 0.5 to 0.9, and more preferably in the range of 0.6 to 0.8. Here, the packing ratio of the packing material which fills the gap between the water tube 6 and the protector 8 is defined by the following equation:

Packing ratio [-] = (the volume [m^3] occupied by the packing material) / (the volume [m^3] of the gap between the outer surface of the water pipe and the inner surface of the protector)

[0048] By employing the packing ratio of the packing material which falls within the above range, when the protector is thermally expanded, the space formed between the surface (upper surface) of the packed bed and the inner surface of the protector by the gravitational sedimentation of the packing material, i.e., a thickness of the space is reduced, thereby ensuring heat transfer to the water tube.

[0049] The protector 8 is made of stainless steel comprising SUS304, SUS316, SUS310S, or the like which has excellent wear resistance and corrosion resistance, and is formed in a hollow cylindrical shape having a wall thickness of 3 to 6 mm. The protector 8 may comprise a stainless steel plate formed in a hollow cylinder or a stainless steel tube.

[0050] The present invention is configured as follows: (1) the protector 8 is made of stainless steel comprising SUS304, SUS316, SUS310S, or the like, (2) the packed bed 7, between the water tube 6 and the protector 8, which has a heat conductivity ranging from 0.4 to 1.4 W/mK is formed in a predetermined thickness, i.e., a thickness of 2 to 4 mm, and (3) the temperature of the fluidized bed 3 (see FIG. 1) in which the immersed heat transfer tubes 5 are disposed and the temperature of the fluidizing particles that enter the heat recovery chambers 15 (see FIG. 2) are maintained in the range of 700 to 900°C.

[0051] By employing the above elements (1) to (3), the surface temperature of the protector 8 can be kept at a temperature ranging from 450 to 650°C, or preferably from 480 to 620°C.

[0052] FIGS. 4A and 4B are views showing the results of comparison between a conventional immersed heat transfer tube having a weld overlay of stainless steel on a water tube and an immersed heat transfer tube according to the present invention which provides the above elements (1) to (4).

[0053] The conventional immersed heat transfer tube has weld overlay of stainless steel having a thickness of 3 mm for surface modification of the water tube. As shown in FIG. 4A, when the temperature of the fluidized bed is 800°C, the temperature of the boiler water is 300°C, and the fluidizing air is supplied to the fluidized bed so that u_o/u_{mf} is equal to 1.5, the heat transfer rate from the fluidizing particles (sand) to the weld overlay is 210 W/m^2K, the surface temperature of the weld overlay is 320°C, the overall heat transfer rate at the inner surface basis of the weld overlay (the outer surface basis of the water tube) is 222 W/m^2K, and the heat transfer amount is 111118 W/m^2. In addition, the temperature difference between the surface temperature of the weld overlay and the surface temperature of the water tube is 20°C.

[0054] On the other hand, the immersed heat transfer tube according to the present invention has a packed bed formed by filling magnesium oxide particles and having a thickness of 2 mm, and a protector made of SUS310S and having a thickness of 3 mm, at the outer circumference of the water tube. As shown in FIG. 4B, when the temperature of the fluidized bed is 800°C, the temperature of the boiler water is 300°C, and the fluidizing air is supplied to the fluidized bed so that u_o/u_{mf} is equal to 2.5, the heat transfer rate from the fluidizing particles (sand) to the protector is 390 W/m^2K, the heat conductivity of the protector is 16.2 W/mK, the heat conductivity of the packed bed formed by filling magnesium oxide (having a thickness of 2 mm) is 1.3 W/mK, the surface temperature of the protector is 513°C, the surface temperature of the packed bed is 491°C, the overall heat transfer rate (at the inner surface basis of the protector) is 246 W/m^2K, and the heat transfer amount is 122957 W/m^2. The temperature difference between the surface temperature of the protector and the surface temperature of the packed bed is 22°C, and the temperature difference between the surface temperature of the packed bed and the surface temperature of the water tube is 191 °C.

[0055] By the way, the overall heat transfer rate at the outer surface basis of the water tube is 263 W/m^2K, and the heat transfer amount is 131586 W/m^2.

[0056] As indicated by the comparison of FIGS. 4A and 4B, the immersed heat transfer tube having the packing material and the protector at the outer circumference of the water tube is used and an amount of the fluidizing air is set so that u_o/u_{mf} is equal to 2.5 or higher to intensify the fluidization of the fluidized beds (moving bed), and the thickness and the heat conductivity of the packed bed are appropriately selected, and thus the following can be achieved:

(1) The heat transfer rate between the fluidizing particles (sand) and the protector can be increased; and
(2) The heat transfer rate between the protector and the water tube can be decreased.

[0057] Thus, it is possible to keep the overall heat transfer rate and the heat transfer amount at the same level as those of the immersed heat transfer tube having the weld overlay, and to keep the surface temperature of the protector at 450°C or higher.

[0058] As can be seen clearly from FIGS. 4A and 4B, the conventional immersed heat transfer tube is designed to transfer the heat of the fluidizing particles in the fluidized bed quickly to the fluid (boiler water) in the heat transfer tube. On the other hand, the immersed heat transfer tube 5 according to the present invention is configured to have the packed bed 7 between the water tube 6 and the protector 8 to achieve gradual heat transfer, thereby increasing the surface temperature of the protector 8. Thus, the corrosive attack by molten salt on the heat transfer tube and thereby resulting the tube thickness reduction can be suppressed and the service life of the heat transfer tube can be prolonged.

[0059] An example of a detailed structure of the immersed heat transfer tubes used in the fluidized-bed boilers shown in FIGS. 1 and 2 will be described below with reference to FIG. 5 and 6.

[0060] FIG. 5 is a front elevational view of immersed heat transfer tubes 5. FIG. 5 shows a heat transfer tube bundle in which two immersed heat transfer tubes 5 are disposed in parallel. The immersed heat transfer tube 5 has a straight tube section and a bent tube section, and a number of fins 9 are provided on the straight tube section.

[0061] FIG. 6 is a vertical cross-sectional view of the immersed heat transfer tube 5. The immersed heat transfer tube 5 shown in FIG. 6 comprises a water tube 6, a packed bed 7, and a protector 8 as with the immersed heat transfer tube 5 shown in FIG. 3, and additional fins 9 provided on the outer circumferential surface of the protector 8. The fins 9 are composed of stainless steel plates of SUS304, SUS316, SUS310S, or the like, and are fixed to upper and lower portions of the outer circumferential surface of the protector 8.

[0062] FIGS. 7A and 7B are view showing an immersed heat transfer tube 5 according to another embodiment. FIG. 7A is a front elevational view of the immersed heat transfer tube 5, and FIG. 7B is a vertical cross-sectional view of the immersed heat transfer tube 5. The immersed heat transfer tube 5 shown in FIGS. 7A and 7B includes a helical fin 34 welded to the entire outer circumferential surface of the protector 8. By adopting the helical fin, attachment of the fin is facilitated and the construction period can be greatly shortened.

[0063] FIGS. 8A and 8B are views showing an immersed heat transfer tube 5 according to still another embodiment. FIG. 8A is a front elevational view of the immersed heat transfer tube 5, and FIG. 8B is a vertical cross-sectional view of the immersed heat transfer tube 5. The immersed heat transfer tube 5 shown in FIGS. 8A and 8B includes fins 35 in the form of pins, rather than plates (vanes), fixed to the outer circumferential surface of the protector 8. A number of pin fins 35 are welded to the outer circumferential surface of the protector 8.

[0064] As shown in FIGS. 5, 6, 7A, 7B, 8A and 8B, since the protector 8 is provided with the fins 9, the fin 34, or the fins 35, the heat transfer rate per inner surface of the protector can be increased. Therefore, the heat transfer rate between the fluidizing particles (sand) and the protector can be increased and the surface temperature of the protector 8 can be kept at a temperature of 450°C or higher. The water tube 6, the packed bed 7, and the protector 8 of the immersed heat transfer tube 5 shown in FIGS. 5, 7A, 7B, 8A and 8B are the same as those of the immersed heat transfer tube shown in FIG. 3.

[0065] Although the embodiment of present invention has been described above, the present invention is not limited to the above embodiment, but may be reduced to practice in various different manners within the scope of the technical concept thereof.

Industrial Applicability

[0066] The present invention is applicable to immersed heat transfer tubes installed in a fluidized bed in a fluidized-bed boiler for recovering combustion heat generated when a fuel such as RDF (refuse derived fuel) with high calorific value containing biomass and plastics, or wastes is combusted.

Reference Signs List

[0067]

1	fluidized-bed boiler
2	furnace
3	fluidized bed
4	hearth plate
5	immersed heat transfer tube
6	water tube
7	packed bed
8	protector
9, 34, 35	fin
11	fluidized-bed boiler
12	furnace
13	partition wall
14	combustion chamber
15	heat recovery chamber
17	incombustible discharge port
18	opening
20	fluidized bed
21	moving bed
22	fluidized bed
23	fluidized bed
30	hearth plate
31	hearth plate
32, 33	air chamber

Claims

1. An immersed heat transfer tube for a fluidized-bed boiler which is installed in a fluidized bed, the immersed heat transfer tube comprising:

    a water tube through which a fluid flows;
    a protector provided at an outer circumferential side of the water tube and configured to protect the water tube; and
    a packed bed provided between the water tube and the protector.

2. The immersed heat transfer tube for a fluidized-bed boiler according to claim 1, wherein a surface temperature of the protector is kept in the range of 450 to 650°C.

3. The immersed heat transfer tube for a fluidized-bed boiler according to claim 1, wherein the packed bed is formed by filling solid particles.

4. The immersed heat transfer tube for a fluidized-bed boiler according to claim 3, wherein the packed bed has a packing ratio of solid particles which is in the range of 0.5 to 0.9.

5. The immersed heat transfer tube for a fluidized-bed boiler according to claim 1, wherein the packed bed has a heat conductivity ranging from 0.4 to 1.4 W/mK.

6. The immersed heat transfer tube for a fluidized-bed boiler according to claim 5, wherein a thickness of the packed bed is in the range of 2 to 4 mm.

7. The immersed heat transfer tube for a fluidized-bed boiler according to claim 1, wherein the protector is made of stainless steel.

8. The immersed heat transfer tube for a fluidized-bed boiler according to claim 7, wherein the stainless steel comprises SUS304 or SUS316 or SUS310S.

9. The immersed heat transfer tube for a fluidized-bed boiler according to any one of claims 1 to 8, wherein the protector has a fin on an outer surface thereof.

10. The immersed heat transfer tube for a fluidized-bed boiler according to claim 9, wherein the fin comprises a helical fin.

11. The immersed heat transfer tube for a fluidized-bed boiler according to claim 9, wherein the fin comprises a pin fin.

12. A fluidized-bed boiler configured to combust a fuel in a fluidized bed and to recover combustion heat by an immersed heat transfer tube, the fluidized-bed boiler comprising:

an immersed heat transfer tube according to any one of claims 1 to 11;
wherein a fluidized-bed temperature is controlled in the range of 700 to 900°C.

13. The fluidized-bed boiler according to claim 12, wherein an amount of a fluidizing air in an area of the fluidized bed where the immersed heat transfer tube is provided is set so that u_o/u_{mf} is in the range of 2.0 to 4.0.

14. The fluidized-bed boiler according to claim 12, wherein the fluidized-bed boiler comprises an internally circulating fluidized-bed boiler which comprises a combustion chamber configured to combust the fuel therein, and a heat recovery chamber having the immersed heat transfer tube therein and configured to recover the combustion heat; and an amount of a fluidizing air in the heat recovery chamber is set so that u_o/u_{mf} is in the range of 2.0 to 4.0 to circulate fluidizing particles between the combustion chamber and the heat recovery chamber.

Amended claims under Art. 19.1 PCT

1. (Amended) An immersed heat transfer tube for a fluidized-bed boiler which is installed in a fluidized bed, the immersed heat transfer tube comprising:

a water tube through which a fluid flows;
a cylindrical protector provided at an outer circumferential side of the water tube and configured to protect the water tube; and
a packed bed provided between the water tube and the protector.

2. The immersed heat transfer tube for a fluidized-bed boiler according to claim 1, wherein a surface temperature of the protector is kept in the range of 450 to 650°C.

3. The immersed heat transfer tube for a fluidized-bed boiler according to claim 1, wherein the packed bed is formed by filling solid particles.

4. The immersed heat transfer tube for a fluidized-bed boiler according to claim 3, wherein the packed bed has a packing ratio of solid particles which is in the range of 0.5 to 0.9.

5. The immersed heat transfer tube for a fluidized-bed boiler according to claim 1, wherein the packed bed has a heat conductivity ranging from 0.4 to 1.4 W/mK.

6. The immersed heat transfer tube for a fluidized-bed boiler according to claim 5, wherein a thickness of the packed bed is in the range of 2 to 4 mm.

7. The immersed heat transfer tube for a fluidized-bed boiler according to claim 1, wherein the protector is made of stainless steel.

8. The immersed heat transfer tube for a fluidized-bed boiler according to claim 7, wherein the stainless steel comprises SUS304 or SUS316 or SUS310S.

9. The immersed heat transfer tube for a fluidized-bed boiler according to any one of claims 1 to 8, wherein the protector has a fin on an outer surface thereof.

10. The immersed heat transfer tube for a fluidized-bed boiler according to claim 9, wherein the fin comprises a helical fin.

11. The immersed heat transfer tube for a fluidized-bed boiler according to claim 9, wherein the fin comprises a pin fin.

12. A fluidized-bed boiler configured to combust a fuel in a fluidized bed and to recover combustion heat by an immersed heat transfer tube, the fluidized-bed boiler comprising:

an immersed heat transfer tube according to any one of claims 1 to 11;
wherein a fluidized-bed temperature is controlled in the range of 700 to 900°C.

. laim 13] The fluidized-bed boiler according to claim 12, wherein an amount of a fluidizing air in an area of the fluidized bed where the immersed heat transfer tube is provided is set so that u_o/u_{mf} is in the range of 2.0 to 4.0.

. laim 14] The fluidized-bed boiler according to claim 12, wherein the fluidized-bed boiler comprises an internally circulating fluidized-bed boiler which comprises a combustion chamber configured to combust the fuel therein, and a heat recovery chamber having the immersed heat transfer tube therein and configured to recover the combustion heat; and
an amount of a fluidizing air in the heat recovery chamber is set so that u_o/u_{mf} is in the range of 2.0 to 4.0 to circulate fluidizing particles between the combustion chamber and the heat recovery chamber.

FIG. 1

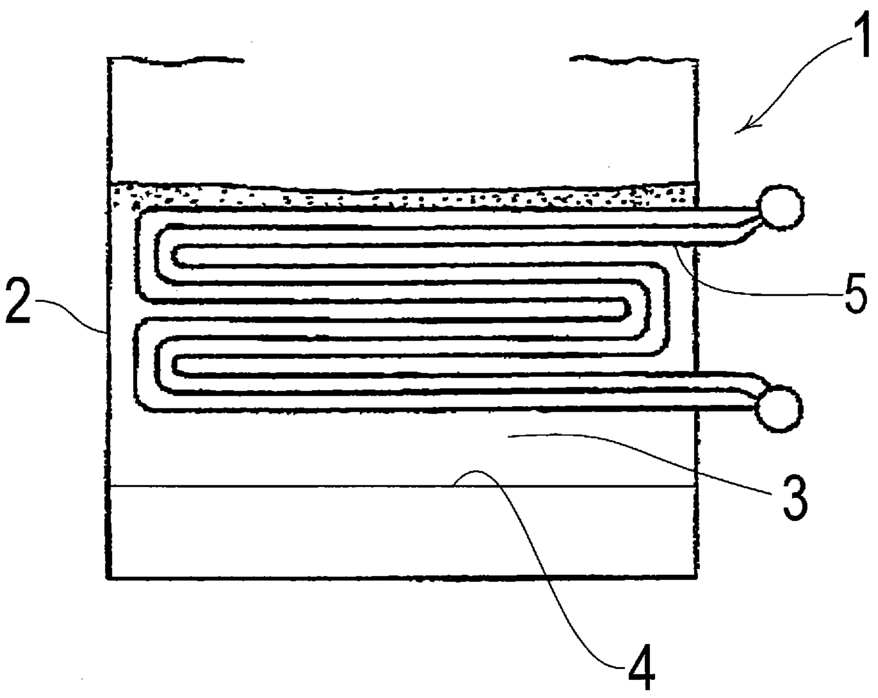


FIG. 2

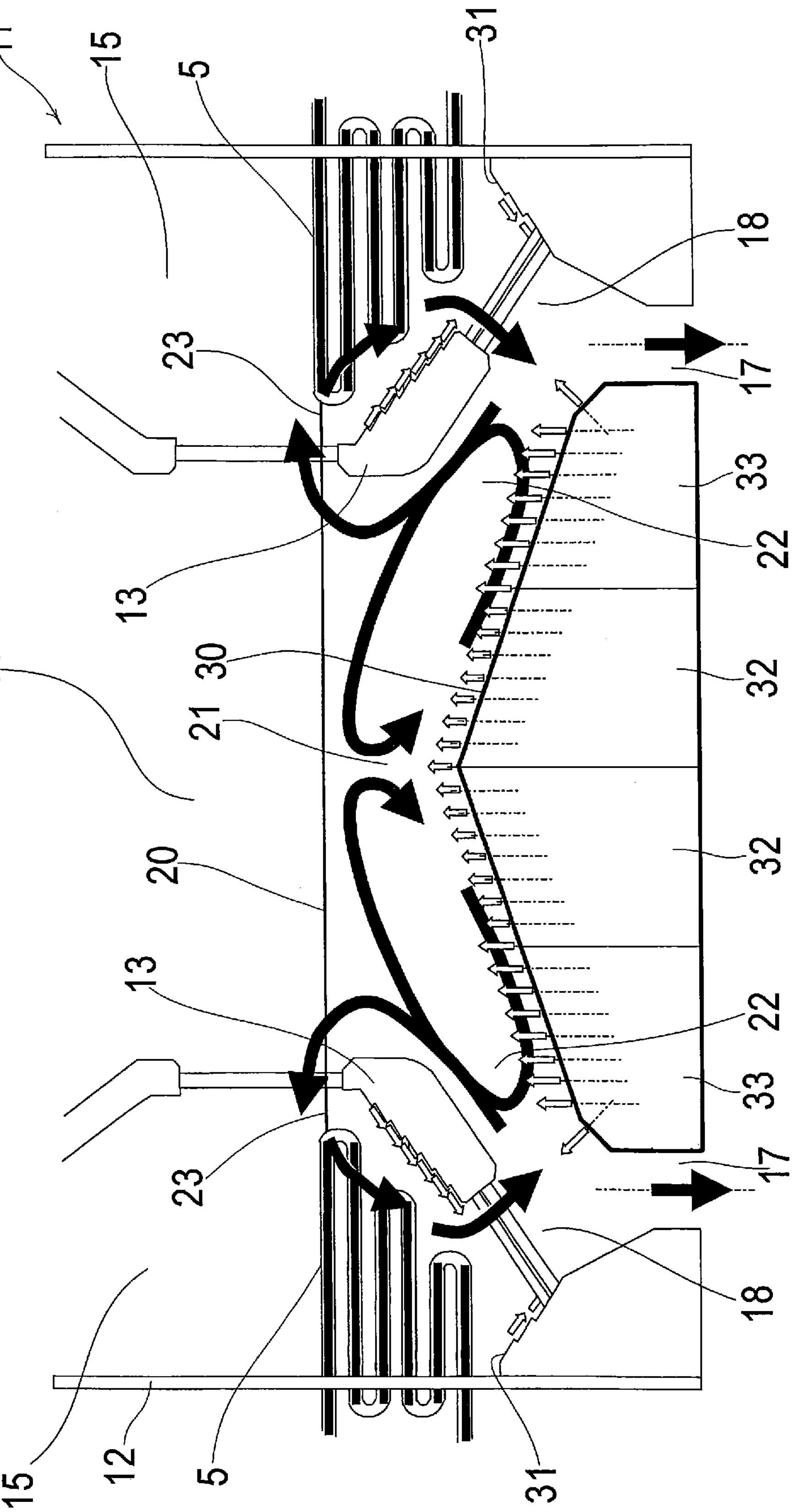


FIG. 3

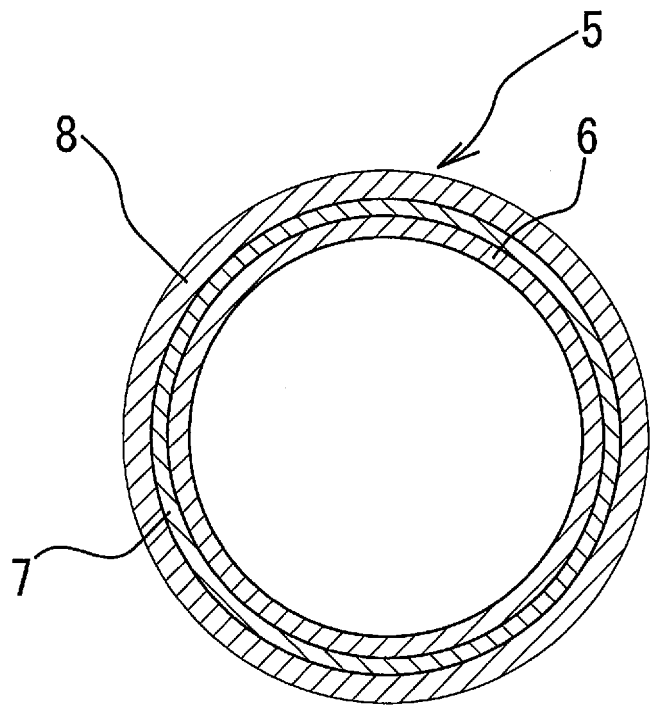


FIG. 4A

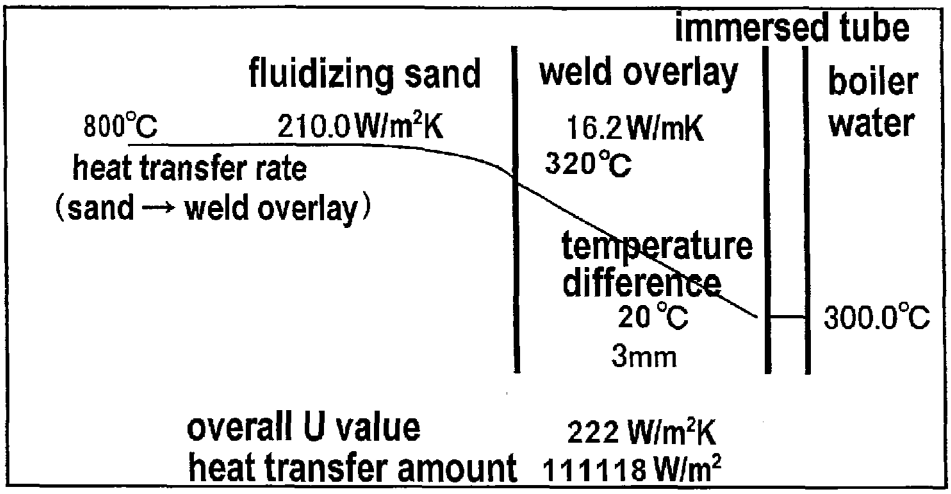

immersed tube
fluidizing sand
weld overlay
boiler water
800°C
210.0W/m²K
16.2W/mK
320°C
heat transfer rate
(sand → weld overlay)
temperature difference
20°C
3mm
300.0°C
overall U value
222 W/m²K
heat transfer amount
111118 W/m²

FIG. 4B

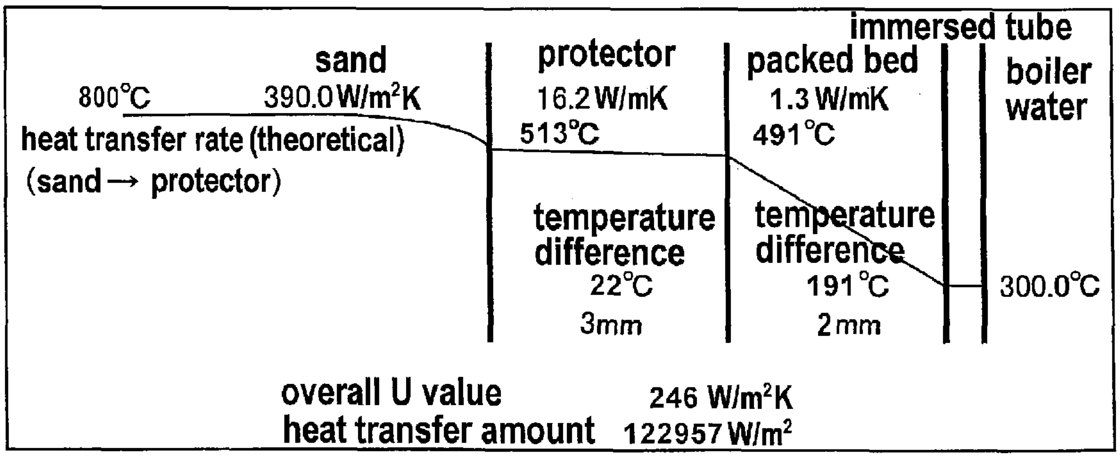

immersed tube
sand
protector
packed bed
boiler water
800°C
390.0W/m²K
16.2W/mK
1.3W/mK
heat transfer rate (theoretical)
(sand → protector)
513°C
491°C
temperature difference
22°C
3mm
temperature difference
191°C
2mm
300.0°C
overall U value
246 W/m²K
heat transfer amount
122957 W/m²

FIG. 5

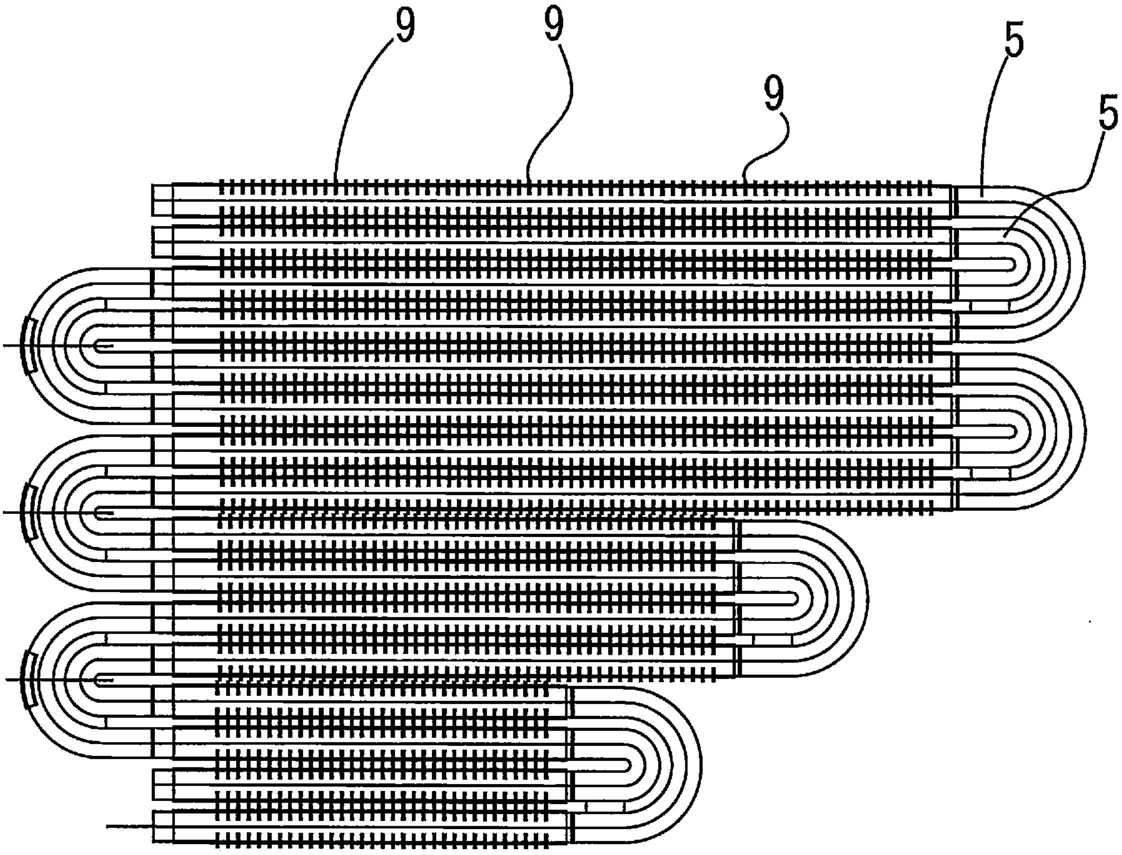


FIG. 6

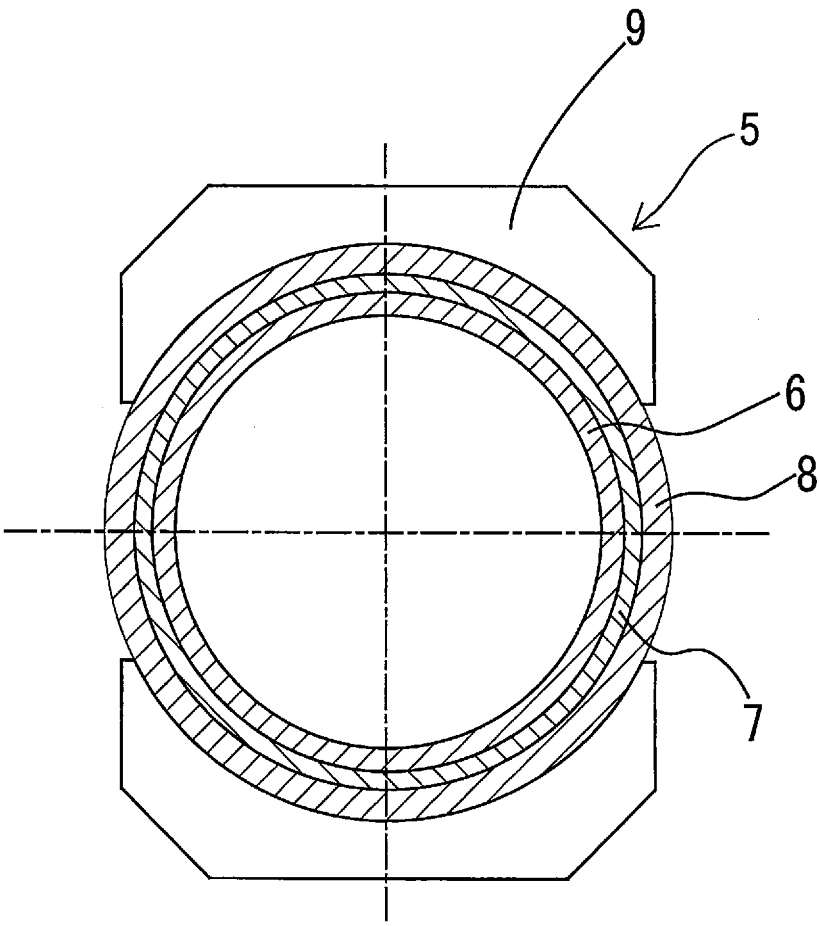


FIG. 7A

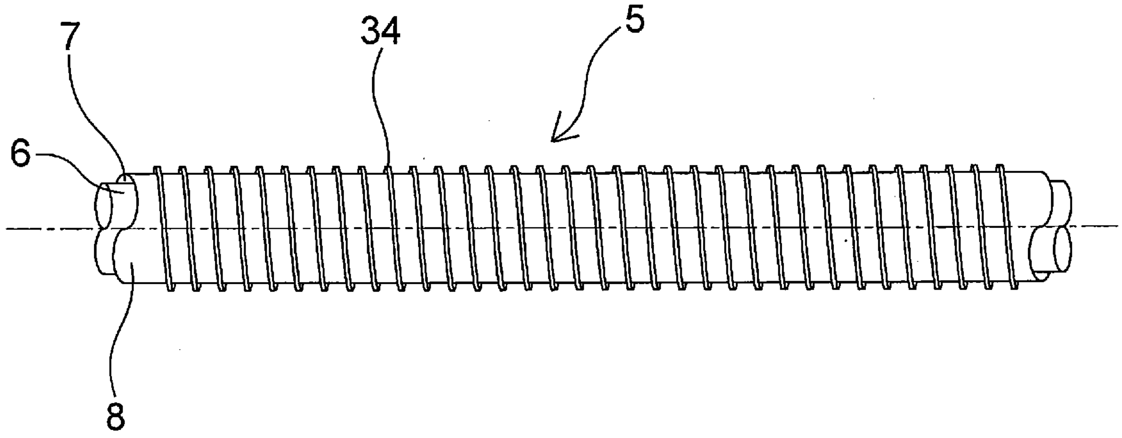


FIG. 7B

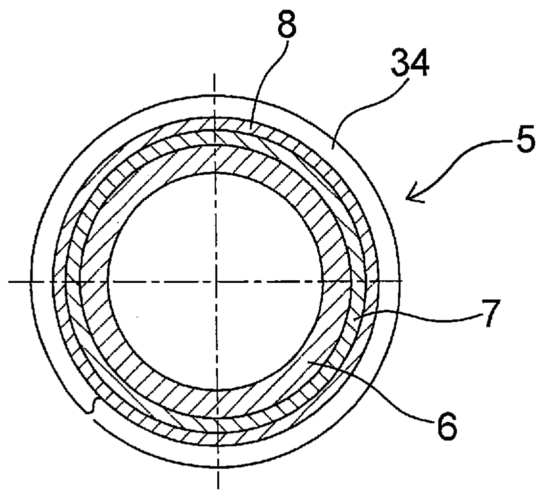


FIG. 8A

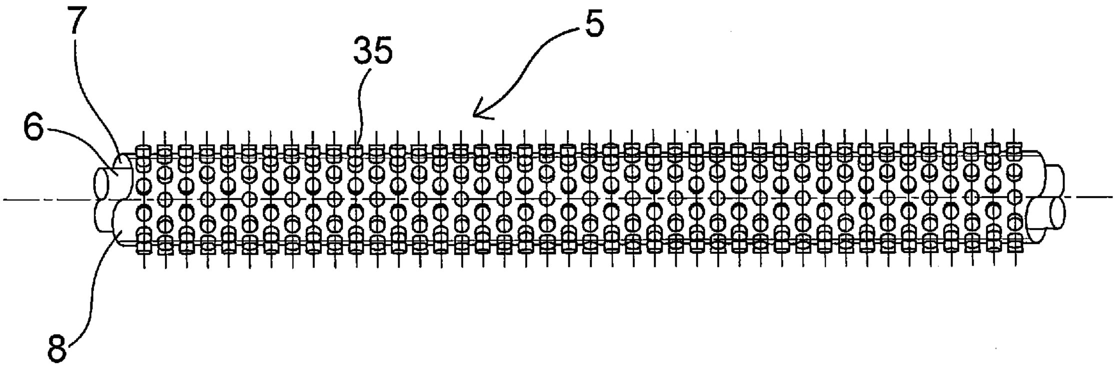
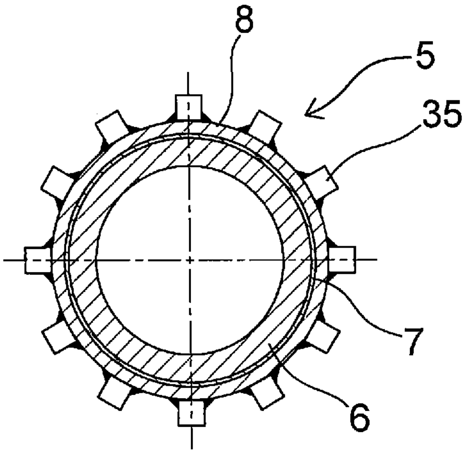


FIG. 8B



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2013/052843

A. CLASSIFICATION OF SUBJECT MATTER
F22B37/10(2006.01)i, *F22B1/02*(2006.01)i, *F23C10/28*(2006.01)i, *F28F1/12*(2006.01)i, *F28F1/36*(2006.01)i

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)
F22B37/10, F22B1/02, F23C10/28, F28F1/12, F28F1/36

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

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2013
Kokai Jitsuyo Shinan Koho	1971-2013	Toroku Jitsuyo Shinan Koho	1994-2013

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	Microfilm of the specification and drawings annexed to the request of Japanese Utility Model Application No. 178692/1984(Laid-open No. 96106/1986) (Mitsubishi Heavy Industries, Ltd.), 20 June 1986 (20.06.1986), entire text; fig. 1 (Family: none)	1-8 9-14
X Y	Microfilm of the specification and drawings annexed to the request of Japanese Utility Model Application No. 1437/1985(Laid-open No. 121306/1986) (Mitsubishi Heavy Industries, Ltd.), 31 July 1986 (31.07.1986), entire text; fig. 2 (Family: none)	1-8 9-14

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 April, 2013 (15.04.13)	23 April, 2013 (23.04.13)

Name and mailing address of the ISA/	Authorized officer
Japanese Patent Office	
Facsimile No.	Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2013/052843

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 2000-266314 A (Babcock-Hitachi Kabushiki Kaisha), 29 September 2000 (29.09.2000), entire text; all drawings (Family: none)	9-11
Y	Microfilm of the specification and drawings annexed to the request of Japanese Utility Model Application No. 377/1985(Laid-open No. 115804/1986) (Mitsubishi Heavy Industries, Ltd.), 22 July 1986 (22.07.1986), entire text; all drawings (Family: none)	9-11

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 5187789 A **[0004] [0006]**
- JP 7217801 A **[0005] [0006]**

Non-patent literature cited in the description

- Powder Reaction. NIKKAN KOGYO SHIMBUN, LTD, 54-57 **[0046]**